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A model for planning locations of temporary distribution facilities for emergency response

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ABSTRACT

We propose a network flow model for dynamic selection of temporary distribution facilities and allocation of resources for emergency response planning. The model analyzes the transfer of excess resources between temporary facilities operating in different time periods in order to reduce deprivation. Numerical analysis shows that the location of temporary facilities is determined by the demand and supply points. This work contributes to the emergency response planning that requires a quick response for the supply of relief materials immediately after a disaster hits a particular area.

1. Introduction

Response planning to meet the needs of people during natural disasters such as hurricanes, floods, and earthquakes is challenging because resources of more than one type have to be delivered to the demand areas in a timely manner and in right quantities. It also requires a carefully planned process of acquiring and distributing the resources. This poses further challenge as the demand in such disasters may vary over time in terms of the type of materials (or service) or in terms of quantity. Rennemo et al. [19] mentions that disasters are characterized by uncertainty and unpredictability; and therefore, demand may change rapidly in such an environment. Additionally, demand for resources in one location at a period may not exist in the next period; or, a particular location may have a very high demand in the subsequent period.

Performance of emergency services is measured in terms of the response time and the total logistics cost [23]. Therefore, if demand is not met on time, the performance of service will degrade. In order to address such a situation, a flexible and efficient emergency response system should be developed so that both social and economic losses due to the aftermath of disasters could be minimized [2]. Therefore, location and allocation of relief distribution facilities becomes critical for an effective emergency response planning.

As disaster may cover a large region, emergency supplies (also called resources) would be needed for several days and in varying quantities even at a single location. A change in demand both in terms of the location and the quantity is usually tackled through the allocation of resources at the prepositioned facilities. However, prepositioned facilities may be small in numbers and distribution of resources to the affected area may require additional funds for transportation and other overhead costs. In such a case, resources can be distributed through a number of temporary facilities that can be located near the demand centers. Research on relief distribution through temporary facilities has gained attention recently. The use of temporary relief centers will decrease response time. Holguin-Veras et al. [10,11] mention that deprivation is caused due to delayed response time. Therefore, when resources are provided as soon as possible to the needy areas, the social cost due to deprivation reduces significantly.

In this paper, we propose a model for emergency response planning. The model provides location and allocation plans for short distribution periods in a planning horizon. It considers periodically changing demand and supply. This change necessitates dynamic decisions on location of temporary relief distribution facilities and allocation of resources. Our model allows delayed satisfaction of demand when resources in a planning period are insufficient, and allows transfer of excess resources from a relief facility to another in the next time period. We believe that the consideration of the dynamic decision, transfer of excess resources and provision of delayed satisfaction of demand make the proposed model unique and more representative to the actual relief distribution.

The organization of this paper is as follows: in Section 2, we review relevant literature in emergency response planning. In

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Section 3, we present the proposed model. In Section 4, we provide numerical analysis to analyze the model. Finally, in Section 5 we provide the concluding remarks, limitations and possible future extension of this research.

2. Relevant literature

One of the comprehensive reviews of the literature on emergency logistics is given in Ref. [5]; which mentions that the research on facility location for the distribution of resources during the response period is gaining attention recently due to the need to make the distribution more efficient. However, the majority of the literature in this area has focused on the location of temporary depots for ambulance vehicles. A large number of researchers (such as [3,4,6,15,18,20]) have studied the location and allocation of relief facilities for the preparedness (pre-disaster) period.

Authors proposing ambulance vehicles location and relocation have generally considered multi-period models [8,9,21,22,25]. These models recognize that relief quantities and travel times are time dependent.

Post-disaster planning for resource allocations and temporary facility locations has gained attention recently. We have identified that three papers [1,14,24] are related to the model being proposed here. These studies consider dynamic nature of demand to propose integrated models for facility location, supply delivery and vehicle routing. Lin et al. [14] consider the total number of facilities to be located as a fixed time independent parameter, whereas [24] and [1] consider it as a time dependent decision variable.

Tzeng et al. [24] have proposed a three objectives model by considering cost, response time and distribution fairness. The cost objective includes setup and operational costs of transfer depots and distribution of relief resources. The response time objective includes the travel time between the collection points, transfer depots and demand centers. The distribution fairness objective includes maximization of satisfaction in distribution fairness by considering a weighted score for the satisfaction value for each relief supply item in different planning periods.

Lin et al. [14] extended the model developed by Ref. [13] which considered a centralized depot for distribution of relief resources. The model proposes the location of temporary facilities for relief distribution by considering the availability of required vehicles and resources. The objective function of the model minimizes the relevant operation costs of disaster relief which includes penalty cost for the delayed satisfaction of demand.

Another model that recognizes the need for temporary facilities is given by Ref. [1]. The authors expect their model to help in the centralized planning of distributing the resources. Their location-allocation model considers the flow of resources from 'source' to the demand points through a chain of facilities and minimizes unsatisfied demand based on the urgency of a particular type of supply at a given time.

Location-allocation models in Refs. [24] and [14] are flexible to allow satisfaction of backordered demand in later periods. Our model also includes such flexibility in demand satisfaction. The proposed location-allocation model has some similar characteristics to that of [14] mainly in terms of the cost-based objective and use of penalty cost function that increases linearly with the number of delayed periods in satisfying the demand. Table 1 summarizes characteristics of the location-allocation model presented in the three relevant papers discussed above and shows how our model differentiates from the rest. It is seen from the table that the existing models overlook the possibility of transfer of supplies between the relief facilities operating in different time periods. Our model addresses this overlooked aspect and is flexible to provide provision of inter transferability of resources between temporary relief facilities operating in different time periods. The provision of inter transferability of the resources among the facilities increase the efficiency of distribution and effectiveness in terms of meeting the unsatisfied demand as fast as possible. Therefore, the model proposed in this paper adds value to the existing literature by examining the effect of transferability of resources from one temporary facility to the next in different demand periods.

3. Emergency logistics resource distribution model

To develop the distribution model, we assume that the distribution is initiated from a central supply point (CSP), which is a collection point that continuously acquires the resources and prepares them for distribution. We consider a planning horizon discretized into short periods, which are referred to as distribution periods. Researchers mention that short distribution periods for resource supply improve the accuracy of modeling the emergency

Table 1
Characteristics of relevant location-allocation models on planning temporary relief facilities.

Reference	Objectives			Decisions variables	Constraints		
	Cost	Time	Other		Requirements and bounds	Capacity	Other constraints and decisions
Tzeng et al. [24]	Minimize logistics cost	Minimize travel time	Maximize demand satisfaction	- Location - coverage - allocation		- Truck capacity - Supply capacity	- Commodity flow - Supply assignment
Afshar and Haghani [1]			Minimize total weighted unsatisfied demand	- Location - Commodity and vehicle flow	Number of facilities	- Facility capacity - Vehicle capacity - Supply capacity	- Commodity flow - Linkage between vehicles and commodities - Vehicles flow - Transportation network decisions
Lin et al. [14]	Minimize logistics and penalty costs			- Location - Coverage - Allocations - Vehicle tours - Backordered demand - Unsatisfied demand	Number of vehicles Number of facilities	- Facility capacity - Supply capacity	- Commodity flow - Vehicles flow
Proposed model	***Minimize logistics and penalty costs***			- ***Location*** - ***Coverage*** - ***Allocations*** - ***Resource transfer*** - ***Backordered demand***		- ***Facility capacity*** - ***Supply capacity***	- ***Commodity flow*** - ***Supply assignment*** - ***Resource transfer*** - ***Demand satisfaction***