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Optimization Model for Relief Distribution After Flood Disaster

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Abstract: Logistics planning is critical and a key component in meeting initial emergency needs in the aftermath of a disaster. The rapid and efficient distribution of logistical aid becomes critically important. In such situations, the construction of temporary depots in strategic locations and the determination of optimal distribution routes play an important role in ensuring that logistics aid can be distributed to the affected areas evenly. In this study, the Multi Depot Vehicle Routing Problem (MDVRP) is used which aims to minimize the total cost of distributing logistics aid which includes shipping costs, vehicle usage costs, temporary depot construction costs, and vehicle travel costs from distribution centers to temporary depots, while still meeting constraints such as logistics aid demand, vehicle capacity, area visits, maximum mileage, and depot construction. This model uses two types of vehicles where vehicle m is tasked with carrying logistics aid from the distribution center to the temporary depot and vehicle n is tasked with delivering logistics aid directly to the point of demand.

Keywords: Logistics distribution, Flood disaster, Multi Depot Vehicle Routing Problem, Integer Linear Programming.

INTRODUCTION

Indonesia is a country located between three plate meetings, namely the Indonesian-Australian plate, the Eurasian plate and the Pacific plate. As a result of the meeting of the three plates, there is an emphasis on the lower layers of the earth which causes the Indonesian archipelago to have a mountainous and relatively rough morphology. Indonesia is also a ring of fire country in the world because it is surrounded by active volcanoes. Based on this geological location, natural phenomena often occur, causing Indonesia to be abundant in natural resources and vulnerable to disasters (Hermon, 2015). Based on data from BNPB (National Disaster Management Agency), natural disaster data in Indonesia experienced an upward trend of 82% when viewed from 2010 to 2022. From the data collected by BNPB during the first 5 months of 2023, there have been 1,675 disaster events. Floods are the most common disaster and ranked first among other natural disasters (Pusdatinkom BNPB, 2024).

Flood is among the hazards that may threaten the livelihood of a city. The intense nature of large floods has been increasing due to heavy rainfall and land conversions as well as bad urban drains systems. Hence, cities need to improve their capacity to deal with disaster flooding. Increasing the city's capacity should be designed well to realize the state of the city that is resilient to disasters or is known as a city resilience. Based on the result of position analysis using Structural Equations Model (SEM), there are four elements that influence the adaptation model of disaster-prone city resilience, including spatial planning, innovative technology, mitigation, and adaptability (Renald et al., 2016). City resilience is defined as a concept that enhances a city's ability to handle harmful effects and is made up of the following of the city's innate and adaptive capacity from such events to respond, adapt and grow whatever type of disruption it will experience (Moghadas et al., 2019).

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Disaster management cycle consists of both the preparedness and response stages in pre- and post-disaster operations. While the preparedness phase includes the processes of monitor and control risks and the response phase is reserved for the processes that organize how the authorities and relief organizations should respond in the event of a disaster (Banomyong et al., 2019). Multimodal transportation can be a quick solution after emergencies when existing transportation resources are limited. This study provides a multimodal aid Distribution Model that uses a three-tier chain consisting of 1. supply points 2. operational logistics areas and 3. disaster affected regions, taking into account multiple trips for emergency response services. It determined the location of the operational logistics area, the mode of transportation used, and the amount of relief supplies allocated to every mode of transportation. In additional, it also considers various stages of critical response elements, such as condition of networks and the infrastructure, as well as the availability of supplies and transportation modes. (Maghfiroh & Hanaoka, 2020).

(Ren & Tan, 2022) proposed a collaborative optimization model for temporary emergency distribution center location allocation, aiming for minimize of rescue time and maximize the demand satisfaction rate. (Halizahari et al., 2021) Humanitarian aid operators must plan for logistical needs, strategize the supplies received and transport supplies to the impacted areas as fast as possible with no waiting time. In addition, the correct preparation for supply transportation is essential, and this requires careful planning. With more disasters occurring every year, humanitarian aid logistics support must be able to ship relief and aid supplies with more effectiveness.

(Manopiniwes & Irohara, 2021) the multi period approach was used to illustrate the problem and the multimodal transportation is assumed to resemble more like realistic flood behavior. (Liu et al., 2019) A bi-objective optimization approach is used for determining the optimal location of temporary medical services and allocation plan of medical services by maximize the total number of life expectancy and minimize the total transportation operational budget by using both ambulance and helicopter. The authors modeled the humanitarian medical service networks as a directed graph $G(V,E)$, where V and E are the set of vertices and arcs. The V set consists of two node sets: the set of affected areas and the set of hospitals and location candidates for temporary medical facility. In the humanitarian medical service operation, it is necessary to decided where to establish a temporary medical facility and how more beds and doctors place in every temporary medical facility.

Natural disasters happen continuously and cannot be stopped, but we can reduce the impact caused by proper logistics distribution to reduce the casualties that can be caused by the disaster (Farahani et al., 2020; Sheu, 2007). However, when distributing logistics requires relatively expensive and large operational costs. Therefore, and based on the problems described above, researchers feel the need to conduct research in this field with the hope that this research can be a consideration for authorized officers in making decisions when a disaster occurs so that logistical assistance can be distributed with minimal operational costs. In this study, the author wants to design a model that focuses on the distribution of logistics after a flood disaster by considering the construction of temporary depots in strategic locations and ensuring that each flood-affected area is served by the nearest temporary depot. The Multi Depot Vehicle Routing Problem (MDVRP) model developed to minimizing the total cost for logistics distribution, including shipping costs, vehicle usage costs, temporary depot construction costs, and vehicle travel costs from distribution centers to temporary depots, while still meeting constraints such as logistics assistance demand, vehicle capacity, area visits, shipping, maximum distance traveled, depot construction, conservation of logistics flow as well as non-negative and binary constraints.

LITERATURE REVIEW

Disasters are a combination of phenomena that can disrupt and threaten the lives and lives of people due to several causes, both natural and nonnatural causes as well as human factors. Leading to casualties of human life, damage to the environment, losses of property, and the impact of psychological and beyond the ability of the community with all the resources it has (Wekke, 2021).

Multi Depot Vehicle Routing Problem (MDVRP) is a complex logistics optimization problem that involves planning routes for multiple vehicles starting from multiple depots to deliver items to a group of customers while minimizing costs and ensuring efficient use of resources. MDVRP is one of kind of the classic Vehicle Routing Problem (VRP) that adds the dimension of multiple depots, thus increasing

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the problem complexity and computational requirements (Jayarathna et al., 2020; Ramos et al., 2020). MDVRP typically aims for minimizing the total costs of transportation, include fuel consumption, driver wages, and other costs. The problem constraint is to ensure that every customer is reached at exactly one time, that each vehicle departs and terminates at a depot, and that the total demand of all customers is met. MDVRP has many applications in real-world logistics and transportation systems, particularly in industries where goods need to be distributed over long distances, such as in the delivery of perishable products or in emergency relief efforts. For example, in the context of disaster relief, MDVRP can be used to optimize the distribution of emergency supplies to disaster-affected areas while minimizing resource usage and ensuring timely delivery (Xu et al., 2023).

The following is the notation used in the MDVRP mathematical model:

I : Set of depots
J : Set of customers
K : Set of vehicles

Index:

i : Index depot
j : Index customer
k : Index route

Parameters:

N : Total of vehicle
C_{ij} : Distance between i and j, $i \in I, j \in J$
V_i : Capacity of depot i
d_i : Demand of customer
Q_k : Capacity of vehicle k

Decision variables:

$$x_{ijk} : \begin{cases} 1, & \text{if vehicle } k \text{ directly from } i \text{ to } j \\ 0, & \text{otherwise} \end{cases}$$

$$Z_j : \begin{cases} 1, & \text{if vehicle depot } j \text{ is use} \\ 0, & \text{otherwise} \end{cases}$$

METHOD

The stage taken in this study to designing the model are as follows:

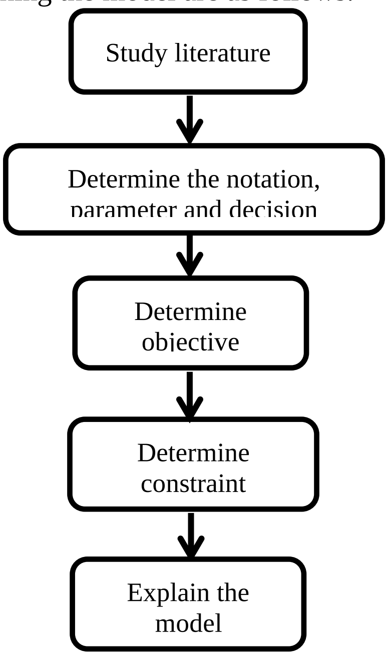

Figure 1. Research Procedure Block Diagram

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RESULT

In this study, the post-flood logistics distribution network is modeled as a directed graph $G = (V, E)$, where V and E are the set of vertices/points and arcs/edges. The set V consists of the set of permanent distribution points, candidate locations for temporary depots and demand points and where E is the set of edges connecting the two points. In logistics distribution operations, it is necessary to determine the appropriate location for a temporary depot to be established. The following are the assumptions for the illustration of the logistics distribution network after the flood disaster.

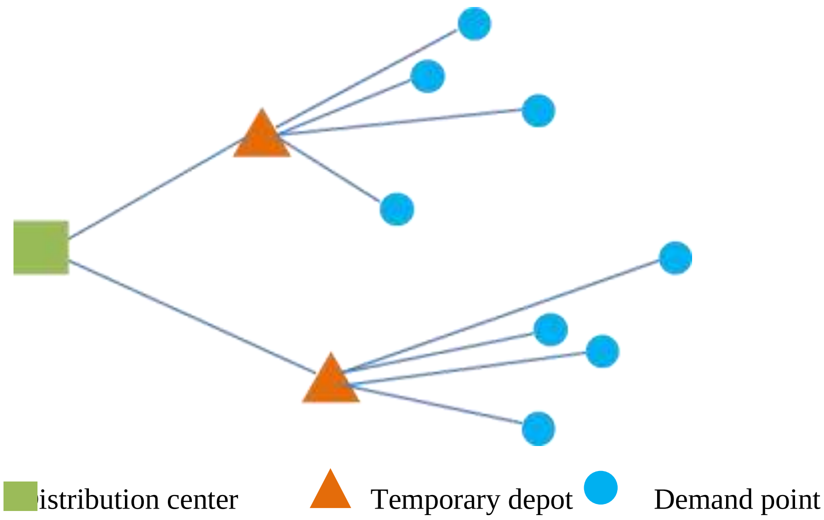

Figure 2. Illustration of logistics distribution network.

The figure above is an illustration of the route from the source distribution center to the temporary depot to the destination to serve each demand point in the area affected by the flood disaster.

This study uses one distribution center that will be the source and then send a number of logistical aids to multi depots built in strategic locations where these locations are assumed to be located in areas that are not affected by flooding but are close to the location of the flood. The temporary depots that will be built serve as a distributor of logistical aids to flood-affected areas. In this model, two types of vehicles are used where the vehicle type m is tasked with carrying/transporting logistical aids from the distribution center to the temporary depots and vehicle n is tasked with delivering logistical aids from the temporary depots to the demand point i area. The following are the assumptions used in this model:

1. The routing of the logistics aid distribution is modeled as a directed graph $G = (V, E)$.
2. Vehicle m is in charge of transporting logistics aid from distribution centers to temporary depots and vehicle n is in charge of delivering logistics aid to demand point i.
3. Each demand point only can be served ones by the available depots.

Notation:

I Demand point
J Temporary depot
D Distribution center
M Set of vehicles m
N Set of vehicles n

Parameters:

F_m : Fixed cost vehicle m
F_n : Fixed cost vehicle n
F_j : Fixed cost for construct temporary depot j
d_i : Amount of logistics demand at demand point i
Cap_m : Capacity of vehicle m
Cap_n : Capacity of vehicle n

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C_{ij}^{n} : Cost of delivery logistics from temporary depot j to demand point i using vehicle n
$R_{\max_m}$: Distance travelled maximum for each vehicle m
$R_{\max_n}$: Distance travelled maximum for each vehicle n
R_{dj}^{m} : Distance between distribution center d to temporary depot j using vehicle m
R_{d}^{n} : Distance between temporary depot j to demand point i using vehicle n

Decision variables:

X_{ij}^{n} : $\begin{cases} 1, & \text{if temporary depot } j \text{ served demand point } i \text{ using vehicle } n \\ 0, & \text{otherwise} \end{cases}$
Z_j : $\begin{cases} 1, & \text{if temporary depot is constructed at location } j \\ 0, & \text{otherwise} \end{cases}$
S_{dj}^{m} : Amount of logistics aid transported by vehicle m from distribution center d to temporary depot j
Y_{ij}^{n} : Amount of logistics aid transported from temporary depot j to demand point i using vehicle n

Model

Based on the notation, parameters and decision variables that have been determined above, a model with objective function and constraint function will be formed as follows:
Objective function:

$$\min \sum_{j\in J}\sum_{i\in I}\sum_{n\in N} C_{ij}^{n}Y_{ij}^{n} + \sum_{m\in M}\sum_{j\in J} F_m S_{dj}^{m} + \sum_{n\in N}\sum_{j\in J}\sum_{i\in I} F_n X_{ij}^{n} + \sum_{j\in J} F_j Z_j + \sum_{j\in J}\sum_{m\in M} R_{dj}^{m} S_{dj}^{m} \quad (1)$$

Subject to:

$$\sum_{j\in J}\sum_{n\in N} Y_{ij}^{n} = d_i, \quad \forall i \in I \quad (2)$$

$$\sum_{i\in I} Y_{ij}^{n} \le Cap_n, \quad \forall j \in J, \forall n \in N \quad (3)$$

$$\sum_{j\in J}\sum_{n\in N} X_{ij}^{n} \le 1, \quad \forall i \in I \quad (4)$$

$$Y_{ij}^{n} \le d_i X_{ij}^{n}, \quad \forall i \in I, \forall j \in J, \forall n \in N \quad (5)$$

$$\sum_{i\in I}\sum_{j\in J} R_{ij}^{n} X_{ij}^{n} \le R_{\max_n}, \quad \forall n \in N \quad (6)$$

$$\sum_{i\in I}\sum_{n\in N} X_{ij}^{n} \le BZ_j, \quad \forall j \in J \quad (7)$$

$$\sum_{j\in J} S_{dj}^{m} \le Cap_m, \quad \forall m \in M \quad (8)$$

$$\sum_{j\in J} R_{dj}^{m} S_{dj}^{m} \le R_{\max_m}, \quad \forall m \in M \quad (9)$$

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$$\sum_{m \in M} S_{dj}^{m} = \sum_{i \in I} \sum_{n \in N} Y_{ij}^{n}, \quad \forall j \in J \tag{10}$$

$$\sum_{m \in M} S_{dj}^{m} = \sum_{i \in I} \sum_{n \in N} Y_{ij}^{n} = \sum_{i \in I} d_i \tag{11}$$

$$Y_{ij}^{n} \geq 0, \quad \forall i \in I, \forall j \in J, \forall n \in N \tag{12}$$

$$S_{dj}^{m} \geq 0, \quad \forall j \in J, \forall m \in M \tag{13}$$

$$X_{ij}^{n} = \{0,1\}, \quad \forall i \in I, \forall j \in J, \forall n \in N \tag{14}$$

$$Z_j = \{0,1\}, \quad \forall j \in J \tag{15}$$

DISCUSSIONS

This model uses the Integer Linear Programming (ILP) form where the objective function of this model is to minimize the operational costs of logistics distribution which consists of five components, namely:

1. Cost of delivering logistics to the point of demand
2. Fixed cost of vehicle usage m,
3. Fixed cost of vehicle usage n,
4. Temporary depot construction cost
5. Travel costs from distribution centers to temporary depots.
6.

This model also uses several constraint functions where the constraint functions are as follows:

1. Demand for logistics aid constraint
2. Capacity of vehicle m and n constraint, respectively
3. Area visit constraints
4. Logistics aid delivery constraints
5. Maximum distance of vehicle m and n constraint, respectively
6. Temporary depot construction constraints
7. Logistics flow conservation constraint
8. Non-negative constraints
9. Binary constraints

CONCLUSION

From the results of the discussion on the distribution of post-flood logistics using the Multi Depot Vehicle Routing Problem (MDVRP), it is evident that the MDVRP model offers a structured, efficient, and cost-effective solution for delivering logistical aid to flood-affected areas. The model incorporates two distinct types of vehicles to optimize the distribution process. Vehicle type m is responsible for transporting logistical aid from the main distribution center to temporary depots. Subsequently, vehicle type n takes over the task of delivering the aid from these temporary depots directly to the points of demand. This two-tiered approach ensures that the distribution of aid is both timely and efficient, addressing the critical needs of the affected population while minimizing logistical complexities and costs.

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