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Optimization Model of Location Routing Problem for Disaster Relief Distribution

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Abstract. Disaster relief distribution is a very important component in the overall disaster response process. Consideration of limited funds, time pressure and surge of demand that come together increase to the complexity of the distribution process that must be done in a short time. Meanwhile, delays in the delivery of relief can lead to a decrease in the level of safety and welfare of disaster-affected victims. This paper proposes a location routing problem optimization model for disaster relief distribution with a multi-objective approach that minimizes waiting time and total costs. This model can help decision makers to determine the number and location of distribution centers which are opened and optimal vehicle routes.

Keywords: Disaster Relief distribution

INTRODUCTION

Some disasters such as earthquakes, hurricanes and floods are large-scale disasters that cause many casualties and huge economic losses. Quick and efficient response immediately after the occurrence of a disaster needs to be done to minimize the loss and damage caused by the disaster. In this case, distribution of disaster relief is the very important component in the overall disaster response process. Disaster relief is supplied from all over the country and abroad to satisfy the huge demands that come simultaneously from various disaster-affected areas. Here, the important role of the distribution center is needed in distributing and transporting relief goods (Zhu, 2014). Thus, the number of distribution centers in suitable locations is very necessary to be determined. In addition, to support the distribution process, the selection of vehicle routes in charge of transporting relief materials from distribution centers to disaster-affected areas is also an important decision to be made (Shen et al., 2019).

Determining the location of the distribution center is called the facility location problem and the selection of vehicle routes is called the vehicle routing problem. The combination of these two problems is called the location routing problem (LRP). Using a full weighted graph the LRP problem in the distribution of disaster relief can be modeled. In this study, a subset of nodes representing beneficiaries, each of which has a specific demand and must be visited using vehicles that have fixed costs and limited capacity, from a subset of nodes representing potential distribution centers with limited set-up costs and capacity. The route taken from the distribution center must return to the same distribution center and for each side traversed, there are travel costs incurred (Prodhon, 2007). So in this case, one of the main focuses to consider is minimizing the total cost. This is because limited funds often occur in disaster situations and it is quite important to maintain public trust in the government by using donated funds economically (Wang et al., 2014). Several previous studies have considered this focus (Prodhon, 2007; Shen et al., 2019; Vahdani et al., 2018; Wang et al., 2014).

In a large-scale disaster situation, (Jiang & Yuan, 2019) identified several problems that became challenges in the relief distribution process. Some of them are large-scale impacts due to disasters that

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cause the scale and complexity of distribution problems to increase, severe damage that causes optimization solutions to distribution problems requiring different goals and criteria, time pressure and urgency which causes decision making related to the distribution process to be carried out quickly and minimize delays because they can result in more severe damage.

One of the challenges related to relief distribution in large-scale disaster situations is the need to make decisions quickly and minimize delays. In order to avoid casualties and reduce the suffering of victims affected by disasters, delays in making decisions and actions must be minimized. The objective function that can be considered in responding to this challenge is to minimize the waiting time for disaster-affected victims as beneficiaries.

Within the scope of LRP for disaster relief distribution, minimizing waiting time is one of the goals developed by (Moshref-Javadi & Lee, 2016). The model is called the Latency Location Routing Problem (LLRP). In this model, the objective function of minimizing the total delay (long waiting time for the beneficiary) is calculated based on the sum of arrival time of the vehicle to the customer, to determine the optimal depot location and vehicle route. From the results of the study it was found that an increase in the number of depots opened and vehicles reduced the total latency of customers. In addition, the comparison of the research results from the best latency solution with conventional LRP results which minimize the total cost, shows results indicating that the minimum latency is quite important to be considered as an objective function in LRP problems. This model was adapted as a reference for model development in this study.

Consideration of limited funds, time pressure and surge of demand that come together in a large-scale disaster situation increase to the complexity of the distribution process that must be carried out in a short time. The integration of several objective functions needs to be considered in overcoming these complex conditions.

Studies related to the design of multi-objective optimization models for the integration of facility location issues and vehicle routes are much less in post-disaster situations (Wang et al., 2014), several studies have been carried out including by (Wang et al., 2014) who built a model nonlinear integer open location-routing for aid distribution problems by considering travel time, total cost, and reliability with split delivery, (Bozorgi-Amiri & Khorsi, 2016) proposed a multi-objective dynamic stochastic programming model for humanitarian aid logistics problems in where decisions are taken for pre- and post-disaster by minimizing the maximum number of shortfalls among the affected areas in all periods, total travel time, and aggregating pre- and post-disaster costs, (Vahdani et al., 2018) suggested a new mathematical model integer nonlinear multi-objective, multi-period, multi-commodity to determine the location of distribution centers, determine timely distribution of vital aids to damaged areas, route vehicles and emergency road repair operations by minimizing travel time and total cost as well as increasing route reliability, (Shen et al., 2019) proposed a fuzzy low-carbon open location-routing problem (FLCOLRP) model with a multi-purpose function, which includes minimum delivery time, total cost and carbon emissions.

From previous studies that have been carried out, there is no research that considers optimization in a multi-objective form to minimize costs and waiting time. Based on this background, this research will show the development of a mathematical model location routing problem for the distribution of disaster relief with two objectives, namely minimizing the total waiting time and minimizing the total cost of the system which includes preparation costs to open a distribution center (DC), costs fixed operation of the vehicle, vehicle travel costs, and penalties for shortages and oversupply.

Disaster Category

A disaster is an event in which a community or society experiences a severe disturbance because it cannot cope with the occurrence of widespread major damage and has an impact on injury, or loss of life

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and property (Schulz, 2009). According to the area of influence and severity, unpredictable events can be categorized into large-scale disasters, small-scale emergencies, and no-emergency healthcare systems (Farahani et al., 2019).

According to the cause, disasters can be categorized into natural disasters and disasters caused by technology or man-made. Meanwhile, according to the speed of occurrence, it is divided into disasters that sudden-onset and slow-onset (Van Wassenhove, 2006). The four categories of disasters are nature disasters that sudden-onset, are earthquakes, hurricanes and tornadoes, nature disasters that slow-onset are famine, drought and poverty, man-made disasters that sudden-onset, are terrorist attack, chemical leak, lastly, man-made disasters that slow-onset, are political crisis.

In this study, relief distribution to deal with large-scale and sudden disasters is the main focus to be resolved, because the characteristics of these types of disasters require high speed and flexibility, making it a big challenge for many researchers today.

Disaster Relief Distribution

The relief distribution system has similarities with the general distribution system. These similarities include demand, supply, and transportation. Supply is represented by relief commodity collection points in safe areas, demand points are represented by disaster-affected areas where relief is distributed to victims who in this case represent customers, distribution centers are represented by large-scale relief materials distribution depots near demand points or disaster-affected areas. The only difference between the two systems is that the relief distribution center is a temporary storage place (Tzeng et al., 2007).

In this study, the selection of a distribution center that will be used to support relief operations is the first decision that must be made in optimizing the relief distribution process. Located in the affected zone, distribution centers distribute relief goods to demand points that actually represent a group of people affected by the disaster. Generally, site selection for distribution centers within the affected zone is carried out from a series of pre-selected sites identified and even pre-positioned, during the preparedness phase. The next type of decision relates to transportation between DCs and demand points which in this case relates to vehicle routes (Anaya-Arenas et al., 2014).

Location Routing Problem

Location Routing Problem considers two interdependent decisions, namely how many facilities are opened and facilities at which location should be opened and to fulfil customer demand, which route should be chosen. The first decision is based on the usual location problem while the second decision is an extension of the vehicle routing problem (VRP) which seeks to serve a set of customers with minimum vehicle and distribution costs (Ponboon et al., 2016).

The LRP problem can be modeled using a fully weighted graph. In the context of disaster relief distribution in this study, a subset of nodes representing relief recipients, each of which has a specific request and must be visited from a subset of nodes representing distribution of potential centers with limited set-up costs and capacity. Furthermore, the purpose of LRP in the distribution process of disaster relief in this study is to visit each point of request only once by creating several routes that will be passed by the vehicle. These vehicles have a fixed cost and limited capacity. The route that starts from the distribution center must return to the same distribution center and travel costs are incurred for each side traversed (Prodhon, 2007).

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Multi-objective optimization

The Multi-objective optimization consists of the set of n decision variables, k objective functions and the set of constraints (m inequalities and p equations) (Verma et al., 2021). The objective function of this model is:

$$\text{Min/Max } y = f(x) = \left(f_1(x), f_2(x), \dots, f_k(x)\right), k \geq 2 \tag{1}$$

Subject to:

$$g_i(x) \leq 0, i = 1,2, \dots, m \tag{2}$$

$$h_j(x) = 0, j = 1,2, \dots, p \tag{3}$$

In Where $x = (x_1, x_2, \dots, x_n)$ is the decision vector n - dimension in $X \subseteq R^n$ (R is the set of real numbers), y is the objective vector k – dimensions in R^k, f defines the mapping function, g_i is the inequality constraint to - i, and h_j is the equality constraint to - j. Constraints (2) and (3) constrain all sets of feasible solutions X.

PROBLEM DESCRIPTION

This study considers a combination of location and routing problem for disaster relief distribution with three main components, namely distribution center (DC), demand points, and vehicles. This problem can be illustrated using a fully weighted graph. Suppose $G(V, E)$ is a graph where V represents the set of vertices and $E = \{(i, j): i, j \in V, i \neq j\}$ is the set of available traffic networks. V is the node set in the disaster relief distribution system which is denoted by C and contains two subsets C_1 and C_2. $C_1 = \{1, \dots, i\}$ is the set of distribution centers candidate and $C_2 = \{1, \dots, j\}$ is the set of demand points. Next, there are vehicles k totaling K tasked with distributing relief from distribution centers with setup costs SC_i and limited capacity to a subset of nodes representing beneficiaries, each of whom has a specific request and must visited once by making several routes that will be passed by the vehicle. This vehicle has a fixed cost FC_k and limited capacity. The route starting from the distribution center must return to the same distribution center and travel cost UC incurred for each side traversed.

Some decisions that must be made in this issue are determining which distribution centers should be opened after a disaster from distribution centers that have been previously established, determining how to assign vehicles to each distribution center and determining the most efficient route that vehicles will take in distributing relief from the distribution center to demand points.

The following assumptions are made to limit the model to be developed based on references from previous studies (Ahmadi et al., 2015; Moshref-Javadi & Lee, 2016; Wang et al., 2014): the distribution network includes only those demand points that can be reached from the traffic network; travel times and demand points are given and deterministic; vehicles are homogeneous and each vehicle has a limited capacity; each vehicle starts its journey from the distribution center where it is located and returns to the same distribution center after completing the delivery task to the demand points; delivery of relief goods to each demand points is only done once; each distribution center has a limited capacity; the type of goods sent to the demand points and stored at each distribution center is homogeneous.

In this study, the model is formulated in the form of a bi-objective mixed-integer programming problem. There are two objective functions that will be optimized, namely minimizing the total system cost obtained from the total DC opening costs, vehicle fixed operating costs, vehicle travel costs and penalty costs for shortages and oversupply and minimizing the waiting time obtained from the total time. vehicle arrival. The second objective function is adapted from the model proposed by (Moshref-Javadi &

*Corresponding author

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Lee, 2016). The length of waiting time to be minimized is calculated from the total arrival time of the vehicle k at the request j which is denoted by t_{jk}.

MATHEMATICAL FORMULATION

The following are symbols and descriptions of the set, indices, parameters and variables used in this study:

1. Sets
   $C_1 = \{1, \ldots, i\}$ is set of candidat distribution centers, $C_2 = \{1, \ldots, j\}$ is set of demand points, C is set of nodes and $C = C_1 \cup C_2$.
2. Indices
   i is indices to candidate distribution centers, j is indices to demand points, a, b are indices to nodes.
3. Parameter
   K is the number of vehicle, SC_i is fixed cost for candidate distribution center i, Cap_i^{center} is capacity of distribution center i, Len_{ab} is distance between node a and node b, T_{ab} is travel time between node a and node b, UC is travel cost per kilometer, FC_k is fixed operating costs of the vehicle k, Cap_k^{veh} is capacity of vehicle k, $\underline{D}_j$ is demand required at the demand point j, $\underline{D}_j$ and $\overline{D}_j$ is minimum and maximum demand required at the demand point j, LT_j is the latest arrival time at the demand point j, P^{demand} is penalty for unfulfilled demand, P^{supply} is penalty for excess supply.
4. Variables
   x_i is 1 if distribution center i is opened, and 0 otherwise, y_{ik} is 1 if vehicle k is placed to distribution center i, and 0 otherwise, z_{abk} is 1 if node a precedes node b on the route of the vehicle k, and 0 otherwise, q_j is the number of goods delivered at the demand point j, t_{ak} is arrival time of vehicle k at the demand point a.

The model is constructed to achieve the following two objectives: the minimum waiting time f_1 and the minimum total cost of the system f_2.

First important component in relief distribution after a disaster occurs is time efficiency which has an impact on the safety of disaster victims, so the waiting time for recipients of relief must be minimized. Based on the model proposed by (Moshref-Javadi & Lee, 2016), objective function (4) calculates the total waiting time defined by the number of vehicle arrival times k at the point of demand j

$$\min f_1 = \sum_{j \in C_2} \sum_{k=1}^{K} t_{jk} \tag{4}$$

Reduce expenses after a disaster occurs will have an impact on the smooth process of emergency response and recovery. Thus, the total cost to be incurred in this problem must be minimized. Objective function (5) calculates the total cost of the system, including the cost of setting up the DC opening, the fixed operating costs of the vehicle, the cost of vehicle travel, and penalties for undersupply and oversupply. The components of the preparation cost of opening DC and the cost of vehicle travel are based on the component of the objective function in the model proposed by (Wang et al., 2014). Meanwhile, the penalty cost component for undersupply is based on the model developed by (Ahmadi et

*Corresponding author

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al., 2015). The development of the two models that become the reference is the additional calculation of the components of the vehicle's fixed operating costs, the penalty cost of oversupply and the penalty cost of undersupply.

$$\min f_2 = \sum_{i \in C_1} SC_i x_i + UC \sum_{a \in C} \sum_{b \in C} \sum_{k=1}^{K} Len_{ab} z_{abk} + \sum_{i \in C_1} \sum_{k=1}^{K} FC_k y_{ik}$$
$$+P^{demand} \sum_{j \in C_2} \max\{D_j - q_j, 0\} + P^{supply} \sum_{j \in C_2} \max\{q_j - D_j, 0\} \tag{5}$$

subject to:

$$\sum_{a \in C} \sum_{j \in C_2} z_{ajk} q_j \le Cap_k^{veh}, k = 1, 2, \ldots, K \tag{6}$$

Constraint (6) ensures that each vehicle carries the amount of goods according to its capacity.

$$\sum_{a \in C} \sum_{j \in C_2} \sum_{k=1}^{K} z_{ajk}\ y_{ik}\ q_j\ \le Cap_i^{center}\ x_i, \forall\ i \in C_1 \tag{7}$$

Constraint (7) ensures that the total number of goods sent from each distribution center should not exceed the capacity of that distribution center.

$$\underline{D}_j \le q_j \le \overline{D}_j, \forall\ j \in C_2 \tag{8}$$

Constraint (8) ensures that the number of items delivered at demand point j (q_j) must exceed the minimum demand required at demand point j $(\underline{D}_j)$ but must not exceed the maximum demand required at demand point $\overline{D}_j$.

$$t_{ak} + T_{aj} - (1 - z_{ajk})M \le t_{jk} \le LT_j, \forall\ a \in C, j \in C_2, k = 1, 2, \ldots, K \tag{9}$$

Constraint (9) is a time window constraint, which ensures that the arrival time of vehicle k at point j must not exceed the latest arrival time at that point and must exceed the time for completion of its delivery at point a plus its travel time from point a to j.

$$\sum_{k=1}^{K} y_{ik} - x_i \ge 0, \forall\ i \in C_1 \tag{10}$$

Constraint (10) from the selected DC candidates, there are a number of vehicles that depart from the DC.

$$y_{ik} \le x_i, \forall\ i \in C_1, k = 1, 2, \ldots, K \tag{11}$$

Constraint (11) ensure that no vehicles departing from DC that are not open.

*Corresponding author

$$y_{ik} = \sum_{j \in C_2} z_{ijk}\,, \forall\, i \in C_1, k = 1, 2, \ldots, K \tag{12}$$

Constraint (12) ensure that the vehicle must depart to the demand point, if it is assigned to a DC.

$$\sum_{k=1}^{K} z_{abk} = 0, \forall\, a, b \in C_1 \tag{13}$$

Constraint (13) ensure that each vehicle passes on the appropriate route.

$$\sum_{a \in C} z_{bak} - \sum_{a \in C} z_{abk} = 0, \forall\, b \in C, k = 1, 2, \ldots, K \tag{14}$$

Constraint (14) is flow conservation constraint.

$$\sum_{a \in C} \sum_{k=1}^{K} z_{ajk} = 1, \forall\, j \in C_2 \tag{15}$$

Constraint (15) is each demand point receives only one delivery of relief.

$$\sum_{i \in C_1} y_{ik} \leq 1, k = 1, 2, \ldots, K \tag{16}$$

Constraint (16) ensure that each vehicle is assigned to only one distribution center.

Constraint (17), (18) and (19) is binary integer constraints for decision variables.

$$x_i \in \{0,1\}, \forall\, i \in C_1 \tag{17}$$

$$y_{ik} \in \{0,1\}, \forall\, i \in C_1, k = 1, 2, \ldots, K \tag{18}$$

$$z_{abk} = \{0,1\}, \forall\, a, b \in C, k = 1, 2, \ldots, K \tag{19}$$

CONCLUSION

In this study, a location routing problem optimization model for the distribution of large-scale disaster relief was developed based on the previous research literature. This model is used to determine the

*Corresponding author

distribution center that will be opened immediately after a disaster occurs and determine the optimal vehicle route to speed up the distribution process from the distribution center to the community affected by the disaster. With two objective functions, this model was developed in the form of a bi-objective mixed integer programming that minimizes waiting time for beneficiaries while minimizing the total system costs incurred. Latency is calculated based on the number of vehicle arrival times at the point of demand and the system cost is calculated by adding up the cost of setting up a distribution center (DC), vehicle travel costs, the vehicle's fixed operating costs, the penalty cost of oversupply and the penalty cost of undersupply.

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