Study on Logistics for Disaster Relief Operation in Developing Country using Electric Circuit Similarity

(電気回路との相似性を用いた発展途上国の災害救助活動時の物資輸送に関する研究)

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Engineering

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September 2021

Abstract

Disasters affect economic damage, people's lives, and the environment in both developed and developing countries. However, relief procedures for disasters in developing countries are more serious than in developed countries due to inconsistent government management procedures and a lack of resources to handle disaster relief efforts by the government. In order to minimize the damage caused by disasters, it is necessary to have a clear disaster relief plan, both short-term and long-term. In such scenarios, quick response to disasters is important as it helps in saving human lives and provide the basic needs. Since basic needs through government channels in developing countries lack resources, government-led disaster relief operations are aided by non-government agencies and citizens. Therefore, to improve the efficiency of disaster relief operations at the quick response phase, this study investigates the importance of third-party logistics service providers in developing countries. To achieve this objective through a case study, this work considered a disaster relief operation using third-party logistics services as a major role in distributing daily necessities.

First of all, this study developed a simulation model of logistics patterns for the disaster relief operation. For this purpose, block simulation models were developed as a novel approach considering the similarity between the water flow in the logistics network and the electric current in the electrical circuit. The simulation models were validated for the centralized, decentralized, and complex logistics networks. In order to validate the simulation model, a disaster relief operation was simulated, considering the number of people, distance from the disaster area to the distribution center, truck capacity, number of available trucks, truck speed during delivery, loading and unloading time, and initial storage of resources in the disaster area. For the transportation process, the following parameters were evaluated: delay in transportation from the warehouse to the affected area, time to meet the requirements of the affected area, and total time to meet the requirements of the affected area. The results show that the block simulation model can explain several logistic network models and their behavior.

Next, the block simulation models were applied to simulate the logistics distribution patterns for disaster relief operations for the government-led and the third-party-led disaster relief operations. The effectiveness of third-party logistics service providers at disaster relief operations was compared and evaluated for pre-transport and transport processes. Primary investigations carried on Thailand's third-party logistics service providers show that the third-party network has the ability and resources to handle disaster relief operations without any other third-party service providers. Hence, this study investigates the use of third-party networks in disaster relief operations scenarios for small to large-scale disasters. The results show that third-party-led disaster relief operations are effective in the pre-transport and the transport processes.

With those results, this study concludes that block simulation models can explain the logistics behaviors of transportation processes. In disaster relief efforts in developing countries, cooperation between third-party logistics service providers and the government can efficiently allocate relief goods in the quick response phase. In the case of a large-scale third-party logistics provider in a developing country, the government can further improve the efficiency of disaster relief operations by collaborating with this provider.

Acknowledgment

I wish to express my sincere and deepest gratitude to many individuals who directly and indirectly provided their support toward the completion of this dissertation. It could not have been accomplished without their contributions.

First, I would like to express my profound gratitude to my supervisor, Associate Professor Toru Sasaki, not only for his gracious guidance and practical wisdom during my master studies but also for his bounteous support and tolerance through all my difficulties. His technical and editorial advice was essential to the completion of this dissertation. Thank you very much for providing insightful recommendations to improve this dissertation.

I extend my respect and appreciation to Professor Nobuhiro Harada, who provided not only effective advice regarding my research but also encouragement. He was extremely supportive, and cooperative. He helped me realize future prospects by providing me the great opportunity to receive a scholarship from the Japanese government.

I also wish to extend my respect and gratefulness to Associate Professor Takashi Kikuchi and Assistant Professor Kazumaza Takahashi for their invaluable kindness and friendly support; their comments and suggestions considerably improved this study.

I wish to express my respect and gratitude to Professor Kazushi Sano for his kindness, guidance, mentoring, and his assistance in the completion of this dissertation.

I express my respect to Examiner Professor Yushi Miura and recognize his valuable comments and guidance in improving this thesis.

I am profoundly indebted to the scholarship donor, Monbugakusho scholarship from the Government of Japan via the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT), for providing financial support during my study at Nagaoka University of Technology. Thank you to Nagaoka University and Japan for affording me opportunities and worthwhile experiences that will certainly aid me as I venture into the world and face the many challenges of life.

My special thanks to Dr. Leon Fernando; I will never forget your kindness and support. Thank you for sharing your opinions and helping me succeed with this study.

Thanks to all laboratory personnel for their assistance when I had trouble comprehending the Japanese language; thank you for all the valuable times that we spent together.

I am proud of my loving parents and all family members. Thank you for your moral support, loving care, and encouragement. Your love truly gave me strength and made my life perfect.

Finally, I am grateful for all your good wishes and support; I cannot mention all of them at this time. Once again, thank you.

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Chapter 1
Introduction

Disasters can be classified as natural and man-made events that adversely impact the daily life of humans and environment. Such events endanger the livelihood of society and cause considerable economic damage. When considering the category of disasters, natural disasters generally wreak more havoc to humans and economy. In particular, natural disasters, such as floods, typhoons, earthquakes, tsunamis, and landslides can randomly occur and affect vast areas. The damage inflicted by these disasters is also reflected in living things, industrial functions, agricultural productivity, and infrastructures [1] [2] [3].

Although the world's modern technologies can explain these random events and predict them to a certain extent, minimizing their overall impact is difficult. Accordingly, researchers, policymakers, governments, industries, and organizations have been consistently involved in identifying methods to prevent the aforementioned disasters and minimize their consequences. Because complete disaster prevention is difficult to achieve, stakeholders devise strategies known as disaster relief management to minimize the impact of unavoidable disasters. The operations involved generally consist of pre-disaster and post-disaster management processes.

The pre-disaster management processes focus on identifying possible disasters that can occur on specific areas and procedures that must be implemented to minimize their impact. The post-disaster management processes involve procedures that must be followed for rapid response when disasters occur. Further, they include mid-term and long-term goals to safely protect life and accelerate economic recovery.

Considering these factors, to safeguard the people and economy, governments worldwide formulate strategies and policies for disaster risk reduction and implement these processes through disaster management organizations. However, the impact of these policies and the performance of organizations vary from country to country depending on the availability of resources and their strength.

1.1 Disaster management

Although disasters are unpredictable, the formulation of strategies to cope with disasters is necessary. These steps can support authorized personnel, such as those from the government, to protect people and resources as well prevent the economy from crashing during disasters. During disasters, proceeding with disaster relief operations is necessary. The transport of disaster relief items for disaster-affected areas must be planned and executed to achieve efficient disaster relief operations.

Considering the importance of disaster management, this section focuses on the investigation of fundamental disaster management processes and their importance to disaster relief operations.

1.1.1 Disaster management process

Predicting the occurrence of disasters and their impact on various spheres affecting human life, such as the economy and environment, is a complex process. The prevention of natural disasters, such as earthquakes and tsunamis, floods, and wildfires due to extreme weather conditions, is unrealistic. However, the negative impact of these disasters on the environment, livelihood, economy, and society can be minimized through precautionary strategies and planning.

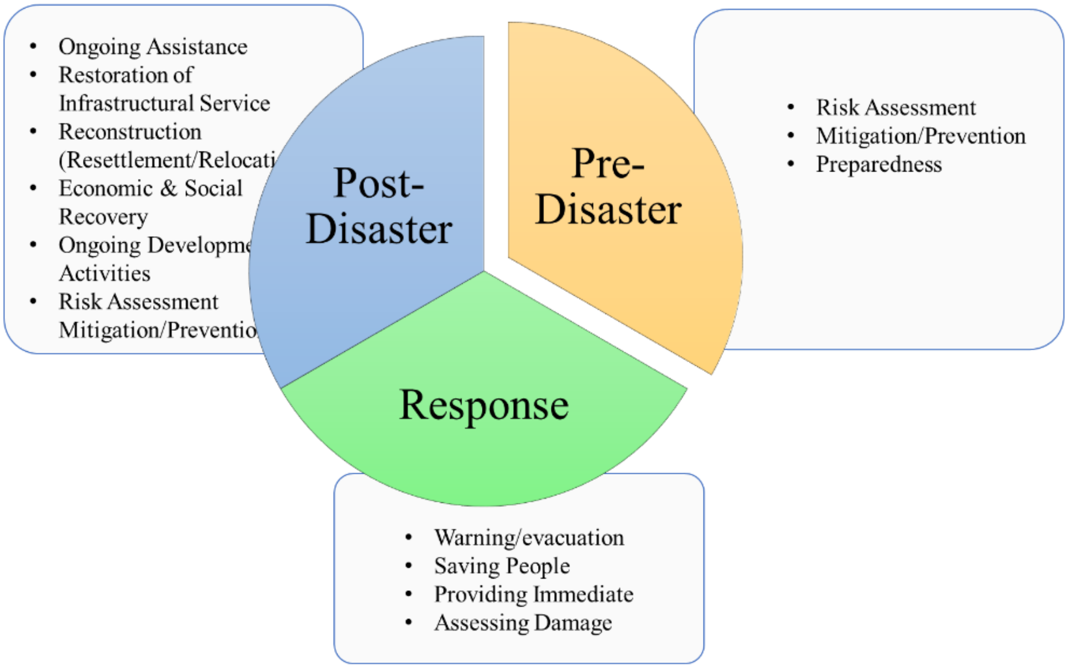


Figure 1-1. Disaster management system [4]

Accordingly, all countries worldwide implement such strategies, planning, and sets of actions to avoid disasters or minimize their impact through disaster management.

Disaster management can be classified into three main phases, as presented in Figure 1-1: pre-disaster, response, and post-disaster phases. The figure also shows the processes and management responsibilities related to each phase. The pre-disaster phase includes a set of actions and plans that must be performed to avoid disasters or minimize their impact when they occur [4] [5]. The response and post-disaster phases involve a set of actions and procedures that must be implemented when an unavoidable disaster occurs, as presented in Figure 1-1. When a disaster that cannot be avoided occurs, actions necessary to safeguard human lives must be implemented [6] [7] [8] [9] [10]. All processes and sets of actions necessary to achieve the foregoing objective are included in the response phase. As the immediate impact of the disaster subsides, the continuous implementation of the set of actions and procedures enabling disaster-affected victims to return to their previous lifestyle is crucial. The foregoing actions are under the post-disaster phase [11] [12] [13].

As shown in the Figure 1-1, the connection among these three phases can be illustrated as a cycle. In this cycle, planning to avoid disasters or minimize the impact of unavoidable disasters is conducted in the pre-disaster phase. Although the conceived strategies may be excellent, some natural disasters are difficult to avoid. Therefore, the implementation of planned actions in the pre-disaster phase is necessary to save lives and restore livelihood in the affected area. Subsequently, the knowledge derived from the response and post-disaster phases is used as basis for reviewing the strategies in the pre-disaster phase to improve the disaster management processes.

1.1.2 Transportation and pre-transportation of disaster relief items

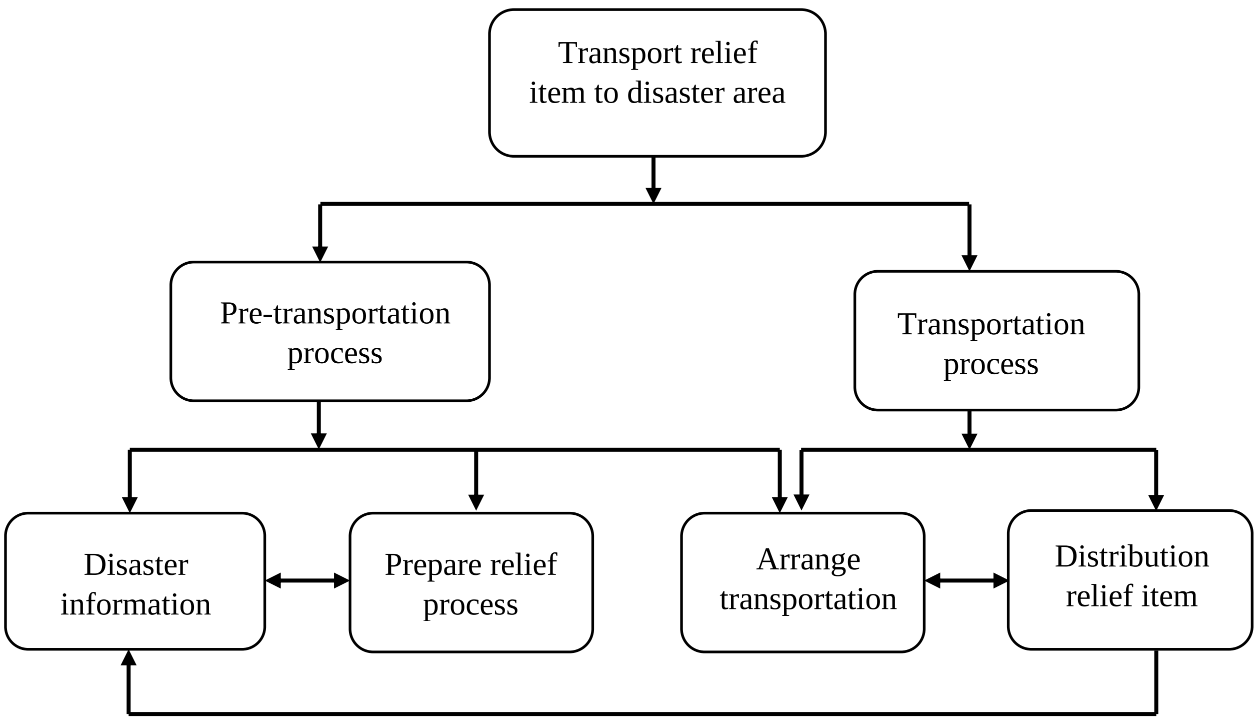


Figure 1-2. Transportation diagram for disaster area [14]

Among the primary processes associated with the response phase when disasters occur is the transport of relief items to disaster victims. The procedures considered in this stage are detailed in the pre-disaster planning phase and executed in the response phase.

Figure 1-2 illustrates the link between the pre-transport and transport of relief items to disaster areas. Two categories are identified to be important in the pre-transport process. The gathering of information related to the disaster is important because the requisites for transporting the items in the disaster relief operation can be identified. Moreover, based on the information, sufficient or possible disaster relief items before the transportation step can be prepared. The preparation of disaster relief items is accomplished through government and/or non-government organizations.

As shown in Figure 1-2, the preparation of disaster relief items also requires feedback information to evaluate the current situation of disaster relief operations.

The transport and distribution of disaster relief items are under the transportation process operation. Here, the prepared disaster relief items are distributed to disaster-affected victims to stabilize them and their livelihood [14] [15]. Accounting for the economic values in the transportation process is necessary. Hence, the collection of information regarding the arrangements for transporting and distributing relief items to disaster areas is required to evaluate the progress of the transport process.

1.2 Phases of disaster relief operation

Disaster relief operations play an important role in sustaining and saving human lives [16]. Countries that are frequently affected by natural disasters must have effective disaster relief operation procedures to minimize the impact of disasters on the population. In contrast, in countries with poor disaster relief operation procedures, the effect of disasters on victims is amplified.

Disaster relief operations perform a major function in coping with disasters and minimizing their devastating impact on humans as well as the economy. The stages of disaster relief operations can be separated into three, as shown in Figure 1-3; this figure also indicates the procedures that must be observed in each phase. Accordingly, this section explains the general procedures that must be followed in each phase and those that can improve the efficiency of disaster relief operations.

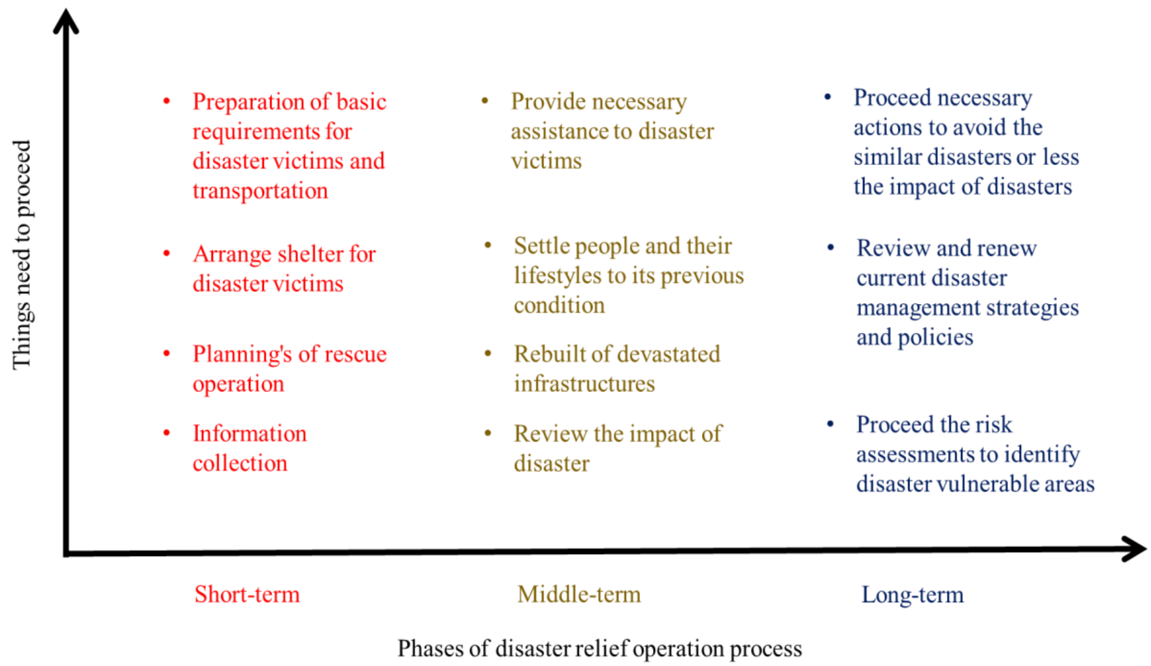


Figure 1-3. Term period of disaster operation [17] [18]

1.2.1 Short-term operation

During a disaster, the main focus includes saving lives and providing the necessities of disaster victims. At this stage, information collection, planning, and other proceedings have to be executed as soon as possible. Hence, the conduct of disaster relief or disaster management at this stage can be defined as short-term or quick-term responses [19] [20] [21] [22]. Generally, the activities in this stage are implemented within three days or one week from the occurrence of the disaster.

The activities mainly involve the collection of disaster relief goods, conduct of humanitarian missions, sheltering disaster victims, and providing their basic necessities. Many studies have investigated the implementation of disaster relief operations via different channels and the means for improving the efficiency of these processes [5] [23] [24] [25]

The effectiveness of this stage can be evaluated by considering the time that elapses to satisfy the demands of disaster-affected individuals. As discussed in Section 1.1.2, the transportation process performs a major role in assessing the effectiveness of disaster relief operations. Figure 1.4 illustrates the important time-step parameters that must be considered in the transportation aspect of disaster relief operations in the quick-response phase.

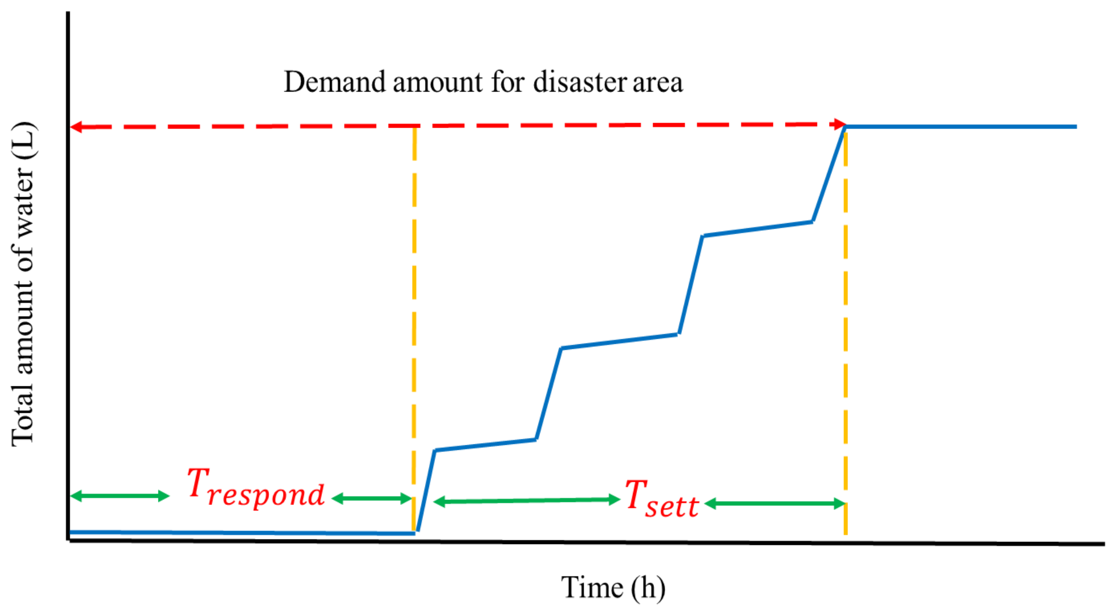


Figure 1-4. Cumulative curve of storage against time

As shown in Figure 1.4, the response time ($T_{response}$) is the time necessary to satisfy the requisites in the disaster area with the relief distribution network. In this process, relief items are obtained from the distribution center (DC) and delivered to the affected area. The time that elapses may be long or short depending on multiple factors, such as distance, available routes, and delivery truck speed.

The settling time (T_{sett}), shown in Figure 1.4, pertains to the time required to satisfy the demand in the disaster area with the distribution network; this time also includes the loading and unloading times.

The saturation time ($T_{saturation}$) is the total time that elapses to saturate the requirements in the disaster area; it consists of response time and settling time, as expressed in Eq. (1.1).

$$T_{saturation} = T_{response} + T_{sett} \quad (1.1)$$

1.2.2 Mid-term operation

As illustrated in Figure 1-3, disaster relief operations, including the relocation of disaster victims and rebuilding of disaster-damaged areas, can be considered as a mid-term response. This stage of disaster relief operations is a follow-up after the short-term or quick-response phase. This stage focuses on the cleanup of disaster-affected areas and restoration of the livelihood and economy of the area to their original state.

The activities in this stage include the cleanup of disaster-affected areas and relocation of disaster victims. These activities also involve providing financial aid to compensate for the current economic losses of victims and for rebuilding the community. The studies conducted on this stage have investigated the alternative actions and procedures that can support and improve the economy after a disaster [26] [27] [28] [29].

1.2.3 Long-term operation

Post-disaster management activities, which are implemented from a few months to a few years after a disaster, fall under the category of long-term response. This phase focuses on identifying reliable solutions to problems resulting from the disaster and the means for coping with similar incidents, as shown in Figure 1-3. Moreover, in this stage, the strategies and policies on disaster management are reviewed and reimplemented to maintain the country’s livelihood and economy.

The features of this stage include identifying technologies for predicting the occurrence of possible disasters, providing society with a strong sense of stability regarding their livelihood and reinforcing it, devising disaster management strategies and policies, and maintaining the foregoing processes as pre-disaster management activities. Studies that are conducted in this stage investigate the current policies on disaster relief operations and adjustments that can be implemented to improve them. Moreover, these studies focus on identifying suitable actions to achieve long-term stability for people in areas experiencing the prolonged effects of disasters [1] [30] [31].

1.3 Disaster relief operation in developing country

Currently, disaster relief operations in developing countries require system improvement to be more effective through rapid execution. Accordingly, this section focuses on the general disaster relief management in developing countries via third-party logistics.

1.3.1 Issue in disaster relief operation

Due to climate change caused by global warming, the number and frequency of natural disasters have increased and affected all parts of the world. These disasters have led to various problems, such as the evacuation of people from their communities, destruction of ecosystems, health problems due to disrupted hygienic practices, and destruction of infrastructure. However, the impact of these problems is mainly observed in developing countries due to their inadequate disaster relief operations or strategies. Some of the reasons for such inadequacy are as follows.

- Many developing countries are geographically located in areas prone to natural disasters, such as storms, droughts, and landslides.
- In developing countries, poverty drives people to migrate to urban areas where they reside in unsafe housing.
- Many people in developing countries are willing to dwell in areas with high disaster risks to derive temporary benefits, such as low housing cost, high income, and easy mobility.
- Most developing countries lack emergency protocols and infrastructure facilities to deal with disasters.

Figure 1-5 shows the frequency distribution of natural disasters around the world from 2000 to 2018.

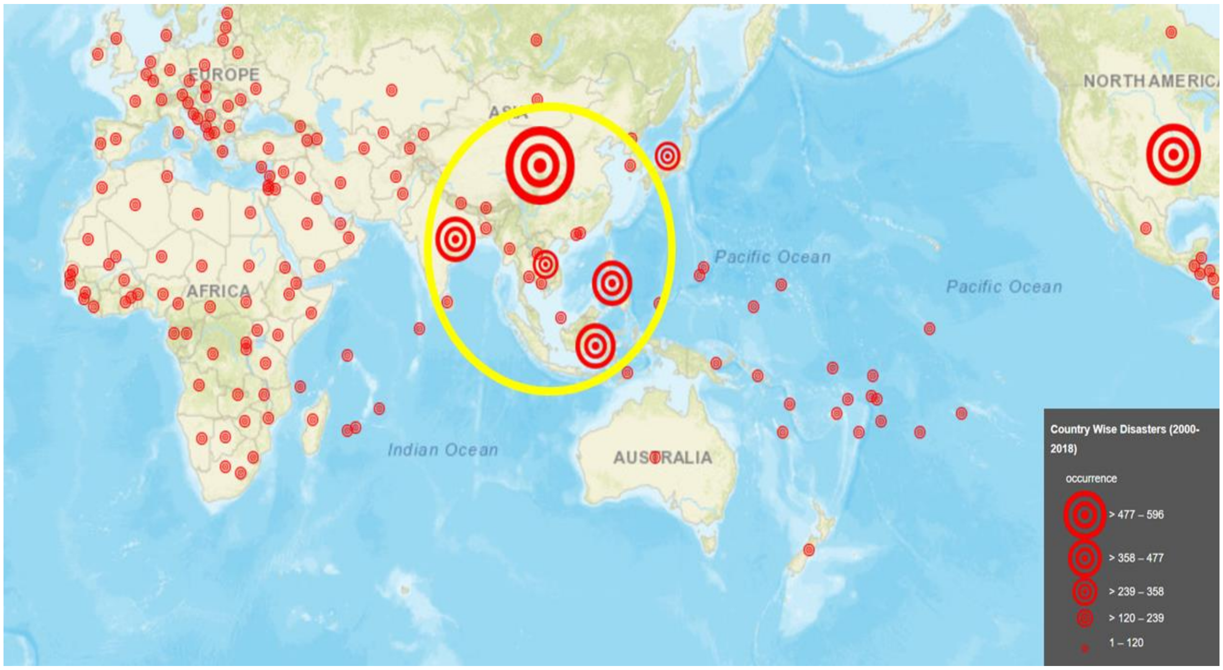


Figure 1-5. Frequency of disaster [32]

As shown in Figure 1-5, disasters have occurred in both developed and developing countries over the last two decades. However, excluding the United States of America, the figure shows that the frequency of disasters in East and Southeast Asia is high, as indicated by the yellow circle. This high disaster incidence is due to the combination of geographic conditions in these regions, i.e., being located in the Pacific and Indian Oceans as well as being on tectonic plates. The Pacific and Indian Oceans are known to generate numerous storms during summer in the northern hemisphere, and the earth’s rotation causes the storms to move in a northwesterly direction. The storms in these oceans carry considerable amounts of water causing heavy rainfall as they approach land. In addition to these storms, the countries within the yellow circle are also prone to earthquakes and tsunamis due to their positions on tectonic plates. In recent decades, the region has experienced powerful earthquakes and destructive tsunamis that have severely affected the lives of the people living in the area. Because the nations in this region are vulnerable to disasters, strategies and plans of actions are critical to minimize the impact of these events. However, these countries typically have inadequate disaster relief plans due to political instability or weak economic foundation. The following summarizes some of the problems associated with inadequate disaster relief planning.

- Poor housing facilities and the lack of infrastructure associated with urban slums in developing countries render them even more vulnerable to natural disasters.
- Communication among key authorities, such as those in emergency services, politicians, and scientists, and people is insufficient during disasters.
- Although technical methods for avoiding and reducing the aftermath of natural disasters are present in these countries, the implementation of these methods is insufficient due to the scarcity of economic and technological resources.
- Government corruption has resulted in the poor allocation of resources for disaster relief efforts and accident recurrence prevention.
- At the municipal level, poorly constructed urban areas result from the lack of personnel with adequate knowledge in managing human and financial resources.

As discussed above, these problems indicate that countries in East and Southeast Asia are more vulnerable to disasters. Therefore, this study focuses on developing a framework for effective disaster relief efforts in these nations and minimizing the effects of problems identified above.

Normally, the disaster relief framework in developing countries does not differ from that of developed countries in terms of government information gathering, coordination and support system, and route clearance procedures for the transport of disaster relief items. However, the implementation of these processes is likely to be more effective in developed countries than in developing countries.

In developing countries, the response times for disaster relief efforts are typically longer due to inadequate government resources for necessary items and services. Most resources as well as essential services and items in these countries are managed by the private sector. Thus, the cooperation of third-party resource providers with government-led disaster relief operations can improve the efficiency of these activities in developing countries.

1.3.2 Third-party logistics in developing country

Section 1.3.1 identified the problems associated with inadequate disaster relief operations in developing countries. This section elaborates on the use of third-party logistics providers to improve disaster relief operations in developing countries by reducing the burden borne by governments during disasters.

A number third-party logistics providers operate in Southeast Asia. These include the CP group, Thai Beverage Public, and CPF company in Thailand; Kerry Express, Petronas, and KK group in Malaysia; Vin group and Vina milk in Vietnam; SM group in the Philippines; City Mart Holding and Sein Gay Har Group in Myanmar; and Alfamart and Indomaret in Indonesia.

As mentioned, many third-party logistics service providers have the resources to provide disaster relief items; moreover, they have strong and efficient transport networks to deliver supplies. Therefore, the participation of third-party logistics providers in government-led disaster relief operations improves the efficiency of disaster management. Such a cooperative relationship between government and third-party logistics providers introduces a number of advantages. For example, large inventories of essential items in large-capacity warehouses become available; established distribution networks become accessible; and efficient processes in item preparation and distribution are enabled. Although third-party logistics providers can ease the burden of government-led disaster relief efforts, note that their services may involve the preparation and distribution of disaster relief items.

In view of the foregoing, the necessity of using third-party logistics providers to improve disaster relief operations by facilitating the supply of demands must be determined. This study evaluates the use of available warehouses and inventories with the distribution networks of third-party logistics providers to improve disaster relief operations.

1.4 Logistics

Logistics is defined according to various categories, such as those in business, transport, supply chain management, and industry [33]. The activities under general logistics are identified in Figure 1-6 [34]. Because this study focuses on disaster management logistics especially in the distribution of relief goods during disasters, the concepts of transportation and warehouse logistics require investigation. Accordingly, this section discusses logistics related to transport and warehouse location.

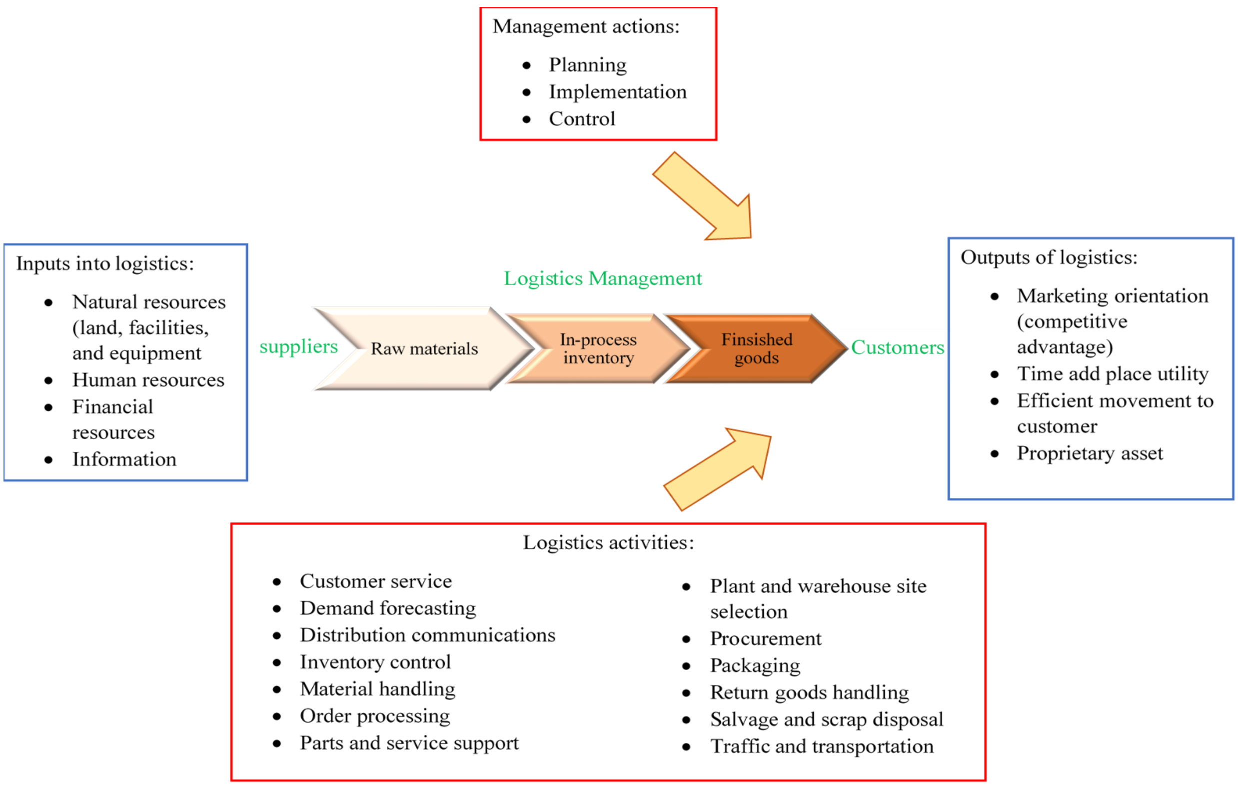
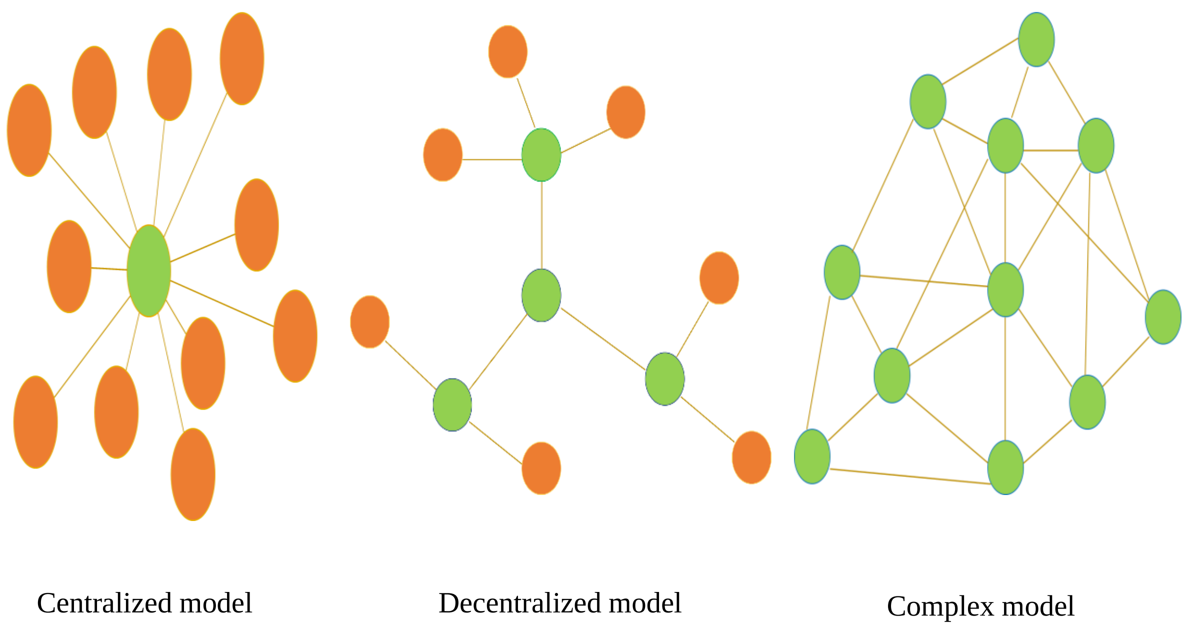


Figure 1-6. Logistics management [34]

1.4.1 Transport network

The goal of logistics management is not only to reduce cost but also improve the efficiency of processes from product handling to transportation.

Transportation is among the major aspects of logistics. The identification of suitable transportation networks according to the requirement can minimize travel time and reduce transportation cost. The transportation network system can be employed to plan the effective transport of products to customers [35] by considering routes, time, and cost for immediately responding to client demands. As presented in Figure 1-7, in general, three different transport network models may be applied considering the demand and available supply centers as well as their interlinkage.



P/S: One green color represent a distribution node (supply distribute goods) to another eleven nodes (demand area) which can represent in orange color as show in ***centralized model****. Four green color represent a distribution node (supply distribute goods) to another seven nodes (demand area) in orange color as show* ***in decentralized model****. While, eleven green color represent the link connection all of node as a distribution node (supply distriubte goods) which show in* ***complex model****.*

Figure 1-7. Typical diagram of transportation network [36]

A centralized network can be considered as the basis of a transport network structure. Such a network model includes a single location as a supply center or warehouse with multiple demand centers. Therefore, the distribution of goods from one supply center can enable distribution to all demand areas.

The inclusion of more than one warehouse in the centralized network to supply demands gives rise to decentralized networks. In this latter type of network, demand areas are linked to one supply center. Infrequently, these networks dually function as sub-DC and demand area.

A network with multiple supply centers linked to multiple demand areas gives rise to a complex network. In this network type, demand areas do not depend on one supply center. Hence, it can assure that demands can be satisfied without depending on a single entity. In addition, this network can accelerate the movement of logistics items from supply areas to demand areas.

1.4.2 Direct systems and outsource systems

Direct and outsource systems form another type of logistics network. These systems depend on the origin of supplies. In the direct system, the original product manufacturers are responsible for the distribution of required goods to demand areas. In this type of logistics, service providers mainly depend on the transportation of goods to consumers through centralized and decentralized networks considering their available warehouses. Direct systems are used in modern trade: for example, they are employed by automobile companies, such as Toyota and Nissan; food and beverage providers, such as KFC, McDonald, and Coca-Cola; and merchandizers, such as Nike, PRADA, and Louis Vuitton.

In outsource logistics systems, the supplier may manufacture some goods and outsource other products from another supplier or outsource all products from other suppliers. The distribution of goods to consumers primarily depends on decentralized or complex transport networks. In modern trade, such logistics systems enable businesses to expand and attain higher levels while maintaining minimal costs in production, storage, or distribution. In the modern world, Amazon, Alibaba, and Uber are examples of companies that employ such systems.

1.5 Motivation of this study

Relief operations perform a major function during disasters to save human lives and restore the devastated economy. A strong disaster relief framework supports countries to act swiftly and minimize the loss of lives and resources during disasters. Fully understanding the impact of disasters and the availability of resources to cope with disaster relief operations aid governments to develop their own disaster management strategies. Such knowledge and strategies are then implemented when disasters strike; concurrently, the effects of devastation are minimized.

Most countries in Southeast Asia are developing nations that lack strong management processes. Moreover, these countries are vulnerable to natural disasters, such as storms, floods, and droughts, due to their geographical location. In these countries, third-party logistics service providers dominate the supply of essential items. They are also capable of managing the logistics network nationwide due to their available resources and transportation networks. The involvement of these logistics service providers in government-led disaster relief operations is expected to reduce the government burden in preparing and distributing disaster relief items.

To investigate the contribution of third-party logistics service providers to disaster relief operations, this study considers the situation of Thailand as a case study. Thailand, among the nations in Southeast Asia, is classified as a developing country. The country is vulnerable to disasters, and their logistics market is dominated by third-party logistics providers. The disaster relief operation in Thailand is also known to be inefficient due to inadequate government management during disasters. Nevertheless, different from other countries in Southeast Asia, the access to information on disaster relief operations and its models is available through various channels in Thailand. Accordingly, this study is focused on investigating the means for improving the efficiency of disaster relief operations in Thailand. For this purpose, linking a single third-party logistics service provider to government-led disaster relief operations is proposed.

To evaluate the performance of the proposed disaster relief model for Thailand, the use of block simulation models is considered. The use of block simulations for disaster relief operations has numerous advantages over conventional algorithm-based logistics model. They enable the feasibility of adapting to dynamic situations without major changes to the models. As for the logistics block simulation model, the similarity between the flow of goods in the general logistics network and the flow of charge in an electric circuit was considered.

To investigate the capability of third-party logistics service provider in government-led disaster relief operations and evaluate its performance, block simulation methods were considered in this study. Accordingly, this study focused on achieving the following objectives.

Objective I: Create a block simulation model with the novel approach of utilizing the similarity between electric circuits and logistics as well as perform validation using logistics parameters.

Objective II: Investigate the use of third-party logistics providers to improve the efficiency of disaster relief operation in Thailand as a case study.

1.6 Scope of this study

The importance of disaster relief operations in the short-term phase had been well studied. In addition, the flow of logistics processes had been thoroughly examined to improve the efficiency of these operations. Necessary aspects, such as linking single-third party logistics service providers to government-led disaster relief operations, were identified to improve the efficiency of operations. Improvements were introduced to disaster relief operations in the short-term phase to improve the efficiency of the aforementioned operations.

A developing country in Southeast Asia was considered to investigate the improvement in the efficiency of government-led disaster relief operations with the cooperation of third-party logistics service providers. Thailand's disaster vulnerability in the past decade and the availability of third-party logistics in this country afford the opportunity to consider this nation as the case study in this investigation. Block simulation models were used to simulate the function of transportation in disaster relief operations. The development of the simulation model was based on the similarity between the flow of goods in logistics and the flow of charge in an electric circuit.

One of the aims of this study is to confirm the similarity between logistics and electric circuits for developing the block simulation models. Furthermore, this study investigates the necessary improvements for government-led disaster relief operations in developing countries, such as Thailand, linked to single third-party logistics service providers.

This thesis includes five chapters that begins with an introduction to disaster relief operation. The basics of logistics, disaster management, disaster relief operations in developing countries, and third-party logistics prospects are discussed in the first chapter; the motivation and scope of the study are also explained in this chapter.

In Chapter 2, the fundamentals of block simulation in the building simulation platform for logistics network are elaborated. The theoretical background for the similarity between the flow of goods in logistics and the flow of charge in the electric circuit is presented. The development of logistics transport networks using block simulation is also explained in this chapter.

Chapter 3 presents the investigation to identify the importance of logistics parameters in disaster relief operations. It also discusses the performance analysis of these parameters examined through the developed block simulation models.

Chapter 4 describes the investigations implemented to determine the importance of third-party logistics to government-led disaster relief operations for Thailand to improve the efficiency of operations. The chapter discusses the disaster-related information concerning Thailand and the developed block simulation model to determine the behavior of disaster relief operations with and without the involvement of third-party logistics service providers.

Finally, in Chapter 5, the summary of the concepts involved in the disaster relief operations for Thailand and the validation of the developed block simulation models are presented. A new framework for Thailand is also proposed and discussed to improve the efficiency of disaster relief operations in this country.

Chapter 2
Similarity of logistics and electric circuit

2.1 Introduction

Fully understanding the concept of disaster relief operations and all aspects involved can aid organizations to implement effective disaster relief operations. Due to the limited availability of resources, governments worldwide have endeavored to minimize the impact of disasters on the economy and human lives. For this purpose, governments incorporate disaster management to their national strategies and policies. Such policies include the nation's strategic policies based on investigations conducted through relevant parties. Although such plans have been formulated, determining the effectiveness over a short-term period is difficult. Accordingly, researchers simulate various scenarios using complex mathematical models or conduct surveys to investigate the effect of such strategies.

Generally, a number of studies prefer simulation methods over surveys to investigate existing methods and the advantages of newly proposed disaster relief models [37] [38] [39]. The main reason for this choice is the considerable amount of time devoted to collect survey data regarding existing and proposed methods compared with time spent using simulation-based evaluation. Simulation-based evaluation enables researchers to investigate and identify the pros and cons of existing and proposed logistics models. However, for such evaluations, complex mathematical foundations are typically required [40] [41] [42].

The use of block simulations over complex algorithm simulation affords many advantages. Block simulation conditions are easy to understand, thorough knowledge of complex mathematics is not required, and simulation platforms are easy to assemble [43] [44]. However, considering logistics operations, a block simulation method for developing simulation platforms is rarely found. Despite its rarity in logistics-related research, many studies demonstrate the use of block simulations to evaluate the performance of electric circuits [45] [46] [47].

The flow of the goods in a logistics transport network is relatively similar to the flow of charge in an electric circuit. Moreover, many logistics studies also apply the concept of electric circuits to investigate the flow behavior in logistics. Accordingly, in this study, an electric circuit similar to the transport logistics network is investigated and developed. Then, the formulated electric circuit is converted to a block simulation model to evaluate the logistics behavior. Therefore, this chapter thoroughly discusses the development of a block simulation platform to create a disaster relief logistics model using electric circuits.

2.2 Disaster relief operation modelling

To analyze the performance of existing and proposed transport disaster relief logistics models, a simulation platform is necessary. Therefore, a simulation model that conforms with the objective of this study must be formulated. For this purpose, this section discusses the basis, advantages, and limitations of the simulation.

2.2.1 Algorithm base

Many studies on logistics-related behaviors tend to use complex algorithms to formulate simulation platforms to analyze the performance of the logistics model [40] [41] [42]. In such simulation platforms, the core concept involves the development of complex mathematical algorithms to link the parameters considered in relevant studies.

The optimization of conditions, such as minimizing or maximizing objectives in the simulation, is discussed in comparison with restraining resources or conditions. Pre-defining the logistics problem or using program coding to run the defined logistics problem is employed to determine optimal conditions.

Because such simulation platforms are based on mathematics, reasonable knowledge of complex algorithms is essential. Moreover, knowledge of coding or programing is also important because the conversion of logistics-based mathematical formulas into the computer is necessary. The implementation of changes and modifications to parameters and their values according to investigated scenarios is facile in such simulations.

However, stakeholders in logistics-based research or studies find these simulation platforms extremely difficult to utilize. The main reason for this problem is the lack of knowledge in complex mathematics and programming languages.

2.2.2 Block simulation base

Another type of simulation platform is the block simulation method. This method enables users to use blocks instead of coding a program to solve complex mathematics. Such simulation platforms are thus user-friendly; however, platforms for logistics block simulation modeling are rare.

Studies related to the performance analysis of electric circuits, which can be employed to develop block simulation models, are available. In these studies, instead of the mathematical behavior of basic electric components, pre-defined blocks or groups of blocks are used. These allow users to facilely understand the mechanism of the simulation model more than the mathematics behind the components.

Compared with algorithm-based simulation, block simulation modeling is user-friendly. As a result, even users with partial knowledge of complex mathematics and programming are also observed to also express interest in developing such simulation platforms. Although these simulation models are easy to develop, note that the implementation of necessary changes to modify the block function is difficult.

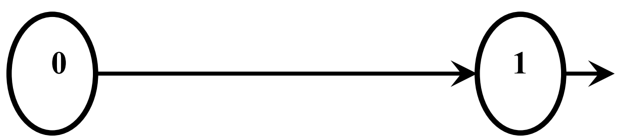
In this study, block simulation, instead of algorithm-based simulation, is used as a novel approach. Hence, logistics-similar electric circuits were considered and converted into a block simulation model. To develop the block simulation platform, MATLAB®/Simulink software was employed.

In comparing the available block simulation systems, this study found that the use of MATLAB®/Simulink had an added advantage in developing block logistics simulation platforms. The amount of available resources in the software for converting the electric circuits into block simulation is vast and improves knowledge in developing block simulations for logistics models. Moreover, MATLAB®/Simulink has dynamic features and enables changes to pre-defined block functions according to the situation [48] [49].

2.3 Similarity between functions of electric circuit and logistics concept

To propose a new disaster relief model, the modeling concept must be considered by comparing the functions of logistics network and electric circuit. For this purpose, the use of MATLAB®/Simulink block platforms was considered because of its ability to convert electric circuit functions into block models. Initially, water was considered a necessary relief item that had to be delivered to the disaster area via the logistics network. logistics with the electric circuit, the amount of water in the logistics network was matched with the amount of charge in the electric circuit. The relationship between these two processes are shown in Figures 2-1 and 2-2, respectively.

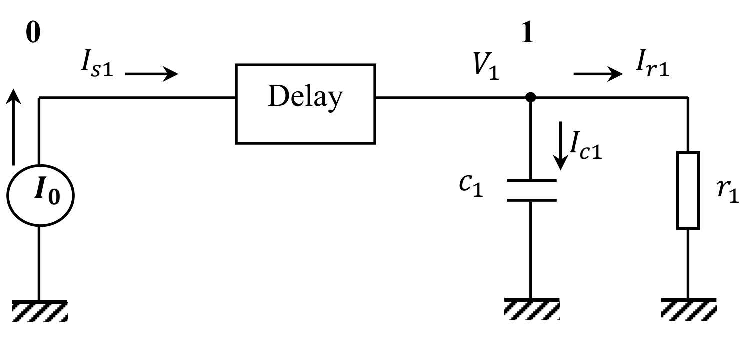
$$\dot{W}_{S1}\ (\ell/h) = \dot{w}_R \times p_1 \qquad \dot{W}_{R1}\ (\ell/h) = \left(\frac{l}{h * p1}\right)$$



$$\dot{W}_{S1}\ (\ell/h) = \frac{v_{01}}{X_{01}} L_{01}$$

Figure 2-1. Basic of a single logistics flow

$$I_{S1}(\mathrm{A}) = \dot{Q}_{S1}\ (\mathrm{C/s}) \qquad I_{r1}(\mathrm{A}) = \dot{Q}_{R1}\ (\mathrm{C/s})$$



$$I_{r1}(\mathrm{A}) = \dot{Q}_{r1}\ (\mathrm{C/s}) = \frac{V_1}{r_1}$$

Figure 2-2. Basic of a single electric flow

In this study, all commodities in the disaster relief logistics are considered as water (unit: L) to facilitate unit conversion. Accordingly, unless otherwise specified, water is used to represent relief items. The relevance of water supply in the logistics model to indicate the connection of all parts is shown in Figure 2-1.

In Figure 2-1, the logistics model supplies water from the DC/warehouse (point "0") to the disaster area (point "1"). A warehouse (water supply storage) at the destination point is assumed to be available.

Water is supplied from the warehouse/DC to people in the disaster area. Here, the water supply rate (i.e., commodity transport) can be defined as $\dot{W_{S1}}(L/h) = \dot{w_R} \times p_1$, where $\dot{w_R}$ is the demand rate of water per person, and p_1 is the number of people. The water supply to people in the disaster area can be defined as $\dot{W_{R1}}(L/h) = \left(\frac{l}{h * p_1}\right)$. Further, the water supply flow is related with distance $X_{01}(km)$ between points 0 and 1, truck speed $v_{01}(km/h)$, and truck capacity $L_{01}(L)$, as shown in Figure 2-1.

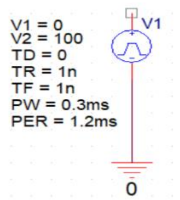
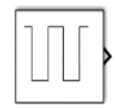
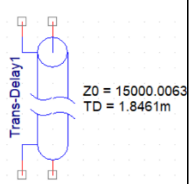
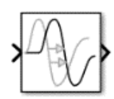
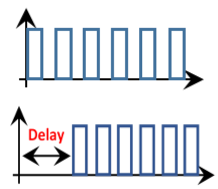
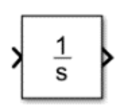
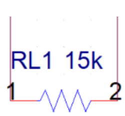
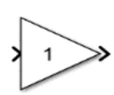
The considered basic electric circuit is similar to logistics flow. The definition of each variable is comparable between the logistics and electric circuit models. The electric circuit network developed for the logistics model is shown in Figure 2-2.

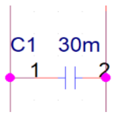
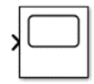
In the electric circuit model, the electric charge flow can be defined to match the logistics flow. For this, the water supply in logistics flow can be expressed as electric charge in the electric circuit, i.e., $I_{S1}(A) = \dot{Q}_{S1}(C/s)$. A delay circuit, which could delay charge flow, was included to match the delay in transportation time from one location to another. To match the water distribution in the disaster area in logistics flow, the discharge of current through a resistor, r_1, was considered. Therefore, the water supply to disaster victims can be written as $I_{r1}(A) = \dot{Q}_{R1}(C/s)$. In this proposed electric circuit, the current source at the origin point and the capacitor at the destination point match the primary warehouse/DC and the warehouse in the disaster area in the logistics network, respectively. The difference between the rates of the supplied and received amounts of water corresponds to the net current in the capacitor, respectively; the relationship can be written as $I_{C1} = I_{S1} - I_{r1}(A)$. The initial storage of water in the destination warehouse in the logistics model is simulated by varying the initial electric charge of the capacitor. The water supply rate is adjusted by allowing the discharge resistor to change the current flow; the relationship can be expressed as $I_{r1} = \dot{Q}_{r1} = V_1/r_1\ (C/s)$.

Because the amount of stored water corresponds to the charge stored in the capacitor; the relationship can be expressed as $Q_1 = C_1V_1$ (C), where C_1 is the capacitance, and V_1 is the applied voltage to the capacitor. In this electric circuit model, a pulse generator is regarded as the water source at the distribution point, and the capacitor placed in the disaster area simulates the water storage tank. The pulse generator simulates truck operations in the logistics model. For transportation, an additional delay circuit directly connected to the output of pulse power supply is used to regulate the distribution time (or time gap in logistics terms) at the branch.

To convert the electric circuit into block simulation, the blocks defined in the MATLAB®/Simulink library were used. Table 2-1 lists the basic block diagrams used in this study to develop the block simulation platform while maintaining the relationship between electric circuits and logistics.

Table 2-1. Block components from MATLAB®/Simulink library correspondent to logistics similar electric circuit

Parameters in logistics	Electric circuit	The reason	Electric circuit correspond	Concept
- Distribution center - Number of trucks - Capacity of truck - Available number of trucks		These logistics parameters consider as a pulse power supply in electric circuit, which it converts to pulse generator block act like an available of source or origin source of logistics.	 Pulse Generator	$I_{S1}(A)$ $= \dot{Q}_{S1}\ (C/s)$
- Distance/Velocity		This logistics parameter considers as a Trans-Delay in electric circuit, which it converts to transport delay block act a find the distance.	 Transport Delay	
- Total amount of water	- Total amount of charge	This logistics parameter considers as a total amount of charge in electric circuit, which it converts to integrator block act like a collect the total amount	 Integrator	$I_c = (A)$ $= (C/s)$ $\int I_{c}dt = Q_1(C)$
- Number of people - Receiving amount of water		These logistics parameters consider as a resistor in electric circuit, which it converts to gain block act like a require amount of water per person	 Gain	R_1

- Storage or initial storage		These logistics parameters consider as a capacitor in electric circuit, which it converts to constant block act like a store amount of goods	 Constant	C_1
- Output	- Output	Both parameters output of logistics and electric circuit convert to show the result	 Scope	- Obtain of distribution behavior pattern

The basic block components functions are summarized in Table 2-1. Their relationship with the electric circuit function and distribution logistics model can be described as follows.

- The water supply distribution from the warehouse/DC was considered as a pulse generator block. The current pulse amplitude was matched with the water supply rate, and the pulse width function was matched with the loading and unloading times in logistics. The number of pulses matched the number of available trucks, whereas the truck capacity corresponded to the pulse area.
- By incorporating a transport delay block, the pulse wave from the generator in the electric circuit can be delayed according to the delay in logistics. It is equal to the distance between two points (origin point to destination point) divided by the truck speed.
- The integrator block was introduced to convert the current into charge in the electric circuit; this is similar to the conversion of water supply rate into the total amount of delivered water in logistics flow.
- The constant blocks used in this conversion are similar to the storage of water in a warehouse other than that in the main DC; this corresponds to the amount of charge stored in a capacitor. The conversion can be described as $Q_1 = C_1V_1(C)$, where C_1 is the capacitance, and V_1 is the voltage applied to the capacitor.
- Gain blocks are used to relate the number of people who are requesting for water in the disaster area. Moreover, the gain blocks are used to calculate the water supply rate per person per day. Therefore, considering a point in the electric circuit and logistics, this can be written as $I_{r1}(A) = \dot{Q}_{R1}\ (C/s)$.

- The block named "Scope" was used to observe the behavior of current or similar logistics patterns.

2.4 Conversion of logistics network to electric network

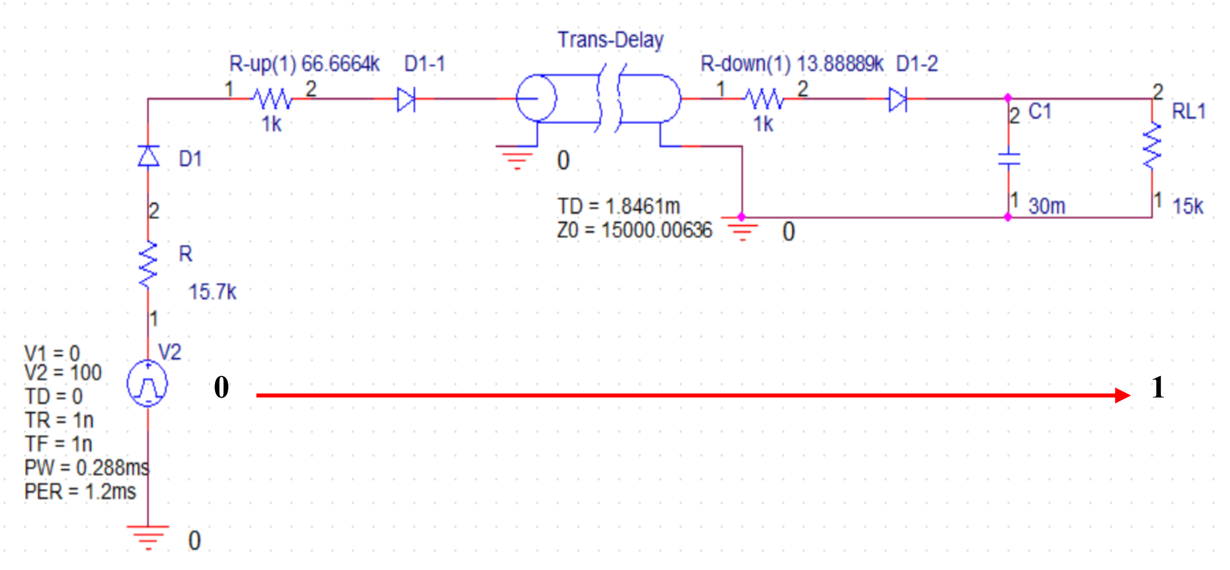


Figure 2-3. Conversion basic of a single logistics to electric circuit

The logistics flow network discussed above is shown in Figure 2-1. As shown in Figure 2-3, it was converted into an electric circuit to investigate its similarity in behavior with the basic logistics network.

Figure 2-3 presents a simple electric circuit in one branch to describe the structure of the basic circuit model. This electrical diagram includes the starting point or center of distribution represented by a pulse generator whose amplitude is set to 100 V at 250 Hz, providing 20 pulses every 24 ms period. The pulse on and off times are set considering the loading and unloading times of the truck in the logistics network, respectively. The diodes, D1-1 and D1-2, are used as rectifiers to remove the negative half cycle or positive feedback. Following the transmission line theory, the transport delay (Trans-delay) component is used to simulate delay in the logistics network. The resistors attached to the sides of this component are used to balance the circuit impendence.

Based on the assumption that current flow is similar to the flow of logistics, the electric circuit model optimizes the applied a voltage to all nodes in parallel, as follows:

$$Q = CV \tag{2.1}$$

$$V = \frac{Q}{C} \tag{2.2}$$

Where, Q is the total amount of charge divided by the capacitance in the electric circuit; Eq. (2.2) is used to define the voltage. The number of pulses in the electric circuit model corresponds to the number of tracks. The resistance and capacitance values correspond to the logistics information of the storage capacity and the number of people in each area, respectively. The total impedance is estimated using the pulse frequency, resistance, and capacitance values to generate current corresponding to the initial logistics distribution pulse; details are provided in Chapter 3.

2.5 Conversion of electric circuit to block simulation

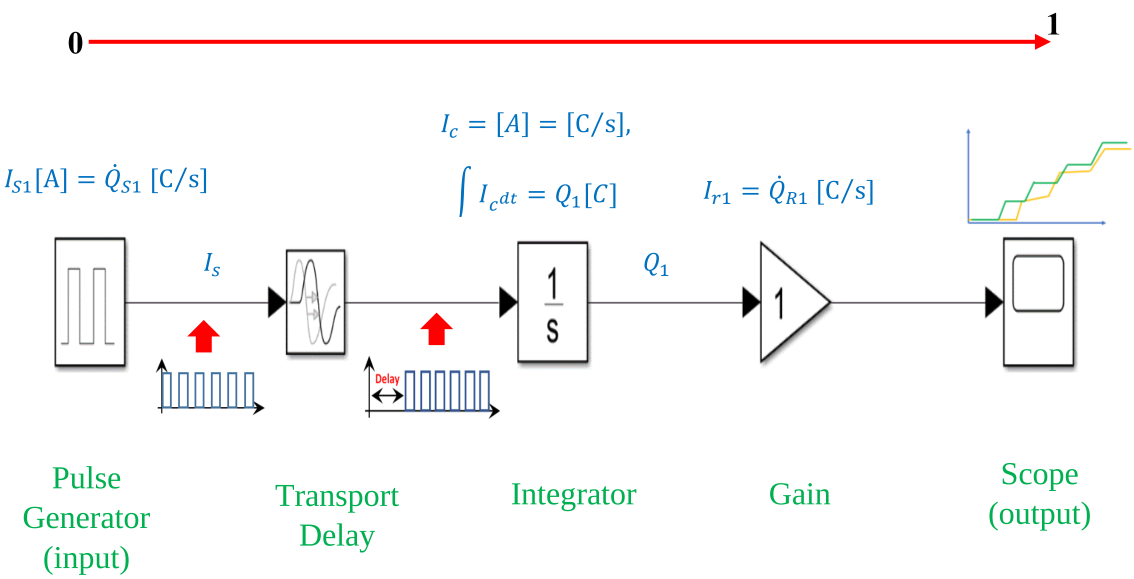


Figure 2-4. Conversion basic of a single electric circuit to block simulation

Figure 2-4 shows the development of block simulation to represent the electric circuit model similar to the logistics model. The electric circuit model shown in Figure 2-3 is converted into the block simulation model using the MATLAB®/Simulink platform, as shown in Figure 2-4. It represents the simple distribution flow of logistics from a node starting from origin point “0” to destination point “1.” As stated in Section 2.3, the pulse generator is used to distribute goods in logistics, with the truck transportation simulated as a pulse in the electric circuit. The delay of distribution from one point to another was achieved using the transport delay block component. The storage in the logistics model is similar to the capacitor in the electric circuit. The function of the stored charge in the capacitor was obtained using the block component of the library. The discharge of water is similar to the discharge of current from the resistor; for this, the block component named “Gain” is used. The flow of goods in the logistics model is unidirectional and simulated using the diodes in the electric circuit. Indicating the flow direction using a single arrowhead maintains this unidirectional distribution in the block simulation model.

2.6 Conclusion

In this chapter, the investigation of development of block simulation for the logistics transport network was presented. To evaluate the performance of existing and proposed disaster relief models, block simulation models were considered. The basics of algorithm-based and block simulation-based evaluations were investigated with their concepts as well as their advantages and disadvantages to identify the usability of block simulation modeling.

Because logistics-based block simulation modeling is rarely reported, this study considers the development of block simulation using an electric circuit. The similarity between the flow of goods in logistics and the flow of charge in the electric circuit were considered. In this study, water was considered to represent all the goods in the logistics network to facilitate the conversion of units into that of electric charge. Moreover, the fundamentals behind the conversion of logistics network into an electric circuit were thoroughly examined to develop a well-defined electric circuit representing the logistics network.

Initially, the fundamentals of the distribution of logistics goods from point to point were represented in the electric circuit using basic electric circuit components, such as resistors, diodes, capacitors, and power supplies. Then, the library components of MATLAB®/Simulink simulation platform were used to convert the electric circuit into the block simulation model.

Fully understanding the similarity of logistics with block simulation is expected to aid in the investigation of logistics-related parameters as well as the performance analysis of existing and proposed disaster relief operation models presented in the next two chapters.

Chapter 3

Development of logistics library for logistics network using electric circuit model

3.1 Introduction

The frequency of natural disasters has increased in recent years primarily due to global warming and climate change, detrimentally impacting lives and economics. Disasters range from localized flooding to huge typhoons; destructive earthquakes have also been experienced [50] [51] [52]. In particular, flood-related disasters are widespread, affecting both urban and rural areas [52] [53] [54] [55]. Recent floods and landslides in July 2018 killed and displaced a number of people living in various prefectures in Japan [56]. In July 2015, Myanmar suffered a flood-related disaster due to the torrential rain caused by Cyclone Komen around the Bay of Bengal and the Andaman Sea. In these situations, disaster operations played a critical role in providing assistance and saving lives. The effect of natural disasters on the population can be minimized if a country has effective disaster relief operation procedures. In contrast, the loss of lives increases, and the impact of disaster on the economy is more severe if disaster relief operations are inadequate [57]. The foregoing observation was clearly demonstrated by the 2004 Indian Ocean tsunami and the 2011 Tohoku earthquake and tsunami. In certain aspects, these disasters were similar in nature. However, the former affected many developing countries in Southeast Asia, whereas the latter only affected the northern region of Japan, which is a developed country [58] [59]. The devastation caused by these disasters had two different outcomes: the 2004 Indian Ocean tsunami killed more than 200 000 people, whereas the Tohoku earthquake and tsunami caused the death of 15 000 people. The main reason for their difference is that most developing countries lack effective disaster prevention and post-disaster policies [60].

In recent years, there has been a growing concern regarding the occurrence of large-scale disasters that can severely endanger the safety of society. However, as with many systems, disaster operation systems has no comprehensive model that can encompass most disaster scenarios. This is primarily because disasters can occur anywhere and at any time. In view of this unpredictability, the development of an efficient logistics network is necessary. Research on how disaster operation logistics can be improved by focusing on several aspects of emergency relief operations has been conducted [9] [61]. These studies focused on facility location, resource allocation, and evacuation location. In most facility location research, consideration is given to either locating a new building facility or choosing an existing facility to stock and distribute relief items [62] [63]. Other studies mainly focused on the location and positioning of relief items based on demand [9] [64] [65] [66]. Another area of research is related to the optimization of the distribution of relief items or limited resources to disaster locations [67] [68]. Note that demands during disasters vary with the disaster type and the area where they occur. However, saving human lives during disasters is the most important aspect of disaster relief operations. Relief operation processes include evacuating people from disaster-hit areas, providing primary supplies and provisions, and mitigating the disaster. Because this study mainly focuses on the logistics of providing primary supplies and provisions, many of the parameters that affect disaster relief operations are identified. Accordingly, this work focuses on providing the maximum quantity of available resources to disaster-affected individuals and communities over a short period.

The main objective of this study is to develop a logistics model using MATLAB block simulation by considering the similarity between the flow of charge in electric circuits and flow of goods in logistics. A logistics model must be developed and analyzed to demonstrate its efficiency using investigated and simulated data [5] [29] [69] [70] [71] [72]. For the simulated data, identifying the parameters that influence logistics routines or flows is necessary. This work focuses on the following parameters: distance, truck speed, truck capacity, number of people, initial storage, number of available trucks, and loading and unloading times. These are general indicators, and generating data on a suitable simulation platform using logistics models is facile. These parameters are important in logistics simulation studies not only to observe behavior but also validate the similarity between the flow of charges in electric circuits and flow of goods in logistics.

The simulated models were those previously developed using mathematical concepts and were computationally inefficient [73]. This problem has been encountered because the similarities between real-time logistics and relevant model behaviors have not been considered. Defining the similarities between logistics and non-logistics flows is a complex process. However, identifying such similarities improves the logistics flow when simulation platforms are used.

To resolve the aforementioned problem, an electric circuit model representing the logistics model is formulated by considering their similarities [74]. The electric circuit is typically simulated in studies because several simulation platforms providing options for research are available, especially those for describing the electrical properties or flow in the circuit. The simulation of electric current flow can be used to explain the behavior of electrical components, such as resistors, capacitors, and inductors. Therefore, considering their similarity, the behavior of capacitors and resistors in electric circuits can be expressed in terms of storage tanks and logistics, respectively [74].

This work investigates the development of block simulation models over complex algorithms, as discussed in Chapter 2. Block simulation models aid application developers in designing simple logistics management systems that only input information for simulation. To achieve this objective, a category similar to logistics behavior is investigated.

The findings indicated that the behavior of electric circuit models for representing logistics behavior was not thoroughly investigated. Therefore, a novel approach of defining the similarity between the flow of water in logistics supply and flow of charge in electric circuit is implemented. To validate the similarity, the electric circuit behavior was simulated using the theoretical logistics behavior.

The concept of employing the similarity between logistics and electric circuits was utilized to develop block simulation models using the MATLAB®/Simulink library. The components defined in this block model simulation were used according to the fundamentals of electric circuits. The similarity between logistics and electric circuits enabled the definition of optimization functions of logistics using the optimization of voltage or current in an electric circuit. This block simulation model, which was developed based on the similarity between logistics and electric circuits, eliminated the necessity of writing complex algorithms for simulations. This block simulation model only requires the input of available resources in logistics as an input file for the simulation platform without formulating any algorithm or modifying any simulation properties.

For the simulation of the logistics network, an electric circuit, which described the behavior of the logistics of centralized, decentralized, and complex models, was developed using general electrical components. Generally, centralized, decentralized, and complex networks are transportation logistics networks used as the basic structure of various systems. Because the similarity between logistics and electric circuits is considered in this study, fully understanding the relationship between these models is necessary. To clarify this relationship, the logistics model must be converted into an electric circuit; moreover, its behavior must be evaluated and verified.

The developed logistics model was simulated using OrCAD to obtain the output patterns and compare them with the theoretical behavior. The electric circuits were then converted to simulation block models using MATLAB®/Simulink, which is one of the most powerful applications for simulating electric circuits [75]. This application, through its in-built and user-defined library components, provides functions for simulation, optimization, statistics, mathematics, and data analysis. Further, the software allows breaking the calculations according to the purpose of the block, changing the micro-scale simulation to a larger scale while increasing the block connections, and defining the blocks using existing block library components. The use of block simulation over the algorithm-based simulation enables non-professional developers to create simulation platforms according to their application. Further, it facilitates not only the construction of simulation models but also the identification of errors in the models [76] [77]. In addition, the development of logistics models with objective functions can open new areas of study to new entrants in the field of logistics. Moreover, the use of electric circuits enables the realization of objective functions, such as voltage or current distribution optimization, through simple circuit models.

An important parameter that must be considered in simulation studies is the simulation step size. The use of MATLAB block simulation in this study requires the numerical output values to be an integer value of the step size to execute the program. This allows the adjustment of the input parameter for the simulation to match the integer values of the step size; this infrequently limits the simulation of dynamic situations in a disaster.

To maintain the similarity between electrical charge flow and logistics flow, decentralized and complex networks were also developed in the MATLAB®/Simulink platform. The validity of the developed electric circuit models was compared with relevant logistics models using theoretical and simulated values.

3.2 Modelling of block simulation for centralized network

This section describes the modeling of a logistics-centralized management network into a block simulation platform. For this purpose, a logistics-like electric circuit was developed by considering the similarity between the charge flow in the electric circuit and logistics network. The transformation of the identified electric circuit into a block simulation model was also accomplished using the MATLAB®/Simulink library. The characteristics of the centralized network were considered in developing the logistics-like block simulation network.

3.2.1 Features of centralized network

A centralized network is a traditional network. In a centralized distribution model, operations are typically limited to a "central" location, and goods are generally distributed to other areas. This network type has advantages and disadvantages.

Advantages

- Fewer locations are required, allowing the effective management of the logistics system
- Resource management is less complex
- Ease of management

Disadvantage

- Being limited to a central location, it has no backup system. Consequently, its use is coupled with a risk (especially in terms of management) that if errors occur, resources are inadequate, or information is insufficient, resolving the problem may require considerable time.

3.2.2 Description of centralized network by block simulation

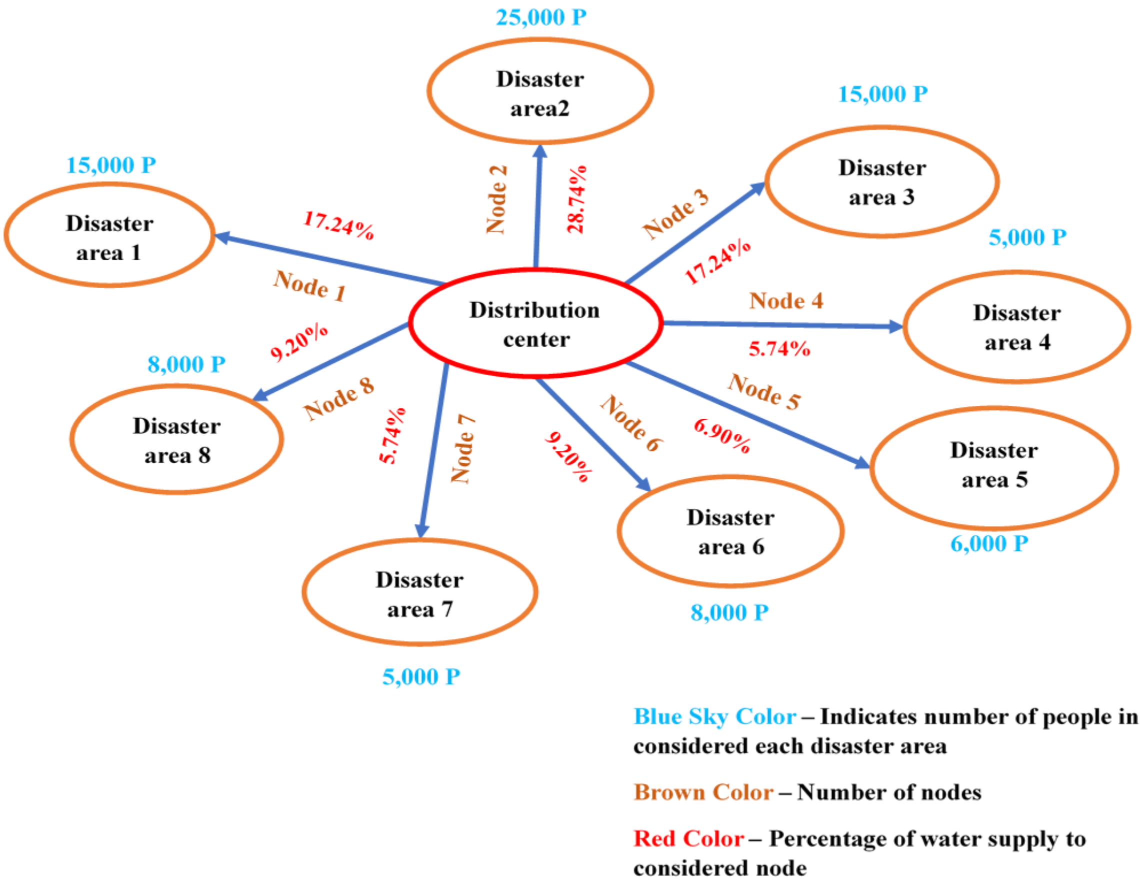


Figure 3-1. Centralized logistic network model [78]

Figure 3-1 shows the simplified centralized logistics network considered in this study with the assumed (approximate) number of people in each disaster area. The areas enclosed by circles represent one DC (red) and eight disaster areas (orange). The blue arrows represent branches that include logistics functions, such as transport delays and storage in disaster areas.

Electric circuit models have been used in various study areas, such as creating biological and chemical models for body communications [79] [80]. Initially, the behavior of a logistics network is investigated to determine the similarity of this network with an electric circuit. For this purpose, the information described in Figure 3-1 is used to develop the equivalent electric circuit model of the centralized logistics network, as shown in Figure 3-2 [78].

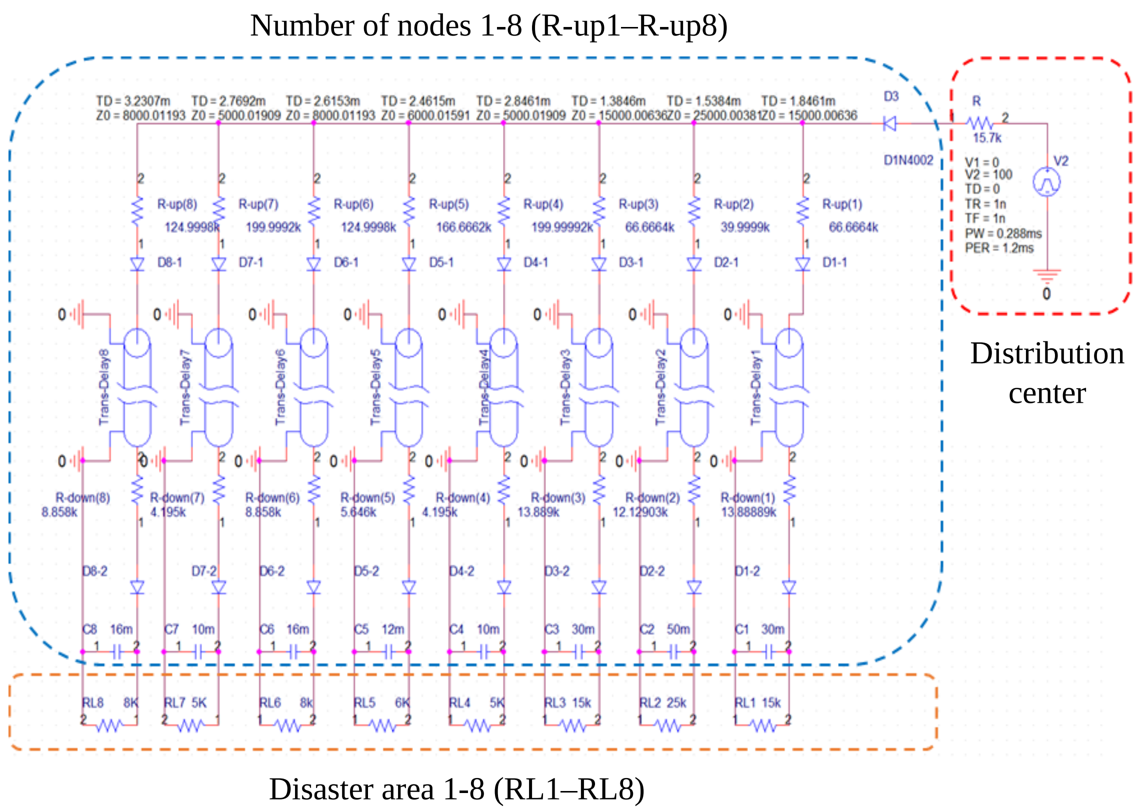


Figure 3-2. Equivalent electric circuit model for centralized logistic model [78]

The electric circuit components were used to simulate the logistics model. In this circuit, the DC was represented by a pulse generator with the amplitude set to 100 V at 250 Hz, providing 20 pulses every 24 ms. The active pulse part corresponds to the amount of charge carried by the pulse; this is similar to truck capacity in logistics. The duty cycle of the pulse corresponds to the combination of loading and unloading times in logistics networks. Because the electric current flow is similar to logistics flow, the resistance and capacitance values on the branches correspond to the logistics information of storage capacity and number of people in each area, respectively. The impedance values of the electric circuit and branches were estimated using the pulse frequency and the corresponding resistance and capacitance values of the entire electric circuit and its branches. A parallel electric circuit concept was applied to distribute the current along different branches. The corresponding current depends on the impedance of each branch; this relationship can be expressed using Ohm's law (Eq. (3.1)):

$$I_{branch} = \frac{V}{Z_{branch}} \tag{3.1}$$

Where, V is the amplitude of voltage pulse. It corresponds to the amount of charge carried in the active pulse (Q_{pulse}) to the connecting node of all the branches in the electric circuit. This is similar to the amount of water carried by each truck in disaster relief operations, as given by Eq. (3.2). The current corresponding to the node is I_{branch}, and the impedance corresponding to the branch is Z_{branch}.

$$Q_{pulse} = \frac{1}{Z_{total}} \int_0^{duty\ cycle} V dt \tag{3.2}$$

The capacitor (C) value was selected to match the storage capacities in disaster areas. The resistance value, represented by RL in Figure 3-2, is selected to represent the number of people in those areas.

A trans-delay circuit was added to this electric circuit to delay the pulse similar to the logistics network. Its delay time was achieved through the impedance balancing of the R, L, and C components within the Trans-delay circuit. Using Ohm's law to distribute the current matching logistics flow, the impedance of each branch was used.

For this distribution, the relationship $I \propto 1/R$ was employed. Two resistance values (*R-up(branch)* and *R-down(branch)*) are used at the two ends of the transfer delay component to match the impedance, as shown in Figure 3-2. The resistance values of the *R-up(branch)* and *R-down(branch)* are estimated using the Eqs. (3.3) and (3.4), respectively:

$$R - up(branch) = \frac{1}{P_{node} * 10^{-6}}\ k\Omega \tag{3.3}$$

$$R - down(branch) = \frac{1}{(P_{total} - P_{node}) * 10^{-6}}\ k\Omega \tag{3.4}$$

Where, P_{node} and P_{total} are the nominal values of the number of people in the disaster area and the total number of people affected by the disaster, respectively. The number of people affected during disasters can vary with disaster. Under such conditions, modifying the resistance values to match the impedance of the transfer delay component is necessary. Therefore, this study suggests using variable resistors at both ends of trans-delay to adjust the impedance according to varying disaster conditions. Considering 1 L of water supply in the logistics network as equivalent to 1 μC in the electric circuit, a multiplication factor of 10^{-6} was applied to convert the amount of water supply logistics to electrical charge.

To assign the delay time in the trans-delay circuit component, impedance is assigned in the *kΩ* scale, and nominal resistance values are estimated using Eqs. (3.3) and (3.4).

The inclusion of resistance in the transfer delay allows the current pulse amplitude to decrease according to the ratio of the people in the disaster area to the total number of people affected. Charging and discharging through the capacitor occurs due to the pulse waveform generator alternating current when the pulse changes from an on state to an off state. Therefore, to maintain the flow of charge in the forward direction, diodes are introduced into this electric circuit.

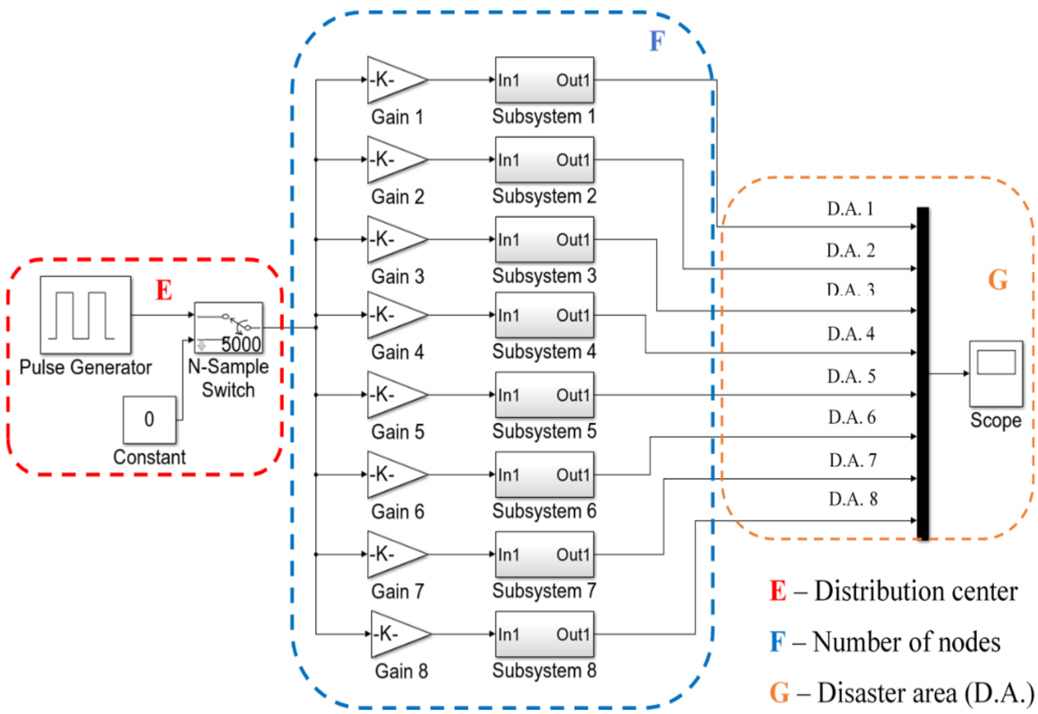


Figure 3-3. Simulation block model for the centralized logistics network using MATLAB®/Simulink [78]

Figure 3-3 represents the MATLAB simulation block model for the centralized logistics network considering current flow. The pulse generator to supplies the pulses similar to those of the electric circuit model, as shown in Figure 3-2. Each of the sub-systems in the relevant node to disaster area network contains the components explained in Figure 3-4 [78]; the transport delivery time is similar to the Trans-delay in the electric circuit. The "Gain" components used in this simulation block model distribute the total pulse according the number of people affected in each node; this similar to the explanation regarding the current distribution in the parallel circuit shown in Figure 3-2.

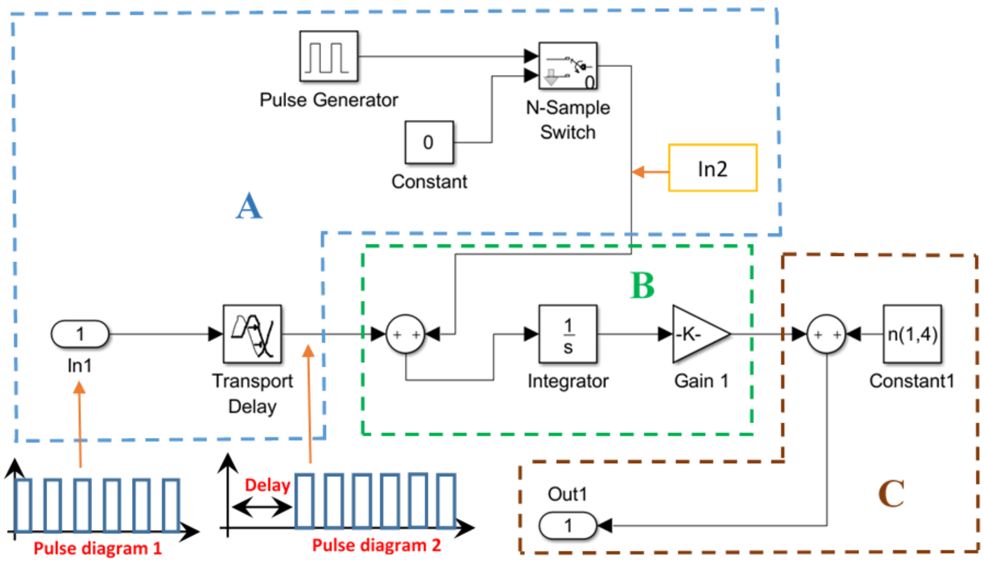


Figure 3-4. Basic sub-systemic logistic block model described by electric circuit [78]

Although the electric circuit model, as initially used, provided the information between the logistics chain and current flow in the electric circuit, the development of such electrical models is a complex process due to numerous disasters and branches/areas. Hence, this study opted to use the simulation platform of MATLAB®/Simulink to convert electric circuits to simple simulation block models.

Figure 3-4 shows the simulation block model developed using MATLAB®/Simulink library components for a single path from the DC to disaster area with relevant conversions. Section A in Figure 3-4 represents the supply of logistics to the disaster area using the pulse generator. The terms "In 1" and "In 2" represent inputs from the distribution/sub-DC and input of resources for the disaster area, respectively. The information regarding pulse amplitude, pulse width, and frequency corresponds to the information of truck capacity, loading and unloading times, and number of pulses, respectively. Because the Trans-delay in the electric circuit delays the pulse, transport delay is used to delay the pulses in the simulation platform. The integrator used in this model is similar to the combined components of C and RL in the electric circuit. Because the time limits of the integrator offset time calculations, Gain 1 is used to adjust the offset values and maintain flow behaviors within the same time domain. In addition, the MATLAB®/Simulink model was modified with components including an additional pulse generator and a constant (Constant1) to introduce an internal pulse generator and capacitor charge, respectively. In this model, "Switch" is used to terminate the distribution pulse after a certain time period or number of pulses.

3.2.3 Results and discussion

To understand the behavior of logistics flows through the electric circuit model, the centralized model is considered, as shown in Figure 3-2. The delivery time for each disaster area was estimated using the velocity along the path (set as 65 km/h) and the distance between the DC and disaster area. By determining the average storage capacity of trucks, 10000 L was assigned as the truck capacity. In addition, the ratio of the number of people in the disaster area to the total disaster-affected people was considered to determine the distribution of logistics to the disaster areas.

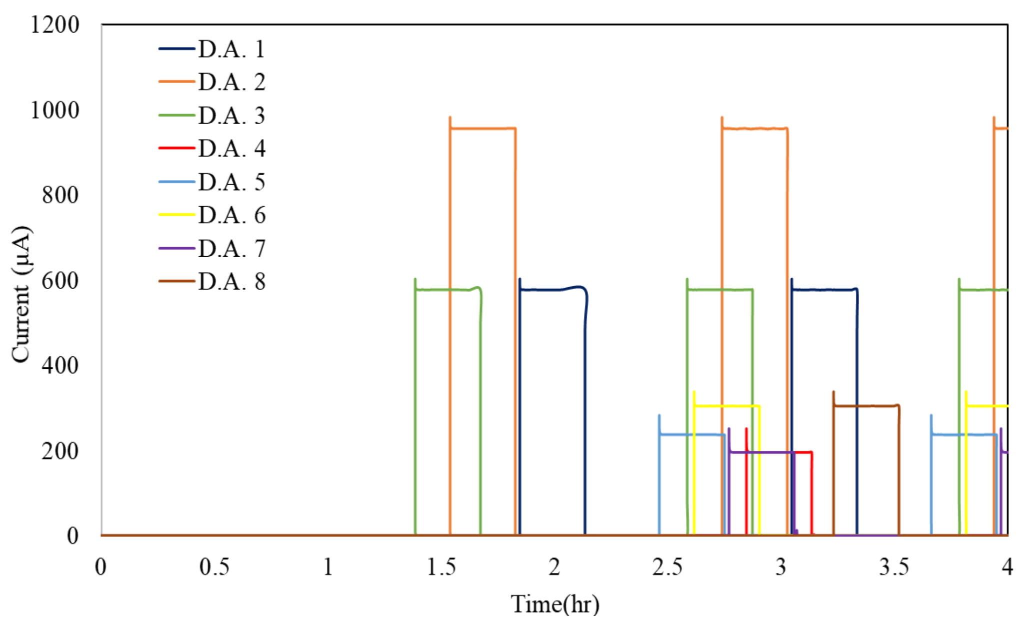


Figure 3-5. Pulse patterns obtained from the simulated electric circuit at R-down (branch/disaster area) [78]

Figure 3-5 shows the pulse amplitude for each of the disaster area (D.A.) with the pulse on time matching the theoretically expected amount of charge distributed to each area. The delay time of each pulse also matches the theoretically estimated values of delivery time for disaster nodes. These behaviors ensure the validity of the electric circuit model in describing the logistics behavior.

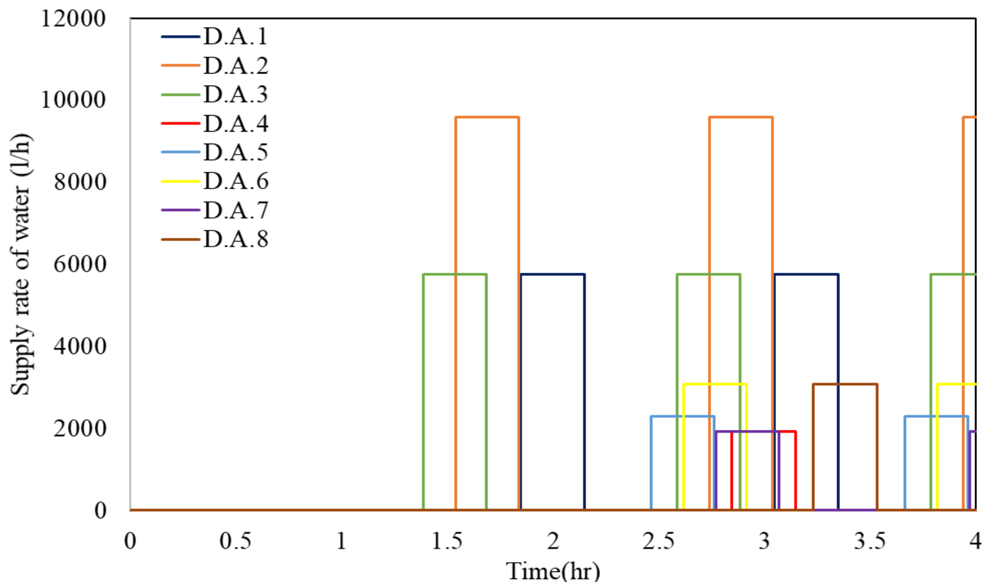


Figure 3-6. Pulse patterns obtained from the MATLAB®/Simulink for centralized model [78]

Figure 3-6 shows the pulse patterns obtained using the MATLAB simulation model. By comparing Figures 3-5 and 3-6, the amplitudes of pulse patterns are found to differ. However, the percentage of delivery to each node is similar in value considering the relationship in Eq. (3.5). Therefore, the amplitude of the current pulse at each branch and that of the total current pulses are replaced with the amplitude of water supply rate at each node and that of the water supply from the pulse generator (Figure 3-3), respectively.

To determine the validity of simulation, the theoretical values for the logistics model and simulated values of the electric circuit are calculated, as summarized in Table 3-1. For this analysis, the percentages of delivery to each node/branch are evaluated with respect to the maximum distribution pulse using Eq. (3.5):

$$Percentage\ of\ delivery = \frac{A_{branch}}{A_{total}} * 100 \tag{3.5}$$

Where, A_{branch} and A_{total} are the amplitude of the current pulse at a branch and that of the total current pulse from the pulse generator, respectively. The amplitude of the total current pulse was set as 3.33 mA with an on time of 0.3 ms. As summarized in Table 3-1, the percentage of delivery to each branch in one pulse in the electric circuit closely approximates the theoretical values.

To determine the percentage of delivery at each node, the ratio of the number of people in each node to the total number of people in the logistics model was used. The electric simulation values listed in Table 3-1 include the phase delay and amplitude of the simulated current pulse at each branch. These current pulses are plotted against time, as shown in Figure 3-5.

Table 3-1. Theoretical estimated values for logistics and simulated electric circuit [78]

Path of node	Theoretical logistics network					Simulated electric circuit (relate to Figure 3-5)		
	Distance from the distribution center (km)	Speed of truck (km/h)	Number of people	Transport delivery (hr)	Percentage from initial delivery (%)	Delivery time (ms)	Percentage of the amplitude of the received pulse	Amplitude of current pulse (µA)
DC-D.A.1	120	65	15000	1.8462	17.2	1.8462	17.25	574.44
DC-D.A.2	100	65	25000	1.5385	28.7	1.5385	28.73	956.71
DC-D.A.3	90	65	15000	1.3846	17.2	1.3846	17.25	574.44
DC-D.A.4	185	65	5000	2.8462	5.7	2.8462	5.72	197.14
DC-D.A.5	160	65	6000	2.4615	6.9	2.4615	6.91	230.01
DC-D.A.6	170	65	8000	2.6154	9.2	2.6154	9.19	306.03
DC-D.A.7	180	65	5000	2.7692	5.7	2.7692	5.72	197.14
DC-D.A.8	210	65	8000	3.2308	9.2	3.2308	9.19	306.03

Table 3-2. Comparison analysis of electric circuit model and MATLAB simulation model [78]

Number of disaster area (D.A.)	Electric circuit model		MATLAB simulation model	
	Amplitude of pulse (μA)	Percentage of delivery (%)	Amplitude of pulse (L/H)	Percentage of delivery (%)
1	574.44	17.25	5747.126	17.24
2	956.71	28.73	9578.544	28.73
3	574.44	17.25	5747.126	17.24
4	197.14	5.72	1915.708	5.747
5	230.01	6.91	2298.850	6.896
6	306.03	9.19	3065.134	9.195
7	197.14	5.72	1915.708	5.747
8	306.03	9.19	3065.134	9.195

The analysis results of the electric circuit model and MATLAB simulation model are summarized in Table 3-2. The table lists the matching percentages of delivery as well the amplitude of current values and those of the water supply rate at each node/branch. However, considering the area of pulses, the amount of charge carried by the pulse in the electric circuit model matches the amount of water carried by the pulse in the MATLAB simulation model. Therefore, the area under the pulse, which equals the amount of charge carried by the electric current pulse, is similar to the amount of water carried by the distribution pulse in the MATLAB simulation. With the correlation between electric charge flow and logistics flow, these results confirm that the electric circuit model matches the simulation block models. Further analysis was implemented to validate the match between the formulated simulation model and electric circuit. The output patterns observed from the electric circuit and simulation block models in each disaster area were compared. Figure 3-7 [78] shows the total amount of charge and water stored in each node/branch versus time in each disaster area for both models.

The voltage pattern measured in the capacitor of the electric circuit was converted to charge using $Q_{disaster\ area} = C_{disaster\ area}V_{disaster\ area}\ (C)$, where $Q_{disaster}$ is the amount of charge stored inside the capacitor with capacitance $C_{disaster\,area}$ under the applied voltage $V_{disaster\,area}$ of the capacitor. For this study, $1\ L = 1\ \mu C$.

The output pattern in Figure 3-7 shows that the electric circuit and simulation block models are identical. These observations confirm that the simulation model developed using MATLAB®/Simulink can be applied to replace the complex electric circuit. To validate their similarities, the delivery time of each concept was analyzed; Table 3-3 [78] summarizes the results.

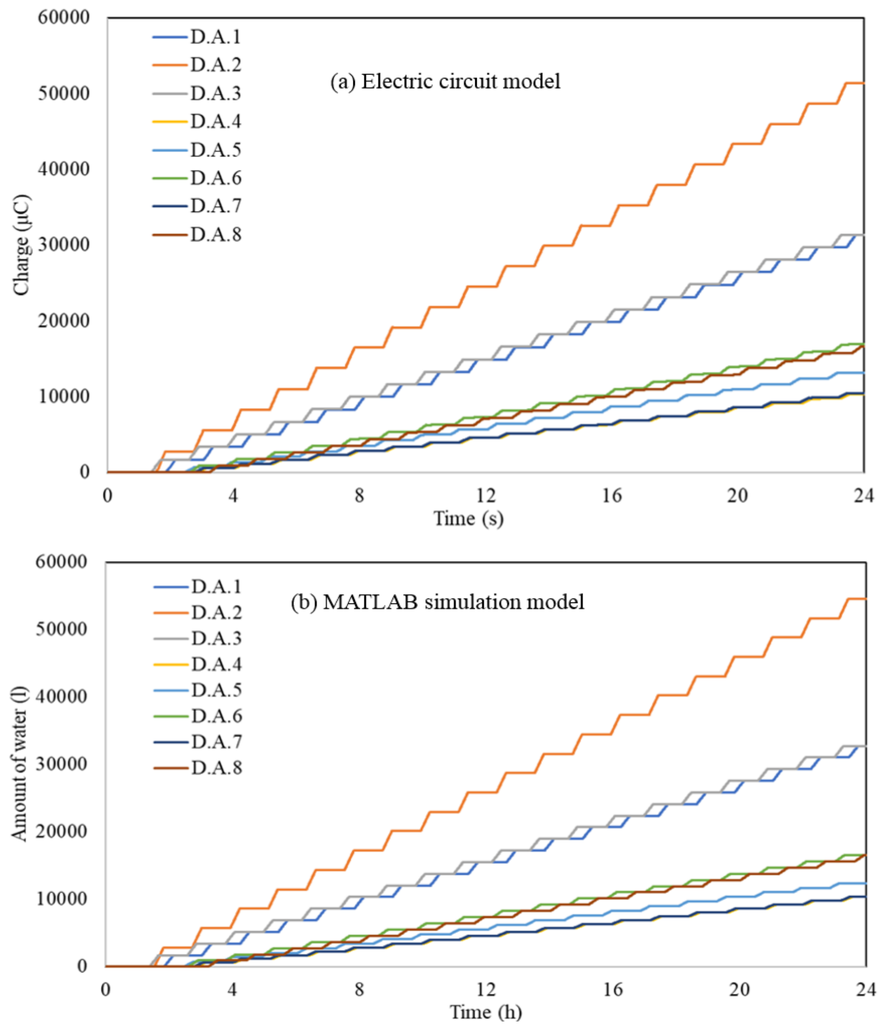


Figure 3-7. Cumulative storage pulse patterns obtained at the disaster area from the (a) electric circuit model (charge stored in capacitor), and (b) simulated block model (water stored in a tank) from the MATLAB®/Simulink for centralized model [78]

Table 3-3. Comparison of delivery times for logistics, electric circuit model, and MATLAB simulation model for centralized network [78]

Path of node	Distance (km)	Avg. speed of truck (km/h)	Total delivery time (1 hr = 1 ms)		
			Theory/ Logistics (hr)	Electric circuit simulation (ms)	Simulation model from MATLAB/Simulation (ms)
DC– D.A.1	120	65	1.846	1.846	1.846
DC– D.A.2	100	65	1.538	1.538	1.538
DC– D.A.3	90	65	1.384	1.384	1.384
DC– D.A.4	185	65	2.846	2.846	2.846
DC– D.A.5	160	65	2.461	2.461	2.461
DC– D.A.6	170	65	2.615	2.615	2.615
DC– D.A.7	180	65	2.769	2.769	2.769
DC– D.A.8	210	65	3.230	3.230	3.230

As listed in Table 3-3, the delivery times at each disaster node are the same for the logistics and electric circuit models. The delivery time for the logistics model was estimated using the theoretical logistics information. The pulse properties were used for the simulated electric circuit and MATLAB block diagrams.

Compared with the electric circuit model, the block simulation model results validly explain the logistics behavior. In disaster relief operations, the amount of disaster relief items distributed to victims depends on the number of people in disaster areas. Furthermore, the quantity of resources and initial storage in disaster areas is important to supply disaster relief items promptly and minimize the disaster’s impact. To optimize the available resources in disaster relief operations, the initial storage was simulated using a validated centralized management model. Figure 3-8 shows the impact of initial storage on the distribution of disaster relief supplies.

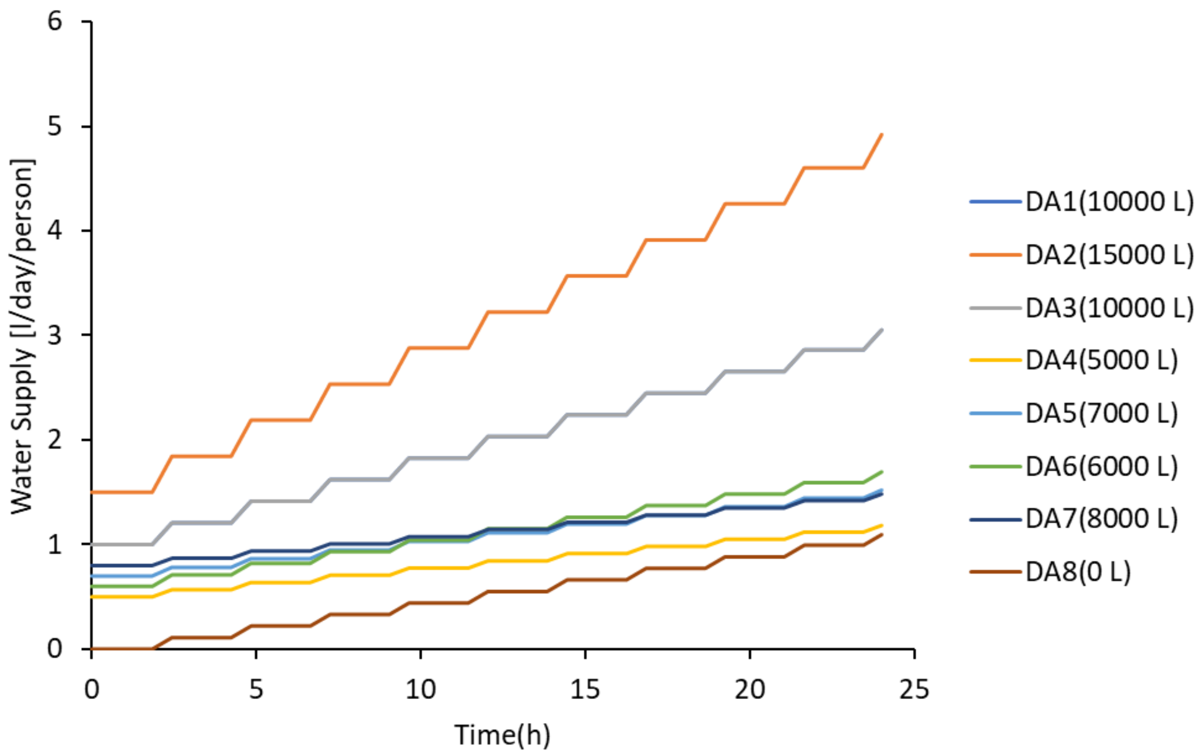


Figure 3-8. Simulation results of centralized model for initial storage

As shown in Figure 3-8, the availability of initial resource in disaster areas can support victims while they await the arrival of disaster relief items from central warehouses. By increasing the initial storage, the amount of resource that can be allocated per person can be increased. The simulation results shown in Figure 3-8 confirm that the placement of initial storage in the disaster area can eliminate delays in distribution. Moreover, the foregoing demonstrates that increasing the amount of initial storage increases the quantity of resource allocated to each person. These results verify that the developed block simulation model can represent the effects of the number of people and initial storage in the logistics network.

3.3 Modelling of block simulation for decentralized network

Modifying the logistics network from a centralized system to one that is decentralized introduces various advantages; for example, some of the areas are able to facilitate sub-distribution other than the central distribution. This section discusses the features of a decentralized network. In addition, the previously discussed centralize block simulation model is modified to incorporate the features of a decentralized network. The validation of decentralized logistics network and logistics parameters using the decentralized block simulation model is elaborated in this section.

3.3.1 Features of decentralized network

A decentralized network is a type of system that utilizes more than one DC in the logistics network. Compared with the centralized network, this system operates with several interconnecting nodes. Moreover, during a disaster, the features of decentralized networks support the formulation of efficient distribution systems. This network has advantages and disadvantages, as follows.

Advantages

- It increases the flexibility of the system because it employs more than one node for distribution.
- It enables the immediate delivery of required items to victims with critical demands.
- It provides the ability to test systems, products, markets, and suppliers on a small scale before full roll, thus allowing an organization to make better data-driven decisions.
- The system enables swift delivery to local addresses, thus increasing the trust between the supplier and customer.

Disadvantage

- The control of operations and culture can be disrupted by the nodes of the supply chain; this may not be relevant for outsourced decentralized supply chains.

3.3.2 Description of decentralized network by block simulation

As discussed in the previous section, the similarity between logistics flow and electrical current flow can be used to develop a logistics simulation model. Considering this formulation, the simulation model developed using MATLAB®/Simulink enables the conversion of logistics into an electric circuit for simulation with the possibility of adjusting the relevant logistics information for numerical execution. Accordingly, in this study, the behavior of the decentralized logistics network developed using MATLAB®/Simulink library is further analyzed.

Figures 3-9 and 3-10 [78] present the decentralized model in logistics and the corresponding electric circuit simulation block model [78], respectively.

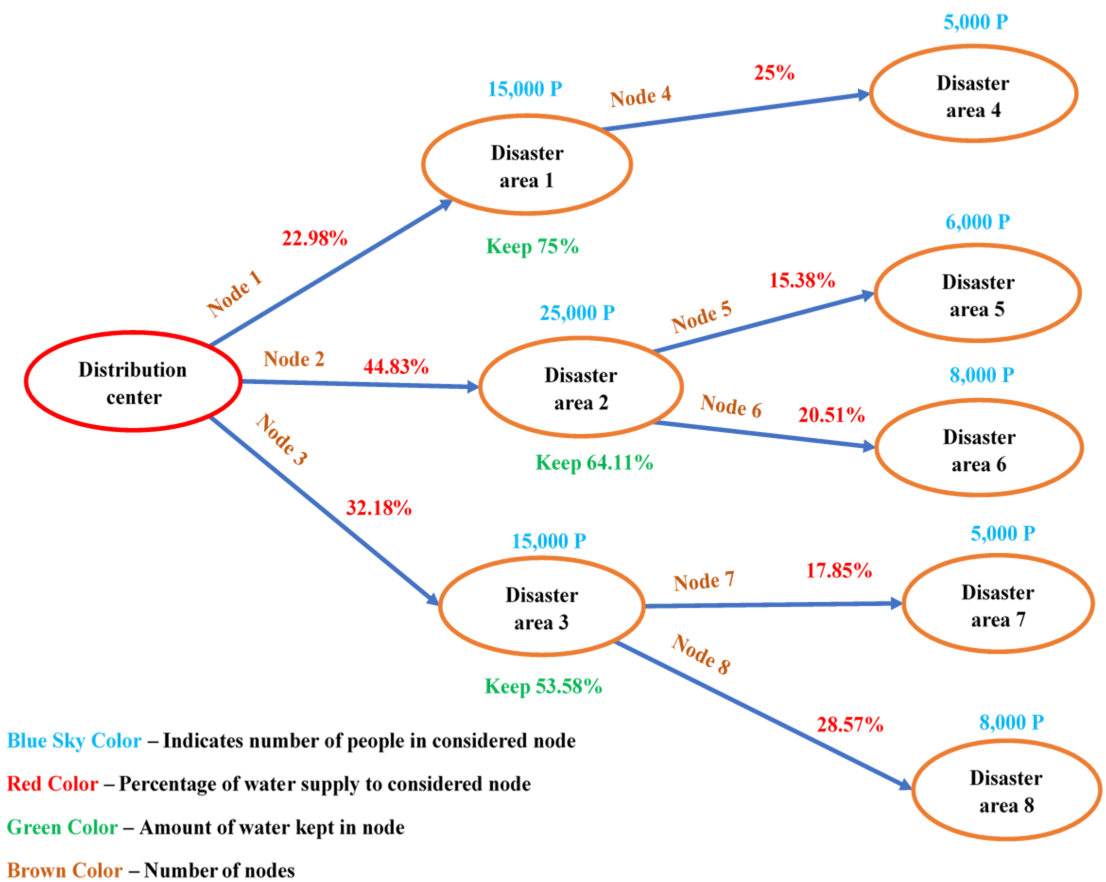


Figure 3-9. Decentralized logistics network model [78]

For this part of the study, disaster areas 1, 2, and 3 are regarded as areas with dual roles; they act as disaster-affected and sub-distribution areas to the next disaster area. Because the decentralized model has other available options for routing disaster relief items, the connections render the model more efficient in delivering supplies to the affected area. Moreover, each node (i.e., location) was assigned its own sub-distribution and storage options. The MATLAB®/Simulink electric circuit used for this model employs similar components for the centralized model. Disaster areas 1, 2, and 3 are the sub-DCs that can distribute drinking water to designated disaster areas. To detect the amount of water stored in the disaster area and that distributed to the next disaster areas as pulses, OUT 1 and OUT 2 are set in the simulation block model and used in the sub-systems, as shown in Figures 3-10 and 3-11, respectively.

As shown in Figure 3-9, the percentage of supply to disaster areas 1, 2, and 3 varies from that shown in Figure 3-1. This is because these nodes now play the dual role of disaster-affected area and sub-distribution area.

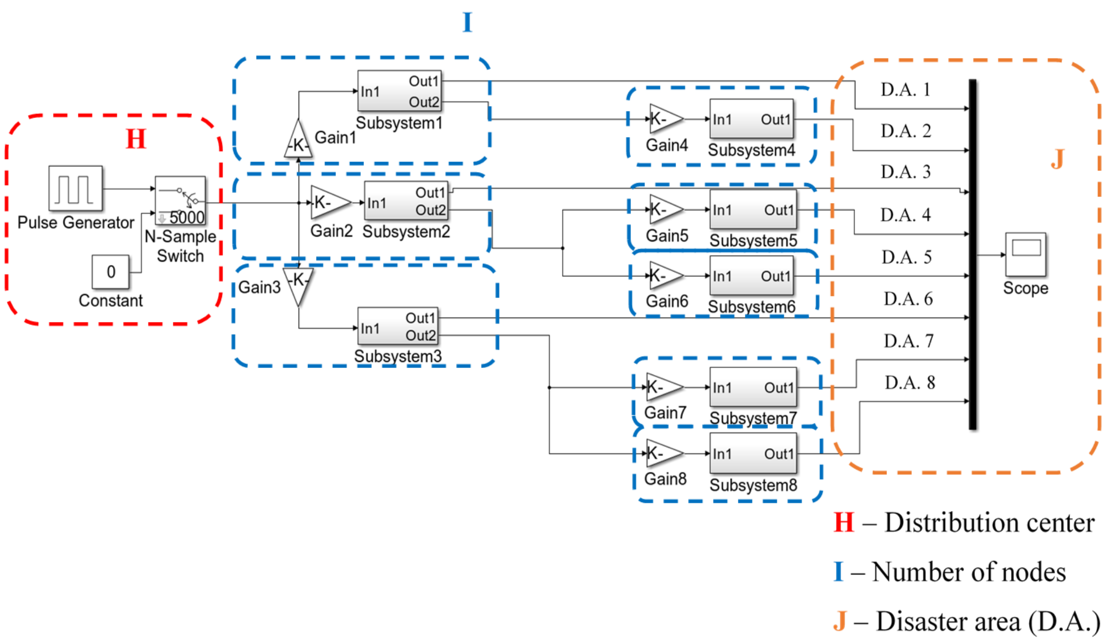


Figure 3-10. Simulation block model for decentralized logistics network using MATLAB®/Simulink [78]

The DC was defined considering the number of people affected along the distribution path. Nodes 1, 2, and 3 were also defined with percentage values accounting for the number of people related to each node. Considering these parameters, the developed simulation block diagram is shown in Figure 3-10. Numerical simulation was implemented for the decentralized model. The pulse pattern obtained from each node is shown in Figure 3-12 [78].

To develop the model, some of the disaster areas considered in the centralized logistics network to have the dual role of disaster area and DC had to be identified. This basis is included in the MATLAB®/Simulation block model, and the model shown in Figure 3-4 is modified to that shown in Figure 3-11 [78].

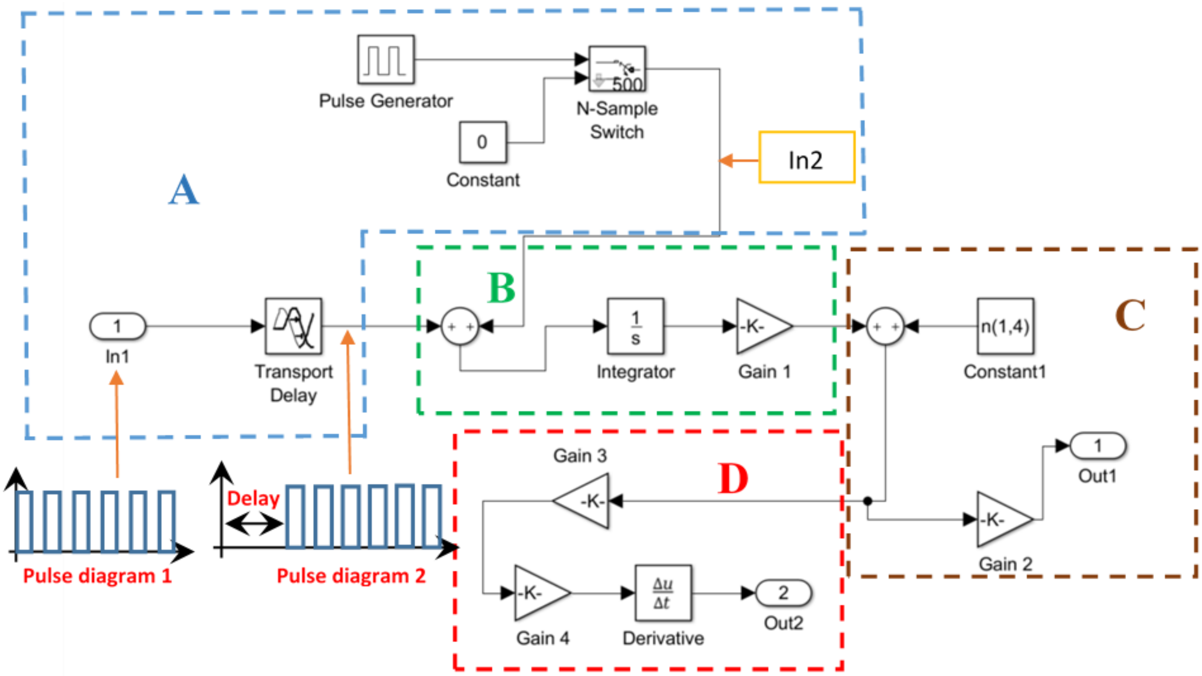


Figure 3-11. Basic distribution sub-systemic logistic block model described by electric circuit [78].

As shown in Figure 3-11, Figure 3-4 is modified to include an additional section (i.e., section D) to simulate the combined disaster area/distribution point described above. In section C, Gain 2 is introduced to assign the percentage of resource to be used by the disaster area.

The main objective of section D is to generate pulses similar to truck distribution with the defined parameter values. Because the distribution sub-system does not consume all resources, the addition of Gain 3 is used to define the percentage of delivery to the next disaster area. The added derivative component provides the means to reverse the integration process and pulse generation. Similar to the mismatch in the time domain discussed above, the pulse generated from the derivative component also has a mismatch in pulse width. Gain 4 was used to adjust the pulse width and compensate for the mismatch in the delivery to the next sub-system. With these modifications, the simulation models developed using MATLAB®/Simulink were used to observe and validate the similarity between logistics flow and electric circuit flow.

3.3.3 Results and discussion

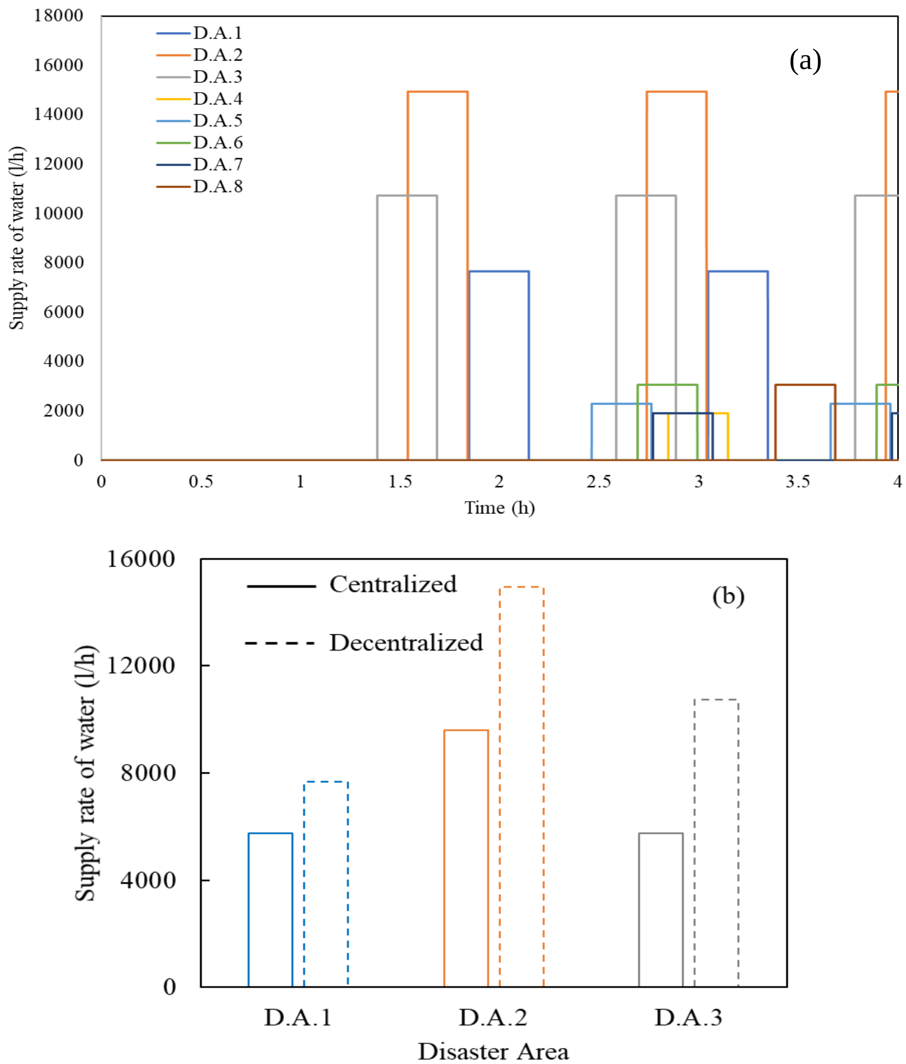


Figure 3-12. (a) Pulse patterns obtained from the MATLAB®/Simulink for decentralized model and (b) comparison of amplitude for D.A.1, D.A.2, and D.A.3 between centralized and decentralized model [78]

As shown in Figure 3-12(a), the amplitudes of pulses in disaster areas 1, 2, and 3 in the decentralized model are larger than those in the centralized model, as shown in Figure 3-12(b).

This change occurs because of the distribution of the total supply from the single DC to disaster areas 1, 2, and 3 for storage and further sub-distribution. Because these disaster areas play the dual role of disaster-affected and sub-distribution areas, they have a certain percentage of input to their designated disaster areas. Disaster areas 4–8 receive the same amount of supply compared with that of the centralized model. In addition, the transport delivery times for the theoretical and simulation models are similar. This information is summarized in Table 3-4 [78] for further reference.

Table 3-4. Comparison between theoretical calculation and simulation of decentralized model [78]

Path of node	Distance (km)	Avg. speed of truck (km/h)	Total distribution time (hr)		Amplitude of the pulse (L/hr)
			Theory	Simulation	
DC– D.A.1	120	65	1.8461	1.8461	7662.835
DC– D.A.2	100	65	1.5384	1.5384	14942.529
DC– D.A.3	90	65	1.3846	1.3846	10727.969
D.A.1– D.A.4	65	65	2.8461 (1+1.8461)	2.8461	1915.709
D.A.2– D.A.5	60	65	2.4614(0.9230+1.5384)	2.4614	2298.851
D.A.2– D.A.6	75	65	2.6922(1.1538+1.5384)	2.6922	3065.134
D.A.3– D.A.7	90	65	2.7692(1.3846+1.3846)	2.7692	1915.709
D.A3– D.A.8	130	65	3.3846(2+1.3846)	3.3846	3065.134

As listed in Table 3-4, the distribution times for disaster areas 1–3 are similar to those of the centralized model. The decentralized model maintains a direct connection between the main DC and nodes 1–3; hence, the values are similar in order. However, the route options for disaster nodes 1–3, and those for succeeding nodes 4–8 have different distances between two adjacent nodes compared with those of the centralized model; consequently, the distribution times vary.

Similar to the explanation in Section 3.2.3, the comparison of logistics patterns in Figure 3-12 with the data listed in Table 3-4 confirms the effectiveness of the block simulation model for representing the distributed logistics model. To derive an optimized logistics pattern, considering the amount of resources available for the disaster area and the number of disaster-affected people is important. However, different from the centralized model, three disaster areas become sub-distribution points in the decentralized model. The logistics behavior at these points using the decentralized block simulation model is shown in Figure 3-13.

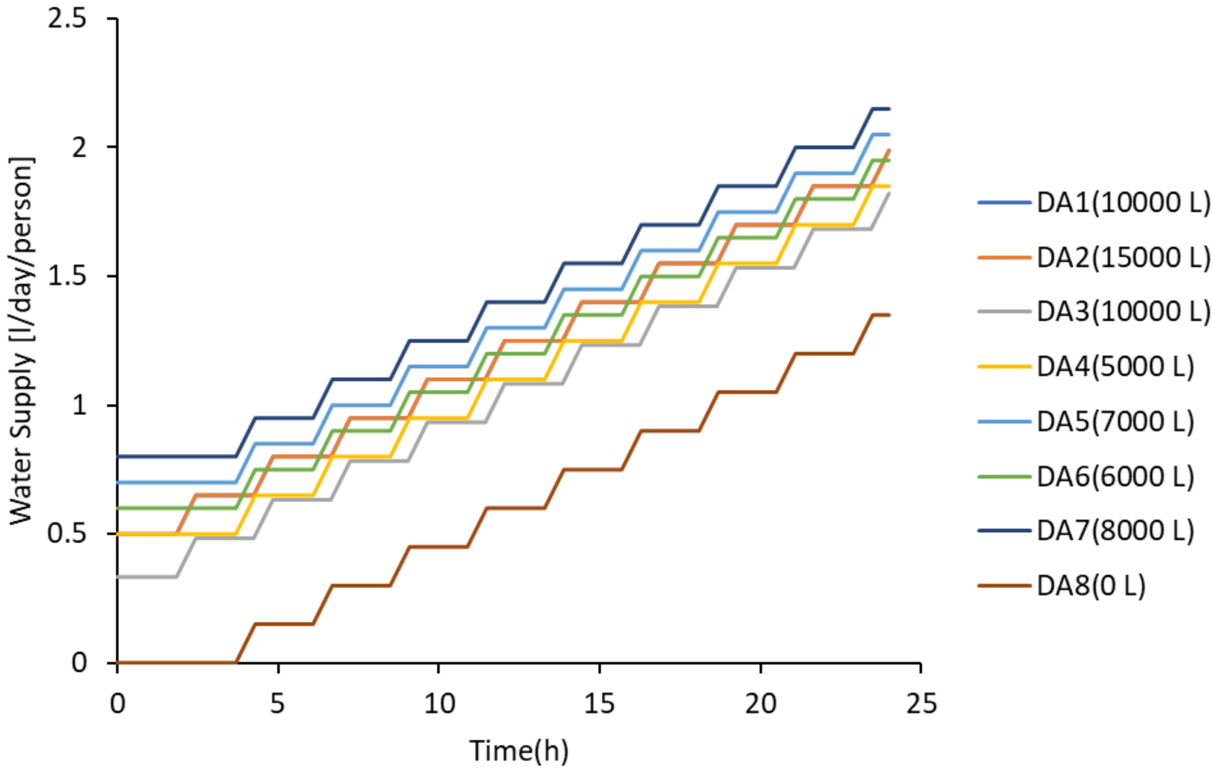


Figure 3-13. Simulation results of decentralized model for initial storage

The resources in areas with initial storage in the decentralized network that are similar to those in the centralized network can be immediately utilized to supply the disaster relief items while awaiting the arrival of more resources from the central distribution point. As shown in the simulation patterns in Figure 3-13, areas with initial storage can immediately distribute disaster relief items. Concurrently, areas without initial storage await distributions from the central warehouse. Therefore, the delay in response is more significant in disaster areas without initial storage. Furthermore, an increase in initial storage is expected to increase the quantity of resources provided during a disaster. Based on this information, the investigation of the conditions for initial storage based on the number of people using the distributed block simulation model was deemed necessary.

3.4 Modelling of block simulation for complex network

This section discusses the features of a complex logistics network system, which differs from previously discussed distribution systems. A complex network has a central location that can manage more systems than centralized and decentralized networks. In general, this network can be expanded over a wide area that is accessible to all concerned entities, allowing them to respond to the information in the system.

3.4.1 Features of complex network

The advantages afforded by the complex model are similar to those of the decentralized model. However, the former has more available routes to reach destinations; consequently, the time that elapses to send relief items to disaster-affected areas can be reduced. This network operates with numerous interconnecting nodes and route connections. It has the following advantages and disadvantages.

Advantages

- Delivery time is fast because the shortest route can be selected.
- Traffic congestion is reduced because the vehicle can travel via different routes to reach the same destination.
- Operating cost is reduced because route distance and travel time are reduced.

Disadvantages

- A satisfactory routing selection algorithm is required to achieve an efficient route.
- Because different routes are available, selected routes may have uncertain and uncontrollable risk factors.
- Complicated planning is required for sufficient quantities of relief items to reach their destination.

3.4.2 Description of complex network by block simulation

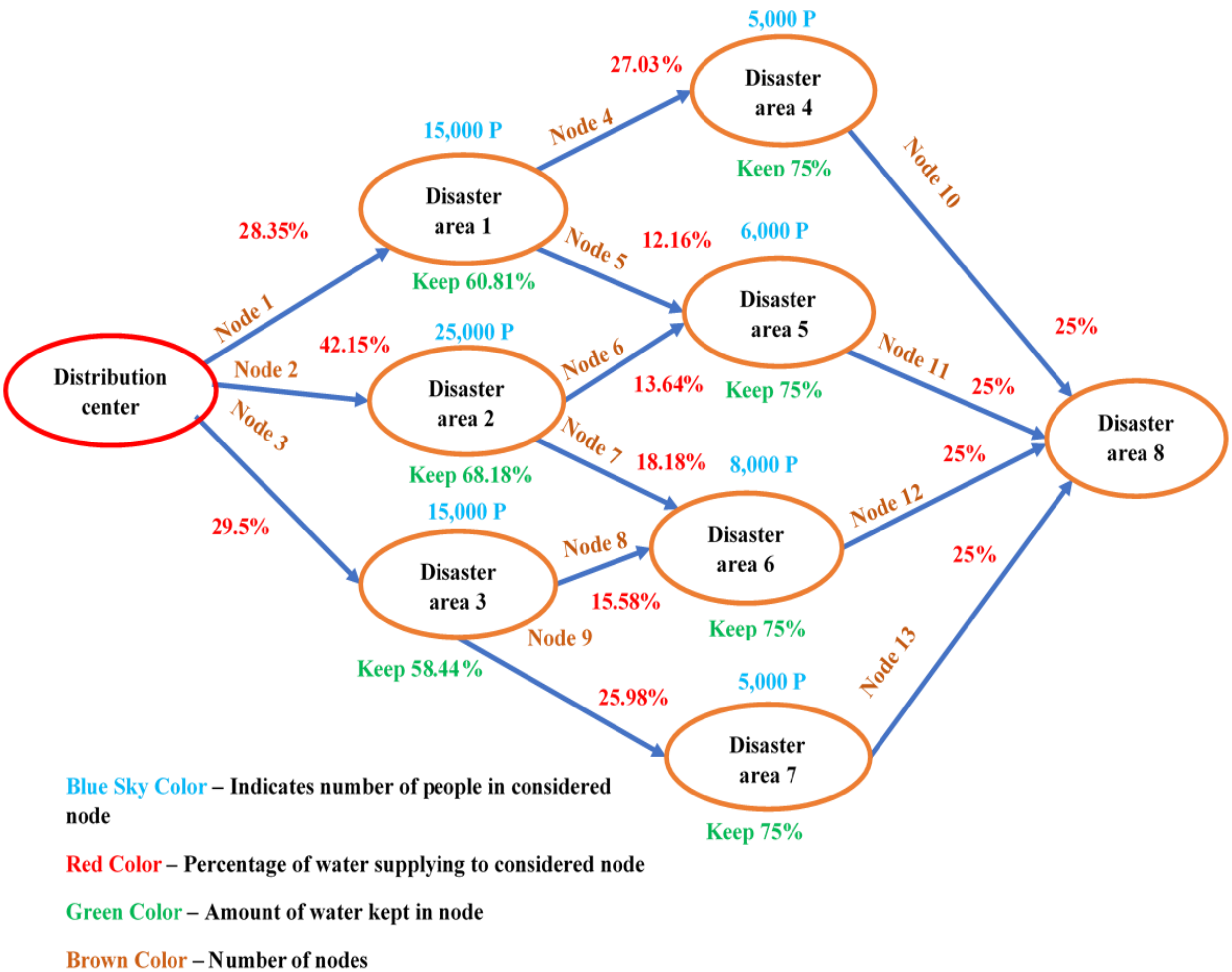


Figure 3-14. Complex logistics network model [78]

Figure 3-14 presents the complex logistics network used in this study to develop the MATLAB block simulation model. Because complex logistics structures contain one or more interconnections between two nodes, considering such information is necessary when developing a simulation block model. By considering the simulation blocks from the centralized and decentralized models, a complex simulation model is developed, as shown in Figure 3-15 [78].

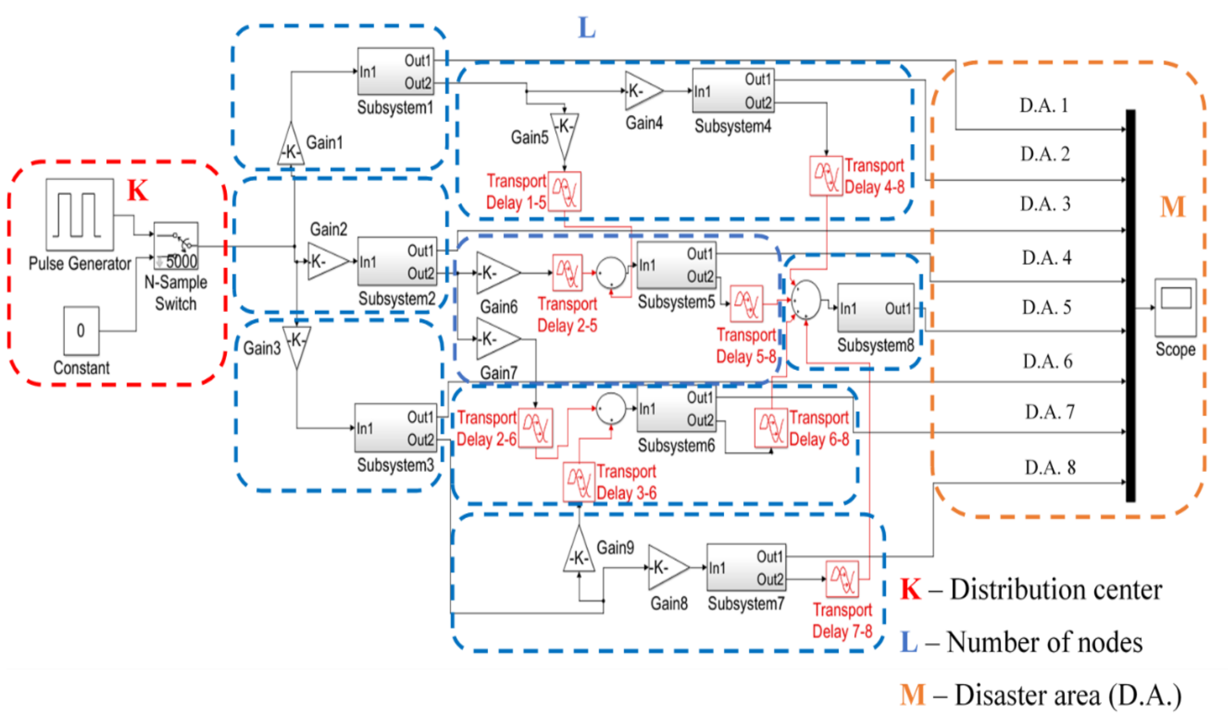


Figure 3-15. Simulation block model for complex logistics network using MATLAB®/Simulink [78]

As shown in Figure 3-15, extra time-delay components are introduced into the simulation block model for disaster nodes. These disaster nodes contain more than one interconnection between two disaster nodes. A numerical simulation is implemented for simulating the complex network using the block model shown in Figure 3-15.

3.4.3 Results and discussion

The supply pulse and total water supply in each disaster area are plotted, as shown in Figures 3-16 [78] and 3-17 [78], respectively.

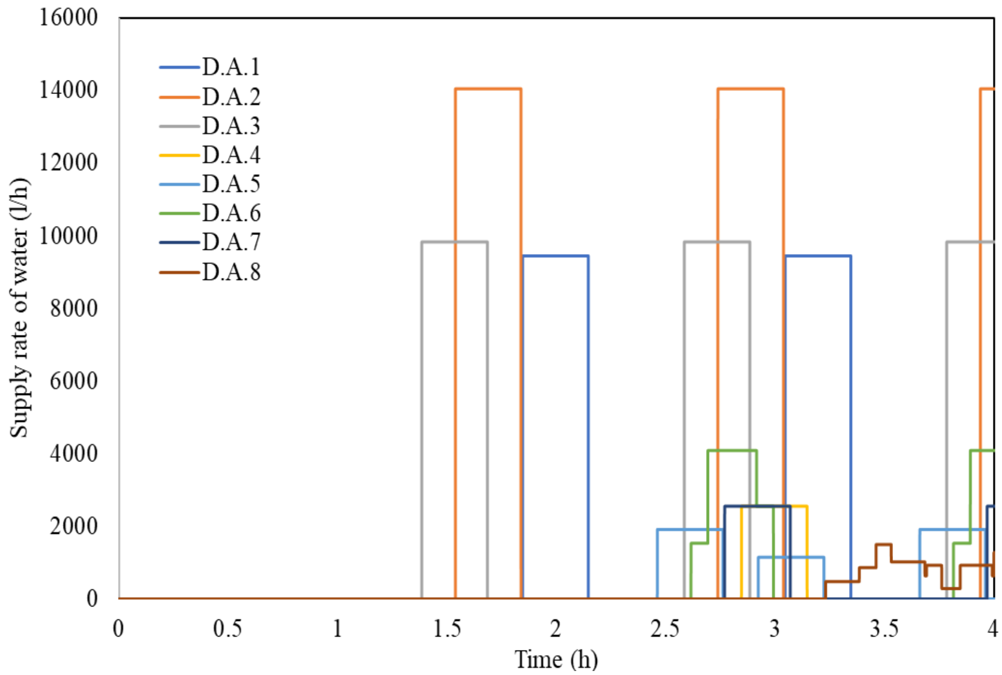


Figure 3-16. Pulse patterns obtained from the MATLAB®/Simulink for complex model [78]

As shown in Figure 3-16, the pulse shapes differ from the single pulse shape previously discussed for disaster areas 5, 6, and 8. This anomaly in pulse shape occurs due to the combination of more than one pulse with different distribution delays in the considered routes. Recall that the number of people in each distribution line serves as a benchmark in deciding the percentage of distribution to each node. The area of each pulse must represent the amount of supply distributed according to the number of people. Such analysis is implemented to validate the model; results are shown in Figure 3-17.

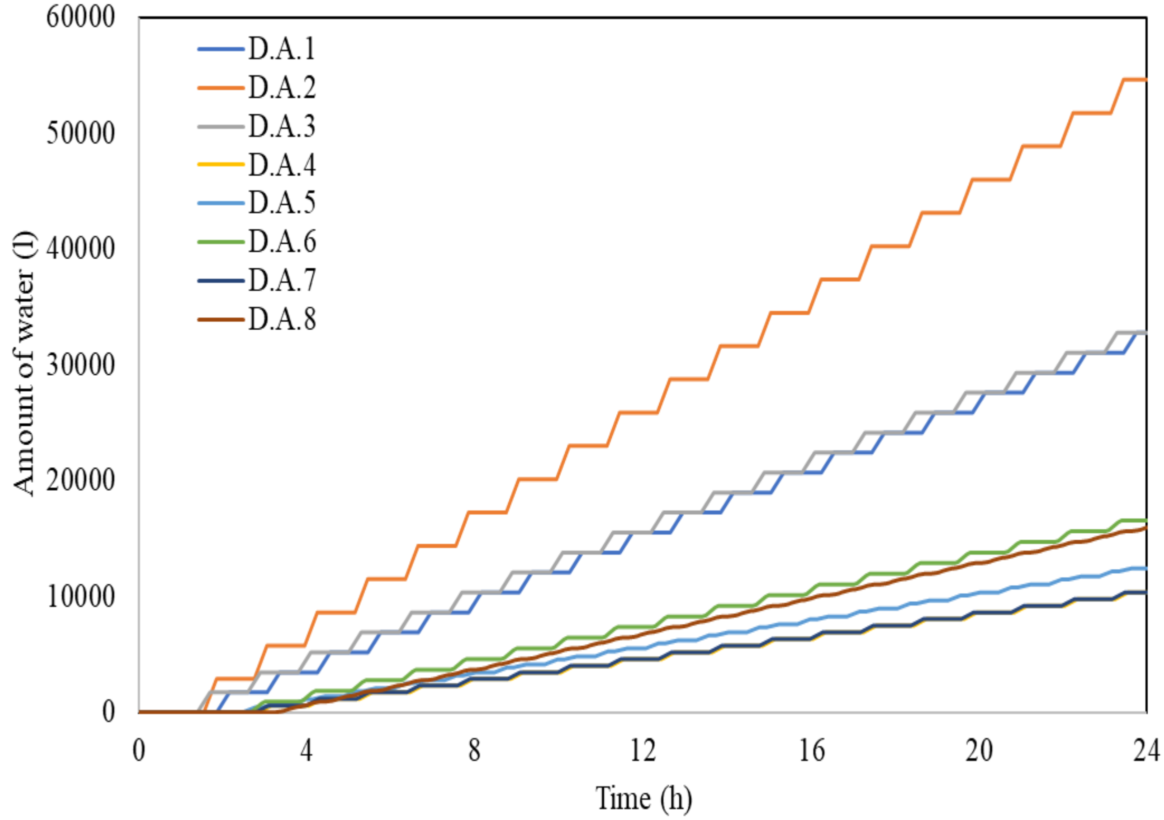


Figure 3-17. Cumulative storage pulse patterns obtained at the disaster area from the simulated block model (water stored in a tank) from the MATLAB®/Simulink for complex model [78]

As shown in Figure 3-17, the total amount of supply after 24 h for each disaster area node is similar in value to that shown in Figure 3-7(b) of the centralized model. However, the distribution pattern changes for nodes 5, 6, and 8 due to the combination of input pulses from different sub-distribution nodes. This information is summarized in Table 3-5 for further reference.

Table 3-5. Comparison between theoretical calculation and simulation of complex model [78]

Path of node	Distance (km)	Avg. speed of truck (km/h)	Total delay time (hr)		Amplitude of the pulse (L/hr)
			Theory	Simulation	
DC – D.A.1	120	65	1.8461	1.8461	9450.574
DC – D.A.2	100	65	1.5384	1.5384	14049.042
DC – D.A.3	90	65	1.3846	1.3846	9833.716
D.A.1– D.A.4	65	65	2.8461(1+1.8461)	2.8461	2554.302
D.A.1– D.A.5	70	65	1.0769	1.0769	1149.378
D.A.2– D.A.5	60	65	2.4614(0.9230+1.5384)	2.4614	1915.761
D.A.2– D.A.6	75	65	1.1538	1.1538	2554.475
D.A.3– D.A.6	80	65	2.6153(1.2307+1.3846)	2.6153	1532.507
D.A.3– D.A.7	90	65	2.7692(1.3846+1.3846)	2.7692	2554.306
D.A.4– D.A.8	75	65	1.1538	1.1538	638.671
D.A.5– D.A.8	50	65	3.2306(0.7692+2.4614)	3.2306	766.284
D.A.6– D.A.8	50	65	0.769231	0.76923	1021.841
D.A.7– D.A.8	70	65	1.076923	1.07692	638.671

The theoretical values summarized in Table 3-5 are estimates based on available logistics information. In contrast, the simulation values are obtained from the distribution patterns of MATLAB block simulation.

Similar logistics patterns are shown in Figure 3-17, and the comparison of data summarized in Table 3-5 validate the block simulation for the complex model. As discussed in Sections 3.2.3 and 3.3.3, the optimization of the amount of resources distributed to disaster areas depends on the available initial storage and number of people. To obtain the simulated logistics behavior with these points, a validated block simulation model is employed as a complex model; the logistics behavior is shown in Figure 3-18.

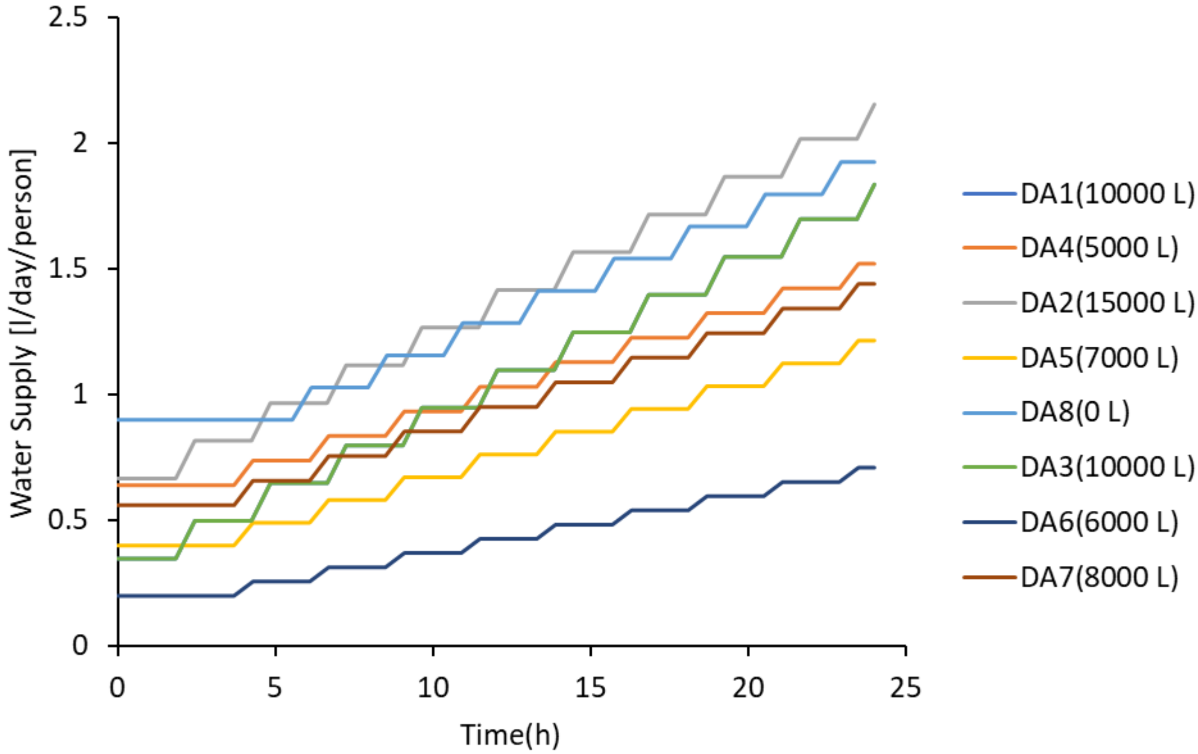


Figure 3-18. Simulation results of complex model for initial storage

Similar to the discussion on the initial storage condition for centralized and decentralized networks, the complex model is expected to affect the initial storage. Disaster areas with initial storage are expected to supply resources immediately while awaiting the arrival of additional resources from the central warehouse. According to the simulation pattern shown in Figure 3.18, areas with considerable initial storage can promptly supply disaster relief supplies. In addition, areas with larger initial storage can provide more resources during the disaster. Accordingly, the block simulation model evolves into a complex model that can investigate the logistics parameters of initial storage and number of people.

3.5 Conclusion

In this study, the behavior of a logistics network using electric circuits considering their similarity is investigated and validated. For this purpose, the logistics water supply flow as electric charge flow was considered. General electric circuit components, such as resistors, capacitors, pulse generators, and transport delays, were used to develop an electric circuit to represent the logistics network. The electrical components were connected to represent the main components of disaster relief logistics network, specifically DCs, distribution nodes, and disaster areas. To reduce the complexity of the electric circuit model, especially for developing large and complex logistics, the circuit was converted into block-circuit models using MATLAB®/Simulink library. A basic logistics network for centralized, decentralized, and complex scenarios were developed and simulated in this study.

The simulated results for electric circuits and simulation block models were observed to be similar in shape to the theoretical logistics values. The analysis of the delivery times of transported disaster relief goods and electrical pulses is similar to those of all logistics-similar simulation block models.

Decentralized and complex logistics models utilized some of the nodes with dual roles: disaster area and sub-distribution node. This causes a change in the amplitude of input pulses. However, these dual-mode nodes distribute a percentage of what is received considering the number of people in the distribution path.

The study demonstrated that the same amount of supply can be provided to all disaster areas regardless of the logistics model used. This confirms that the behavior of a logistics supply chain can be simulated using an electric circuit model.

Although this section of the study has focused on validating the similarity between logistics flow and flow of charge in electric circuits, only a single power supply unit is used in the electric circuit model. However, the study has demonstrated that electric circuits with more than one power supply units connected in series or parallel can be designed as electric circuits representing decentralized and complex logistics networks. The addition of extra power supplies can be used further when developing the connection networks of DCs.

The development of an electric circuit model with numerous paths is possible through the block simulation model. However, developing such an electric circuit model using electric components has its limitations. The inclusion of additional distribution paths in the electric circuit causes changes to the node and overall impedance values. Changes in the number of available paths to single node also affects node impedance. Consequently, balancing the impedance in such cases using the electric circuit model may be difficult.

Chapter 4

Cooperation between single third-party logistics and government for emergency disaster in Thailand

4.1 Introduction

Disasters cause severe devastation, economic drawbacks, and considerable toll on human lives [57] [81] [82] [83]. All governments appreciate the importance of disaster management in restoring social and economic conditions. In general, disaster management comprises three phases: pre-disaster preparation, emergency response during disasters, and post-disaster relief operations [5] [82] [84] [85] [86]. Although these phases are not considered individually, the emergency response during a disaster is crucial for saving human lives. Accordingly, the efficient implementation of disaster relief operations in this phase is an important aspect that must be thoroughly evaluated. The responsibilities involved in the emergency response phase include search and rescue, provision of emergency medical care and shelter, and logistics to aid disaster-affected individuals to survive [83] [87] [88]. The speed of this phase determines the impact of the disaster on the economy and people's livelihood. Recent studies on disaster relief operations found that the impact of a disaster can be reduced while maintaining basic humanitarian operations with the involvement of government authorities through private–public partnership [89] [90] [91] [92] [93] [94] [95] [96].

Countries worldwide design their own disaster management mechanisms after considering their local topography, resources, and policies. Thailand is one of the developing countries that has been confronted with considerable economic drawbacks due to the occurrence of disasters in the past few decades [97] [98] [99] [100]. Thailand has experienced a number of disasters, such as cyclones, droughts, earthquakes, floods, and landslides, depending on the geographical features of the region. Thailand is located in Southeast Asia, which is adjacent to the Pacific Ocean and Indian Ocean, and has been frequently ravaged by cyclones from these oceans through flooding. In addition, the aftermath of these disasters have been observed to severely affect other regions. Many people suffer due to the impact of disasters. Hence, identifying solutions that can alleviate such suffering is necessary.

In Thailand, disaster management is implemented according to the following organizational structure. It is led by the Thai central government (GOV) represented by the Prime Minister and the Minister of Interior. To support people in disaster areas, the local government (LGOV), experts, and military commanders manage and provide the necessary action plans. However, the efficiency of the disaster relief operations led by GOV is observed to be low due to mismanagement, inadequate resources, and lack of coordination. As a result, to manage emergencies, disaster relief operations have been supported by donations from the general public and foreign sources [97] [100] [101]. In addition, the collection of disaster relief items and their transport to disaster-affected areas have been observed to last longer than the emergency responses of developed countries, such as Japan [102] [103].

The study conducted of Banomyong *et al.* [14] suggested that the use of third-party logistics providers, such as department stores, can reduce the response time in such cases. Although such measures reduce the response time, the coordination of several department stores during a disaster may also be more time-consuming.

The selection of specific department stores for providing the necessary items can be a complicated process because these resources must be moved to coordination areas for disaster relief distribution. Considering such conditions, the selection of a single department store dedicated to emergencies is expected to further reduce the response time for implementing disaster relief operations. Thailand can exploit the services of various department stores and chains [104] [105] [106] [107] [108]. Accordingly, this study proposes the use of a third-party logistics provider to cooperate with the government during emergencies. In Thailand, employing a single third-party logistics provider may be advantageous. For example, 7-Eleven has a wide coverage and is found throughout Thailand. Its inventory movement, number of outlets, and especially its numerous regional DCs (RDCs) are spread over numerous routes throughout Thailand. Moreover, the company's available product lines suitable for disaster relief operations cover a wide range. The company has its own transport vehicles traversing the country throughout the year that can also be used as distribution sources for disaster relief operations. Furthermore, the logistics structures of 7-Eleven are easily found through various channels; this can facilitate the analysis of the company's impact. Such a partnership between government and third-party logistics service providers for disaster relief operations is expected to provide mutual benefits. From the private organization's perspective, the company is afforded publicity at zero marketing cost along with opportunities to further expand their market share. In contrast, the government can focus on devising and implementing mechanisms for avoiding disasters, saving lives, and rebuilding the infrastructure instead of preparing disaster relief items.

In this study, the importance of employing a single third-party logistics provider for disaster relief operations instead of coordinating more than one entity is analyzed. The implementation of disaster relief operations in the emergency response phase to identify the current response time for such operations in Thailand was considered. Three scenarios were examined: the government involvement alone, the government working with third-party logistics providers, and the coordinated operation of third-party providers without government participation. To understand their impact on the disaster relief response time, the evaluation process was separated into two parts: the pre-transport process of disaster relief items and actual transportation process.

4.2 Disaster background of Thailand

Countries bordering the Pacific Ocean, such as Japan, Indonesia, and Philippines, are susceptible to natural disasters (e.g., floods, landslides, tsunamis, and wildfire) due to their geographical location. In Southeast Asia, floods frequently occur mainly during the monsoon and tropical storm seasons. Thailand is one of the countries in Southeast Asia that is vulnerable to disasters, such as floods, because of its proximity to the Pacific Ocean and Indian Ocean. In Thailand, the destruction caused by floods generally affects many areas [97] [109]. However, the relief operations in this country during disasters do not result in the expected outcome because of several reasons.

According to the research presented in Chapter 3, the distribution of relief items to different locations can reduce the response time of disaster relief operations. In developing countries, the inventories of the government and government-owned warehouses typically indicate the lack of resources, whereas third-party logistics providers are regarded as well-resourced and functioning. This chapter presents the improvement in the operational efficiency of government-led disaster relief activities coordinated with third-party logistics service providers considering Thailand as a case study.

The reasons for choosing Thailand as the case study in the formulation of a disaster relief plan for a developing country are as follows.

- Thailand is a developing country that frequently experiences flooding.
- Thailand has no adequate disaster relief infrastructure.
- Thailand has many third-party logistics service providers, which can be investigated and compared.
- Information on third-party logistics service providers, including their processes, can readily be obtained from Thailand's information center.

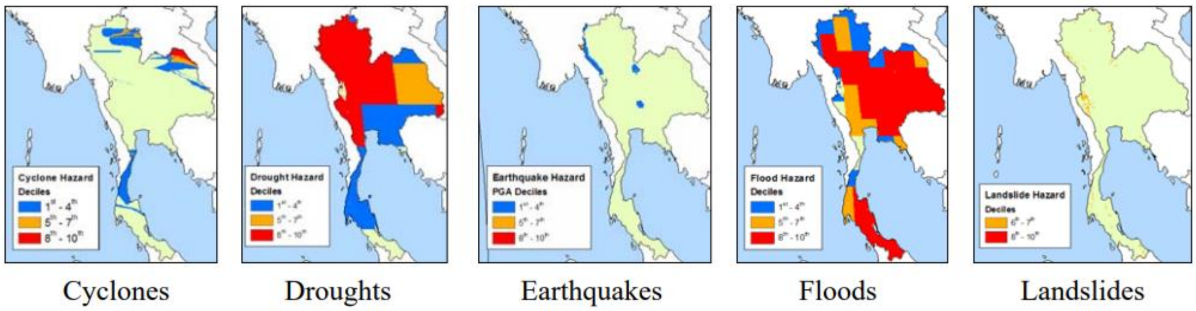
Therefore, understanding the background of disasters in Thailand aids in identifying the impact of disaster relief on areas experiencing the protracted effects of disasters. In particular, the information gained can be used to improve the current disaster relief efforts in Thailand. Accordingly, this section presents an overview of Thailand's geography, its disaster vulnerability, and current disaster management process.

4.2.1 Geographical viewpoint in Thailand

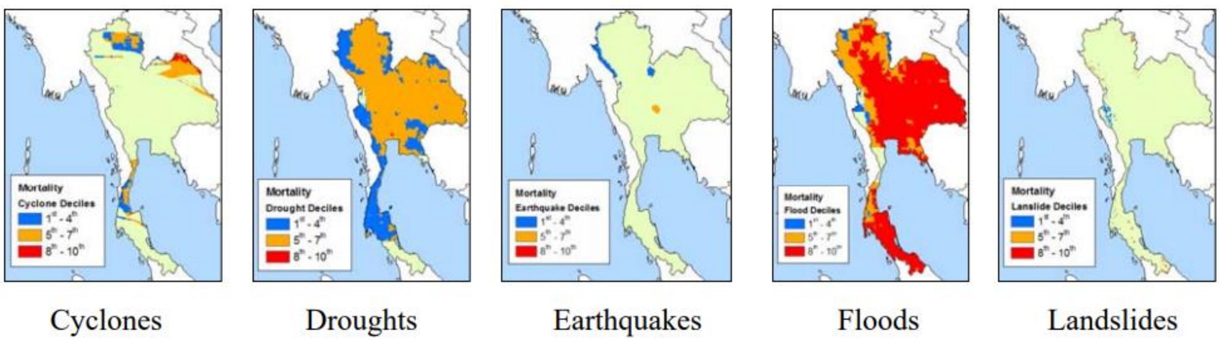
Figure 4-1. Geographical of Thailand [97] [110]

Thailand is located in Southeast Asia, bordering the Andaman Sea and the Gulf of Thailand. The country comprises 76 provinces, which are divided into 878 districts (amphoe), 7255 rural administrative subdistricts (tambon), and 74965 villages (mooban). Its population is approximately 66 million [111]. Its neighboring countries include Burma, Cambodia, Laos, and Malaysia, as shown in Figure 4-1 [97] [110] [112]. The geography of Thailand consists of a mountain range in the west and a southern isthmus that joins the landmass with Malaysia. The government system is a constitutional monarchy; the chief of the state is the king, and the head of government is the prime minister. Thailand has a mixed economic system with a variety of private freedom combined with centralized economic planning and government regulation. Thailand is a member of the Asia-

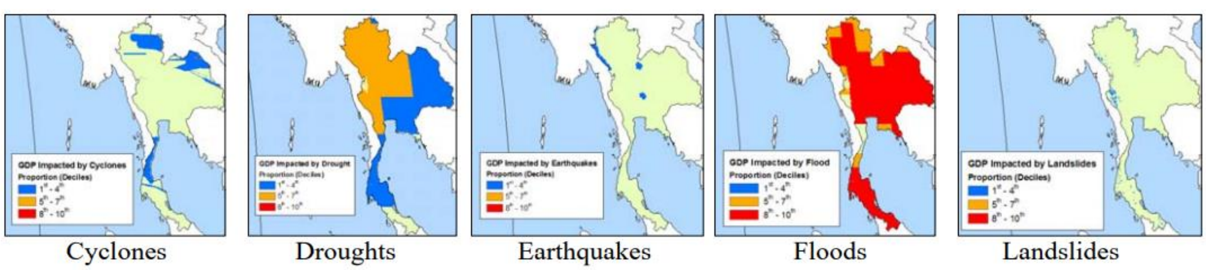
Pacific Economic Cooperation and the Association of Southeast Asian Nations [97] [110] [111] [113].



Natural Disaster Risk Hotspots (a)



Natural Disaster Risk Hotspots (Weighted by Mortality) (b)



Natural Disaster Risk Hotspots (Weighted by Proportion of GDP Impacted) (c)

Figure 4-2. Disaster risk hotspot in Thailand with difference estimation [114]

Droughts and floods are the foremost threats to Thailand, affecting the entire country with varying degrees of risk. The entire country is severely affected by floods when weighed in terms of mortality and GDP, whereas droughts are only ranked in the low to moderate deciles. Cyclones also pose as a minor risk to the northern portions of the country. The multi-hazard disaster risk maps shown in Figure 4-2 [114] indicate that Thailand is extremely affected by hydrological and drought events, particularly in the central, eastern, and southern regions [97] [111].

Typhoons are likely to occur in the northern and southern parts of Thailand that have close proximity to the Pacific and Andaman Oceans. Droughts usually occur in the landlocked regions, mainly in the central and northern parts of Thailand. Earthquakes are less likely to occur in Thailand mainly because the country has no active volcanoes and few fault lines. Floods are extremely common events in Thailand due to its geographic location, which annually experiences heavy monsoon rains [115].

Thailand is currently a developing country. Many of its management approaches are not top-level and therefore expected to have low efficiency. Thus, over the years, several natural disasters have caused considerable suffering to the Thai people. Several regions in Thailand do not have proper disaster management protocols. Consequently, these regions are unprepared for and vulnerable to disasters, leading to the unnecessary loss of human lives and damage to economy.

Data on the loss of human lives due to various types of disasters are summarized in Table 4-1; cyclones and floods are evidently the most dominant types of disasters. Table 4-2 lists the frequency of different disaster types from 2005 to 2010. The information summarized in both tables indicates that the most dominant disaster that suddenly occurs and severely affects human well-being is flooding.

Table 4-1. Summary of natural disaster types and its aftermath [114]

Disaster	**Number of Events**	**Total Killed**	**Avg. Number of Killed**	**Total Affected**	**Avg. Number of Affected**
Cyclone	23	1,468	64	3,167,905	137,735
Drought	4	0	0	13,500,000	3,375,000
Earthquake	1	0	0	0	0
Flood	47	2,427	52	27,193,357	578,582
Volcano	-	-	-	-	-

EM-DAT Information (1901-2004):

Table 4-2. Frequency of natural disasters between year 2005-2010 [116]

year	Disaster type	Frequency	Killed	Injured	Total affected	Damaged (Baht)	Damaged (USD)
2010	Flood	7	266	1,665	13,485,963	16,388,772,341	536,577,088
	Drought	n/a	0	0	4,077,411	1,415,223,466	46,476,961
	Cold Spell	n/a	0	0	10,609,301	n/a	n/a
	Storm	2,192	30	174	407,271	198,845,340	6,530,244
	Fire	1,903	29	83	8,912	1,283,787,066	42,160,494
2009	Flood	5	53	22	8,881,758	5,252,613,976	172,499,637
	Drought	n/a	0	0	17,353,358	108,346,716	3,558,184
	Cold Spell	n/a	0	0	10,588,881	n/a	n/a
	Storm	1,348	24	26	360,154	207,373,975	6,810,311
	Fire	5,127	83	312	6,549	817,334,839	26,841,866
2008	Flood	6	113	16	7,921,127	7,601,796,302	249,648,482
	Drought	n/a	0	0	13,298,895	103,900,841	3,412,178
	Cold Spell	n/a	0	0	9,554,992	n/a	n/a
	Storm	1,995	15	30	242,944	227,549,741	7,472,897
	Fire	1,696	30	92	8,392	1,424,889,050	46,794,385
2007	Flood	13	36	17	2,326,179	1,687,865,982	55,430,738
	Drought	n/a	0	0	16,754,980	198,304,732	6,512,470
	Cold Spell	n/a	0	0	5,910,339	n/a	n/a
	Storm	2,233	10	71	245,619	234,547,154	7,702,697
	Fire	1,901	45	156	9,761	875,791,793	28,761,635
2006	Flood	6	446	1,462	6,050,674	9,627,418,620	316,171,383
	Drought	n/a	0	0	11,862,358	495,275,738	16,265,213
	Cold Spell	n/a	0	0	2,303,703	n/a	n/a
	Storm	1,883	29	39	142,849	92,244,108	3,029,363
	Fire	1,734	37	66	9,708	1,083,845,622	35,594,273
2005	Flood	12	75	0	2,874,673	5,982,283,276	196,462,504
	Drought	n/a	0	0	11,147,627	7,565,861,139	248,468,346
	Cold Spell	n/a	0	0	3,742,793	n/a	n/a
	Storm	1,313	13	0	61,429	148,871,750	4,889,055
	Fire	1,559	48	68	23,250	931,101,005	30,580,985

4.2.2 Disaster management in Thailand

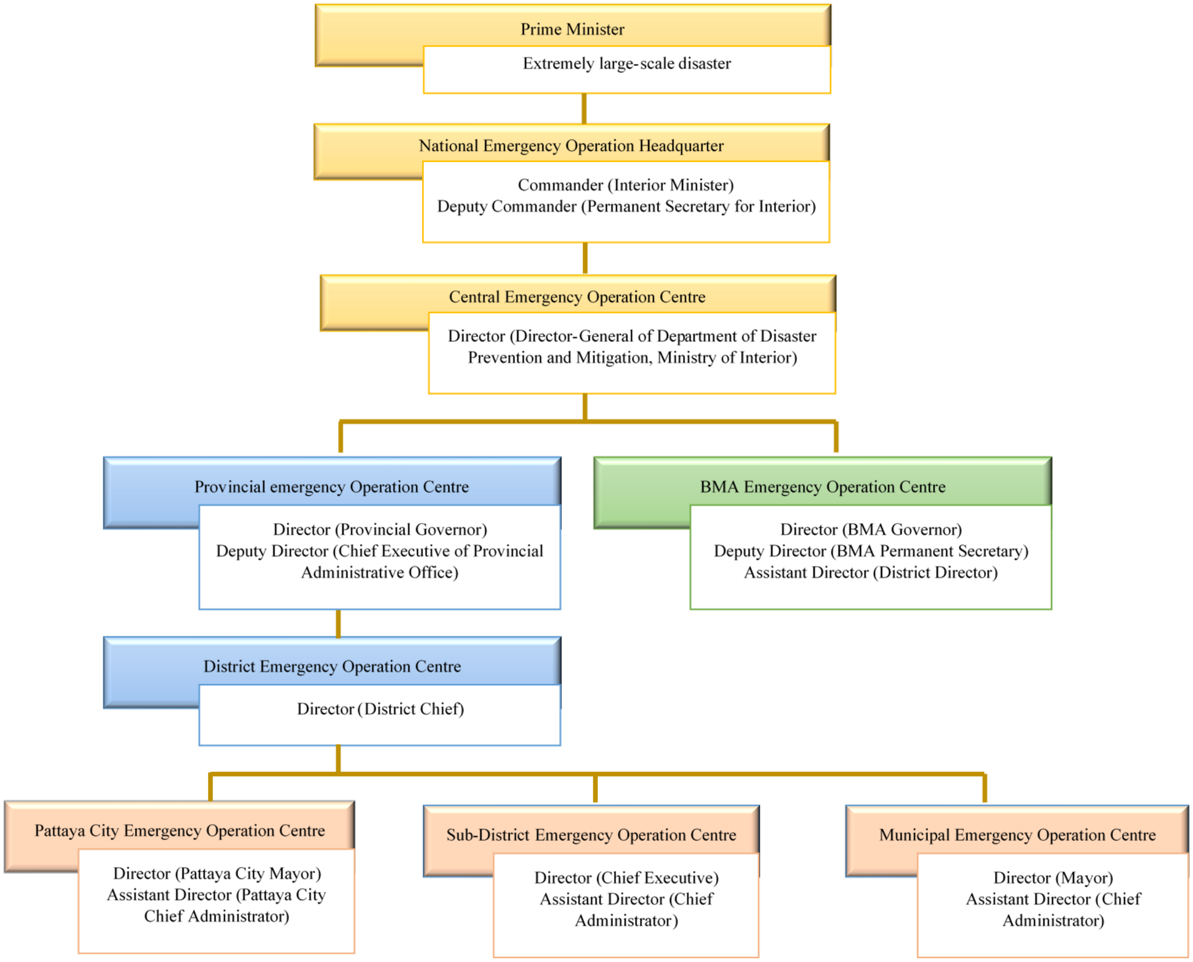


Figure 4-3. Structure for disaster management in the Thailand [97]

Over the past few decades, Thailand has experienced an increase in disasters and their damage, particularly natural disasters, such as floods, droughts, and fires [111]. To cope with these disasters, save lives, and protect the economy, the government of Thailand implements disaster relief operations through the Department of Disaster Prevention and Mitigation (DDPM) formed under the Disaster Prevention and Mitigation Act 2007 [117]. Under this Act, the National Disaster Prevention and Mitigation Committee (NDPMC), headed by the Prime Minister with the Minister of Interior and supported by experts including military commanders, is established to monitor disasters and devise as well as implement necessary action plans [117]. Under the leadership, sub-committees are also formed to oversee different tasks and perform smooth and well-coordinated disaster relief operations. Similar to the NDPMC, an additional committee (called Provincial DPMCs) is organized to coordinate all disaster relief operations at the provincial level [117]. During the emergency response phase, the main tasks of these committees are to assess the situation, prepare the necessary logistics, clear the transport routes for delivering logistics, prepare shelters for affected people, and transport disaster relief items. An overview of the hierarchy of the disaster management process is shown in Figure 1-7.

In developing countries, such as Thailand, the inadequacy of coordination between government agencies and resources can delay disaster relief operations, and the lack of infrastructure prevents the effective implementation of such operations [14] [118] [119]. Such situations were observed in the 2004 tsunami and 2011 floods. Accordingly, the assistance of non-government organizations, such as the Thai Red Cross, plays a major role in relief operations. However, because these non-government organizations do not have the necessary information regarding the impact of the disaster, their performance was also affected [115] [116] [118] [120] [121].

4.2.3 Disaster relief operations in Thailand

The framework of disaster relief in Thailand may not be functioning up to the satisfactory level to accomplish rescues and disaster relief operations. However, the government of Thailand has already rendered their best possible performance in disaster relief operations based on the defined strategies and policies of the state. The existing logistics network of Thailand is presented in Figure 4-4 [122].

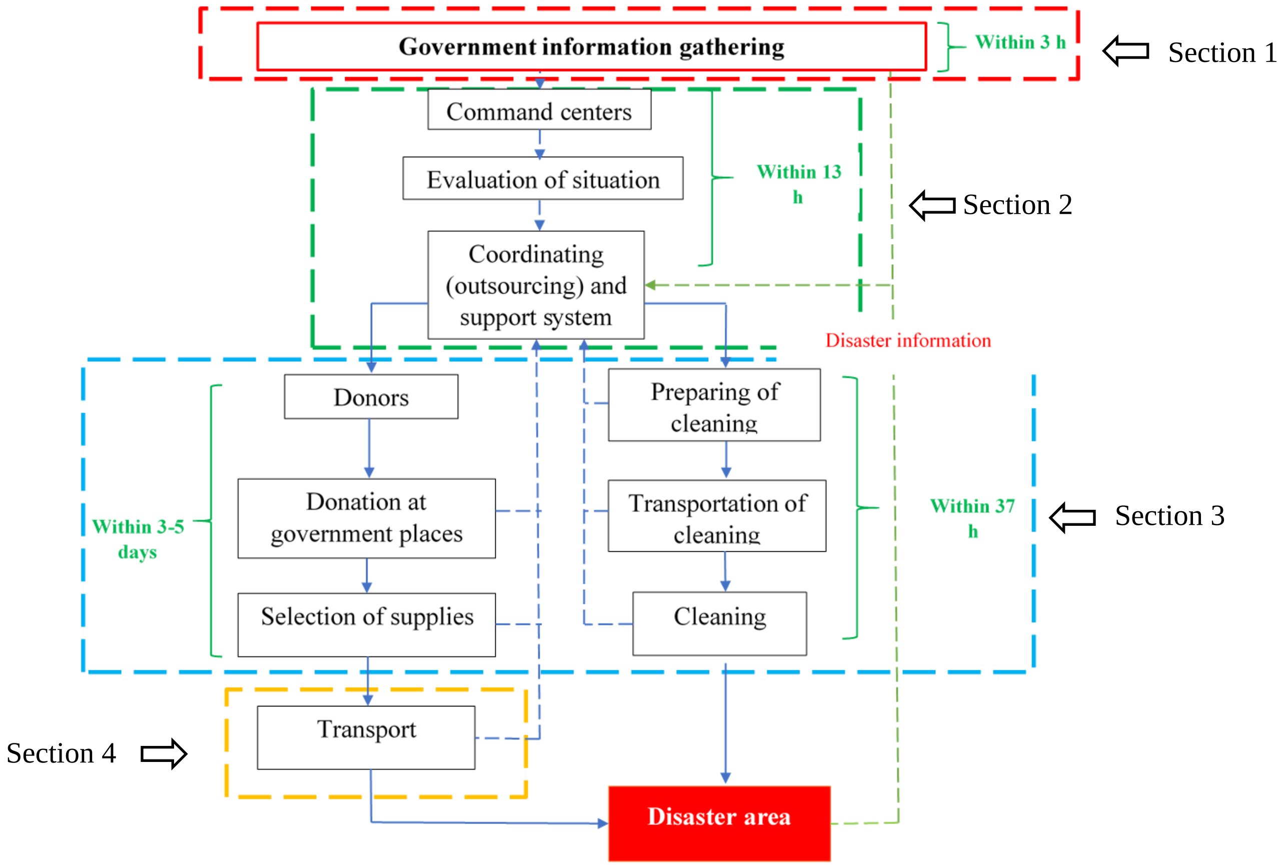


Figure 4-4. Disaster relief operation model for Thailand [14] [122]

As shown in Figure 4-4, the disaster relief process consists of four main sections. In the first phase, the government gathers information about the disaster and evaluates its impact. The requirements that must be included in these operations are determined according to the situation to enable affected areas to cope with the disaster. Typically, this process requires approximately 3 h to complete.

Then, for the next 13–22 h, the government and other first aid agencies coordinate their missions to prepare disaster relief items. Concurrently, government-led units, such as the military, fire departments, and local government infrastructure agencies, coordinate with the government to conduct the rescue missions and distribution of disaster relief items. This process requires the preparation of transportation networks or creating temporary routes if direct transport networks are damaged. Based on the analysis of previous disaster relief operations, an average of approximately 37 h is necessary to accomplish these tasks, as shown in Figure 4-4.

Depending on the scale of the disaster, the government and/or non-government agencies spends 3–5 d in preparing disaster relief items. This is due to the lack of immediately available resources for relief operations. As a result, the action of the government to transport and distribute disaster relief items is delayed, and the requirements of disaster-affected areas are not satisfied.

To improve the efficiency of disaster relief operations in Thailand, a study conducted by Banomyong *et al*. [14] suggests the incorporation of third-party logistics service providers in the current logistics model. Incorporating department stores as third-party service providers for the preparation process of disaster relief items is expected to reduce the processing time by up to 2 d. The main reason for this anticipated improvement is that, different from the government, these service providers have available resources.

The cooperation with such providers can benefit government operations in disaster relief. For example, the government does not have to maintain stores or inventories of logistics that can be quickly moved. Moreover, the transportation services of these providers can be immediately dispatched for rapid response.

A model of such cooperative disaster relief operations for Thailand is presented in Figure 4-5 [14]. Nevertheless, although the preparation of disaster relief items through third-party outsourcing can reduce the response time, such coordination is difficult to achieve without a proper mechanism. Accordingly, coordinating with a single third-party logistics provider instead of cooperating with many providers may solve this problem. By considering its operation mechanisms and resources, 7-Eleven in Thailand has the ability to single-handedly coordinate the third-party disaster relief operations for Thailand over other third-party logistics providers [104] [123] [124]. Moreover, 7-Eleven dominates the market share in logistics services and has numerous regional DCs throughout Thailand.

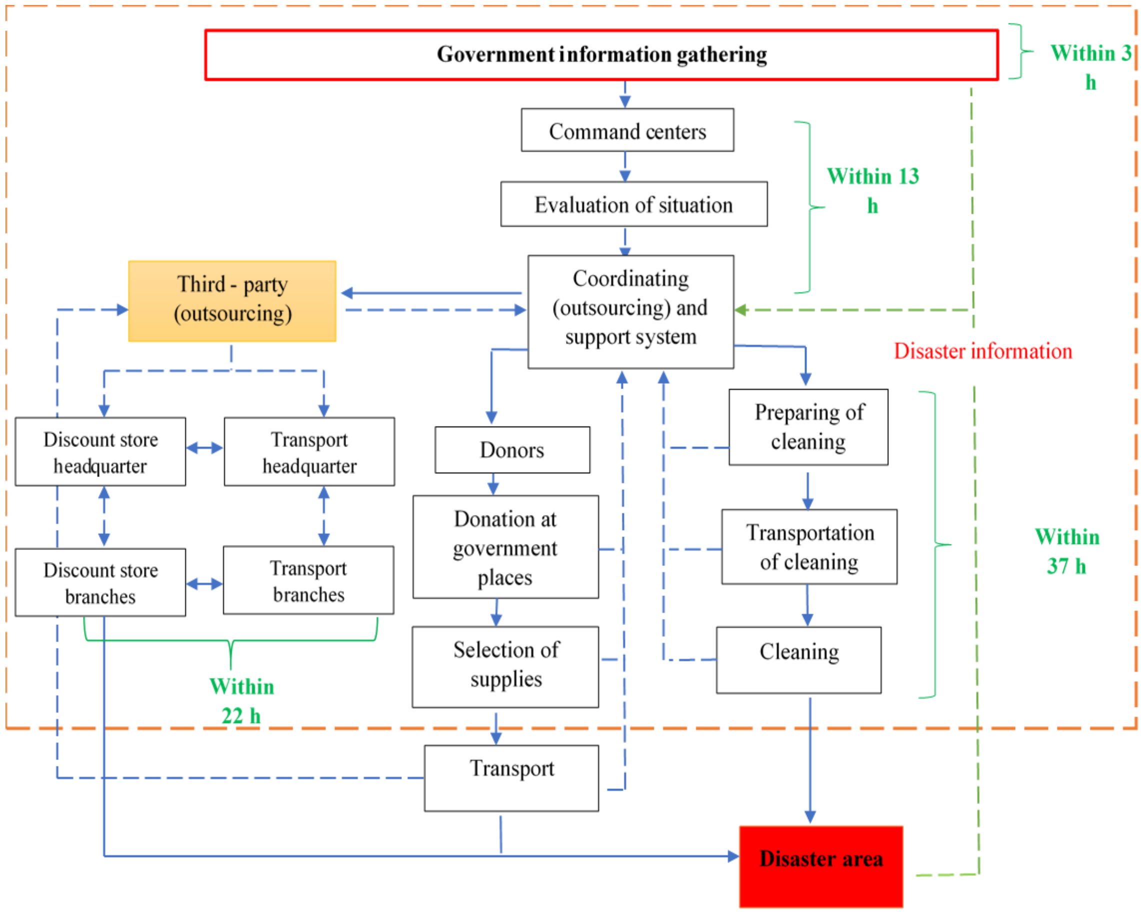


Figure 4-5. Proposed model for disaster relief operations in Thailand using linkages with third-party logistics providers [14] [122]

Considering these options for disaster relief operations, a case involving government and LGOV participation and the outsourcing of logistics services to a single third party is examined. The investigation was conducted by dividing the operations into two parts (pre-transport and transport) to identify their significance. The first part includes the span of time that elapses from the occurrence of a disaster through the logistics preparation to the distribution process. The second part determines the amount of time consumed in transporting disaster relief items, as listed in Table 4-13. To identify the distribution patterns and their processing times, logistics flow is simulated in the investigation [74] [78].

4.3 Third-party logistics in Thailand

Disaster relief can assume many forms, including transporting water and food for disaster victims, securing shelters, and providing relief to disaster victims. This study focuses on transporting goods, which is a considerable problem during disasters. Governments are the primary resource providers in disaster relief efforts, although they may not have sufficient resources to implement these promptly. In this regard, Table 4-3 summarizes the advantages of the government and third-party logistics providers in supporting disaster operations in Thailand.

Table 4-3. Comparison between the government and third-party logistics in Thailand

The government in Thailand	**Third-party logistics in Thailand**
- Lack of logistics management personnel with knowledge and capabilities at both operational and planning levels	- Third-party logistics provider have both logistics network and item readily available
- Less of logistics service providers	- Good management and infrastructure (truck, distribution center (DC), employee)
- Problems in transportation infrastructure and commercial facilities	- Have the large market share in Thailand
- Establish government policies without any basic or preparation in each area.	- DC/RDC location all over Thailand
- Does not have existing logistics network for disaster area	- International connection

In Thailand, some transport agencies can be used as third-party logistics service providers to specific sub-DCs. These centers can be used to provide rapid response in disaster relief operations.

As summarized in Table 4-4, a single third-party logistics provider, i.e., CP Group with 7-Eleven, the largest private company in Thailand, dominates the convenience store market and has the largest number of stores in Thailand.

As listed in Table 4-5, with 7-Eleven having most number of stores in Thailand, its convenience stores can be found even in remote areas of the country. Therefore, collaborations with such stores can be advantageous during emergencies. Convenience stores are more effective than other logistics companies, such as DHL and Fed Ex. Convenience store chains have their own logistics supply chain network and are well-stocked with essential commodities in times of disaster.

Table 4-4. Convenience store distribution in Thailand

Convinience Store	Number of store	MarketDomination (%)
7-Eleven	8000	66
Tesco Express	1580	13
Family mart	1139	9.5
Mini Big C	641	5.3
Jiffy	151	1.2
Select	76	0.63
Tops Daily	65	0.54
AT mart	23	0.191
108 shop	338	2.8

Table 4-5. 7-Eleven convenience store distribution in Thailand

Region	Numbers
North	731
South	1280
East	1231
Central	2884
West	447
Isan (north east)	1377

Based on the information listed in Tables 4-4 and 4-5, 7-Eleven is deemed to be an effective single third-party logistics service provider in Thailand in the early stage of disasters. This organization and other companies have their own distribution networks and provide logistics services throughout Thailand; this is a positive point considered in the investigation. By employing third-party services, the government can use the logistics networks of these companies to respond to disaster relief situations as quickly as possible. The following are some of the advantages and disadvantages of including a single third-party logistics provider, such as 7-Eleven, in planning and implementing disaster relief operations.

Advantages

- Faster response time: Convenience stores have a more efficient and proven logistics system that can likely outperform a temporary logistics network established by the government.
- Improved response efficiency: By utilizing an efficient logistics network, the overall response efficiency can be increased.
- More lives may be saved: The improvement in response efficiency could save more lives during disasters because some of the relief items critical for human survival are available.
- Reduced management responsibilities: When responsibilities are delegated to many parties, the management tasks of which each party is involved are also reduced.
- Availability of inventories and distribution networks: Different from other logistics companies, such as DHL, UPS, or FedEx, which do not process logistics relief items, convenience stores, such as 7-Eleven, have both relief items and effective logistics distribution network.

Disadvantages

- Providing sufficient disaster relief resources and managing distribution during large-scale disasters may be difficult.
- Miscommunication or changes in government policies may affect coordination.
- The involvement of many parties in disaster relief operation may lead to misunderstanding among relevant parties if their responsibilities are not properly defined.
- The involvement of third-party logistics service providers with disaster-affected victims at the grassroot level may create doubts in their involvement and that of the government during disasters.

4.4 Material and method

In this study, the impact of employing a single entity, such as 7-Eleven, to support Thailand's emergency response operations is investigated. The methodology described in this study is based on the data derived from the latest available datasets over the last 10 years. The information was evaluated to define the infrastructure of the simulation model used in this study. The simulation model is employed to analyze and estimate the response time in the transportation phase of the disaster relief operation. The following thoroughly describes the data collection phase and the implementation technique applied to achieve the objectives of this study.

4.4.1 Data collection

Disaster-related data from 2010 to 2019 for Thailand were collected [125] [126] [127] [128]. These data were analyzed to identify parameters, such as disaster scale, high-risk areas, frequency of disaster occurrence in such areas, number of people affected by the disaster as well as their demands, and government response during disaster relief operations.

The statistical information from these data was used as input parameters in our block simulation model [74] [83] to simulate the logistics distribution patterns. In the analysis, the primary response mode was observed as GOV or LGOV involvement; disaster relief operations were assisted by donations collected from the general public and foreign resources. A few areas are affected by disasters virtually every year. The 10-year data also suggest that Thailand experiences a large-scale disaster every 2–3 years. Using these data, sites frequently identified as D.A.s, capacity of GOV and LGOV resources, and connection routes among D.A.s. Moreover, the D.A.s in which the LGOV was involved in disaster relief operations were also considered by defining the distance between the DC and D.A.s as 0 km.

The data collected from various sources were also used to evaluate the response time of the pre-transport process. Disaster relief operations were conducted by either the GOV and LGOVs or the GOV with third-party logistics providers. The delivery preparation process only starts after placing an order with the third party.

4.4.2 Simulation model

The distribution patterns of disaster relief logistics for the scenarios discussed in latter sections were simulated using the previously defined simulation block model. In the author's previous work, the logistics behavior of block simulation models demonstrated the similarity between the flows of logistics and charge [74] [129]. Moreover, MATLAB®/Simulink was used to develop the block simulation models corresponding to the logistics network [74][83]. Through the use of simple simulation platforms, such modeling avoids the complexity of algorithm simulations, which are required in logistics-based studies. Further, the author's previous work confirms that such models can be constructed for all possible logistics networks [83]. The block simulation model was then used to analyze the response time in the transport process of disaster relief operations. In this study, disaster relief operations were evaluated according to the relationship between the total time to supply disaster-affected people and the operating method. The parameters considered were the amount of logistics (water) received by each D.A., the available number of trucks as well as their capacity in each DC, and the distance between D.A.s and DCs; variations in these parameters are listed in the latter sections of this paper. The number of people in each D.A. was kept constant irrespective of the scale of disaster.

The frequent disaster areas in Thailand were mapped (8 D.A.s) to evaluate the GOV-led disaster relief operations. Furthermore, RDC centers (10 RDCs) and their internal distribution network from third-party logistics providers were also marked to analyze the behavior of disaster relief operations. By combining the foregoing, the logistics networks utilized by the GOV and by third-party RDCs during relief operations in D.A.s 1–8 are illustrated in Figure 4-6 [122]. The figure shows that the GOV disaster relief operations are conducted through a local point and flow through the network connecting the D.A.s. Compared with the GOV network, the network of third-party logistics has more RDC connections.

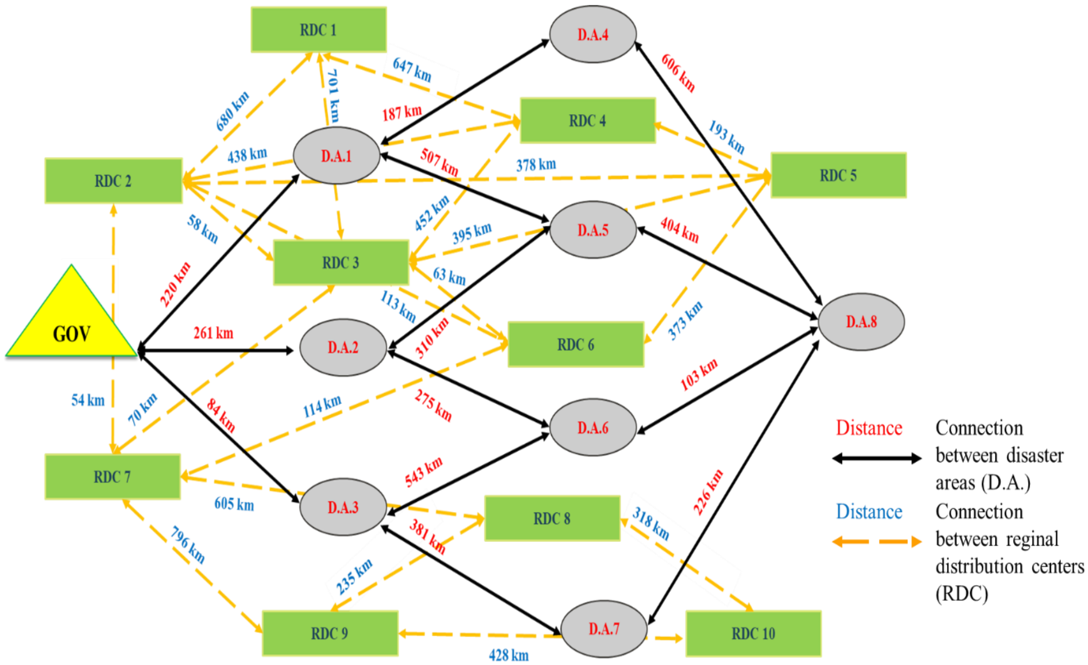


Figure 4-6. Combined logistic networks of the government and third-party distribution entities involved in disaster relief operations [122]

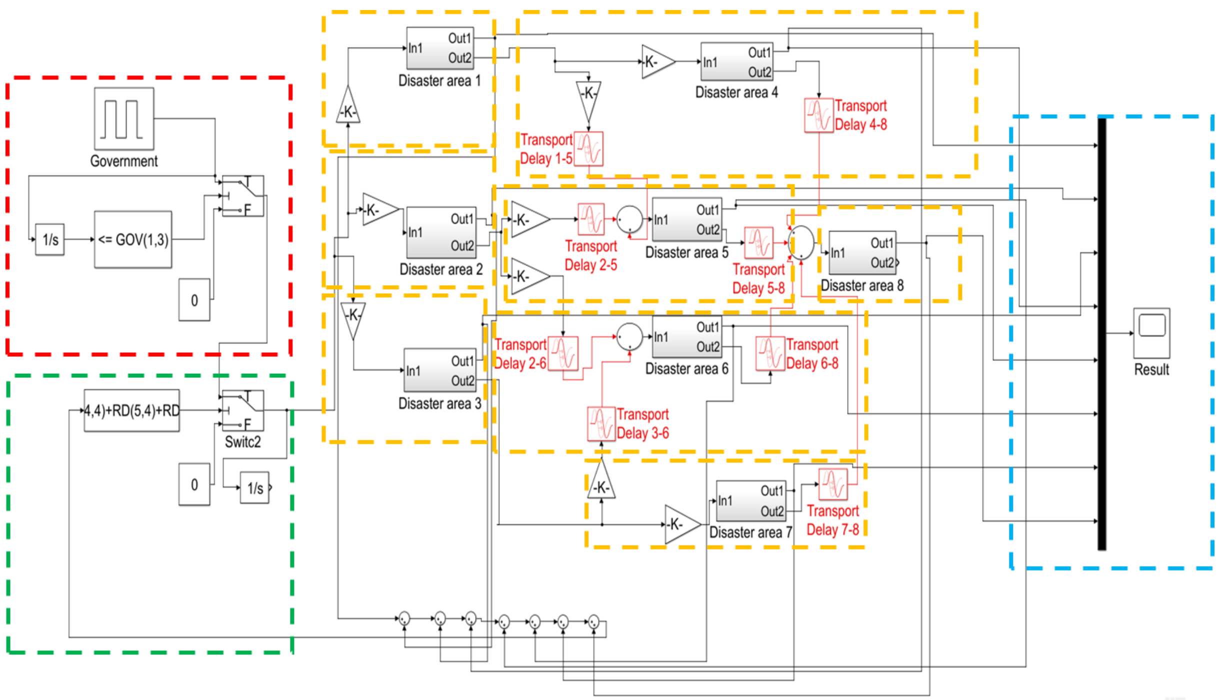


Figure 4-7. Block simulation model incorporate with third-party logistics for complex logistics network using MATLAB®/Simulink

The models shown in Figures 4-7 and 4-8 was developed from the model presented in Chapter 3 (Figures 3-13 and 3-10). Figure 4-7 shows the use of the previous complex model (introduced in Chapter 3 (Figure 3-13)) and its application to a realistic situation. This section describes the GOV control (red box), which is a modification of that presented in Figure 3-13, as the central control.

Comparison blocks were applied to control the inventory, as follows.

1. If the total inventory is equal to the total amount necessary for distribution, then the distribution must be halted.
2. If the required amount is less than the inventory, then the pulse must be terminated after it has provided the necessary quantity.

To achieve the abovementioned conditions, this study used the “compare to constant component.” The red and green boxes control situations 1 and 2, respectively. Switch was controlled using the “compare to constant” components to utilize the available resources according to the requirement. The yellow and sky blue boxes represent the number of disaster nodes and the total disaster area or image processing of results, respectively.

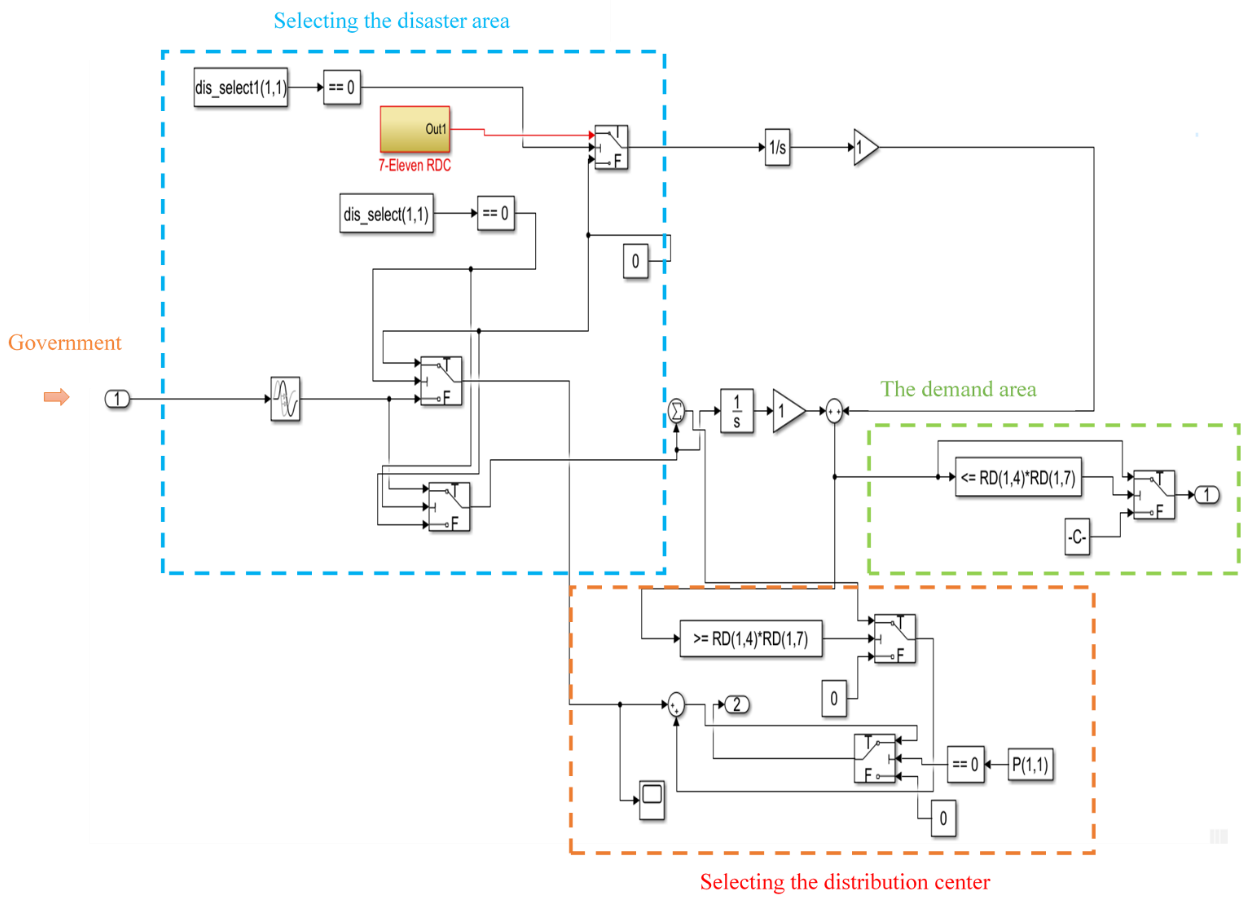


Figure 4-8. Basic modification distribution sub-systemic logistics block model described by electric circuit

Similar to the control of the DC, each sub-system is also modified to control their involvement in disaster relief operations. For this purpose, the previously described sub-system model is modified, as shown in Figure 4-7. This modification is implemented using the structure defined in Figure 3-10 (Chapter 3) that includes the following three sections to control the sub-system in disaster relief operations.

1. The components in the sky blue box were used to define the disaster location. A constant component, labeled as “dis_select” was used. Its values were defined as “0” and “1” disaster and non-disaster areas, respectively. The “compare to constant” component activated the use of their own resources that were available during the disaster.

2. The components in the green box were employed to illustrate the demand in the disaster area. When the total amount is less than or equal to the demand, it can be considered as

labeled “<=RD(1,4)*RD(1,7).” If the total amount is more than or equal to the demand, it can be labeled as “>=RD(1,4)*RD(1,7)” to match its distribution with the orange color components.

3. The components in the orange box was used to define whether or not the sub-system was to act as a sub-DC. For this purpose, “constant P (1,1)” was defined as “0” to function as a sub-DC and “1” to stop the distribution to the next sub-system.

Using all these components, the distribution can be controlled using the available resource information without changing any component or requiring any manual calculation in the defined MATLAB models.

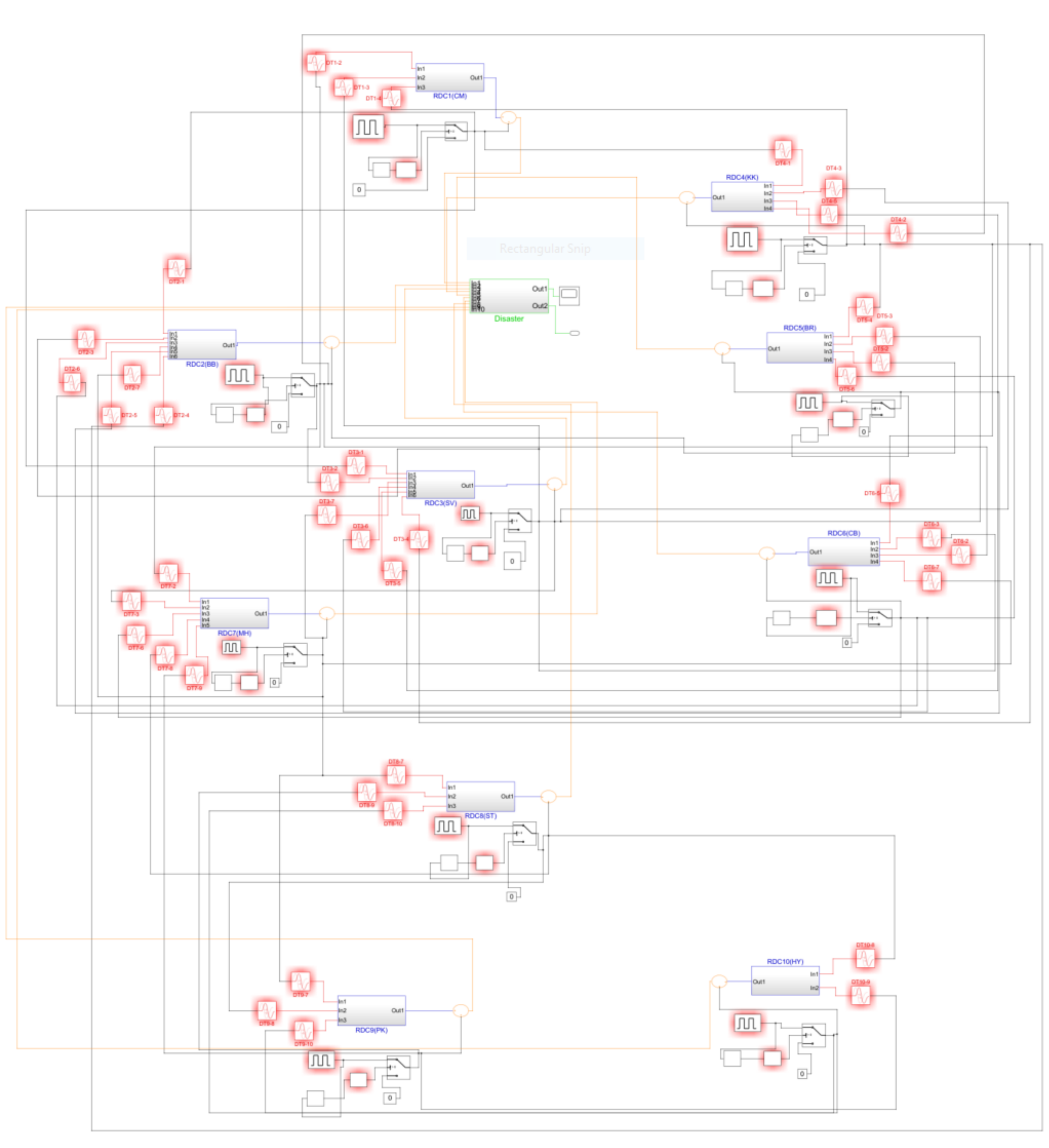


Figure 4-9. Disaster relief model with RDC's block

To control the selection of RDC for the disaster area, the yellow box shown in Figure 4-8 identified as "7-Eleven RDC" was used. Figure 4-9 shows the block simulation model connections in selecting the suitable RDC for quick response from third-party services.

To consider DCs for the disaster area, Figure 4-9 presents the sub-subsystem inside the “7-Eleven RDC” block. The author recommends the use of the DC network of a single third-party provider, such as 7-Eleven, for disaster response in Thailand. Ten RDCs or warehouses store products and distribute these to convenience stores within the area controlled by each RDC. The RDCs are linked to each other, and many available routes for interconnected distribution can be found. Such a network utilizes available resource and shares these among RDCs when a sudden decrease in logistics occurs. According to the author’s investigation, the following RDCs cover the regions of Thailand.

1. North region covered by
    - Chiangmai RDC
2. Central region covered by
    - Bank Bua Thong RDC
    - Suvanabhumi RDC
    - Mahachai RDC
3. Northeast region covered by
    - Khon Kaen RDC
    - Buri Ram RDC
4. Eastern region covered by
    - Chonburi RDC
5. South region covered by
    - Surat Thani RDC
    - Phuket RDC
    - Hatyai RDC

In the block simulation model, when a disaster occurs in a certain location, the formulated model selects the appropriate RDC. The nearest disaster relief route is also identified using the

“<=CP (1,3)” block if the RDC has sufficient inventory to supply the demand. The aim of this proposed model is to swiftly support victims with the available disaster relief items.

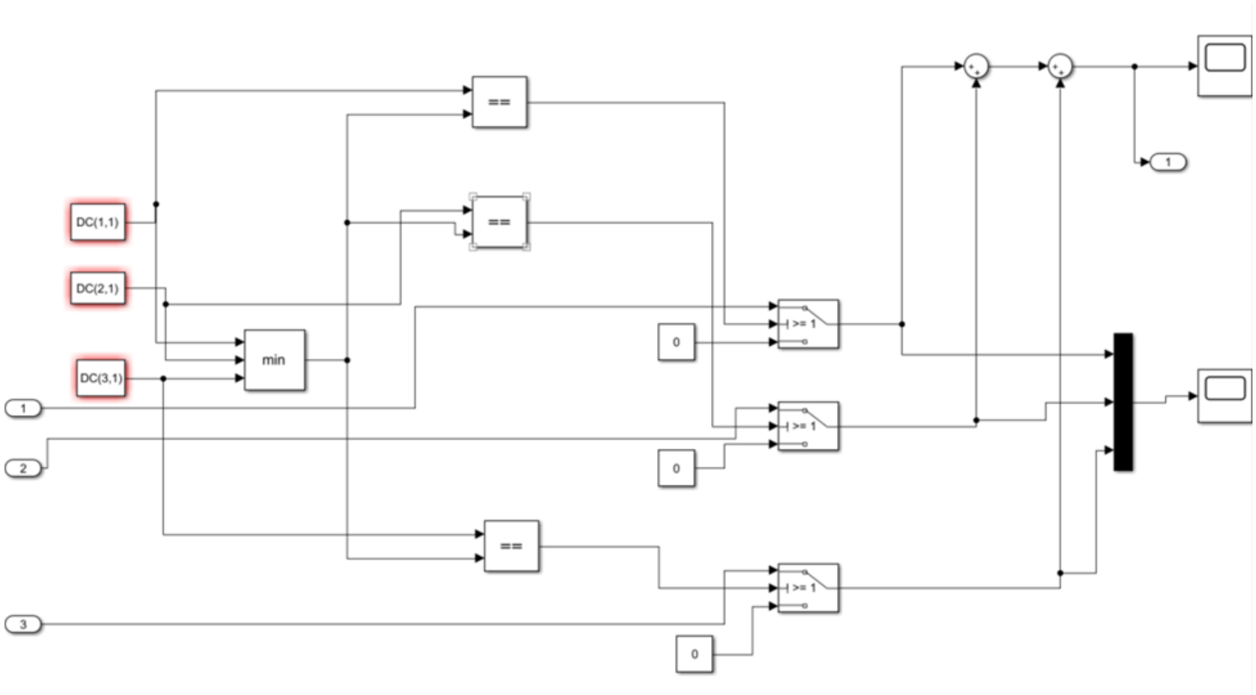


Figure 4-10. Sub-systemic component in each RDC’s block

To control the route selection of each RDC block, Figure 4-10 describes the process to identify the shortest available route. This aids in controlling the selection of routes for transporting and distributing the relief supply to victims in the disaster area.

The block constant, “DC (1,1),” defines the distance of each route; the different transit times depend on this distance and truck speed along each route. To select a transport route, the “Min” or minmax block can be used to estimate the shortest or longest distance; however, in this study, the objective is to find the shortest route to deliver the items to victims quickly. To confirm the selection of the shortest route, the “Relation Operation” block is used to re-check possible errors in the selection. To select the route, the Switch block accepts the input from the rational operator; if the rational operator output is 1, the switch is activated (closed), allowing the contents to flow through the selected route.

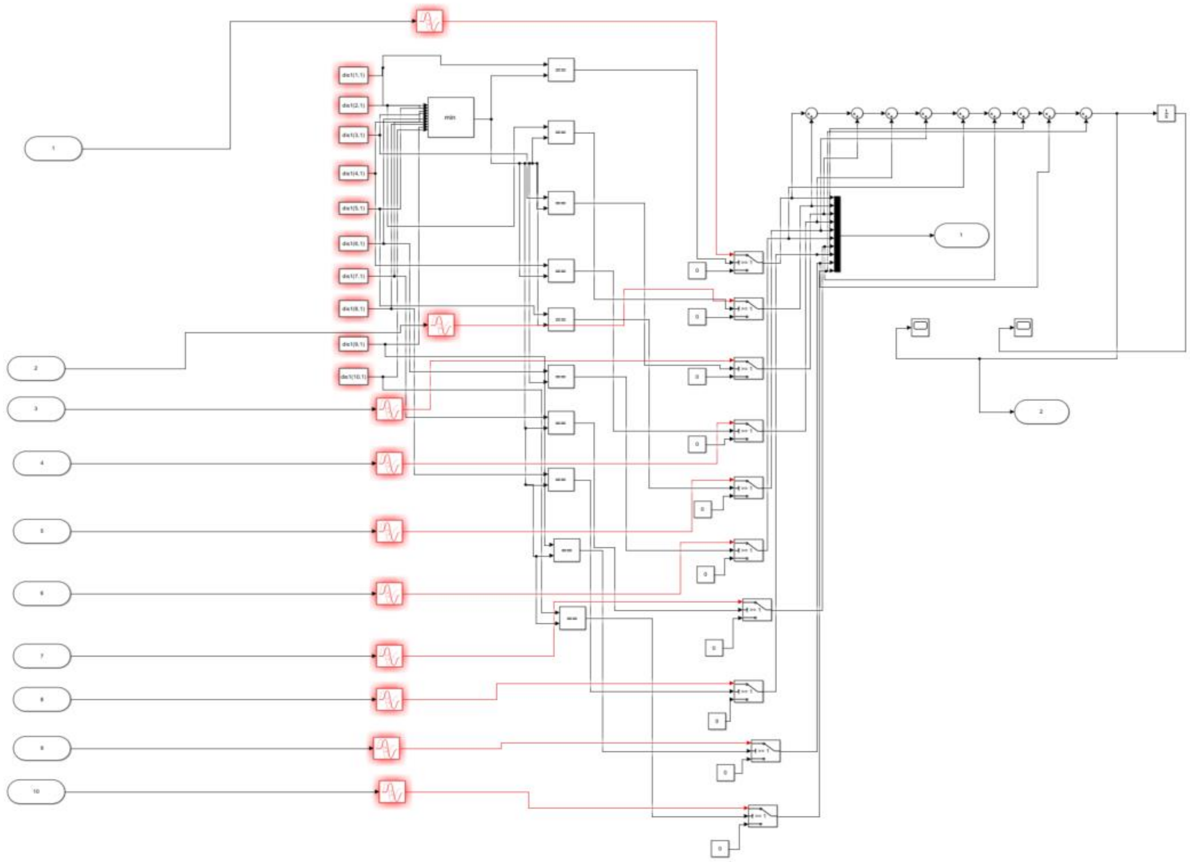


Figure 4-11. Sub-systemic component in disaster area block

Figure 4-11 presents the “Disaster” block, which identifies the location of the disaster, thereby allowing the selection of the nearest relief distribution route to the victims. Therefore, Figure 4-11 describes the link of components inside the disaster block. Within this block, the constant, “dis1(1,1),” indicates the selection of the shortest and fastest routes from the 10 RDCs to the final destination or disaster area to quickly deliver disaster relief items.

To select suitable route from the 10 RDCs, the “Min” or “minmax” block was used to compute the shortest or longest distance. However, in this work, the focus is to identify the shortest route to achieve the objective of this study, i.e., for relief items to reach disaster victims immediately. To confirm that the selected shortest route was the correct path, the “Relation Operation” block was employed. Transport delay was considered in matching the distance to determine the delay or response time. The final decision is derived using the “Switch” block to control the route. This block is activated if the condition for the rational operator output is satisfied, verifying that the selected route is certainly the minimum distance between the disaster area and RDC.

In addition to minimizing the time delay in the distribution of disaster relief items from the closest RDC center, this model is capable of checking whether or not the resources available at the closest RDC are sufficient. If the disaster area requires more resources than that available in the closest RDC, then the system notifies other close RDCs to supply the deficiency. The coordination of such information among RDCs enables the efficient supply of disaster relief items. Therefore, this block simulation model can optimize the connections among RDCs to perform efficient disaster relief operations.

4.5 Results and discussion

This section focuses on comprehending the behavior of the transport of relief items to disaster areas in a government-led operation with a single third-party service provider, such as 7-Eleven, supporting the relief distribution operation. This section presents the evaluation, analysis, and comparison of the efficiency of distribution operations performed by the GOV with LGOVs and third-party logistics service providers. In addition, the investigation results on the pre-transport process efficiency in disaster relief operations led by the government and single-third party are discussed.

4.5.1 Involvement of GOV and LGOV in disaster relief operation

This section describes four scenarios to analyze the importance of maintaining disaster relief logistics centers close to disaster areas. For all scenarios, all identified D.A.s were assumed to be simultaneously affected by a disaster. The distribution patterns and response time (T_{res}) were considered as parameters for evaluating the defined scenarios. The four scenarios are described as follows: (I) only the central government is involved in disaster relief operation (only GOV operations); (II) the central government and a few local governments are involved (GOV + few LGOV operations); (III) only a few local governments are involved with no central government role (no GOV + few LGOV operations); and (IV) all LGOVs are involved in the operations (all LGOV operations).

In the evaluation of collected data, as described in Section 4.4.1, disaster-prone areas are identified. Moreover, their provincial governments were observed to be consistently responsible in the implementation of rescue operations. The number of people affected by the disaster, truck capacity, and number of available trucks for the GOV and LGOV were also estimated using the collected data. This information is summarized in Table 4-6 [122]. The truck capacity listed in the table has been increased by a factor of 10 to match the batch distribution of the standard truck capacity by the GOV.

Table 4-6. Summary of evaluated information for year 2010-2019 on disaster relief operations for Thailand [122]

	Number of trucks	Capacity of trucks (L)	Number of people affected by disaster
GOV	12	183,000	0
D.A.1	10	18,300	61,168
D.A.2	12	18,300	81,948
D.A.3	15	18,300	115,500
D.A.4	10	18,300	60,584
D.A.5	20	18,300	169,379
D.A.6	15	18,300	102,379
D.A.7	3	18,300	12,853
D.A.8	20	18,300	178,297

As per the author's investigation, this study identified that certain areas (D.A.2, D.A.4, D.A.6, and D.A.8) were capable of performing their own relief operations because they have their own resources. In reality, although not all areas have resources to perform disaster relief operations, in this study, this logistics behavior is simulated in scenario IV by assuming that all the areas have their own resources. The resources identified and assumed to simulate the possible scenarios are listed in Table 4-7 [122].

Table 4-7. Evaluated inventories for four scenarios [122]

	only GOV operations (L)	GOV + few LGOV operations (L)	no GOV + few LGOV operations (L)	all LGOV operations (L)
GOV	3,500,000	3,500,000	0	0
D.A.1	0	0	0	250,000
D.A.2	0	300,000	300,000	300,000
D.A.3	0	0	0	400,000
D.A.4	0	200,000	200,000	200,000
D.A.5	0	0	0	500,000
D.A.6	0	350,000	350,000	350,000
D.A.7	0	0	0	100,000
D.A.8	0	550,000	550,000	550,000

The simulation time was set as 2 d because the disaster relief operators are expected to sufficiently satisfy all the requirements of disaster-affected people within that period. Moreover, the truck loading and unloading times were also evaluated by defining the water requirement per person per day as 2 L. The common simulation conditions for the four scenarios are summarized in Table 4-8 [122].

Table 4-8. Common simulation conditions for evaluation [122]

Time of simulation (h)	48
Loading/unit (min)	45
Water requirement/person/day (L)	2

The received logistics (total amount of water) and the related truck distribution pattern in each D.A. for scenario I (using the information listed in Tables 4-6, 4-7, and 4-8) are illustrated in Figure 4-12 [122].

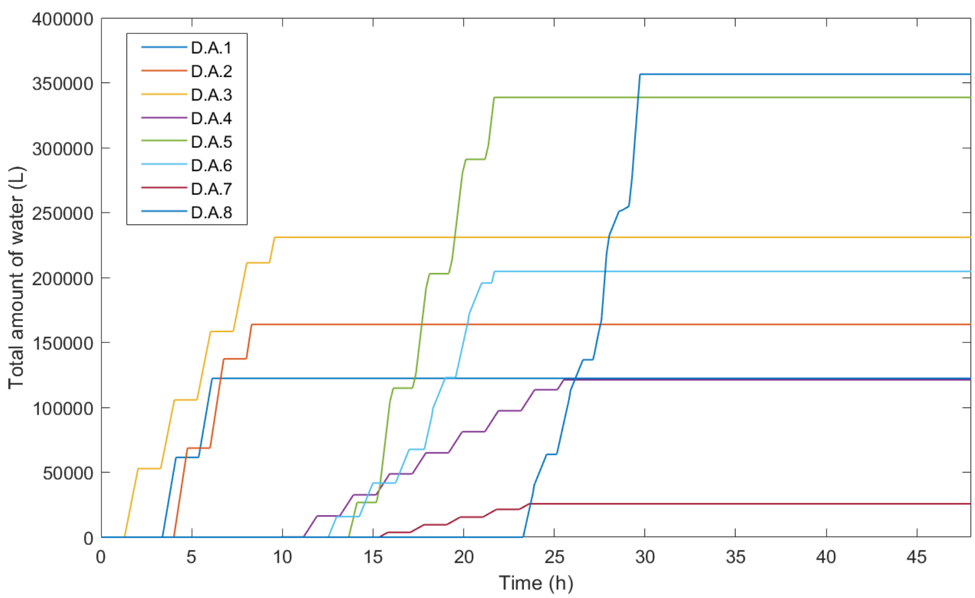


Figure 4-12. Cumulative storage pattern; only GOV operation (Scenario I) [122]

As shown in Figure 4-12, the recipient during the first response time varies with the D.A.. Scenario I considers the only-GOV operation through one distribution point, causing the variation of distance to the central distribution point, as shown in Figure 4-6. In this simulation case, GOV-led operations first assist the D.A.s closer to the central distribution point before proceeding to more distant D.A.s. Such operations increase the first response time, as shown in Figure 4-12.

According to Figure 4-12, every node reaches saturation (i.e., the D.A. demand is satisfied) within 48 h; the time that elapses for node saturation also depends on the distance between the D.A. and GOV DCs.

According to the logistics network shown in Figure 4-6, the GOV disaster relief operations first focus on satisfying the demand of the closest D.A. before proceeding to a more distant D.A., thus increasing the first response time in the operation.

A distribution simulation was performed for all four scenarios in three selected areas, i.e., D.A1, D.A.2, and D.A.5, whose response time patterns are similar; a summary of the distribution of disaster relief items for each D.A. is shown in Figure 4-13 [122]. Additionally, the evaluation of the first response to each D.A. for the four scenarios is listed in Table 4-9 [122].

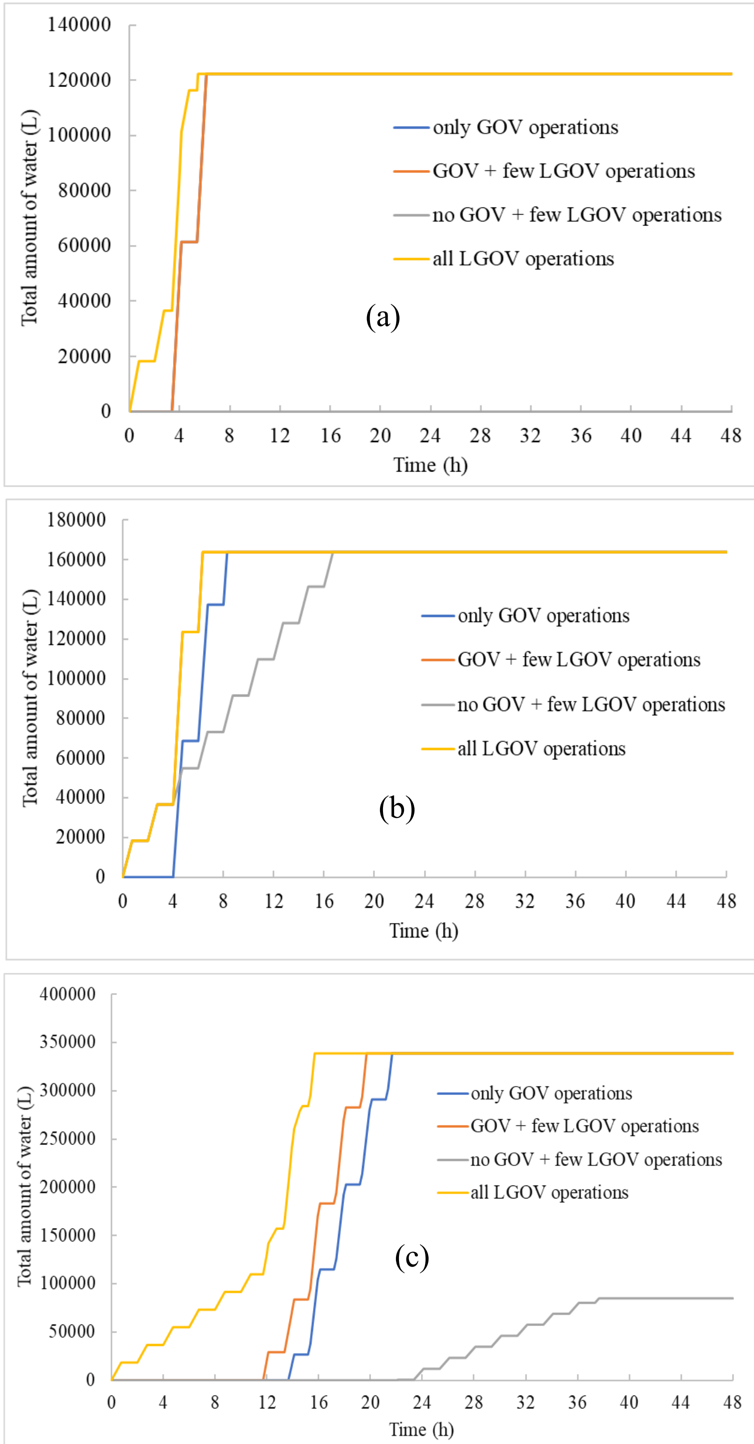


Figure 4-13. Cumulative storage patterns in (a) D.A.1, (b) D.A.2, and (c) D.A.5 for all the four scenarios [122]

Table 4-9. Summary of first response time for four scenarios (h) [122]

	only GOV operations (h)	GOV + few LGOV operations (h)	no GOV + few LGOV operations (h)	all LGOV operations (h)
D.A.1	3.4	3.4	NR	0
D.A.2	4.0	0	0	0
D.A.3	1.3	1.3	NR	0
D.A.4	9.9	0	0	0
D.A.5	13.6	11.7	22.1	0
D.A.6	12.5	0	0	0
D.A.7	15.3	15.3	NR	0
D.A.8	23.3	0	0	0

*NR: disaster relief items not received

Considering the information summarized in Table 4-9, the response time patterns for D.A.1, D.A.3, and D.A.7 are similar for all simulated scenarios. Figure 4-13(a) shows that the distribution pattern for D.A.1 is similar to those of D.A.3 and D.A.7 but with a different response time. Areas D.A.2, D.A.4, D.A.6, and D.A.8 also show a similar behavior in response time for all simulated scenarios; their response time and distribution patterns differ from those of D.A.2, as illustrated in Figure 4-13(b).

By evaluating all conditions, the importance of the involvement of GOV and LGOV in disaster relief operations can be summarized with the following points.

(I) An increase in the distance between a DC and D.A. in the GOV-led disaster relief operations increases the first response time.

(II) Maintaining the initial storage or inventory in D.A.s under the oversight of LGOVs enables the quick response to these D.A.s and reduces the waiting time for the arrival of disaster relief items, particularly those from the central government.

(III) The response time to D.A.s connected to sub-distribution areas (i.e., LGOVs) with resources can be reduced even when only a few of these LGOVs have sufficient resources.

(IV) When D.A.s are unable to manage disaster relief operations themselves and only depend on GOV operations, the disaster scenario in those areas is expected to deteriorate.

All these points suggest that maintaining disaster relief logistics in identified D.A.s can reduce the response time in terms of receiving supply, with or without GOV involvement. However, because of various reasons, such as the unpredictability of disasters, warehouses eventually degrade or are left in a non-functioning state with spoiled or expired disaster relief items, such as food and water. These factors contribute to the inability of the central and local governments to store and maintain disaster relief resources.

4.5.2 Involvement of third-party logistics in disaster relief operation

As suggested in Section 4.5.1, the local maintenance of disaster relief items in D.A.s can be a complicated process. Hence, outsourcing to third-party logistics providers can aid in managing disaster relief operations quickly and smoothly. Accordingly, considering the logistics providers available in Thailand, a single entity, 7-Eleven, is identified as an option for third-party logistics support in this study.

The resource capacity of 7-Eleven, especially its RDCs, logistics network distribution, and available transport system, can be readily utilized for logistics purposes; it stands out over other third-party logistics service providers. Considering these points and the network of third-party RDCs connected to the D.A.s shown in Figure 4-6, the impact of appointing a third party as an alternative to GOV and LGOV operation in disaster relief is evaluated. The resources available in each RDC are listed in Table 4-10 [122]. The simulated distribution patterns based on the data summarized in Table 4-10 and the distances presented in Figure 4-6 are shown in Figure 4-14 [122].

Table 4-10. Evaluated information of number of trucks, truck capacity, and available inventories for RDCs in the third-party network [122]

	Number of trucks	Capacity of trucks (L)	Inventory (L)
GOV	12	183,000	1,000,000
RDC 1	12	183,000	4,921,192
RDC 2	12	183,000	6,219,360
RDC 3	12	183,000	21,209,992
RDC 4	12	183,000	4,782,984
RDC 5	12	183,000	2,660,504
RDC 6	12	183,000	3,726,680
RDC 7	12	183,000	4,397,976
RDC 8	12	183,000	6,318,080
RDC 9	12	183,000	1,550,000
RDC 10	12	183,000	2,500,000

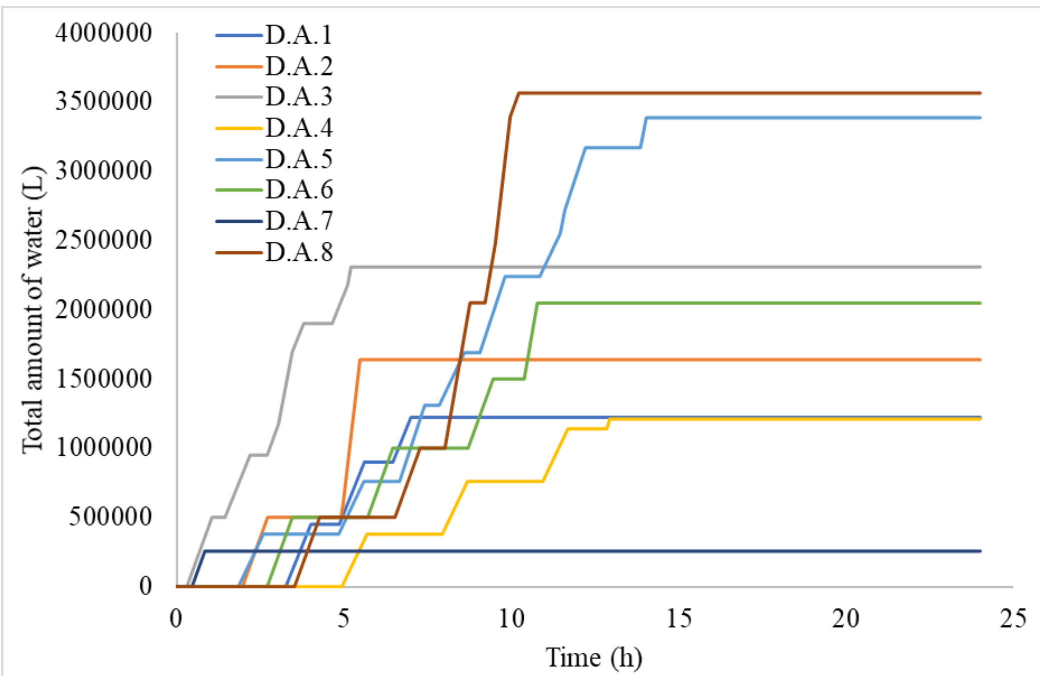


Figure 4-14. Cumulative storage patterns in D.A. for third-party disaster relief operations [122]

As shown in Figure 4-14, the first response time for supplying disaster relief items to the D.A. is reduced due to the involvement of the third-party. In addition, its involvement helps fulfill the demand of each D.A. within 24 h. This is because of the closer proximity of its warehouses to the D.A.s than those of the GOV.

4.5.3 Comparison of the importance of third-party in disaster relief operation with that of the GOV

A comparison between the GOV-led and third party-led disaster relief operations was further performed based on two parameters: response time ($T_{respond}$) and settling time (T_{sett}). The time required to move the disaster relief logistics from warehouses to a D.A. was defined as $T_{respond}$, whereas the time necessary to satisfy the demand of D.A. through a distribution network was defined as T_{sett}. Figure 4-15 [122] illustrates the basics of these two parameters. The sum of these parameters, denoted as $T_{saturation}$, can be considered as the total time required to saturate the demands of the D.A. reckoned from the start of relief goods distribution; the foregoing relationship is expressed by Eq. (4.1).

$$T_{saturation} = T_{respond} + T_{sett} \tag{4.1}$$

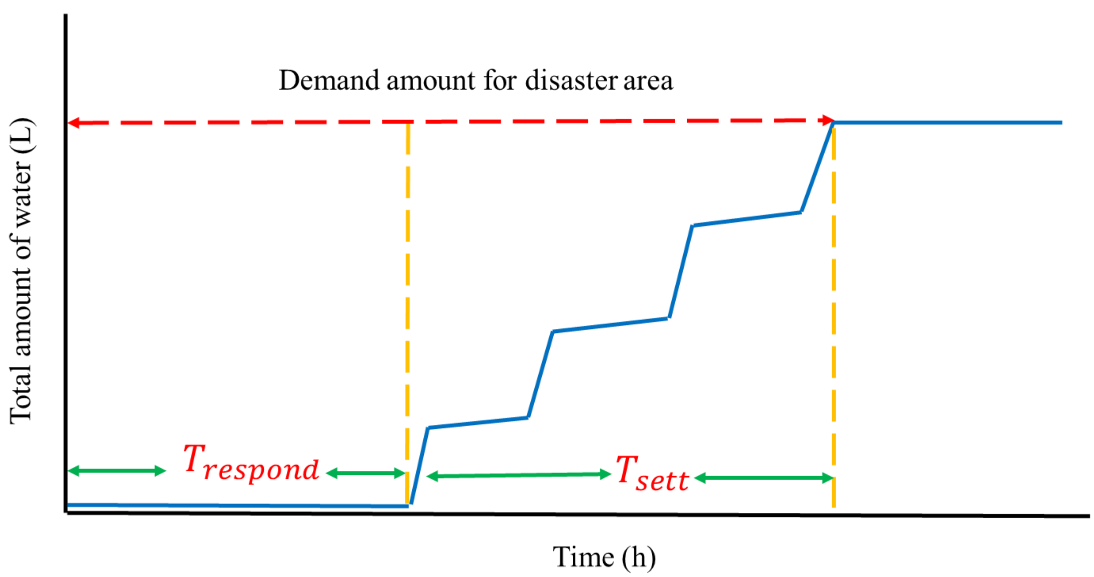


Figure 4-15. Cumulative curve of storage against time [122]

For the analysis of the GOV-led and third-party (7-Eleven)-outsourced disaster relief operations, actual cases in Thailand were considered. Small-scale, medium-scale, and large-scale disasters were identified using data over the past 10 years. The scale of a disaster, its location, and number of affected people are summarized in Table 4-11 [122].

Table 4-11. A summary of the scale of disasters along with the affected areas and number of affected people [122]

Number of people affected by disaster					
Area	Small-scale disaster	Area	Medium-scale disaster	Area	Large-scale disaster
D.A.1	0	D.A.1	0	D.A.1	0
D.A.2	0	D.A.2	0	D.A.2	81,948
D.A.3	0	D.A.3	0	D.A.3	0
D.A.4	16,600	D.A.4	19,993	D.A.4	60,584
D.A.5	0	D.A.5	0	D.A.5	169,379
D.A.6	0	D.A.6	0	D.A.6	102,279
D.A.7	0	D.A.7	0	D.A.7	0
D.A.8	0	D.A.8	68,222	D.A.8	178,297

The data summarized in Table 4-11 are used with the evaluation information for the GOV-led and 7-Eleven-led disaster relief operations through MATLAB block simulation. The distribution patterns were analyzed for each case in terms of $T_{respond}$ and T_{sett} values. The analyzed information is summarized in Table 4-12 [122].

Table 4-12. Comparison of response and settling times between GOV-led and third-party-led disaster relief operations [122]

	Small-scale disaster					Medium-scale disaster					Large-scale disaster			
	GOV operations (h)		Third-party operations (h)			GOV operations (h)		Third-party operations (h)			GOV operations (h)		Third-party operations (h)	
Area	T_{res}	T_{sett}	T_{res}	T_{sett}	Area	T_{res}	T_{sett}	T_{res}	T_{sett}	Area	T_{res}	T_{sett}	T_{res}	T_{sett}
D.A.1	0	0	0	0	D.A.1	0	0	0	0	D.A.1	0	0	0	0
D.A.2	0	0	0	0	D.A.2	0	0	0	0	D.A.2	4.0	2.1	1.9	0.7
D.A.3	0	0	0	0	D.A.3	0	0	0	0	D.A.3	0	0	0	0
D.A.4	7.2	2.6	4.9	2.6	D.A.4	7.2	4.1	4.9	4.1	D.A.4	7.2	30.7	4.9	0.5
D.A.5	0	0	0	0	D.A.5	0	0	0	0	D.A.5	11.2	4.9	1.8	2.6
D.A.6	0	0	0	0	D.A.6	0	0	0	0	D.A.6	10.3	6.4	2.7	2.1
D.A.7	0	0	0	0	D.A.7	0	0	0	0	D.A.7	0	0	0	0
D.A.8	0	0	0	0	D.A.8	20.3	14.3	3.6	8.8	D.A.8	21.9	6.0	3.5	2.7

In a small-scale disaster, third-party-led disaster relief operations compared with GOV-led operations can reduce the first response time because the D.A. and RDC of the third party are closer.

In a medium-scale disaster, the first response time increases in the GOV-led disaster relief operation compared with that of the third-party-led operation. At this scale, the GOV-led operation first accesses the D.A. (D.A.4) closer to the central warehouse and satisfies its demand before proceeding to another location. As for the 7-Eleven-led operation, the company's RDCs are close to each D.A. and have direct access, thereby reducing the first response time. Moreover, the settling time also decreases for the single third-party-led disaster relief operations compared with the GOV-led operations. Because the GOV-led operations require settling the demand of the closest D.A.s (e.g., D.A.4) first before proceeding to more distant D.A.s (e.g., D.A.8), the quantity of available resources reduces as the operation progresses. This is mainly because the GOV-led operations or warehouses are stationed only in one area. As for the third-party-led operations, the provider maintains several warehouses in different areas, covering the entire country even for their general operations. The availability of such warehouses enables the third party to utilize the resources of the warehouse closest to the D.A. instead of using its central warehouse.

Large-scale disasters under similar conditions used in simulating the GOV-led and single third-party-led disaster relief operations are found to considerably affect the settling time. In large-scale disasters, GOV-led operations require the supply of a considerable quantity of resources at a certain distribution point to cope with demands. However, as relief operations proceed to distant D.A.s, the number of available resources decrease, increasing the settling time.

By comparing these three disaster scales, outsourcing disaster relief operations to third-party entities, especially a single provider, is observed to reduce the time required to saturate disaster relief demands.

4.5.4 Pre-transportation process

As described in Figure 4-5, the disaster relief operation is differentiated into two parts. Considering the pre-transport logistics process, Table 4-13 [122] summarizes the comparison of time consumed in each sub-process by the GOV, GOV with a third party, and a single third-party logistics provider during disaster relief operations.

Table 4-13. Evaluation of time taken for each sub-process for GOV-led, GOV-led with third-party, and single third-party-led disaster relief operation [122]

Process	GOV	GOV + third-party logistics	Single third-party logistics
1. Information gathering	3 h [14]	3 h [14]	3 h [14]
2. Coordinating and support subsystem	13 h [14]	13 h [14]	13 h [14]
3. Route clearance procedure for transportation	37 h [14]	37 h [14]	37 h [14]
4. Preparing disaster relief items	3–5 days [130]	22 h [14]	6 h [104]

As summarized in Table 4-13, the first two processes are the basic steps necessary to gather information about the disaster, such as the D.A., its impact, the communication procedure of this information, and decision-making on disaster relief operations. Generally, the first three processes are handled by the government; accordingly, in this study, the same amount of time for the three categories discussed in this study is used. However, after receiving the appropriate communication from the coordinating center of Thailand disaster relief operations (DDPM/NDPMC), the preparation time for disaster relief logistics is found to be higher in GOV-led operations. Compared with multiple logistics providers, the use of a single third party reduces the coordination time among various disaster relief agencies and considerably reduces the preparation time.

The summarized results in Table 4-13 indicate that the GOV-led disaster relief operations generally require 3–5 d to prepare logistics items. Government-led operations mainly depend on limited resources at the government level; moreover, they are not acquainted with logistics-related activities. Furthermore, the extent of operations further expands because donations are received from local and international sources, rendering the preparation of disaster relief items time-consuming.

The present study indicates that the time spent for GOV-led disaster relief operations in coordination with third-party logistics providers is approximately 22 h. This approach reduced the preparation time for disaster relief supplies mainly because the third-party logistics service provider had sufficient resources to supply during the critical period. However, one of the drawbacks of such a coordinated operation is miscommunication among the third-party logistics service providers.

Therefore, as proposed in this study, employing a single third-party logistics provider, such as 7-Eleven in Thailand, can reduce the time for preparing disaster relief supplies to approximately 6 h. The internal logistics preparation procedures of private organizations are more effective compared with GOV-led procedures. In addition, the use of a single third-party service provider reduces the time spent communicating with other third-parties.

4.6 Conclusion

In this study, the use of third-party logistics for disaster relief operations in Thailand was evaluated. To analyze the importance of third-party logistics, in the emergency response phase, disaster relief operations were divided into two sections: pre-transport and transport of logistics. For the transport process, the operational time variations between the GOV-led and single third-party-led disaster relief operations obtained through the simulation platform are summarized in Table 4-14 [122].

Table 4-14. Operation time difference between government-led and single third-party-led disaster relief operations [122]

	Small-scale disaster (Time difference between government - third-party operations)				**Medium-scale disaster (Time difference between government - third-party operations)**				**Large-scale disaster (Time difference between government - third-party operations)**		
Area	T_{res}	T_{sett}	Total (T_{res} + T_{sett}) (h)	Area	T_{res}	T_{sett}	Total (T_{res} + T_{sett}) (h)	Area	T_{res}	T_{sett}	Total (T_{res} + T_{sett}) (h)
D.A.1	0	0	0	D.A.1	0	0	0	D.A.1	0	0	0
D.A.2	0	0	0	D.A.2	0	0	0	D.A.2	2.1	1.4	3.5
D.A.3	0	0	0	D.A.3	0	0	0	D.A.3	0	0	0
D.A.4	2.3	0	2.3	D.A.4	2.3	0	2.3	D.A.4	2.3	30.2	32.5
D.A.5	0	0	0	D.A.5	0	0	0	D.A.5	9.4	2.3	11.7
D.A.6	0	0	0	D.A.6	0	0	0	D.A.6	7.6	4.3	11.9
D.A.7	0	0	0	D.A.7	0	0	0	D.A.7	0	0	0
D.A.8	0	0	0	D.A.8	16.7	5.5	22.2	D.A.8	18.4	3.3	21.7

As summarized in Table 4-14, third-party-led disaster relief operations exhibit reduced response times in medium-scale and large-scale disasters compared with that in small-scale disasters. In certain disaster areas, a reduction of more than 12 h in supplying disaster relief goods was achieved by third-party logistics service providers compared with GOV-led operations. An increase in the number of D.A.s and centralized distribution systems increases the transport operation times for GOV-led disaster relief operations. These drawbacks can be easily avoided using third-party logistics providers because their resources and transportation networks are closer to the affected areas. As for the pre-transport process, GOV-led operations require 3–5 d of preparation for disaster relief logistics, whereas third-party operations only require a few hours (maximum: half day), considerably reducing the preparation time.

Therefore, after evaluating various stakeholders that can lead disaster relief operations in Thailand, utilizing the services of a single third-party logistics provider for disaster relief operations is found to significantly reduce the response time to disasters. Hence, to improve disaster relief operations in Thailand, this thesis proposes a new model for the emergency response phase, as presented in Figure 4-16 [122].

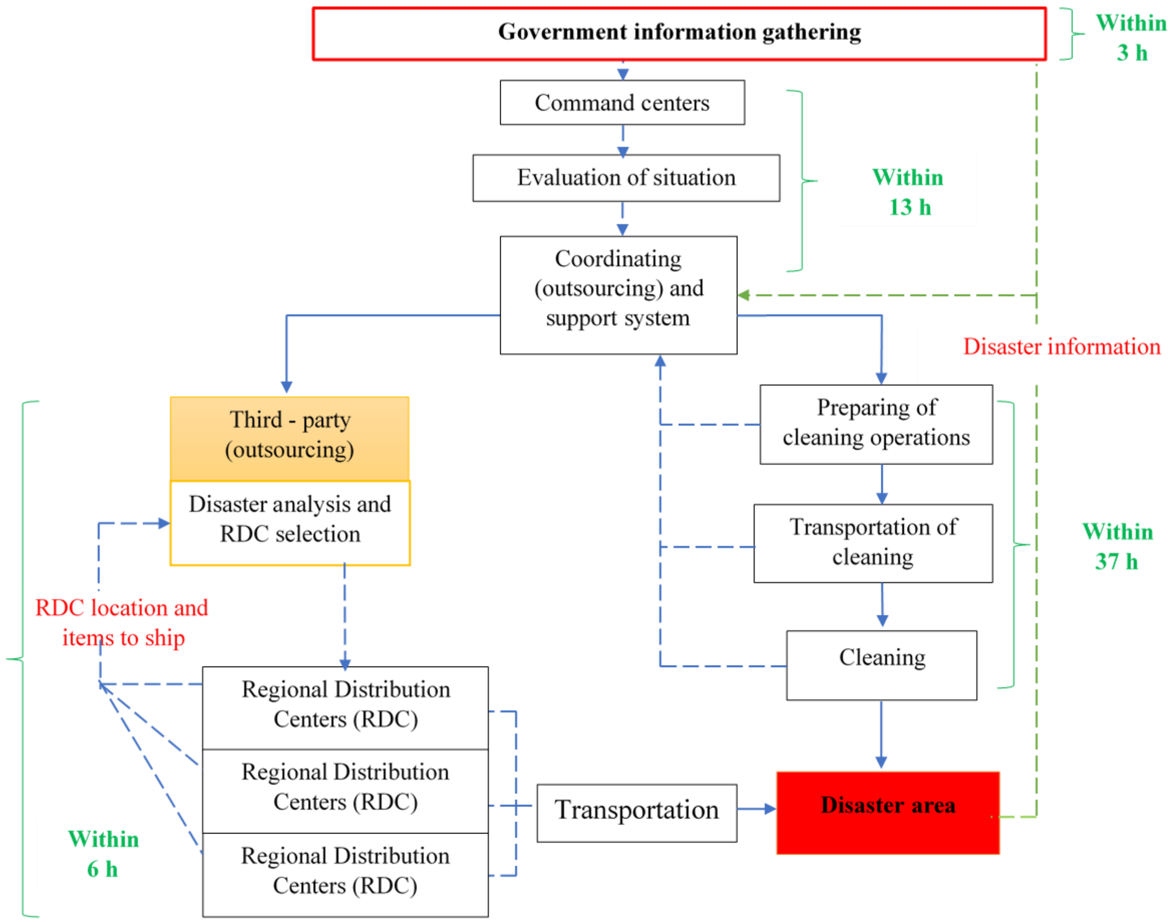


Figure 4-16. Proposed emergency response phase model for Thailand with coordination of 7-Eleven as outsourced third-party [122]

Although this study identifies the use of a single-third party logistics service provider to improve disaster relief operations in Thailand in the emergency phase, further assessments are necessary to develop partnerships between the government of Thailand and third-party organizations. Developing countries in Southeast Asia other than Thailand can also cooperate with third-party logistics service providers for their disaster relief operations because these private organizations possess considerable amounts of logistics-related resources exceeding those of governments.

In addition to identifying the use of a single third party in disaster relief operations, this study offers an additional advantage over previous studies. In previous research, the development or identification of disaster relief logistics models was accomplished using complex algorithms. The processes involved in these mathematical models limit the adoption of dynamic parameters, such as the number of disaster-affected people and variations in available input resources. Because this study employs a block simulation model, such variances can be facilely inputted as variables without modifying any of the commands in the model. Compared with previous analysis models for disaster relief operations in Thailand, the block simulation model does not require knowledge of higher mathematics in processing the scenarios. Hence, people at the base level in disaster relief operations can also be involved in the analysis and identification of suitable logistics distribution behaviors through this model.

Chapter 5
Overall conclusions

Disaster relief operations are vital to all governments worldwide not only to implement smooth and effective rescue operations when disasters occur but also mitigate the impact of these events to the country's economy. In most developing countries, disaster relief operations become wayward, severely deviating from their intent, due to inadequate resources and mismanagement. To improve disaster relief operations in developing countries, available resources and areas that may be improved must be identified. Accordingly, this study considers using Thailand as a case study to determine the areas that can be improved in their existing disaster relief operations using the country's available resources.

The geographical background and records of previous disasters indicate an increase in the frequency of disasters, such as cyclones, floods, and droughts in Thailand. The occurrence of cyclones and floods severely affect Thailand, not only devastating people's livelihood but also causing deaths over a short period of time. However, government-led disaster relief operations in Thailand are observed to be inadequate, being unable to quickly respond to the demands of disaster areas. In view of these, this study investigates the performance of the current disaster relief procedures of Thailand and identify the areas that can be modified to improve their relief operations.

To analyze the performance of logistics operations, this study employs the block simulation platform as a novel approach. Although studies on logistics performed through the block simulation are not available, such simulation methods are widely applied to the performance analysis of electric circuits. To utilize the block simulation platform, this study considers the similarity between the flow of goods in logistics and the flow of charge in electric circuits to define a logistics-similar electric circuit. Then, using the MATLAB®/Simulink platform, the logistics-defined electric circuits are converted to block simulation models.

Logistics distribution networks, such as centralized, decentralized, and complex networks, were developed using this block simulation model to evaluate their performance in various scenarios. The evaluation information on these distribution networks is found to closely match theoretical logistics behaviors and validates the use of block simulation in developing logistics distribution networks. Moreover, the number of people, inventory of warehouses, available number of trucks, truck capacity, distance between two nodes, truck speed, and handling time of logistics goods—all known to be parameters that affect logistics behaviors—have been investigated using block simulation models. The distribution flow behaviors versus these parameters was found to match the theoretical logistics behavior, confirming the usability of block simulation in the performance analysis of disaster relief operations. Although this study considers the use of certain values with the validation model, this block simulation model is capable of modifying its input variables to match the available physical information. Compared with conventional algorithm-based studies, block simulation models only require changes in parameter values without modifying any defined algorithms. Therefore, such models, which are deemed feasible in the simulation of logistics behavior conditions in the environment, vary.

The information regarding disasters and performance analysis of disaster relief operations in Thailand are found to be primarily affected by the lack of resources. Disaster relief operations in Thailand are mainly performed by the government. These operations are observed to be effective for disaster-affected areas near the capital. This information suggests that the Thai government distributes disaster relief goods using a centralized distribution network. The information further indicates that Thailand has inadequate resources to quickly act during the response phase of relief operations. To supply the demands of disaster areas, considerable quantities of disaster relief items are observed to be collected from the general public, further delaying the preparation time of disaster relief items.

In evaluating the available resources of Thailand, this study identified the availability of third-party logistics service providers with sufficient resources to quickly support disaster relief operations. The performance analysis results and evaluated information in this study suggest that the use of a single third-party logistics service provider instead of multiple providers can increase the efficiency of disaster relief operations. The preparation process of logistics goods implemented by third-party logistics service providers are found to reduce the preparation time considerably, i.e., from 5–6 d (government-led operations) to 6 h. Moreover, the performance analysis on the use of transport networks of third-party logistics service providers compared with those of the government shows a reduction in the distribution time of logistics items. The availability of warehouses or resource centers throughout the country enables third-party logistics service providers to use a complex distribution network better than a centralized network.

Evaluating all the collected information regarding disasters in Thailand and its disaster management system, this study proposes a new framework for the nation’s disaster relief operation model to improve efficiency. Hence, linking a single third-party logistics service provider to the processes involved in preparing disaster relief items and using the provider’s distribution network for disaster relief operations in Thailand are proposed. These changes in the existing disaster relief operation model of Thailand in the quick response phase are expected to reduce the government’s burden in preparing and distributing disaster relief items.

In the future, the author intends to extend this investigation to include the introduction of warehouses with dual roles (i.e., warehouses that also function as sub-distribution areas) and third-party logistics providers to improve the logistics model for disaster relief operations.

The author intends to perform further analysis on other more complex logistics networks not only for situations involving disasters but also other transportation logistics; note that these complex networks utilize more than one mode of transportation. In addition, the use of third-party logistics is proposed by the author to the Thai government as an option to consider in the event of a disaster. Further, the author plans to evaluate whether the proposed approach may be applied to other developing nations, such as Myanmar.

List of publications

Journal publications

1. "Development of logistics library for disaster relief using electric circuit model" Yorvarak Chata, W.T.L.S. Fernando, Kazumasa Takahashi,Takashi Kikuchi, Nob. Harada, Kazushi Sano, Toru Sasaki. Journal of Advanced Simulation in Science and Engineering. 2020 Volume 7 Issue 2 Pages 242-261 DOI: https://doi.org/10.15748/jasse.7.242

2. "Cooperation between single third-party logistics provider and government for emergency disaster relief operations in Thailand" Yorvarak Chata, W.T.L.S. Fernando, Kazumasa Takahashi,Takashi Kikuchi, Nob. Harada, Kazushi Sano, Toru Sasaki. Journal of Emergen cy Management. 2021.

Conference publication

1. "Modelling of Logistic Network of Disaster Relief using Similarity to Electric Circuit" Chata Yorvarak, Kazumasa Takahashi, Toru Sasaki, Takashi Kikuchi and Nob. Harada. IEEE International Conference on Systems Science and Engineering at HCMC University of Technology and Education HO Chi Minh City, Vietnam. 2017 / No.179, Electronic ISSN: 2325-0925, DOI: 10.1109/ICSSE.2017.8030974

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