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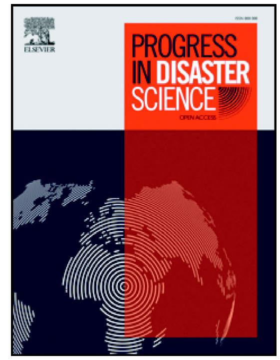

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Multi-modal Relief Distribution Model for Disaster Response Operations

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Abstract

Multi-modal transportation may be a solution in the immediate aftermath of a disaster when transportation resources are scarce. This study presents a multi-modal relief distribution model using a three-level chain composed of (1) supply nodes, (2) logistics operational areas, and (3) affected areas, while considering multiple trips for disaster response operations. The model determines the location of logistics operational areas, modes of transport utilized, and amount of relief goods allocated for each mode of transport. In addition, the model considers the different phases of essential response factors, such as network and infrastructure conditions, as well as accessibility of supplies and modes of transport. Data from the Yogyakarta Earthquake of 2006 in Indonesia are examined, revealing 11 selected logistics operational areas in which all modes of transport were utilized for relief delivery—mainly trucks and airplanes. For all goods delivered, multi-modal transportation comprised 45.67% of total use (31.98% for airplane–truck, 7.95% for sea vessels–truck, and 5.74% for airplane–helicopter). The results provide an example for decision makers regarding relief distribution systems with multi-modal transportation.

Keywords: relief distribution, multi-modal transportation, disaster response

1. Introduction

Humanitarian logistics planning networks involve identifying optimal distribution routes that are intended to minimize people suffering (Klose and Drexl, 2005). Humanitarian relief activities are vital as slight improvement in planning and implementation may substantially reduce suffering (Ertem et al., 2017). Humanitarian logistics preparedness must be developed based on vulnerability and available resources. Thus, many alternative routes and modes must be considered when designing preparedness plans. Efficient planning should achieve a robust yet flexible relief distribution plan that is suited to the nature of the disaster in affected areas (AAs).

During a disaster, variations in demand, network and facility damage, and resource shortages are expected. In particular, transport networks—such as road accessibility, airport and seaport availability, or unexpected events while traversing routes—change over time. As it is not possible to forecast the effects of a disaster, it may be difficult to identify damaged distribution networks such as roads and railways or determine airport and seaport availability. Different disasters may result in the inability to access various modes of transport (Long and Wood, 1995).

Combined modes of transport (such as sea–road, air–rail, and air-road) may improve the performance of humanitarian relief distribution systems. Multi-modal transportation can be a solution when transportation resources are scarce during the immediate aftermath of a disaster. As an alternative to road transportation in the short term, other modes of transport (such as railways) can transport higher quantities of relief supplies in a single trip. Air transportation is also significant in disaster response operations—especially for distributing relief goods—as it covers AAs rapidly and efficiently (Choi and Hanaoka, 2017). However, due to the probability of node failure, relief networks may face disruption; hence, reconfiguring the network flow between several modes of transport is vital. In response to disasters, decision makers often consolidate available transportation tools to deliver relief supplies. Several studies have discussed multi-modal transportation in disaster response, such as the multi-commodity and multi-modal network flow models formulated by Barbarosolu and Arda (2004) and Özdamar et al. (2004), respectively, or the multi-mode stochastic model presented by Najafi et al. (2013).

Hence, generating relief good distribution and transportation plans is challenging, and several notable issues must be addressed. Some variables—such as supply, demand, number of vehicles, and capacities—are time-varying due to changes in available information. Commonly, the first relief goods transported to AAs are from inventories of prepared goods from disaster preparedness stage. The availability of emergency resources, including vehicles and supplies, is always limited. As information concerning the occurrence of the disaster is dispersed, more relief goods are donated and sent to affected countries, affecting the total number of available supplies. From the perspective of AAs, demand value also changes over time as the amount of information increases. Further, post-disaster environments change over time. During the initial period, some important transportation resources in AAs, such as airports and ports as nodes or railways and roads as networks, are commonly destructed and are not able to transport goods. Any restoration attempts change the availability status of such important nodes.

This study purposes a multi-modal model for relief distribution networks with time-varying features and multiple trips by maintaining undisrupted network services in large-scale failure scenarios. The time-varying features include three phases of disaster response operations: (1) emergency response; (2) continuum response; and (3) initial recovery. The model aims to discover the relationship between time-varying data input that are predictive of any of several time-varying outcomes. A general strategic distribution plan is developed for the island of Java, Indonesia, while a specific example is provided that focuses on Yogyakarta Province. A case study of distribution networks and multi-modal transportation systems in Java is conducted as well. The comparison is evaluated considering how different response phases depict essential factors such as network condition and demand fluctuation.

2. Literature Review

Humanitarian logistics have received increased attention in the literature in recent decades. Many studies focus on approaching the problem of relief distribution by using facility location as a foundation from which and modes, deciding on routes, and inventory considerations are developed. Current relief distribution networks also vary according to the type of distribution levels, type of planning horizon, facility location function, number of echelons, transportation mode selection, and infrastructure states. In disaster contexts, distribution networks must be planned and organized even though the knowledge of the situation is minimal (Beamon, 2004; Long and Wood, 1995; Tomasini and Wassenhove, 2009). Although the goal of relief distribution is to meet the population's urgent needs in the shortest time and fewest resources possible (Tomasini and Wassenhove, 2009), flexibility to deal with time-varying or dynamic demands may be even more critical.

Numerous studies have attempted to address the multi-modal distribution problem in the context of disasters. One of the studies conducted by Barbarosolu and Arda (2004) proposed a multi-commodity and multi-modal network flow model for relief supply transportation in disaster responses. Their study is closest to ours in that they examine the regional distribution network by considering multi-modal transport mechanisms. Their study, however, only focused on utilizing roads and helicopters and posited that the mode shift will only occur if roads are not available. Özdamar et al. (2004) modeled emergency logistics as a multi-period, multi-commodity network flow problem with different modes of transport. Hu (2011) built an integer-linear-programming model for container multi-modal path selection in the context of emergency relief while Lin et al. (2011) proposed a logistics model to deliver prioritized items in disaster relief operations by considering multiple items, vehicles, periods, soft time windows, and a split delivery strategy scenario. Haghani and Oh (1996) formulated the distribution problem as a multi-commodity, multi-modal network flow model with time windows and presented two heuristic algorithms to solve the model. Najafi et al. (2013) proposed a multi-modal stochastic model to manage the logistics of both commodities and injured persons in earthquake response operations and developed a dynamic model for the same problem. In these studies, multiple modes of transport (including air, railways, water, and roads) were simultaneously considered to select suitable modes with varying efficiency and urgency in the transport of various kinds of relief supplies.

The proposed model focuses on regional distribution systems or the upstream levels of supply chains. Time-varying models are being increasingly considered due to the limitation of historical data in related study areas. The critical point of this study is to fit relief goods to suitable transport modes based on infrastructure availability. As each disaster has different impacts on infrastructure, the stochastic approach is not suitable as it provides an optimal result based on several disaster probabilities. Regional distribution networks mainly focus on configuring different nodes to improve distribution efficiency (Zhang et al., 2017). Thus, this study aims to develop a time-varying, multi-modal model for relief distribution networks with multiple trips by maintaining undisrupted network services. As the effect of disasters cannot be predicted, identifying damaged distribution networks such as roads, rails, or airport availability may be difficult. Although it is crucial for humanitarian logistics, network information is not readily available in the aftermath of a disaster. Therefore, it takes time to understand the present status of transportation modes. However, studies focusing on relief network design have always emphasized last-mile distribution as it exhibits the most breakdown among all. In these studies, multiple transportation modes including air, railways, and roads were simultaneously considered with the aim to select suitable modes with different transportation efficiencies for various relief supplies in different urgency degrees. Multi-modal transportation will be incorporated to capture authentic situations during relief distribution, as solely utilizing one type of mode of transport cannot assure large amount of relief distribution to be delivered in acceptable time. Furthermore, multiple periods will be incorporated to demonstrate how time-varying relief goods are received during disaster response.

3. Problem Description and Model Development

3.1. Response Phase and Time-Varying Supply

Time-varying features in the disaster context are often used to understand how the environment and several parameters depend on time. Adapting the features outlined by Sheu and Pan (2014), this study divided disaster response into three phases as follows:

a. Initial response period

   After a disaster occurs, response operations immediately follow. This is regarded as the most critical period for searching for and rescuing survivors (Sheu 2007). This period may extend to three or four days.

b. Continuum response period

   Following the initial response, this period begins when search-and-rescue is almost complete and when it is the appropriate time to meet the basic subsistence needs of survivors, including shelter, water, food, and emergency medical assistance (IDNDR/DHA 1992; UNDP/UNDRO 1992). This period may last from two to three weeks. At the beginning of the period, the number of relief supplies will increase and decrease slowly as the urgent needs are all delivered.

c. Initial recovery response period

   This period follows the continuum response as the early recovery period in which the environment is cleaned and damaged infrastructure is repaired in the AAs.

Supplies during will become available during the response phase in a time-varying manner due to updated information and additional resources for improving the distribution system. In summary, the amount of relief goods supply tends to vary according to the progress of the relief response. Supply and demand will increase within 3 days–1 week after the disaster. This study suggests the three-response phase in which each phase is driven by the urgency of the needs. As a time-dependent logistics problem, there are high stakes associated with the accurate delivery time of relief supplies. For example, during the initial response phase, decision makers will focus on speed of delivery, as the challenge will be to minimize the delay in the arrival of relief goods at the AA. Supplies will reach maximum numbers within the first week following the disaster. Thus, the focus will shift from delivery time to sufficiently meeting all needs. During this continuum response period, it is expected that all transportation modes will be utilized. After several weeks of response, the AA will receive a smaller number of relief goods, which again shifts the focus of distribution to cost reduction. During the initial recovery response phase, the relief supply chain begins to resemble a regular business supply chain (Tomasini and Wassenhove, 2009).

3.2. Logistics Capacity, National Disaster Management Agency, and Logistical Challenges in Indonesia

Logistics capacity is a qualitative measurement of the readiness in the logistics sector to operate if a disaster occurs. As part of the preparedness phase, it is necessary for a country to conduct a logistics capacity assessment. The assessment provides information about related logistics resources and comprises logistics infrastructure and service, transportation infrastructure and service, area capacity, and vital locations or nodes for emergency humanitarian response operations. The results are expected to be shared among various organizations that provide emergency response locally, regionally, nationally, and internationally to enhance coordination during actual response operations.

Based on the result of logistics capacity, the primary consideration for the model developed in this study is transportation infrastructure, transportation mode, multimodality, node and vehicle capacity, number of available vehicles, and time-varying trends of relief supplies. By understanding logistics capacity, decision makers will be able to develop a relief distribution network and coordinate with several supporting bodies prior to a disaster. The Indonesian government has prioritized developing and improving a disaster management system over the last decades, designating Badan Nasional Penanggulangan Bencana (BNPB) as the national disaster management agency. It functions as a coordinator and commander during emergency response operations. At the regional and local level, the provincial disaster management agency (BPBD Provinsi) and district disaster management agency (BPBD Kabupaten) are tasked with managing emergencies at provincial and local levels, respectively.

During a disaster response, many relief goods are sent directly to AAs without considering the availability of storage, handling, and people who are able to sort and distribute goods. The provision of excessive supplies may lead to a bottleneck in relief distribution operation. Further, congestion may also occur due to disproportionate vehicles in the network. Cooperation among regional governments is essential to achieve an effective emergency response since one critical entity (port, airport, and node) would not be able to cope with its capacity. Learning from previous disasters, decision makers experience the necessity to form a relief distribution network with a hub concept. The hub will act as a LOA in which relief goods will be moved to other transport modes based on the established links and transport infrastructure availability.

In this context, the underlying problem is the manner by which a limited number of transportation resources—which can include various modes and their availability—may be assigned to the shipment of goods as demands arise in specific locations. After a disaster occurs, the transportation network and important nodes may or may not be damaged. Disruptions in the delivery network are managed by removing the impacted nodes and links and shifting the relief goods to different routes and modes. During a transportation decision-making process, the goal is to deliver the required demand by considering objective functions for each period. Concurrently, the process must remain flexible throughout changes in the transportation network configuration, which may be the result of the inciting disaster.

This study developed a multi-modal distribution model with a three-layered relief distribution network: (1) a supply node (SN), (2) a logistics operational area (LOA), and (3) a relief distribution operation area/affected area (AA) as presented in Figure 1. SNs include all national and regional points of entry for relief goods. Since the transportation of relief supplies is essential in emergency response and directly affects the efficiency and effectiveness of disaster relief, decision makers often integrate different modes of transport to deliver relief supplies as quickly and effectively as possible. Nodes in the time-space network represent the physical locations of the supply and demand points for each mode of transport and represent their changes over time while links represent the connecting routes for each mode between these points. Multi-modal relief distribution is represented by different types of modes utilized between nodes and changes in modes of transport between LOA nodes. In this study, multi-modal transportation considered including trucks, trains, airplanes, helicopters, and sea vessels. Furthermore, the logistical operations of the three layers are characterized by the status of time-varying logistics operations, represented by a time period. A physical network is converted into a time-space network, and a disaster scenario is generated to represent different scales and disaster aftermath situations, such as node availability and link accessibility.

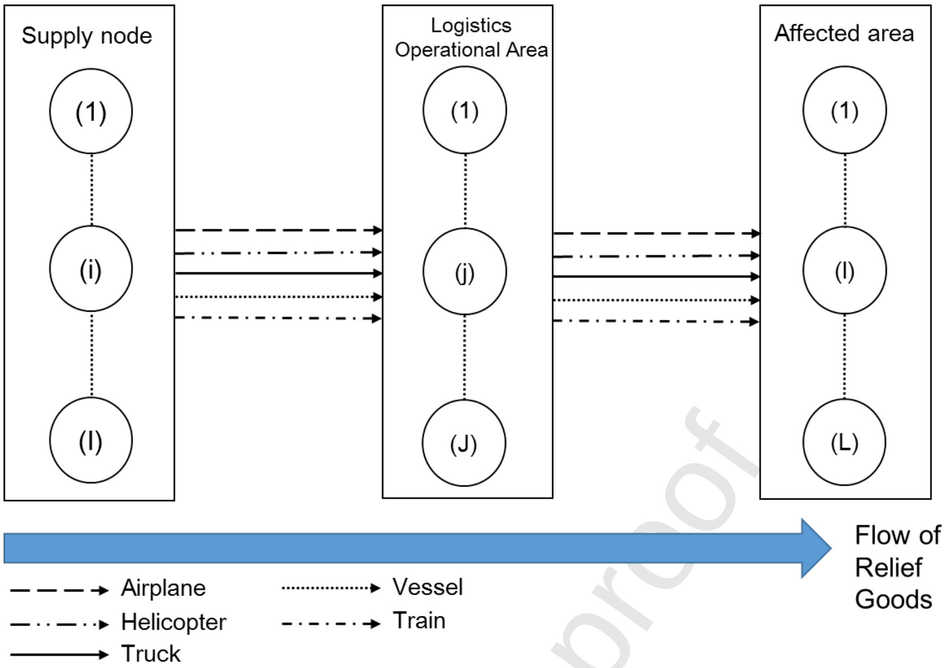

Figure 1. Humanitarian Relief Goods Distribution Flow

Humanitarian logistics utilize three performance measurements as targets for its operation. The efficiency factor is usually represented by transportation cost, inventory cost, or distribution cost (Haghani and Oh, 1996; Barbarosoglu and Arda, 2004). The effectiveness factor is represented by the level of demand satisfaction, time minimization (Ozdamar et al., 2004; Yi and Kumar, 2007), and equity, which refers to fairness during the relief distribution operation (Lin et al., 2011). Many researchers have used single and multiple objectives to visualize the trade-off between each type of measurement. This study integrates cost and time aspects by calculating them as one objective function.

All decisions relating to transport mode selection are assumed to occur over a finite horizon divided into 3-day periods, which are further divided into hourly micro-periods. In the beginning of each period, new information about supplies, demand, number of resources (vehicles), and availability of vital nodes will be updated. In disaster situations, the number of vehicles available to transport large quantities of relief goods is limited. In some cases, the capacity is smaller than that needed to provide all relief goods. Thus, a vehicle can be reused, which allows them to perform multi-trip distribution throughout the period. When multiple trips are not permitted, the vehicle can only perform one round trip delivery in a given period. In that case, the number of vehicles required to meet demand should be assumed to be unlimited, which is not practical. Thus, if multi-trip delivery is allowed, vehicles can perform other deliveries. The illustration of multi-trip transportation is show in Figure 2.

3.3. Model Development

3.3.1. Assumptions and Limitation

a. Number of affected areas (AAs), logistics operational areas (LOAs), and supply nodes (SNs) are known.
b. The links and their availability statuses for initial response can be obtained during the first period after a disaster.
c. Link and node availability is updated for each period after the end of the previous period.
d. Modes of transportation used are trucks, trains, sea vessels, airplanes, and helicopters.
e. Loading and unloading time is considered and included in the travel time for each mode of transportation.
f. For each mode of transportation, only one type of vehicle (homogeneous), with the same capacity and configuration, is considered.
g. The total supply available in each SN is different.
h. The demand of each AA depends on the number of affected people, should be fulfilled within the same time period, is considered as the maximum allowable time for relief goods delivery.
i. Each vehicle is allowed to take multiple trips within one working period.
j. LOAs and AA nodes can only be served using the resources status in each period (no availability of port/airport will affect the decision).
k. The maximum number of the available vehicles is determined per node.
l. The cost for mode changes is not considered, and the transfer of goods from one transport mode to others is assumed to be independent.

3.3.2. Decision Variables and Notations

Notations

i = set of nodes in the Supply layer *(I)* (i=1,2,…I)

j = set of nodes in the Logistics Operational layer *(J)* (j=1,2,…J)

l = set of nodes in the Demand layer *(L)* (l=1,2,…L)

k = set of transportation modes (k=1,2,…K)

h = set of periods (h=1,2,…H)

τ = set of micro-periods (τ=1,2,3,…,T)

Parameters

t_{ij}^{k} = travel time (hours) required to transport goods from node i to j using mode k

Vc_k = fixed cost for using mode *k*

c^k = unit cost (USD/ton.hr) for using transportation mode *k*

$M_i^{k\tau}(h)$ = maximum number of vehicles available for *k* mode in node *i* in micro-period *τ* during period *h*

$S_i(h)$ = relief supply (ton) in SN *i* during period *h*

Cap_i = capacity available of facility in node

Q_k = vehicle capacity (ton) of transportation mode *k*

$\delta_l(h)$ = demand (ton) in node *l* during period *h*

Decision Variables

$X_{ij}^{k\tau}(h)$ = equal 1 if there is a relief delivery from SN *i* to LOA *j* using transportation mode *k* in micro-period *τ* during period *h*, equal 0 if otherwise.

$X_{jl}^{k\tau}(h)$ = equal 1 if there is a relief delivery from LOA *j* to AA *l* using transportation mode *k* in micro-period *τ* during period *h*, equal 0 if otherwise.

$Y_{ij}^{k\tau}(h)$ = amount of relief delivered (ton) from SN *i* to LOA *j* using transportation mode *k* in micro-period *τ* during period *h*

$Y_{jl}^{k\tau}(h)$ = amount of relief delivered (ton) from LOA *j* to AA *l* using transportation mode *k* in micro-period *τ* during period *h*

Period (3 days)	Period 1														Period 2													⋯	Period H									
Micro-period (hour)	1	2	3	4	5	6	7	8	9	10	.	70	71	72	73	74	75	76	77	78	79	80	81	82	83	.	144	⋯	.	.	.	.	.	.	.	.	T−1	T
Vehicle 1	Trip 1				Trip 2						.				Trip 19				Trip 20									⋯			Trip f−1				Trip f			
Vehicle 2	Trip 1					Trip 2					.		Trip 15					Trip 16										⋯						Trip f				
Vehicle 3	Trip 1										.	Trip 8																⋯	Trip f									

Figure 2. Illustration of Multi-Trip Relief Distribution System

3.3.3. Objective function

The objective function consists of two parts. The first part focuses on minimizing delivery time, which will be the focus of decision makers during the initial response phase from period 1 to period $h_{initial}$.

Time-period $h_1 \sim h_{initial}$

$$min \sum_{h=1}^{h_{initial}} \left[\sum_{i}^{I} \sum_{j}^{J} \sum_{k}^{K} \sum_{\tau}^{T} Y_{ij}^{k\tau}(h)\, t_{ij}^{k} + \sum_{j}^{J} \sum_{l}^{L} \sum_{k}^{K} \sum_{\tau}^{T} Y_{jl}^{k\tau}(h)\, t_{jl}^{k} \right] \quad (1)$$

The second part, representing the continuum response period from period $h_{initial+1}$ to $h_{continuum}$, is focused on minimizing total cost for transporting goods from SNs to AAs including vehicle cost, cost of transporting goods from SNs to LOAs, and cost for transporting goods from LOAs to AAs demand areas.

Time-period $h_{initial+1} \sim h_{continuum}$

$$\min \sum_{h_{initial}+1}^{h_{continuum}} \left[\sum_{i}^{I} \sum_{j}^{J} \sum_{k}^{K} \sum_{\tau}^{T} X_{ij}^{k\tau}(h)\, Vc_k + \sum_{i}^{I} \sum_{j}^{J} \sum_{k}^{K} \sum_{\tau}^{T} Y_{ij}^{k\tau}(h)\, c_k t_{ij}^{k} \right.$$
$$\left. + \sum_{j}^{J} \sum_{l}^{L} \sum_{k}^{K} \sum_{\tau}^{T} X_{jl}^{k\tau}(h)\, Vc_k + \sum_{j}^{J} \sum_{l}^{L} \sum_{k}^{K} \sum_{\tau}^{T} Y_{ij}^{k\tau}(h)\, c_k t_{jl}^{k} \right] \quad (2)$$

3.3.4. Constraints

$$S_i^{\tau}(h) = \sum_{j}^{J} \sum_{k}^{K} \sum_{\tau}^{T} Y_{ij}^{k\tau}(h) \ \forall i, h \quad (3)$$

$$\sum_{l}^{L} \sum_{k}^{K} \sum_{\tau}^{T} Y_{jl}^{k(\tau - t_{ij}^{k})}(h) = \sum_{i}^{I} \sum_{k}^{K} \sum_{\tau}^{T} Y_{ij}^{k\tau}(h) \ \forall j, h \quad (4)$$

$$\sum_{j}^{J} Y_{ij}^{k\tau}(h) \le Cap_i^k(h) \ \forall i, k \quad (5)$$

$$\sum_{i}^{I} Y_{ij}^{k\tau}(h) \le Cap_j^k(h) \ \forall j, k \quad (6)$$

$$Y_{ij}^{k\tau}(h) \le \ Q_k \ \forall i, j, k, \tau, h \quad (7)$$

$$Y_{jl}^{k\tau}(h) \le \ Q_k \ \forall j, l, k, \tau, h \quad (8)$$

$$\sum_{i}^{I} X_{ij}^{k\tau}(h) \le I \ \forall j, k, \tau, h \quad (9)$$

$$\sum_{j}^{J} X_{jl}^{k\tau}(h) \leq J \ \forall l,\ k, \tau, h \tag{10}$$

$$\sum_{i}^{I} \sum_{\tau'=\tau-(2t_{ij}^{k}-1)}^{T} X_{ij}^{k\tau} \leq M_{i}^{k\tau}(h) \ \forall i, k, \tau, h \tag{11}$$

$$\sum_{j}^{J} \sum_{\tau'=\tau-(2t_{jl}^{k}-1)}^{T} X_{jl}^{k\tau} \leq M_{j}^{k\tau}(h) \ \forall l, k, \tau, h \tag{12}$$

$$\sum_{j}^{J} \sum_{k}^{K} \sum_{\tau}^{T} Y_{jl}^{k\tau}(h) \geq \delta_{l}(h) \ \ \forall l, h \tag{13}$$

$$Y_{ij}^{k\tau}(h) = 0, \exists j \in \{j: K_j \leq 0\} \tag{14}$$

$$Y_{jl}^{k\tau}(h) = 0, \exists l \in \{l: K_l \leq 0\} \tag{15}$$

$$Y_{ij}^{k\tau}(h), Y_{jl}^{k\tau}(h) \geq 0 \ \forall i, j, k, \tau, h \tag{16}$$

$$X_{ij}^{k\tau}(h), X_{jl}^{k\tau}(h) \in \{0,1\} \ \forall i, j, k, \tau, h \tag{17}$$

Constraints (3) and (4) conserve the flow of relief goods from SN to LOA and from LOA to AA, respectively. Constraint (3) postulates that the number of total relief goods delivered to all LOAs should not exceed the total relief supply available for each period while Constraint (4) ensures that the number of total relief goods delivered to AAs should be the same as total available goods in the LOAs for each period. The same constraint also ensures the availability of relief goods, in which the relief goods in LOA are available during micro-period τ when it sends from SN during micro-period $\tau - t_{ij}^{k}$. Constraints (5) and (6) entail the maximum capacity for the SN node per transport mode and a maximum capacity for each node (LOA) per transport mode, respectively. The vehicle capacity constraint that ensures relief delivered at micro-period τ should not exceed the transport mode capacity k is depicted by Constraints (7) and (8). Constraint (9) indicates that each LOA can be served by multiple SNs, and Constraint (10) ensures that each AA demand node can be served by multiple LOAs. Constraints (11) and (12) ensure that only available vehicles at a given node may be used to deliver relief goods. Constraints (11) and (12) indicate the maximum vehicles available for each mode of transportation in each node during micro-period τ, while Constraint (13) ensures that all demand is satisfied in each AA. Constraints (14) and (15) prevent the allocation of relief goods to nodes that are not available during micro-period τ. Constraints (16) and (17) indicate the decision variables for this problem.

3.4. *Solution Methodology*

The problem formulation proposed requires a large amount of time to be solved by commercial solvers such as CPLEX. Further, rather than taking a dynamic approach for dealing with information evolution, we divided the post-disaster stage into several periods (h) and assume that, within each period, the environment and information is static. Thus, for each period h, different input value decisions can be evaluated clearly. The problem is then independently solved for each period h to provide a better understanding of how time-varying values should be considered in different disaster response periods. Thus, a simplified model is proposed instead.

Although Constraints (11) and (12) are quite general, allowing for multiple trips within periods results in a bigger solution space. Thus, partial multi-trips are considered. Consequently, additional parameters are introduced by calculating the maximum frequency (f) of each round trip in one period for each transport mode from origin to destinations node, based on capacity of the vehicle. Consequently, using τ to represent micro-periods is relaxed, and all decision variables are modified as $X_{ij}^k(h)$, $X_{jl}^k(h)$, $Y_{ij}^k(h)$, and $Y_{jl}^k(h)$. The simplification of the model also ensures that, by the beginning of each period, all numbers of vehicle will be available. New decision variables $f_{ij}^k(h)$ and $f_{jl}^k(h)$ represent delivery frequency from node to node, respectively.

Further, Constraints (11) and (12) are modified as follows:

$$f_{ij}^k(h) \le \frac{72}{2t_{ij}^k(h)} \ \forall i, j, k, h \tag{18}$$

$$f_{jl}^k(h) \le \frac{72}{2t_{jl}^k(h)} \ \forall i, j, k, h \tag{19}$$

Each period in this study is equal to 3 days = 72 hours micro-periods. The number of trips for transport mode k from SN to LOA is defined as Constraint (18) and that from LOA to AA is defined as Constraint (19). Thus, objectives and constraints (1)–(17) must be modified by relaxing the micro-period constraints. The model developed is a mixed integer linear programming problem coded in C++ that is solved using Branch and Cut with optimization software CPLEX 12.8; it was executed on a computer with Intel i5 2.66 GHz CPU and 16 GB RAM running the Windows 7 64-bit operating system.

4. Logistics Capacity in Java Island

As a country located at an intersection of three large plates (Eurasian plate, Indo-Australian plate, and Pacific plate), Indonesia experiences movement of the three plates, which makes it disaster-prone to earthquakes, tsunamis, and volcano eruptions. Sumatra and Java Island are two islands that are often affected by earthquakes. Based on data from United States Geological Survey (Jones et al., 2014) from January 1973 to April 2017, 488 earthquakes with magnitude ≥ 5 and depth ≤ 70 km occurred in Java Island. As an effort to reduce risk and improve disaster response, a logistics capacity calculation is indeed necessary.

4.1. Overview of Major Nodes in Java and Bali Island

It is prominent that—as a wealth and economic activity center—infrastructure development is emphasized on Java Island. The state of transportation infrastructure in Java Island vary between ports, airports, railways, and toll/highway roads, and road infrastructure dominates the mobility of people and goods (Leung, 2016). Adopting the centrality concept, this study evaluated 13 critical nodes in Java Island and Bali Island and ranked them according to their degree of centrality as shown in Table 1. The centrality concept is used to evaluate whether the node is critical and linked with another node by different types of transportation mode (Bloch et al., 2017). Figure 3 shows important nodes (cities) available on Java Island.

Table 1. Node centrality ranking in Java Island and Bali Island

Node	Degree of Centrality	Ranking
Jakarta	1	1
Surabaya	0.8235	2
Semarang	0.5882	3
Surakarta	0.5882	3
Yogyakarta	0.5882	3
Bandung	0.5294	4
Malang	0.4705	5
Cilacap	0.4706	5
Bali	0.4117	6
Tasikmalaya	0.2941	7
Magetan	0.2941	7
Cirebon	0.1765	8

Pangandaran	0.1176	9

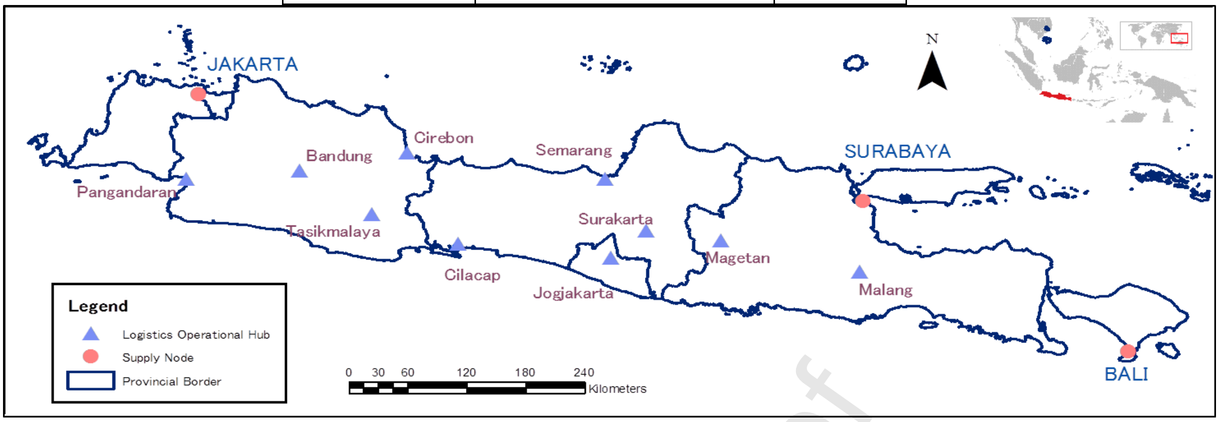

Figure 3. Major Nodes based on degree of centrality in Java Island

4.2. Overview Rail/Road Transportation and Major Airport and Port in Java Island

4.2.1. Valuation of Port and Airport in Java Island

From the existing major ports and airports, the overall strategy for Java Island relief distribution plan can be summarized and divided based on function. The chosen logistical operational expedition locations depend on the AAs and availability of transportation resources within a defined period. International airports in Java—Soekarno-Hatta Airport in Jakarta and Juanda Airport in Surabaya—are chosen as international relief entry points for air transport. Further, two major ports located in Jakarta and Surabaya serve as international corridors for sea transport.

The operation plan must be developed and adjusted based on the operational advancement and opening of new routes to access AAs. Thus, support transportation networks must be evaluated to understand the logistics capacity in Java Island. Aside from international corridor nodes, information about military airports, cargo airports, support ports, and fishery ports may support relief good distribution during the early response phase. Thus, evaluating alternative airports and ports is essential for developing a distribution plan framework.

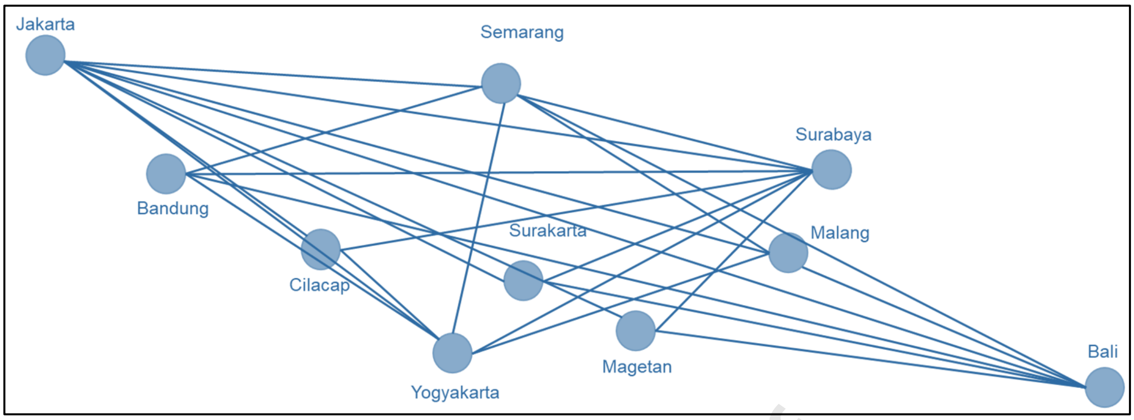

Figure 4. Airlift Network for Disaster Relief Operation in Java Island (Indonesia Ministry of Transportation. 2010)

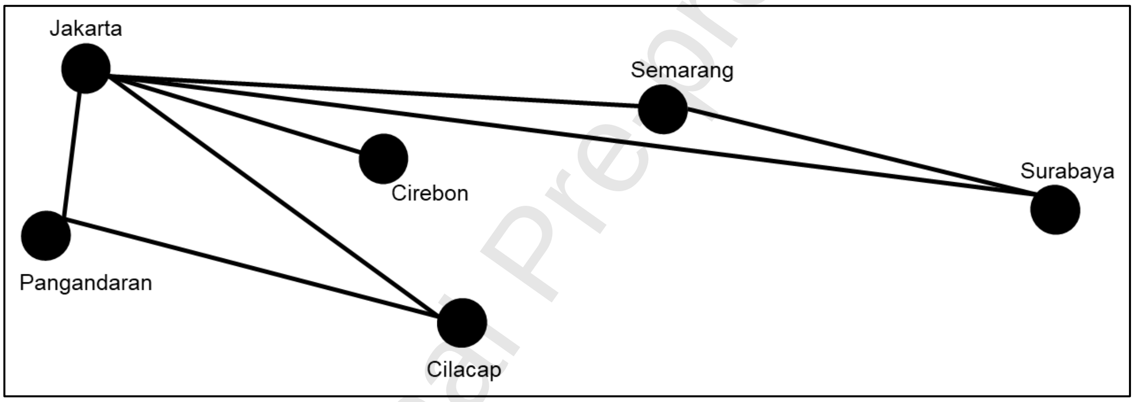

Figure 5. Sealift Network for Disaster Relief Operation in Java Island (Indonesia Ministry of Transportation. 2016)

The airplane/airlift network in Java Island is shown in Figure 4, and the vessel/maritime network is shown in Figure 5. While many fishery ports are available in the southern part of Java Island, their capacity to be used in an operational logistics expedition is likely to be less adequate than other port types. However, in the case that earthquakes in the southern coast of Java occur, these fishery ports may be utilized as entry corridors for the consolidation area. The situation must be assessed based on seasonal conditions. A detailed summary and information about existing transport infrastructure in Java Island and its function in the distribution network plan can be found in Table 2.

4.2.2. Valuation of Road Network

As the vital road connecting the west and east regions of Java Island, the 1,430 km Jalur Pantai Utara (North Coast Line) passes through Jakarta, Cirebon, Semarang, Surabaya, and

Banyuwangi with roughly 20,000–70,000 vehicles (Leung, 2016). The road branches from Cikampek to Bandung, Purwokerto, and Yogyakarta and goes east toward Surakarta and Madiun. The new toll road from Semarang to Surakarta 76 km is in the central part of Java Island. The North Coast Line is categorized as a national road that may hold heavy loads up to approximately 43 tons. The province-level road has a heavy load limit of approximately 20 tons (Indonesia Ministry of Public Works, 2012). The road network in Java Island is illustrated in Figure 6. Rail transportation may increase the effectiveness of a relief distribution network if the infrastructure is available.

Table 2. Summary of Java Island Distribution Network Plan

Function	**Main location**		**Alternative location**	
	Airport	**Port**	**Airport**	**Port**
Point of Entry	Soekarno-Hatta International Airport	Tanjung Priok Port, Jakarta	N/A	Lamong Bay Port, Surabaya
	Juanda International Airport, Surabaya	Tanjung Perak Port, Surabaya	-	Banten Port, Tangerang
	Halim Perdana Kusuma Airport, Jakarta	-	-	-
Logistics Operational Expedition	Achmad Yani Airport, Semarang	Tanjung Emas, Semarang		Lamong Bay Port, Surabaya
	Tunggul Wulung Airport, Cilacap	Tanjung Intan Port, Cilacap	Wiriadinata Airport, Tasikmalaya	Ciwandan Port, Banten
	Adi Soemarno Airport, Surakarta	-	Nusawiru Airport, Pangandaran	-
	Adi Sutjipto Airport, Yogyakarta	-	Gading Military Airport, Yogyakarta	-
	Raden Saleh Airport, Malang	-	Iswahyudi Airport,	-

Function	Main location		Alternative location	
	Airport	Port	Airport	Port
			Magetan	
Consolidation Area	The nearest airport of the affected region			

With limited air transportation and road capacity, rail transportation offers an alternative transportation mode with relatively moderate speed with low expenses. Although Java Island has two central railways connecting West Java and East Java, rail transportation, however, is not considered in this study. Considering rail transportation would require including rail reliability problem and lack of maintenance (JICA, 2009; Leung, 2016), possibility of extending the reconstruction period (Anand, 2005; Palliyaguru et al., 2007), and low rail cargo capacity (ADB, 2012), mainly focusing on passengers' movement. Nevertheless, rail transportation can be utilized for transporting specific products, such as fuel or gasoline, to AAs. Cilacap and Cepu, major oil refineries in Central Java (IEA, 2014), can be involved as SNs for fuel and gasoline by streamlining distribution via rail transportation.

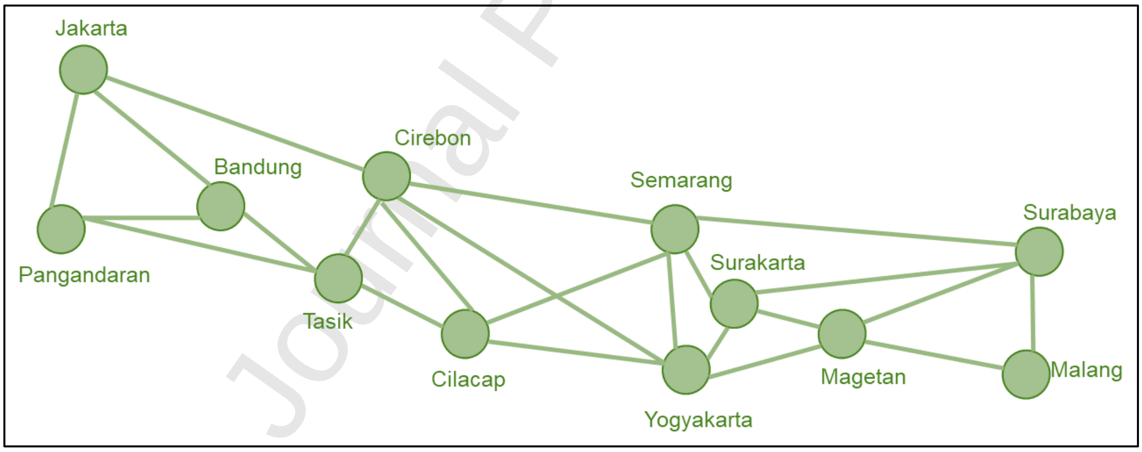

Figure 6. Road Network for Disaster Relief Operation in Java Island (Indonesia Ministry of Transportation, 2010)

5. Numerical Example

5.1. Scenario and Input Parameters

A numerical illustration was performed using disaster data from the Yogyakarta earthquake of 2006. An earthquake with a magnitude of 6.3 occurred near the city of Yogyakarta, destroying the city and its surroundings. The destruction included the railway connecting to Purwokerto and Surakarta; national and provincial roads connecting to other cities and several villages in more remote areas south of Yogyakarta and around Bantul were the most severely affected (Elnashai, et al., 2007). Tremors were felt through the region as far as Semarang and Surabaya, on the opposite coast of Java. The airport runway could not be used by commercial airplanes but could be accessed by helicopters. The runway requires time to operate, but roads can still be partially accessed during restoration. Based on the disaster location, the operational logistics nodes are selected as shown in Figure 7.

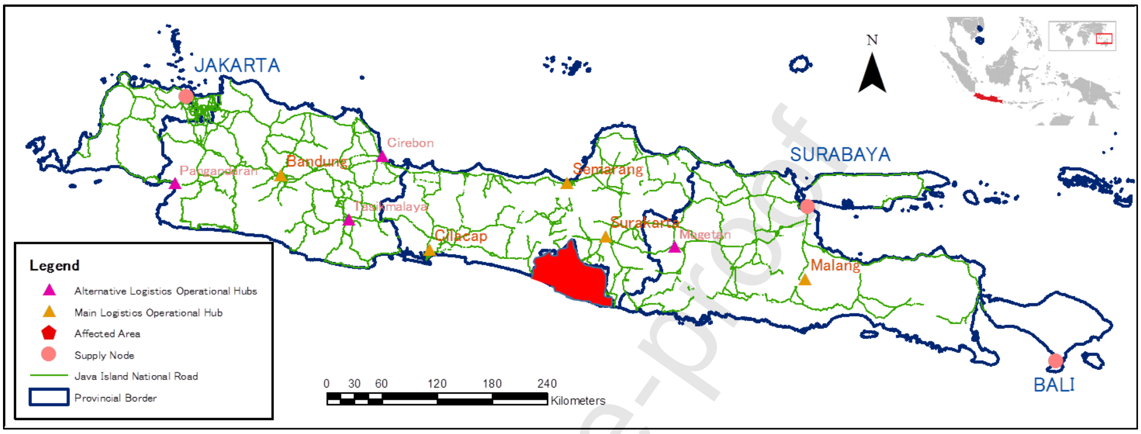

Figure 7. Major Node and its Function during Disaster Relief Operation in Java Island

A quick assessment concluded that 12 cities, represented by nodes, function as the SN area, LOA, and central distribution center in AA. In this study, the SN acts as a point of entry from the national and international donor and supply point for relief delivery. Jakarta, Surabaya, and Bali are selected as supply corridors due to their capacity to handle sudden upsurge of relief goods from international donors. LOA nodes are chosen based on their degree of centrality, as discussed previously. The AA represents the location of aggregate demand, which includes the western, eastern, and southern areas of Yogyakarta Province. The number of available supplies is assumed to be time-varying, increasing rapidly during the first period, and decreasing and stagnating after some time before decreasing until supply is no longer needed. Each operational horizon is assumed to be 3 days, and each 0.8 kg of relief emergency can sustain an individual for one day. The summary of the distribution configuration is shown in Table 3.

Table 3. Summary of Relief Delivery Configuration

Function	Details
Supply Corridor	3 cities: Jakarta, Surabaya, Bali
Logistics Operational Area	9 cities: 5 main locations with 4 alternatives
Affected Area	3 demand nodes in Yogyakarta

5.2. Result and Discussion

The aim of this study is to develop a transportation network from each SN to AA via LOA with the lowest cost using the only available vehicles. Vehicle availability in each node is limited, which affects the movement of goods between other LOA or another transportation mode in consideration of cost. Tables 4-7 show the results of optimizing multi-modal relief distribution based on the Yogyakarta earthquake case.

Table 4 depicts the detailed results of the selection of logistics operational nodes, including transportation modes required from the Jakarta corridor. Five LOAs are selected; trucks are the dominant mode of transportation, followed by airplanes to Cilacap, Surakarta, and Semarang. Table 5 presents the delivery flow from Surabaya, and Table 6 entails the detailed flow from Bali. Delivery flow from Surabaya is centered in Surakarta as LOA, with Magetan and Semarang as additional LOAs for exceed goods. Trucks are the main transportation used for delivering relief, followed by airplanes. As with the relief flow from Jakarta, sea vessels only comprise a small percentage of relief transportation. In the relief flow from Bali, airplanes are the only allowable transportation, thus dominating the network. Further, Table 7 shows the results for relief distribution of each LOA to the AA, Yogyakarta. Due to the high accessibility of road transportation from LOAs to two AAs, trucks dominate relief flow. However, one AA is located in the mountainous area, which only allows for air transportation (helicopter) to deliver relief goods. This mode of transportation changes from period 1 to period 2 due to changes in airport accessibility status (from inaccessible to accessible).

Based on the results of the optimization, peak relief flow occurs in period 2, immediately following the initial response phase due to the drastic change in available relief goods in SN. In this phase, the most transportation modes must be utilized, including sea vessels in Semarang and Cirebon, to accommodate the number of goods that need to be delivered to the AA. Surakarta and Cilacap become critical nodes and act as LOA, covering the eastern and western regions of Java, respectively. Furthermore, Magetan supports the flow of relief goods from Bali while Semarang supports the rest of the goods delivered from both the west and east side. By multiplying cost/unit-time with the time required to deliver each ton, the results suggest that air transportation will remain highly utilized compared to sea vessels as it requires less time to reach the target node. Accordingly, road transportation meets all cost and time needs, making it suitable for relief delivery in the case that road infrastructure is accessible.

In a disaster situation, it is expected that the required number of vehicles will not be sufficient during the beginning of the response period. In the developed model, we restrict vehicle availability at each node, and indexing by h (3 days) allows the parameter input to specify the number of vehicles available over the time. This study believes that as disaster response is initiated, decision makers will be able to secure more vehicles for relief goods distribution. The additional vehicles may be donated by the military, NGOs, or private sector entities. The model initially chooses trucks or airplanes based on cost and time considerations. However, as the number of each transportation mode is limited, sea vessels will be utilized to ensure that the remaining relief goods to are delivered, fulfilling vehicle constraints. Limited trucks at each node leads to the high utilization of airplanes, regardless of the relatively high cost. Although the model employs the multi-trip concept, it only allows the vehicle to deliver goods within one layer (SN to LOA, or LOA to AA). In this way, the distribution system may be easier to manage than a pooling system, which allows vehicle movement to nodes that exhibit high vehicle demand.

Table 4. Relief Distribution Flow from Jakarta to LOAs

Period	**Jakarta** (Ton)											Total Cost (USD)
	Semarang			Cilacap			Tasik		Surakarta	Cirebon		
	Sea vessels	Truck	Airplane	Sea vessels	Truck	Airplane	Truck	Airplane	Airplane	Sea vessels	Truck	
1	4,200	2,772	3,216	0	3,168	2,412	3,564	1,675	4,824	4,200	3,168	$85,417
2	10,500	5,572	9,648	0	6,400	14,472	5,400	6,700	12,060	21,000	3,168	$243,518
3	0	8,400	9,648	0	6,400	14,472	375	6,700	12,060	3,245	6,400	$212,199
4	0	8,400	4,824	0	8,000	9,648	5,400	0	6,030	0	3,200	$136,307
5	0	8,400	3,216	0	8,000	4,824	4,320	0	4,824	0	3,200	$106,110
6	0	8,400	3,216	0	8,000	2,412	3,564	0	4,824	0	1,600	$91,537
7	0	8,400	1,608	0	8,000	0	0	0	3,618	0	0	$59,813
8	0	8,400	0	0	8,000	0	0	0	0	0	0	$41,000
9	0	0	0	0	8,000	0	0	0	0	0	0	$20,000
10	0	0	0	0	5,000	0	0	0	0	0	0	$12,500

Table 5. Relief Distribution Flow from Surabaya to LOAs

Period	**Surabaya** (Ton)							Total Cost (USD)
	Semarang			Surakarta		Magetan		
	Sea vessels	Truck	Airplane	Truck	Airplane	Truck	Airplane	
1	0	0	3,216	2,772	4,824	2,772	3,216	$54,381
2	0	2,772	9,468	8,400	12,060	5,600	8,940	$151,614
3	0	0	2,772	8,400	12,060	1,484	8,940	$110,289
4	0	0	0	8,400	7,236	5,600	2,412	$69,732
5	0	0	0	8,400	7,236	2,772	0	$53,979
6	0	0	0	8,400	6,030	2,772	0	$49,638
7	0	0	0	8,400	2,412	0	0	$29,683
8	0	0	0	7,672	0	0	0	$19,180
9	0	0	0	3,360	0	0	0	$8,400
10	0	0	0	0	0	0	0	$0

Table 6. Relief Distribution Flow from Bali to LOAs

Period	**Bali** (Ton)			Total Cost (USD)
	Malang	Magetan	Surakarta	
	Airplane	Airplane	Airplane	
1	4,800	1,000	0	$20,880
2	12,060	4,020	0	$57,888
3	9,648	0	0	$34,732
4	7,236	0	0	$26,049
5	6,513	0	0	$23,446
6	5,547	0	0	$19,969
7	3,618	0	0	$13,024
8	2,412	0	0	$8,683
9	1,206	0	0	$4,341
10	0	0	0	$0

Table 7. Relief Distribution Flow from LOAs to Affected Area

Period	Semarang			Cilacap			Cirebon	Tasik	Surakarta		Malang	Magetan		Total Cost (USD)
	Yogyakarta (TON)													
	Truck	Airplane	Helicopter	Truck	Airplane	Helicopter	Truck	Truck	Truck	Helicopter	Truck	Truck	Airplane	
1	10,800	0	1,520	5,580	0	0	7,169	5,239	3,870	8,550	4,800	6,988	0	$202,959
2	18,600	16,080	1,228	14,400	5,712	760	24,168	12,100	19,695	12,825	12,060	10,424	11,256	$561,271
3	4,560	16,080	0	14,400	5,712	760	9,645	7,075	19,695	12,825	9,648	0	10,424	$372,505
4	15,938	0	0	14,400	3,248	0	3,200	5,400	21,666	0	7,236	8,012	0	$315,100
5	11,616	0	0	12,824	0	0	3,200	4,320	20,460	0	6,513	2,772	0	$246,820
6	11,616	0	0	10,412	0	0	1,600	3,564	19,254	0	5,547	2,772	0	$219,060
7	10,008	0	0	8,000	0	0	0	0	14,430	0	3,618	0	0	$144,224
8	8,400	0	0	8,000	0	0	0	0	7,672	0	2,412	0	0	$105,936
9	0	0	0	8,000	0	0	0	0	3,360	0	1,206	0	0	$50,264
10	0	0	0	5,000	0	0	0	0	0	0	0	0	0	$20,000

5.3. Analysis of multi-modal transportation

This study focuses on how multi-modal transportation can improve relief distribution systems with a transshipment system. In this case, different objectives from the initial response phase and continuum response phase resulted in a different transportation mode configuration. During the initial response phase (Periods 0–3), the focus is to deliver all supplies to the AA using the fastest transportation mode, such as airplanes and helicopters. In the continuum response phase, however, the focus on delivering includes two considerations: time and cost. Regarding vehicle capacity and number of available vehicles per mode, multi-modal options provide an alternative on how to deliver relief goods while maintaining objectives and constraints. Table 8 shows the percentage of transportation modes transferred in the relief distribution. Multi-modal transportation accounts for 45.67% (31.98% for airplane-truck, 7.95% for sea vessels-truck, and 5.74% for airplane-helicopter) of the transportation of all goods within 10 periods. The highest percentage is the airplane-truck combination, followed by vessel-truck, and airplane-helicopter.

Table 8. Percentage of transportation mode transferred

From \ To	Truck	Airplane	Helicopter	Sea vessels
Truck	45.97%	0.00%	0.00%	0.00%
Airplane	31.98%	8.36%	5.74%	0.00%
Helicopter	0.00%	0.00%	0.00%	0.00%
Sea vessels	7.95%	0.00%	0.00%	0.00%

5.4. Sensitivity Analysis

5.4.1. Effect on Limited Type of Transport Mode

Our model focuses on how multi-modal transportation helps improve relief distribution operations while maintaining efficiency and effectiveness. The results in the previous section demonstrate that in Periods 2 and 3, which have the highest number of relief supplies, sea vessels are utilized to deliver the rest of the supplies when other transport modes are fully occupied. This sub-section analyzes the use of limited transport modes during relief distributions and compares them in terms of cost, average delivery time, and unmet demand. The number of available vehicles per each transport mode is the same as the previous section. We let unmet demand transpire without penalty.

Table 9 shows the results of the analysis using only an airplane, combination of airplanes and trucks, and all type of transport mode. Within the same period, the function of sea vessels as one transport mode choice is significant. In particular, during the initial response phase in which available transport is not adequate, the unmet demand without utilizing sea vessels accounted for approximately

40%. Moreover, only using an airplane as the transport mode choice lead to constant unmet demand throughout operations. This study, however, limits the number of available vehicles that can be used, even after additional vehicle retrieval. This consideration is not suitable for developing countries with abundant resources and active cooperation with private sector entities.

Table 9. The results of transport mode limitation

Period	Airplane			Airplane + Truck			Airplane + Truck + Sea vessels		
	Total cost (USD)	Unmet demand (%)	Total delivery time (hour)	Total cost (USD)	Unmet demand (%)	Total delivery time (hour)	Total cost (USD)	Unmet demand (%)	Total delivery time (hour)
1	$216,679	41.43%	265.0	$321,779	39.02%	423.4	$363,637	0%	753.4
2	$676,556	39.10%	561.0	$835,941	33.19%	1139.1	$1,014,292	0%	1,968.2
3	$598,496	29.59%	445.7	$757,898	4.79%	1061.1	$729,727	0%	1,133.2
4	$480,216	8.97%	387.4	$538,429	0.00%	845.7	$547,190	0%	845.7
5	$406,086	7.17%	315.2	$430,352	0.00%	755.0	$430,356	0%	755.0
6	$371,120	4.33%	314.2	$380,208	0.00%	726.9	$380,204	0%	726.9
7	$264,230	1.00%	183.1	$246,745	0.00%	437.2	$246,745	0%	437.2
8	$194,718	0.00%	125.0	$174,799	0.00%	353.3	$174,799	0%	353.3
9	$92,301	0.00%	175.0	$83,005	0.00%	476.8	$83,005	0%	476.8
10	$36,000	0.00%	12.5	$32,500	0.00%	53.4	$32,500	0%	53.4

5.4.2. Effect on Logistics Operational Area

The notion of including an LOA in this study arose from the field interview conducted with the Provincial Disaster Management Agency (BPBD Yogyakarta), which revealed that destinations with hub function are necessary to improve the relief distribution system and allow it to operate seamlessly. During the previous disaster, supplies were transported directly to AAs, thus overwhelming the local logistician in sorting, consolidating, and managing them. It resulted in chaos and bottlenecked the operation. The inclusion of LOAs also ensures inter-regional infrastructure coordination and sharing. The hub function may also hinder relief distribution operations if coordination is insufficient or no logisticians are available to manage the LOA. Furthermore, once the continuum response period has begun, the AA is assumed to be ready to receive relief goods directly from SNs. A sensitivity analysis is conducted to understand the effects of direct distribution from SNs to AAs.

The result of model modification and comparing the modified model's results with the proposed model's results are presented in Table 10. Although modification can minimize the total cost required to transport supplies from SNs to AAs, it may also be observed that for the first 3 periods, the mixed network model resulted in slower average delivery time. The results, however, reveal that using mixed network can reduce both average delivery time and total cost from period 4 onward. The hub network, although beneficial for the initial response phase, leads to higher cost as relief goods must to be transported first to LOAs before being transported to AAs. However, not pooling vehicles in the SN resulted in faster delivery time when limited vehicles or large amount of relief goods are presents in Periods 1, 2, and 3. Once the number of relief goods stabilizes, accompanied by an adequate number of vehicles, a mixed network with direct delivery may be suitable.

Table 10. Comparison of hub and mixed networks for relief good delivery

Period	Hub network		Mixed network	
	Total delivery time (hours)	Cost (USD)	Total delivery time (hours)	Cost (USD)
1	753.4	$363,637	774.46	$297,168
2	1,968.20	$1,014,292	2118.66	$770,439
3	1,133.20	$729,727	1305.68	$483,757
4	845.7	$547,190	673.54	$332,257
5	755	$430,356	615.3	$271,814
6	726.9	$380,204	613.42	$241,800
7	437.2	$246,745	408.89	$162,634
8	353.3	$174,799	373.48	$125,712
9	476.8	$83,005	525.95	$59,952
10	53.4	$32,500	92.59	$25,000

5.5. *Logistics Capacity Assessment*

Based on the optimization results, some nodes are confirmed to be vital as LOAs in the relief distribution system. LOA Surakarta handled 27% of the total relief goods delivered from the SN to AA, with 60.9% transported via airlift and another 39.1% transported using trucks. In addition, Semarang was also vital with 21% relief goods delivered from the SN to AA. From Semarang, 40.0% goods were transported via airlift, 48.4% via truck, and small percentage (11.6%) transported using sealift/sea vessels. Cilacap ranked third, with 58.8% relief goods transported via truck and 41.2% transported via airlift.

The optimization results reveal that some alternative/candidate nodes such as Tasik, Cirebon, and Magetan were utilized several times during the initial period as the capacity of other nodes and available vehicles for each transport mode are limited. However, two nodes, Bandung and Pangandaran, were not utilized for transporting relief goods. Although the optimization results did not contradict with the degree of centrality results, they demonstrate the vitality of several nodes in the Yogyakarta case, which should be prepared in advance. Thus, rather than simply focusing on establishing proactive capability and measuring all nodes based on the degree of centrality level, preparing vital nodes may be beneficial.

Table 11. Additional Capacity Needed with Selected LOA Nodes

LOA Nodes	Additional Capacity for all transport mode (%)
Surakarta	35.337%
Cilacap	52.139%
Semarang	55.32%

This assessment was conducted by calculating additional node capacity that should be added for selected vital nodes to accommodate a disaster scenario. This approach is intended to yield a deeper understanding for decision maker in developing disaster responses. Hence, we limit the nodes selected and focus on three most vital nodes: Surakarta, Semarang, and Cilacap. The results are presented in Table 11.

6. Conclusions and Practical Implications

Relief supply distribution is a critical process in disaster management, and logistical support is one of the most significant activities in disaster response. Relief goods such as food, shelter, and medication must be sent from supply nodes (SNs) to the affected areas (AAs) quickly and efficiently to support disaster operation. In a disaster preparedness planning, decision makers must develop robust but flexible distribution networks to increase the efficiency in the relief distribution process. Although every disaster may be different, reactions and responses remain relatively similar. The difference lies in the type of disaster that occurs; number of people affected; resources required at national, regional, and local levels; and ease of working on-site. From an SN, a large number of commodities must be transported; thus, multi-modal transport is utilized.

The lack of available transport resources may hinder the optimal usage of all transportation modes. This study develops a model for relief distribution networks considering multi-modal transportation and multi-trip distribution systems. A strategic distribution plan is developed for Java Island, Indonesia in general and Yogyakarta Province as a specific example. During the first phase of the response, time become the primary factor. Thus, transportation modes such as helicopters and airlifts are mostly utilized. In the second phase, the transport mode shifts from air transportation to road transportation until demand decreases sufficiently. During the last phase, the distribution system becomes more similar to commercial distribution, with cost as the primary factor. Thus, utilization of road transportation is maximized. Although the model employs the multi-trip concept, it only allows vehicles to deliver goods within one layer (SN to LOA, or LOA to AA). In this way, the distribution system may be more manageable rather than using a pooling system, which allows vehicle movement to a node with the high demand for vehicle.

The study contributes to current knowledge on transport mode choices for relief distribution at the upstream level. Accordingly, governments, as decision makers, should first understand their logistics capacity before developing their distribution network. The proactive choices, during disaster preparedness, includes assessing multiple alternatives for important nodes and links, allocating multiple strategies and fortifying hub nodes, and conducting a survey of transport service providers, government entities, and private organizations with fleets that can assist humanitarian operations. Furthermore, after the disaster, decision makers should initiate reactive capability by resuming links after the disaster (limitation on time and budget) or even change the plan by selecting alternative nodes (port, airport) and transportation modes based on link availability.

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