Transportation Research Part B 67 (2014) 284–305

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

A method for designing centralized emergency supply network to respond to large-scale natural disasters

Jiuh-Biing Sheu *, Cheng Pan

Department of Business Administration, National Taiwan University, 1, Section 4, Roosevelt Road, Taipei 106, Taiwan

ARTICLE INFO

Article history:
Received 13 December 2013
Received in revised form 21 May 2014
Accepted 21 May 2014

Keywords:
Centralized emergency supply network
Emergency logistics
Mixed-integer linear programming model

ABSTRACT

This paper proposes a method for designing a seamless centralized emergency supply network by integrating three sub-networks (shelter network, medical network, and distribution network) to support emergency logistics operations in response to large-scale natural disasters. The proposed method primarily involves three stage multi-objective (travel distance minimization, operational cost minimization, and psychological cost minimization), mixed-integer linear programming models. The three sub-networks are designed using the proposed programming models. The distinctive features of the proposed method are as follows. (1) The proposed method is demand-driven. The order of the designed sub-networks is shelter, medical, and distribution, with the connections of the latter networks based on the arrangements for the former. (2) The objective functions of three stage programming models include not only traditional objectives such as minimizing total travel distance and operational cost, which supply-side members focus on, but also minimizing the psychological cost experienced by demand-side members. Model tests are conducted to demonstrate that the superiority of a centralized emergency supply network designed by the proposed method over a decentralized one, especially with regard to distribution network design.

1. Introduction

When a large-scale natural disaster occurs, such as the typhoon in Taiwan in 2009, the tsunami in Japan in 2012, and the storm that hit southern Britain in 2013, emergency logistics are triggered by supply-side members, including the host government and local nongovernment organizations (NGOs). Before implementing emergency logistics, an effective and efficient emergency supply network must be established. However, designing an emergency supply network differs from designing a traditional business supply network. For example, the purpose of an emergency supply network designed by the supply-side members is to support the emergency logistics operations, e.g., locating emergency shelters that provide temporary safe spaces for evacuees. In contrast, the purpose of a business supply network that is designed by company managers is to support business logistics operations, e.g., locating warehouses that store materials or goods. In addition, the service targets of an emergency supply network differ from those of a business supply network. An emergency supply network services both supply-side and demand-side members such as relief suppliers and affected people. A business supply network services companies and/or customers. The establishment of an emergency supply network is temporary as it is a response to the occurrence of a disaster and it may be maintained for only a few days or weeks. The lifetime of a business supply network

* Corresponding author. Tel.: +886 2 3366 1069.
E-mail addresses: jbsheu@ntu.edu.tw (J.-B. Sheu), d00741001@ntu.edu.tw (C. Pan).

http://dx.doi.org/10.1016/j.trb.2014.05.011
0191-2615/

depends on the strategy of the business, which may last for several years. Clearly, an emergency supply network cannot be designed using the conceptual framework of a business supply network.

A host government is usually incapable of designing a suitable emergency supply network alone. Since large-scale natural disasters typically cause severe damage, which have a considerable impact on demand-side members, and government funding to deal with the aftermath of such disasters is limited, the ability of an emergency supply network that is established by the government may not suffice to satisfy the demands and support all emergency logistics operations. Local NGOs usually self-deploy and distribute relief resources through their own emergency supply network without collaborating with the host government, potentially causing a secondary disaster impact, such as an imbalance in the distribution, or an oversupply or undersupply, of relief resources to affected areas and emergency facilities (Caunhye et al., 2012; Kovacs and Spens, 2007). Therefore, to support overall emergency logistics operations, satisfy demand, and alleviate the impact of any secondary disaster caused by the supply side, a host government and local NGOs should collaborate to form a seamless, centralized emergency supply network during the mitigation phase of preparing for large-scale natural disasters. In this centralized emergency supply network, a host government and local NGOs would share resources such as emergency facilities, labor, commodities, and medical supplies.

An emergency supply network usually involves three essential sub-networks including shelter, medical, and distribution networks. Each sub-network normally comprises its corresponding emergency facilities, which include emergency shelters (ESs) in the shelter network, emergency medical centers (EMCs) in the medical network, and emergency distribution centers (EDCs) in the distribution network, as well as route lines. In this work, an emergency shelter refers to a building such as a school, church, temple, or hotel, which provides temporary living spaces for people who are forced to evacuate the affected areas (AAs). An emergency medical center is established at a local hospital or clinic and is utilized to provide medical care to injured persons. An emergency distribution center may be established at a railway station, bus station or warehouse; its primary function is to store relief resources that are obtained from relief suppliers and deliver relief resources to AAs, ESs, and EMCs through the designed distribution network.

In designing a centralized emergency supply network, the above three sub-networks are interdependent. For example, when an shelter of the shelter network is located in a place where is easily reached by evacuees, an medical center of the medical network ought to be situated not only close to AAs but also close to ESs in the shelter network, because the travel distance is important. Additionally, an emergency distribution center must be placed within the distribution network at a location that is at an acceptable distance from ESs, EMCs, and AAs. The decision about the location of an emergency facility in the corresponding network should be in accordance with the decisions about the locations of other, related facilities or AAs (Arabani and Farahani, 2012). Thus, if disaster managers use only one of the three sub-networks or design a centralized emergency supply network without considering how one sub-network will integrate with the other two, the result may be inefficient and lack the ability to support emergency logistics operations for large-scale natural disasters.

Despite the fact that the design of an emergency supply network is critical to emergency logistics, no research has focused on this issue. Instead, the research to date has focused on the design of one of the sub-networks or the location of one type of emergency facilities. Regarding shelter network design and shelter location, Li et al. (2011) studied shelter network planning and operations for natural disaster preparedness; Liu et al. (2011) analyzed and applied the principles of selecting the sites of shelters in the context of a disastrous earthquake; Li et al. (2012) developed a scenario-based bi-level programming model to optimize the selection of shelter locations. Regarding the location of medical centers, Jia et al. (2007) proposed models to determine the locations of facilities for medical supplies in response to large-scale emergencies; Mete and Zabinsky (2010) developed a stochastic optimization approach for the distribution of medical supplies and the location of distribution facilities. Concerning the location of distribution centers, Chang et al. (2007) developed a decision-making tool for planning? flood emergency logistics. The decision variables included the structure of the rescue organizations, locations of the rescue resource storehouses, allocations of rescue resources under capacity restrictions, and the distribution of rescue resources. Naji-Azimi et al. (2012) discussed the location of satellite distribution centers that supply relief to affected people throughout a disaster area. Lin et al. (2012) presented a method for locating temporary depots around the disaster-affected area, and determining the required vehicles and resources to improve logistical efficiency. Lu and Sheu (2013) located urgent relief distribution centers on a given set of candidate sites, using a robust vertex p-center model.

According to previous investigations, the variables of the objective functions that are related to the network problem include logistical costs, travel time, travel distance, or unsatisfied demand (Chang et al., 2007; Yi and Ozdamar, 2007; Mete and Zabinsky, 2010; Ben-Tal et al., 2011; Li et al., 2011; Rawls and Turnquist, 2010; Daganzo and So, 2011; Lin et al., 2012; Naji-Azimi et al., 2012; Li et al., 2012; Afshar and Haghani, 2012). Those variables are extensively utilized in the multi-objective or single objective functions. Holguín-Veras et al. (2013) suggested that social costs (including logistical costs and cost of deprivation) should be incorporated in the design of post-disaster logistical models. As for demand-side members, when a large-scale natural disaster occurs evacuees usually choose to go to nearest shelter and injured people are shifted to nearest medical center. Travel distance is therefore essential when designing the shelter and medical networks. With respect to supply side members, even an advanced host government, for example, considers not only the travel distance for delivering relief resources, but also the operational cost of an emergency supply network for large-scale natural disasters in the context of a limited budget. Hence, travel distance and operational cost are fundamental concerns when designing an emergency supply network, and both are addressed in the proposed programming models.

Disasters cause serious psychological harm to demand-side members. People who are exposed to a disaster can experience psychological problems, including posttraumatic stress disorder, grief, depression, anxiety, stress-related health costs,