Logistics Network Designing for Humanitarian Relief Distribution: An Integration of Disaster Preparedness and Response

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Abstracts: Designing a logistics network for the prompt and efficient distribution of humanitarian relief is crucial to preparing for natural and human-made disasters. The objective of this research was to plan for the distribution of necessary goods to disaster-prone areas through the implementation of GIS-based network analysis. The study aimed to identify the ideal locations for distribution centers to enable prompt delivery of aid to communities affected by disasters. The research ap-plied the concepts of humanitarian logistics and Geographic Information Systems (GIS) for humanitarian relief distribution and to cover the maximum possible area affected by disasters. The research scenario in this study is based on a model that responds to and provides aid to 34 high and moderate-risk communities in Chonburi Province, Thailand. The research findings indicated that humanitarian relief was distributed by various organizations both internationally and domestically. Subsequently, the necessary items are forwarded to the main distribution centers (MDC) located in five areas of the province. Each center is responsible for delivering aid to local distribution centers (LDC) in all 49 sub-districts, covering the minimum travel time and distance. This research focused on an analysis of community response and aid provision during disasters, including response time, distance, and number of transport vehicles. The results of this study serve as a preparation and response guideline for future disasters and emergencies to enhance the efficiency of emergency responses in the future.

Keywords: Logistics Network Design, Humanitarian Logistic, Relief Distribution, location-allocation analysis, geographic information systems (GIS).

1. INTRODUCTION

In the past decade, numerous large-scale disasters have occurred, resulting in significant consequences on the economy, society, and environment, as well as human life and property. The increasing risk of disasters has been felt worldwide, and the emergence of the COVID-19 virus has caused many people to lose their lives or suffer from the impacts of disasters (UNDRR 2020)(Rezaei-Malek and Tavakkoli-Moghaddam 2014). In the future, the frequency and potential of disasters and their influences are expected to intensify due to climate change and global warming, resulting in storms, sea waves, flooding, earthquakes, and disasters likely occurring with greater frequency and severity in every region of the world [3]. In addition, population growth and urbanization are expanding the areas of human settlement and economic activity into increasingly disaster-prone areas, making the loss and management of disasters more complex [4].

The United Nations Office for Disaster Risk Reduction (UNISDR) contributes the 2030 agenda for Sustainable development and the Sendai Framework for Disaster Risk Reduction 2015-2030. It is a transformative plan of action for all countries and all stakeholders to reduce disaster risk, build a resilient and achieve the Sustainable Development Goals (SDGs) and targets [5]. Reducing the risk of disasters will help to alleviate risks in various other aspects, in line with the SDGs. It shows that there are goals related to reducing the risk of disasters, with 10 out of 17 sustainable development goals setting the role of disaster risk reduction as a main strategy for development [6].

Logistics for humanitarian relief plays an important role in delivering assistance and managing resources in catastrophic situations [7]. The United Nations office of the Coordination for Humanitarian Affairs (OCHA) stated, “Logistics and the lack of transport re-main the key constraints to the delivery of aid” after the earthquake in Haiti[8] This can be divided into continuous aid work and disaster relief, which involves timely assistance after a disaster, whether natural or man-made[9]. The actions of the community and the business sector affect various activities. From a logistics perspective, these activities can be divided into two main parts including 1) the impact on the demand aspect in disaster prone areas, wherein the public requires assistance from the government in providing necessary supplies, and 2) the supply aspect when disasters occur, whether natural or man-made. Government

agencies play an important role in providing assistance for the delivery of essential items to aid the affected population. This includes the transportation of medical equipment and the delivery of convenience items or equipment to affected are-as, which are crucial and must be considered when planning for the distribution of goods and transport routes, or even the areas for disaster relief or main areas for the distribution of convenience items to the public, which cannot be overlooked.

While reducing the risks of disasters and emergencies is considered crucial nowadays, these risks can occur anywhere and at any time. Whether caused by natural disasters such as earthquakes, tsunamis, floods, or human-caused disasters, such as the recent Covid-19 pandemic, each situation is considered an adverse public health tragedy that will affect people's livelihoods. The strategic direction for the implementation to build the resilience to disaster and sustainability through Thailand's National Disaster Risk Management Plan. This National Plan includes the development of disaster prevention and preparedness system and the enhancement of awareness for disaster risk reduction before, during and after disaster [10].

According to statistical data on disasters that occurred between 2012 and 2022, it was found that disasters in Chonburi Province occurred every year. This is mostly due to the physical characteristics of the province, which consists of hills, plains, and coastal areas in locations at risk of danger, which can be divided into two major sectors including the industrial and service sector, and the agricultural sector. In Chonburi Province, there are industrial factories, high-rise buildings, department stores, commercial buildings, hotels, and tall residential buildings with densely populated communities. In line with the government's policy to focus on urban and economic development, Chonburi Province is an important economic area in the Eastern Economic Corridor (EEC), both in terms of logistics systems and popular tourist destinations. These conditions enhance the risk of disasters in various forms for the areas in and around Chonburi Province, including land transportation accidents, floods, fires, cyclones, droughts, water transportation accidents, and hazards from chemicals and dangerous substances [11]

Preparing for natural and man-made disasters, which involves planning for emergency response or situations that cannot be predicted, is crucial in Chonburi Province. De-signing a logistics network for the distribution of humanitarian relief is necessary to pre-pare for and respond to disasters. During such events, the network plays a role in distributing necessary items such as medical tools, medication, special assistance equipment, rescue personnel, and survival kits, among others, to the affected area quickly and efficiently. Those involved must consider preventive measures and ways to reduce the impact, as well as provide assistance to those affected. The logistics network for distributing humanitarian relief is necessary to plan for the management and distribution of essential items to the affected areas quickly during disasters. Setting up a humanitarian aid distribution center is one approach to connecting the transportation and movement of necessary items to affected areas, and GIS-based network analysis can be used to identify the location of the center to maximize coverage of disaster-prone areas.

The objectives of this research include 1) to prepare for disasters and emergency response plans during disasters in Chonburi Province, 2) to plan suitable locations and routes for the distribution of humanitarian relief, and 3) to enable prompt and immediate responses and assistance to communities when disasters and emergencies occur. The contribution of this research is the provision of guidelines for disaster preparedness and response, as well as enhanced efficiency for emergency response in Chonburi Province.

The remainder of this paper is organized as follows. Section 2 provides materials and methods. Then, in Section 3, the proposed research framework. The results of the analysis for planning the distribution of humanitarian relief are presented and discussed in section 4. Finally, conclusions, limitations, and directions of future research are discussed in Section 5.

2. MATERIEL AND METHODS

2.1. Humanitarian Logistics

Humanitarian logistics refers to "the efficient planning, execution and control of the flow and storage of goods, services and related information from the point of origin to the point of consumption to alleviate the suffering of

people who require assistance". Humanitarian logistics is a branch of logistics that focuses on logistics operations to assist victims of disasters. According to Bhimani & Song [7], humanitarian logistics is a set of actions that organizations use to move data, goods, and services with the goal of assisting beneficiaries, the environment, and society [12].

Humanitarian logistics are the logistics process that being used for humanity operation [13]. Humanitarian logistics plays a crucial role in delivering aid and managing re-sources in response to various disasters. The ultimate goal of these operations is to assist human survival and recovery. Humanitarian logistics can be divided into two main aspects comprising continuous aid work and disaster relief. Disaster relief is the immediate response to a disaster, whether caused by natural occurrences (earthquake, avalanche, hurricane, flood, wildfire, volcano eruption, etc.) or human activities [14]

Humanitarian supply chain management is the administration of the flow of aid in-formation and services efficiently, intending to reduce the impact of disasters on human life [15]. It includes operations to alleviate the suffering of affected people and areas, such as providing lifesaving aid, medical assistance, food distribution, transportation, and shelter [16]. Logistics for humanitarian purposes differ from business logistics since the goal is to serve society, where events are uncertain and difficult to predict, and time is of the essence as it concerns people in need. The beneficiaries are the recipients of aid. In contrast, business logistics aim to generate profit, where time is money, and the customers are the recipients of the service [17].

Research on the problem of selecting a location to prepare for and respond to emergencies and disasters has received increasing attention and continuous research. Chiappetta Jabbour et al. [15] analyzed literature related to logistics for humanitarian and supply chain management, emphasizing the importance of disaster management as a direction for future research and study. In particular, there has been growing interest in using knowledge concerning humanitarian logistics and supply chain management (HLSCM), and this has attracted more attention from academics, practitioners, and policymakers. Consequently, the number of research studies related to HLSCM logistics for humanitarian and supply chain management has increased significantly. Suggestions have been made that future research should use the concept of HLSCM in different con-texts, such as geographic perspectives, to test the validity of the theories used in the re-search, to understand the context of HLSCM, and to practice humanitarian work between countries, including non-profit organizations.

Jiang and Yuan [18] reviewed previous literature on emergency logistics in the context of large-scale disasters, as responding to such emergencies can be complex and challenging. Therefore, developing a comprehensive model that can manage emergency logistics processes to address large-scale disasters requires improving the flexibility of emergency logistics networks and creating simulated scenarios from suitable models as a direction for future research. Ma et al. [19] reviewed literature related to models for selecting emergency shelter locations in the event of natural disasters in order to identify research issues and improve the efficiency of reducing the severity of disasters and emergency response. The objective of establishing emergency shelters is to reduce evacuation times and/or distances, reduce the costs associated with constructing shelters, and reduce risks during evacuation while meeting the requirements within the service radius. The method for ad-dressing the problem of selecting locations for emergency shelters in disaster-prone areas should be considered in future research, including 1) developing models that can be used to select emergency shelter locations for various types of disasters, 2) considering uncertainty, 3) improving algorithms or models to address large-scale allocation problems, and 4) developing resource-efficient designs that are sustainable and applicable by planners and policymakers in real-world situations.

2.2. Geographic Information System: GIS

The Geographic Information System (GIS) is a framework for collecting, managing, and analyzing data [20]. GIS combines various types of data, which can be analyzed spatially and displayed as layers on a map. The integration of spatial data in GIS can be useful for logistics operations by using related databases. The GIS model focuses on improving route efficiency and integrating non-spatial databases related to logistics. For example, it can improve transportation cost efficiency [21].

GIS refers to computer hardware, software, and geographic data used for managing, analyzing, and displaying geographic reference data. GIS can also help answer questions related to geography in many ways, such as planning distribution networks, selecting lo-cations, and identifying market target groups to meet the needs of businesses and support various government services. Therefore, the application of GIS can cover both private and public sectors, including industries and agriculture, to solve problems such as customer analysis, marketing analysis, location selection, risk analysis, territory management, asset management, supply chain management, and logistics management, among others.

2.2.1. Facility Location Problem

Location allocation is the process of minimizing the overall distance between demand points and the location of facilities that provide convenient services [22]. Location allocation has been used in a variety of situations, though generally for the establishment of service facilities that respond to demand in the most appropriate manner [23]. It involves allocating facilities to select the best possible locations to efficiently meet customer needs and provide services. In addition, various measures are used in the Location Allocation Problem to find the most suitable locations in terms of travel distance, travel time, and cost. Currently, location-allocation techniques are used to identify the most suitable locations for facilities such as fire stations, hospitals, post offices, warehouses, schools, libraries, banks, waste disposal sites, and other convenient facilities [20].

Finding suitable locations for establishing facilities is essential for operations in both the public and private sectors. However, there are distinct differences between the locations of public and private facilities. This is because the private sector prioritizes increasing profits and market share, while the objectives of the public sector include reducing social costs, which means providing services and maximizing efficiency to the greatest extent possible [24]. In addition, service provision by the government focuses on increasing the efficiency and coverage of service areas equally. This can be considered a significant problem for applying the location-allocation problem in the public sector. The objective of establishing facilities is to reduce travel distance while accommodating people or needs in the surrounding area to the greatest extent possible [25]. Therefore, this research aims to minimize the travel distances required by facilities and increase coverage as much as possible.

Maximum Covering Location Problem (MCLP)

$$\text{Maximize} = \sum_{i \in I}^{n} a_i y_i \quad (1)$$

$$\sum_{j \in N_i} x_j \geq y_i \quad ; \forall i \quad (2)$$

$$\sum_{j \in N_i} x_j \quad (3)$$

$$x_j \in \{0,1\} \quad ; \forall j \quad (4)$$

$$y_i \in \{0,1\} \quad ; \forall i \quad (5)$$

where a_i : weight value
i : facility location
j : location of alternative sites
P : number of alternative sites
X_j = {1 if choosing the district hospital at location j; 0 if not.}
y_i = {1 if the SHPH at the location j is correct; 0 if not.}

The purpose of solving location selection problems using the MCLP theory is to find suitable locations for alternative sites that cover the maximum number of objectives or requirements, subject to the constraint of the number of alternative sites available, P, as shown in equation (2). Variable x_j from equation (3) takes a value of 1 when location j is selected, and the variable y_i (4) takes a value of 1 when location I is an accessible objective within the response time r, which is subject to the constraint of equation (5). Variable y_i affects variable x_j in selecting new

locations for alternative sites.

In the research work of Boonmee, Arimura, and Asada [26], a review of the data modeling approach was conducted to select suitable locations for logistics management to assist disaster victims in emergency situations. The study found that responsiveness and risk were key criteria for consideration, both before and after a disaster. The models mainly aimed to reduce response time and/or distance, minimize transportation costs (distance and time), and provide open convenience facilities, as well as reduce operating costs and maximize service coverage to meet the highest demand. In addition, Zhou, Wu, Xu, and Fujita [27] collected ideas, theories, and characteristics of emergency decision-making (EDM) for natural disasters and short-term decision-making. They found that most research methods used mathematical modeling and GIS as the systems to support emergency decision-making. The decision-making methods can be divided into 4 methods including 1) decision-making based on mathematical models, 2) decision-making based on the situation, 3) decision-making based on knowledge management, and 4) group decision-making based on theoretical methods.

Abdalla [28] collected ideas for problem-solving to be used for preparedness and response in emergencies, using spatial analysis and GIS applications that can be applied to disaster management by describing the use and risk assessment. Spatial analysis and GIS applications also emphasize practical work by integrating spatial data for mapping and risk perception plans. Important components in spatial analysis include the accuracy of data, processing time, and coordination among stakeholders.

Feng, Su, and Sun [29] studied the emergency resource scheduling model (ERSM) for distributing emergency supplies in case of disasters. ERSM has been widely used in post-disaster management to determine the best and quickest routes to deliver emergency supplies using the Geographic Information System (GIS). Additionally, ERSM evaluates the best rescue routes under different emergency conditions using the Analytic Hierarchy Process (AHP) decision-making method. The indicators analyzed in the AHP method include traffic conditions, travel distance, and urgency of disaster relief. Oscar Rodríguez-Espíndola and Pavel Albores [30] studied the improvement of efficiency in disaster management in Mexico by integrating the analysis of flood situations using Raster GIS and creating a model. The study found that the results of disaster operations could be improved by reducing the number of facilities.

Beamon and Kotleba [31] studied the selection of locations for disaster relief centers based on the Maximal Covering Problem, which aims to maximize the number of lives saved or minimize the damage caused from the start of a disaster to the post-disaster recovery process. The objective was to increase the efficiency of logistics management in transporting necessary goods from the sources to the relief centers and from the centers to the affected individuals. Yi and Özdamar [32] discussed the use of location-distribution models to coordinate logistics and operations during disasters, which is essential for emergency logistics planning when delivering necessary goods to affected areas. This includes medical equipment and personnel, rescue equipment and teams, food, medicine, and other items that are distributed to centers in the affected area and for the evacuation or movement of injured people. It is necessary to establish temporary emergency and shelter centers in affected areas to increase the speed of medical care as well as the treatment of injured survivors. Therefore, coordinating logistics during a disaster is related to selecting a location that covers the at-risk area.

3. PROPOSED RESEARCH FRAMEWORK

This research proposes the design of a logistics network framework for disaster relief distribution planning and emergency preparedness in Chonburi Province. The framework aims to assist in the planning of location positioning and appropriate routes for the distribution of humanitarian relief, which is one of the activities in managing the supply chain for effective humanitarian assistance to communities in the area. Therefore, the re-searchers outlined the scope of this research, as shown in Figure 1.

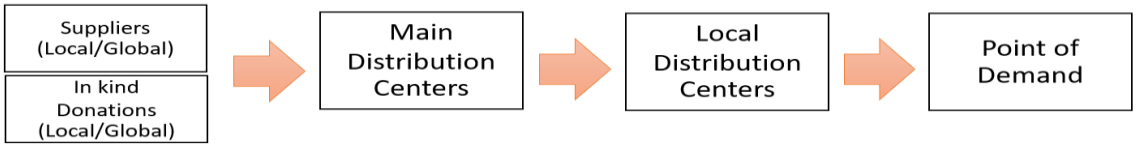

Figure 1. Scope of the Research

When a natural disaster occurs, the affected area may receive humanitarian relief from both foreign and domestic organizations. Relevant agencies will then forward that relief to the main distribution centers (MDCs) designated as locations for the distribution of humanitarian relief. Subsequently, the aid will be forwarded to the local distribution centers (LDCs) located near the affected areas, which will distribute essential goods and ser-vices to the disaster-stricken areas as quickly as possible. However, the researchers have proposed certain assumptions for the research based on the research framework above, as shown in Figure 2.

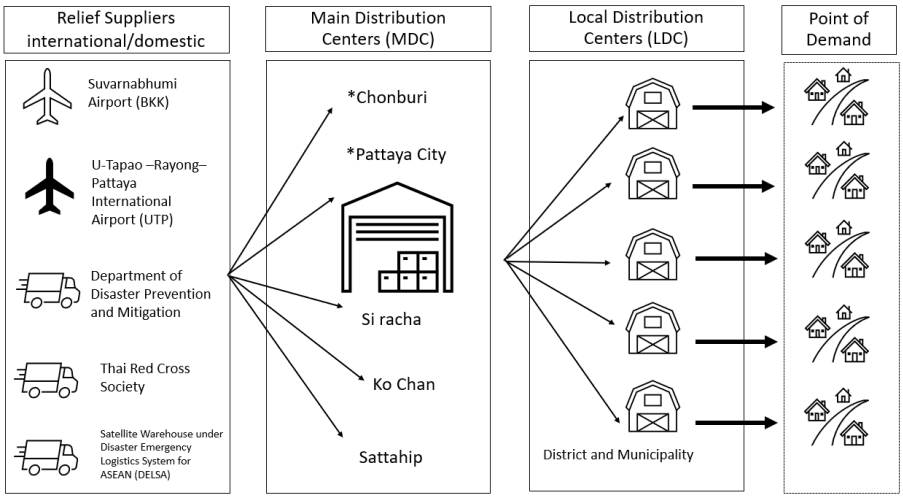

Figure 2. Research Conceptual Framework

Figure 2 shows the research hypothesis for designing a logistics network for the distribution of humanitarian relief. Based on the study of data from the Department of Disaster Prevention and Mitigation, it was found that Chonburi Province is one of several provinces located in disaster-prone areas (red area). Most of the disasters in Chonburi Province comprise floods, storms, landslides, and droughts. Therefore, planning for the appropriate locations and routes for the distribution of humanitarian relief should enable the relevant agencies to respond to and assist the community immediately in the event of a disaster. Thus, it is necessary to prepare the distribution of humanitarian relief in Chonburi Province using data from the locations of disaster-prone areas in the province.

This research was used to plan the location of Relief Supplies according to the implementation guidelines of the National Disaster Prevention and Mitigation Plan 2021-2027 as follows.

- Suvarnabhumi Airport: Suvarnabhumi Airport: BKK (IRS1)
- U-Tapao-Rayong-Pattaya International Airport: U-Tapao-Rayong-Pattaya International Airport: UTP (IRS2).
- Department of Disaster Prevention and Mitigation (Department of Disaster Prevention and Mitigation) (DRS3)
- Relief and Community Health Bureau, Thai Red Cross Society) (DRS4)
- Satellite Warehouse under Disaster Emergency Logistics System for ASEAN (DELSA) under ASEAN

Coordinating Centre for Humanitarian Assistance on disaster management: AHA Center (DRS5) [33]

Figure 3. Location of Potential Main Distribution Centers (MDCs).

Main Distribution Centers (MDCs) collects and stores necessary items from abroad and domestic agencies to distribute humanitarian aid to Local Distribution Centers (LDC). Figure 3 shows the locations of potential main distribution centers (MDC) for relief. The re-searchers designated them to be in close proximity to areas in Chonburi Province with high and moderate risk. They also designated military camps in Chonburi Province as lo-cations for the storage and transportation of goods to assist disaster victims. This is because they have sufficient space and military personnel as well as vehicles to provide safe and efficient relief and transportation. These locations include the 14th Military District, the First Naval Area Command, and the Thai Maritime Enforcement Command Center (Thai-MECC), which support personnel and vehicles for relief and transportation to aid disaster victims.

This research designated the Mueang Chonburi district as the central hub for disaster prevention and mitigation management, under the responsibility of the governor of Chonburi Province and the city of Pattaya, which is a special administrative area within Chonburi Province under the responsibility of the mayor of Pattaya in his capacity as the head of the administration department of the special administrative area.

In determining the locations for potential main distribution centers (MDCs) in Mueang Chonburi and Pattaya City, the details are as follows.

•The first location is Nawamindhachini Army Base (MDC1)

•The second location is Pattaya City Hall (MDC2).

•The third location for MDCs in the area is based on the sites of high and moderate-risk areas in Chonburi Province. The third location is Air Defense Battalion 12 Air Defense Regiment 1 (MDC3)

•The fourth location is the 2nd Infantryman Battalion 111st Infantry Regi-ment (MDC4)

•The fifth location is Sattahip Naval Base (MDC5).

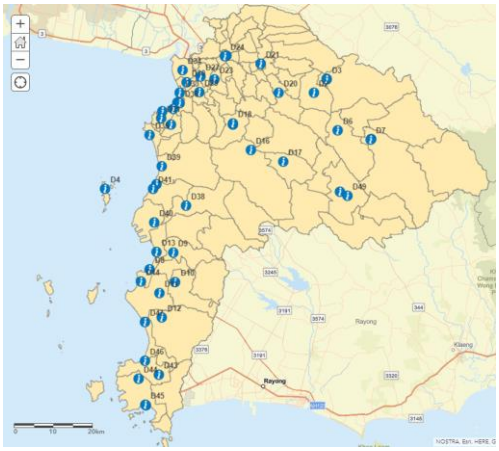

Figure 4. Locations of local distribution centers (LDCs).

This research defines local distribution centers (LDCs) as the number of registry of-fices in Chonburi Province, which is 49, as shown in Figure 4. Disaster victims will receive humanitarian relief from LDCs through the local registry offices that oversee the villag-es/communities in need of assistance. The distribution of humanitarian relief from the af-fected registry offices will be efficient as they are experienced in travel and can recommend effective routes for distributing humanitarian relief to the villages/communities in need.

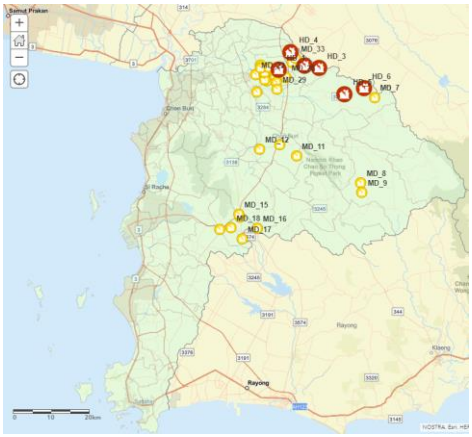

Figure 5. the locations of villages/communities with high and moderate risk levels.

Regarding the preparedness plan, Figure 5 shows the locations of villag-es/communities in need of assistance (Points of Demand). This research defines this as the locations of villages in Chonburi Province that are at high risk of disaster, consisting of 6 villages (HD_1 - HD_6), and villages that are at moderate risk of disaster in Chonburi Province, consisting of 29 villages (MD_7 - MD_34), for a total of 34 villages.

4. RESULTS AND DISCUSSIONS

4.1. The result of the analysis for planning the distribution of humanitarian relief from international organizations to the main distribution centers (MDC)

The results of the analysis for the humanitarian relief distribution planning under the transportation route with the fastest delivery time for essential aid items sent from foreign organizations via air to Suvarnabhumi Airport (IRS1) to the 5 Main Distribution Centers (MDCs). The researchers analyzed the delivery of aid for disaster-affected areas from foreign organizations along the transportation route from Suvarnabhumi Airport (IRS1) to U-Tapao International Airport, Rayong-Pattaya (IRS2) to the locations of all MDCs, under the shortest transport time, as shown in the time and distance for the distribution of humanitarian relief with the minimum transportation time.

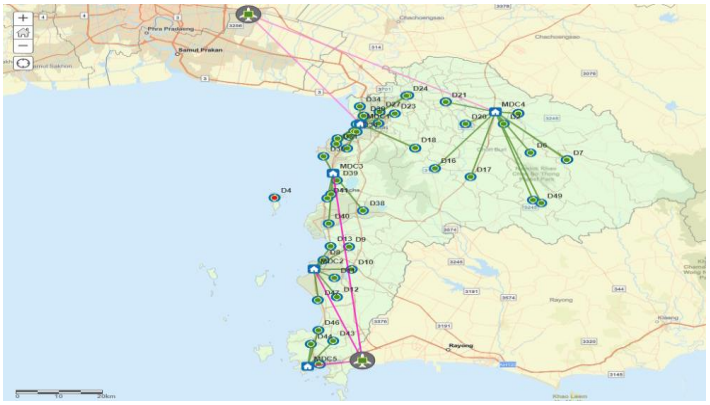

Figure 6. Humanitarian relief distribution from foreign agencies

The analysis shows the results for the distribution of humanitarian assistance from foreign organizations through Suvarnabhumi Airport (IRS1) and U-Tapao-Pattaya International Airport (IRS2) for delivering aid to disaster-stricken areas as quickly as possible (Figure 6). In the event of a disaster or emergency in an area under the responsibility of MDC1 and MDC4, assistance from foreign countries should be provided as quickly as possible through Suvarnabhumi Airport (IRSS1). In the case of a disaster or emergency in areas under the responsibility of MDC2, MDC3, and MDC5, however, foreign assistance should be provided as quickly as possible through U-Tapao-Pattaya International Airport (IRSS2). The analysis under this assumption shows that the shortest transport times to each MDC to deliver humanitarian relief as quickly as possible will vary, as shown by the comparison of transport times in Table 1.

Table 1. Time and distance for distributing humanitarian assistance from foreign organizations

International relief supplier_ ID	Main DC_ID	Trucking Time (Minutes)	Reduce Trucking Time (Minutes)	Trucking Distance (Kilometers)	Reduce Trucking Time (Kilometers)
IRS1	MDC1	68.745	17.398	63.568	26.821
	MDC4	96.012	17.648	95.13	2.746
	MDC2	38.721	90.839	45.054	78.605
IRS2	MDC3	77.386	10.193	76.324	7.174
	MDC5	26.664	132.941	17.579	143.735
Total		**307.528**	**269.019**	**297.655**	**259.081**

The results of the analysis for the time and distance required for planning the distribution of humanitarian relief found that IRS1 to MDC1 took less time and distance than IRS2 to MDC1, which was 17,398 minutes and 26,821 kilometers, respectively. Addition-ally, IRS1 to MDC4 took less time and distance than IRS2 to MDC1, which was 17,648 minutes and 2,746 kilometers, respectively. Furthermore, it was found that IRS2 to MDC2 took less time and distance than IRS1 to MDC2, which was 90,839 minutes and 78,605 kilometers, respectively. IRS2 to MDC3 also took less time and distance than IRS1 to MDC3, which was 10,193 minutes and 7,174 kilometers, respectively. Finally, IRS2 to MDC5 took less time and distance than IRS1 to MDC5, which was 132,941 minutes and 143,735 kilometers, respectively. The total time and distance were 307,528 minutes and 297,655 kilometers, respectively, with a decreased time and distance from using a single airport of 269,019 minutes and 259,081 kilometers, respectively.

4.2. Analysis results for planning the distribution of humanitarian relief from domestic organizations to main distribution centers (MDCs)

In this section, the researchers presented the results of the analysis for planning the distribution of humanitarian relief from domestic organizations to main distribution centers (MDCs) under the transportation routes with the

fastest delivery time requirements for essential goods. The aid was sent from domestic organizations to 5 MDCs, as shown in the analysis results in Figure 7 and Table 2.

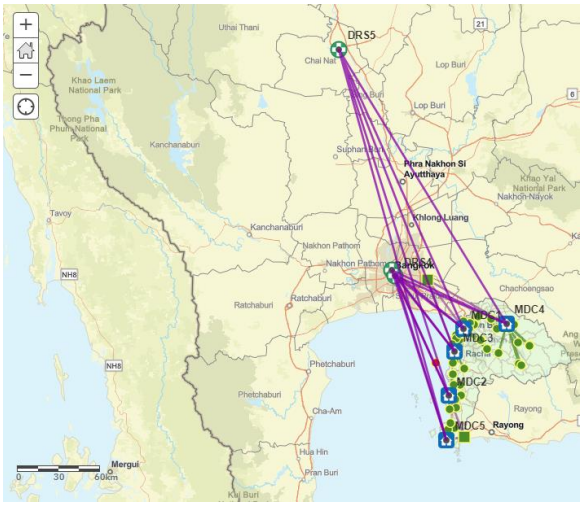

Figure 7. Distribution of humanitarian relief from organizations within Thailand

The analysis of the distribution of humanitarian relief from organizations located in other provinces in Thailand to the 5 main distribution centers (MDC) in Chonburi Province can help plan the timely delivery of necessary goods to disaster-affected areas. It can be seen that the delivery of necessary goods from DRS3 and DRS4 can be faster than DRS5 because DRS3 and DRS4 are located in Bangkok, while DRS5, which is a distant aid warehouse for ASEAN, is located in Chai Nat Province. Therefore, prompt disaster relief may need to be supported by DRS3 and DRS4 first, followed by DRS5. In the case of a dis-aster in areas under the responsibility of the MDC, DRS3, DRS4, and DRS5 can plan the delivery of aid according to time and distance to prepare for the shortest possible travel time.

Table 2. Time and distance for humanitarian relief distribution from domestic organizations

Domestics relief supplier_ ID	Main DC_ID	Trucking Time (Minutes)	Trucking Distance (Kilometers)
DRS3	MDC1	100.396	81.807
	MDC2	161.211	141.898
	MDC3	119.23	101.737
	MDC4	127.663	113.369
	MDC5	191.256	179.553
Total		**699.756**	**618.365**
DRS4	MDC1	85.524	74.901
	MDC2	146.34	134.992
	MDC3	104.358	94.831
	MDC4	112.792	106.462
	MDC5	176.384	172.647
Total		**625.398**	**583.832**
DRS5	MDC1	235.437	259.534
	MDC2	296.252	319.625
	MDC3	254.27	279.464
	MDC4	262.704	291.096
	MDC5	326.296	357.28
Total		**1374.959**	**1506.998**

The results of the analysis concerning time and distance for humanitarian relief distribution from the Department of Disaster Prevention and Mitigation (DRS3) to all MDCs show a total of 699.756 minutes and 618.365 kilometers, respectively. For the Relief and Community Health Bureau, Thai Red Cross Society (DRS4) to all MDCs, the total time and distance are 625.398 minutes and 583.832 kilometers, respectively. Lastly, the total time and distance are 1374.959 minutes and 1506.998 kilometers, respectively, for the Satellite Warehouse under the Disaster Emergency Logistics System for ASEAN (DELSA) (DRS5) to all MDCs.

The MDC is required to be a point for receiving and delivering assistance from agencies in the country and distributing humanitarian relief to LDCs and forwarding it to dis-aster-affected areas in communities/villages. For example, the travel time and distance from DRS3 to MDC1 are 100.396 minutes and 81.807 kilometers, respectively. For DRS4 to MDC1, the travel time is 85.524 minutes and the distance is 74.901 kilometers. Both agencies are located in Bangkok, allowing for the rapid delivery of aid. However, the travel time to MDC1 from DRS5, which is located in Chai Nat Province, is 235.437 minutes and the distance is 74.901 kilometers.

4.3. Results of the analysis for response and assistance to communities during disasters and emergencies by main distribution centers (MDC)

This research study is based on simulated scenarios using data from communities in Chonburi Province that face high and medium risk in the event of a disaster or emergency. In terms of the analysis of response and assistance to communities during a disaster or emergency, the assisting organizations will collect items from the main distribution centers (MDC) and distribute them to local distribution centers (LDC) using the shortest transportation route possible. Subsequently, the necessary items for humanitarian relief will be transported to the affected areas, which include the communities/villages within the LDC's administrative jurisdiction, as shown in Figure 8 and Table 3

Figure 8. Response and assistance to the community by local distribution centers (LDC)

All 5 main distribution centers (MDCs) are responsible for providing services at the local level to respond to and assist communities in the event of disasters and emergencies. This requires distribution from local agencies, namely local distribution centers (LDCs), which have the best understanding of the characteristics of the affected communities and the ability to communicate closely with affected individuals to deliver aid. The analysis found that MDC1 is responsible for providing services to 16 LDCs, followed by MDC4, which must serve 13 LDCs. MDC4 has the longest distance and transportation time com-pared to other MDCs. Additionally, MDC3 is the only MDC that must distribute aid through water transportation from a location near its site to the pier on Ko Sichang Island (LCD4).

Table 3. Duration and distance for community response and assistance

Main DC_ID	Local DC_ID	Number of total Local DC	Trucking Time (Minutes)	Trucking Distance (Kilometers)
MDC1	LDC15, LDC 18, LDC22, LDC23, LDC24, LDC25, LDC26, LDC27, LDC28, LDC29, LDC30, LDC31, LDC32, LDC33, LDC34, LDC36	16	191.527	172.285
MDC2	LDC8, LDC9, LDC10, LDC 11, LDC12, LDC13, LDC14, LDC47	8	130.251	84.890
MDC3	LDC35, LDC37, LDC38, LDC39, LDC40, LDC41, LDC4	7	91.292	65.607
MDC4	LDC1, LDC2, LDC3, LDC5, LDC6, LDC7, LDC16, LDC17, LDC19, LDC20, LDC21, LDC48, LDC49	13	290.220	297.470
MDC5	LDC42, LDC43, LDC44, LDC45, LDC46	5	71.012	45.329
TOTAL		49	774.303	665.580

Table 3 shows the service areas for MDCs to LDCs under the conditions of the mini-mum distance from an MDC to an LDC. It was found that MDC1 had a total time of 191.527 minutes and a total distance of 172.285 kilometers. In the case of MDC2, which is responsible for distributing aid to 8 LDCs, the total time was 130.251 minutes and the total distance was 84.890 kilometers. MDC3 is responsible for distributing aid by truck to 6 LDCs, and the total time and distance were 130.251 minutes and 84.890 kilometers, respectively. In addition, transportation by water from the location for MDC3 to D4 had a distance of 16.7 kilometers and took 60 minutes. MDC4 is responsible for distributing aid to LDCs and had a total time of 290.220 minutes and a total distance of 297.470 kilometers. Lastly, MDC5 is responsible for distributing aid to 5 LDCs and had a total time and distance of 71.012 minutes and 45.329 kilometers, respectively.

4.4. Results for the analysis of the emergency response and community assistance of local distribution centers (LDC) during disasters and emergencies

In this analysis, the researchers designed a logistics network to distribute humanitarian relief. In this section, the researchers used risk assessment data from the Department of Disaster Prevention and Mitigation to simulate scenarios for response and com-munity assistance. The scenarios sent aid from the local distribution centers (LDC) to affected communities/villages, which comprised the demand points, as shown in the results of the analysis in Figure 9 and Table 4.

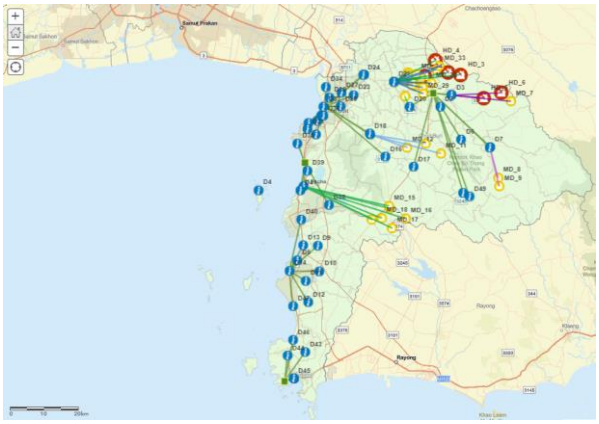

Figure 9. Response and assistance to the community by local distribution centers (LDC)

Pre-disaster and mid-disaster planning are essential to provide immediate response and assistance to affected communities during catastrophes and emergencies (as shown in Figure 9). As observed, the LDCs are conscious of the service areas of the organizations responsible for disaster management in order to enable immediate response

and assistance, as well as their respective areas of responsibility according to the Department of Provincial Administration. When a demand point in an affected area is identified, the LDC responsible for that area will assist at the demand point.

Table 4. Communities in need of humanitarian aid from local distribution centers (LDCs)

Main distribution centers (MDC)	Local DC_ID	Demand Point	Number of households	Number of Population	Level of Risk area
MDC4	D19	HD_1	254	718	High
MDC4	D19	HD_2	455	1337	High
MDC4	D19	HD_3	376	1430	High
MDC4	D19	HD_4	241	814	High
MDC4	D3	HD_5	537	1456	High
MDC4	D3	HD_6	296	1184	High
MDC4	D19	HD_1	254	718	High
MDC4	D19	HD_2	455	1337	High
MDC4	D3	MD_7	326	1084	Medium
MDC4	D7	MD_8	376	1295	Medium
MDC4	D7	MD_9	250	1046	Medium
MDC1	D15	MD_10	249	884	Medium
MDC1	D15	MD_11	578	1260	Medium
MDC1	D15	MD_12	926	1486	Medium
MDC3	D37	MD_13	982	1205	Medium
MDC3	D37	MD_14	803	1029	Medium
MDC3	D37	MD_15	1205	952	Medium
MDC3	D37	MD_16	382	851	Medium
MDC3	D37	MD_17	1859	2259	Medium
MDC3	D37	MD_18	273	763	Medium
MDC4	D20	MD_19	262	749	Medium
MDC4	D19	MD_20	136	497	Medium
MDC4	D19	MD_21	75	271	Medium
MDC4	D19	MD_22	172	415	Medium
MDC4	D19	MD_23	103	324	Medium
MDC4	D19	MD_24	441	1448	Medium
MDC4	D19	MD_25	47	154	Medium
MDC4	D19	MD_26	409	1427	Medium
MDC4	D19	MD_27	158	460	Medium
MDC4	D19	MD_28	282	834	Medium
MDC4	D19	MD_29	349	1283	Medium
MDC4	D19	MD_30	400	881	Medium
MDC4	D19	MD_31	248	636	Medium
MDC4	D19	MD_32	207	573	Medium
MDC4	D19	MD_33	584	1252	Medium
MDC4	D19	MD_34	158	420	Medium

Table 4 shows data on communities (demand points) in need of humanitarian relief from local distribution centers (LDCs). Six high-risk communities (HD) are identified. For example, HD_1 will receive relief supplies from D19 if it is an affected area under the responsibility of MDC4. Similarly, HD_5 will receive relief supplies from D3 if is affected, which is also under the responsibility of MDC4. Therefore, D19 and D3 are local organizations responsible for distributing necessary aid received from MDC4 according to the needs of the population in that area.

In this research, the population residing in communities/villages affected by disasters or emergencies is identified as the recipient of humanitarian relief provided by the government under the operation of local administrative units according to the Department of Provincial Administration. This research requires the distribution of survival bags to the population for response and assistance to communities in the area. Each person is entitled to

receive a 10-kilogram survival bag. Transportation for the distribution of humanitarian relief will be provided by trucks. It is necessary for the LDC to know the size of the population in order to prepare sufficient supplies to meet the demand, as well as the number of survival bags, the number of trucks needed, and the duration and distance for both one-way and round-trip transportation, as shown in Table 5.

Table 5. Duration, distance, and number of transport vehicles for response and assistance to communities

Local DC_ID	Demand Point	Number of survival bags	Total Trucking Time/Round Trip (Minutes)	Trucking Distance/ Round Trip (Kilometers)	Number of Vehicles Required (2.5 Tons)	Number of Vehicles Required (5 Tons)	Number of Vehicles Required (10 Tons)
D19	HD_1	718	23.773	22.396	3	2	1
D19	HD_2	1,337	41.098	39.482	6	3	2
D19	HD_3	1,430	52.512	47.458	6	3	2
D19	HD_4	814	43.270	36.783	4	2	1
D3	HD_5	1,456	22.703	20.305	6	3	2
D3	HD_6	1,184	39.359	31.691	5	3	2
D3	MD_7	1,084	34.569	36.810	5	3	2
D7	MD_8	1,295	20.744	20.601	6	3	2
D7	MD_9	1,046	25.777	26.482	5	3	2
D15	MD_10	884	33.942	35.416	4	2	1
D15	MD_11	1,260	64.845	47.359	6	3	2
D15	MD_12	1,486	26.647	24.252	6	3	2
D37	MD_13	1,205	134.597	64.389	5	3	2

D37	MD_14	1,029	116.991	52.553	5	3	2
D37	MD_15	952	138.159	67.223	4	2	1
D37	MD_16	851	137.230	76.025	4	2	1
D37	MD_17	2,259	134.972	68.105	10	5	3
D37	MD_18	763	120.600	59.174	4	2	1
D20	MD_19	749	7.012	6.886	3	2	1
D19	MD_20	497	33.881	20.670	2	1	1
D19	MD_21	271	32.892	16.286	2	1	1
D19	MD_22	415	13.466	7.693	2	1	1
D19	MD_23	324	19.148	12.386	2	1	1
D19	MD_24	1,448	23.443	18.315	6	3	2
D19	MD_25	154	29.469	14.803	1	1	1
D19	MD_26	1,427	45.535	24.566	6	3	2
D19	MD_27	460	18.565	12.817	2	1	1
D19	MD_28	834	44.488	27.082	4	2	1
D19	MD_29	1,283	46.074	27.583	6	3	2
D19	MD_30	881	35.410	30.856	4	2	1
D19	MD_31	636	18.424	12.416	3	2	1

D19	MD_32	573	20.340	12.832	3	2	1
D19	MD_33	1,252	36.444	33.331	6	3	2
D19	MD_34	420	26.254	17.368	2	1	1
TOTAL		32,677	1,662.631	1,072.396	148	79	51

From the simulation, the number of survival bags for response and assistance to communities in the area is 32,677, with a total time of 831,316 minutes and a total distance of 536,198 kilometers. This research project specifies the transport vehicles to be used for transporting survival bags to the area, with two types of loading weights depending on the impact on the area and severity:

•In the case of minor damage or an undamaged route, the weight for loading is calculated based on the normal weight that can be carried on the road.

•In the case of major damage, the weight for loading is calculated based on the weight that can be carried in the country, which will result in a reduced weight capacity for loading.

This research specifies that military trucks, specifically the 4x4 type, have a road-loaded weight of 5,000 kilograms (5 tons) and a cross-country loaded weight of 2,500 kilograms (2.5 tons). Additionally, military trucks of the 6x6 type have a road-loaded weight of 10,000 kilograms (10 tons) and a cross-country loaded weight of 5,000 kilograms (5 tons).

Based on the aforementioned, this research defines the load-carrying capacity of military trucks into three levels comprising 2,500 kilograms (2.5 tons), 5,000 kilograms (5 tons), and 10,000 kilograms (10 tons). The analysis results are as follows:

1.Load capacity of 2,500 kilograms (2.5 tons): Military trucks of the 4x4 type can carry a load of 2,500 kilograms (2.5 tons) for 148 trips when the road is heavily damaged.

2.Load capacity of 5,000 kilograms (5 tons): Military trucks of the 4x4 type can carry a load of up to 5,000 kilograms (5 tons) on undamaged or lightly damaged roads, or when the damage is significant; Military trucks of the 6x6 type with a load capacity of 5,000 kilograms (5 tons) will be required for 79 trips.

3.Load capacity of 10,000 kilograms (10 tons): Military trucks of the 6x6 type can carry a load of up to 10,000 kilograms (10 tons) on undamaged or lightly damaged roads for 51 trips.

The transportation route that can respond to and assist the community, which is designated as the transportation route that takes the shortest time from the LDC to the disaster-affected area, is shown in Figures 10 and 11.

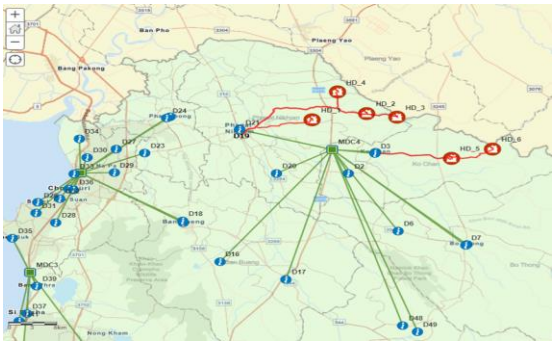

Figure 10. Transportation route that can respond to and assist communities in high-risk areas

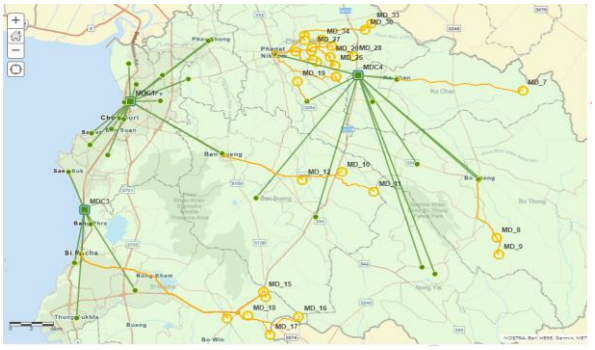

Figure 11. Transportation route that can respond to and assist communities in areas with moderately high risk

From the design of a logistics network to simulate the delivery of humanitarian relief from local distribution centers (LDC), the local organization is responsible for distributing aid to the community at demand points. In the case of an emergency or disaster area, such as if HD_1 is a community in a disaster or emergency area, D19 must respond to and assist the community by delivering 718 bags of essential relief to the affected population. For a one-way trip, it was found that the travel time was 11.886 minutes and the distance traveled was 11.198 kilometers. For a round trip, it was found that the travel time was 23.773 minutes and the distance traveled was 22.396 kilometers.

In the case of severe damage to transportation routes in the area and the need for military 4x4 trucks (with a load capacity of 2.5 tons), the LDC requires 3 trucks. Alternatively, three round trips will be needed to deliver the required number of survival bags if there is only one truck available. If military trucks of the 6x6 type (with a load capacity of 5 tons) are used for transportation, the LDC requires 2 trucks. However, in the case of minimal damage to transportation routes or routes that have not been affected, the LDC requires 2 military trucks of the 4x4 type (with a load capacity of 5 tons) or 1 military truck of the 6x6 type (with a load capacity of 10 tons) for transportation. The duration and distance from the LDC to the research area in this study are specified to show the time and distance required for transportation when the transportation routes in the area are minimally damaged or undamaged. This information is intended to pro-vide guidance for responding and providing assistance to communities affected by disasters as quickly as possible.

CONCLUSIONS

Currently, situations related to natural disasters and emergencies such as earth-quakes, floods, or even the spread of infectious diseases such as COVID-19, all have an impact on the economy, society, and environment of every country around the world. In the future, the likelihood of disasters and emergencies may become even more severe. Thus, it is crucial to prepare and plan for emergencies and natural disasters as they can occur without warning, anywhere, and cannot be predicted. This study concerns the de-sign and preparation of a logistics network for the distribution of humanitarian relief in order to respond to catastrophic situations. Appropriate relief in the form of distributing necessary goods during a disaster or in its immediate aftermath plays a crucial role in recovery. In this

study, the objectives were to prepare for catastrophic situations and plan emergency response measures for future catastrophes using Chonburi Province in Thailand as a case study. The study aimed to determine suitable locations and routes for the distribution of humanitarian relief in order to respond immediately and provide assistance to communities when disasters occurred. The researchers applied the concepts and theories of Humanitarian Logistics and Geographic Information Systems (GIS).

The distribution of humanitarian relief is one of the activities carried out by logistics and supply chain management for humanitarian aid so assistance can be provided efficiently to communities in need. The results of the plan to determine suitable locations and routes for distributing humanitarian aid under the research hypothesis in this study showed that disaster areas may receive aid from both foreign and domestic organizations, with a total of 5 agencies designated as primary senders. Associated agencies will then forward the aid to potential main distribution centers (MDC) as the second-level senders, which serve as locations for the distribution of aid. The aid will then be sent to the local distribution centers (LDC) as the third-level senders, with a total of 49 registration offices located near the disaster areas to distribute the necessary aid as quickly as possible. The fourth-level senders, comprising points of demand, included 34 villages or communities in need of assistance.

According to the analysis of planning and response to support communities during disasters and emergencies, it was determined that foreign organizations would provide the quickest relief to MDC1 and MDC4 through Suvarnabhumi Airport (IRSS1) in case of a disaster or emergency in their area of responsibility. Similarly, MDC2, MDC3, and MDC5 should receive assistance through U-Tapao Rayong-Pattaya International Airport (IRSS2). Due to their shorter delivery times, DRS3 and DRS4 are capable of delivering necessary items faster than DRS5 from domestic organizations. As a result, DRS3 and DRS4 may need to provide initial support for relief items in the early stages. If the relief items are insufficient, DRS5 may need to be contacted for additional assistance. After that, the MDC in Chonburi Province will distribute the relief items to the LCD.

From the research findings, it was revealed that MDC1 has been allocated to serve the largest number of LCDs (16) owing to its location in the city district and suitability for distribution to local organizations close to major roads, thus enabling the greatest coverage of humanitarian relief distribution. The second largest is MDC4, which serves 13 LCDs and has the longest transportation times and distances compared to other MDCs. MDC4 is the only humanitarian aid distribution center located in an area that is not on the coast of the Gulf of Thailand, resulting in it handling the largest service area coverage. However, the population density in this area is lower than that of the coastal areas of the Gulf of Thailand. In addition, MDC3 is the only MDC that has to distribute aid by water transportation from the coast near its location to the ferry terminal on Koh Sichang Island. Furthermore, the LDC must survey the population in the area, including the hidden population that is not registered but living in the area of responsibility, to determine the needs and prepare necessary items or survival kits to help as many disaster victims as possible.

The recommendations for future research include two key areas. Firstly, related organizations should study the location data for the center and routes of humanitarian relief distribution. Lessons learned from past disaster events should be extracted and information collected on the problems and obstacles encountered during disaster management. All organizations should be informed of these findings for potential adaptation to their respective areas of responsibility. Secondly, further study is required to examine the understanding and preparedness of logistics management organizations for humanitarian purposes before, during, and after disasters. This study provides particularly valuable in-sights and knowledge from lessons learned to aid future disaster management in Chonburi Province.

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DOI: https://doi.org/10.15379/ijmst.v10i2.3099