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Facility Location Problem in Emergency Logistic

Yousef Abu Nahleh, Arun Kumar, Fugen Daver

Abstract**—**Facility location is one of the important problems affecting the relief operations. The location model in this paper is motivated by arranging the flow of relief materials from the main warehouse to continent warehouse and further to regional warehouse and from these to the disaster area. This flow makes the relief organization always ready to deal with the disaster situation during shortest possible time. The main purpose of this paper is merge the concept of just in time and the campaign system in emergency supply chain,so that when the disaster happens the affected country can request help from the nearest regional warehouse, which will supply the relief material and the required stuff to support and assist the victims in the disaster area. Furthermore, the regional warehouse places an order to the continent warehouse to replenish the material that is distributed to the disaster area. This way they will always be ready to respond to any type of disaster.

Keywords**—**Facility location, Center-of-Gravity Technique, Humanitarian relief, emergency supply chain.

I. Introduction

MANAGING supply chain network has become a vital global issue in the context of the severe effect of natural disasters and a wide variety of other reasons such as industrial plant fires, transportation delays, work stoppages, and it remains a largely unexplored area in research and practice. With increasing numbers of natural and man–made disasters, organizations are facing challenges due to limited number of available experienced logistics experts and the need for better coordination of those involved in vulnerable logistics networks. Moreover, companies running lean operations no longer have inventory or excess capacity to make up for production losses, resulting into rapid escalation of material flow problems to wide-scale network disruptions.

The dynamic nature of the global supply chain environment dictates that the companies with resilient supply chains in the future will have a sustainable competitive advantage over other firms.

Over the past three decades, the number of reported disasters has increased fourfold. Around 6.1 billion people have been affected by disasters with an estimated damage of almost 2.3 trillion dollars [1]. An adequate level of mitigation measures and a coordinated post-disaster relief logistics management may help to reduce the loss of both human lives and economic damage. Time plays a critical role in the logistic plan, and it directly affects the survival rate in affected areas. This makes the task of logistics planning and supply chain management more complex than conventional distribution problems.

The emergency supply chain differs from the normal supply chain in many ways such as huge surge of demand with a short notice, damaged roadways, chaotic behavior of victims, break-down of infrastructure and communication lines, short lead time, major uncertainties about what is actually needed and what is available at the site, large volumes of critical supplies to be transported and so on. Under these critical conditions, delivering supplies becomes an extremely difficult task for the suppliers with limited or nonexistent transportation capacity. The design of a reliable emergency supply chain network is hampered by a lack of (1) knowledge about how emergent supply chains operate and interact, (2) methods to analyze and coordinate the flows of both priority and non-priority goods, and (3) scientific methods to analyze logistics systems under extreme conditions. Furthermore, forecasting and evaluating the reliability of transportation networks are significant for path selection in emergency logistics management under earthquake and other natural disasters. The reliability of arcs and nodes of a transportation network is time-varying under disaster conditions.

In major non-natural disasters such as terrorist attacks (e.g., September 11, 2001) or natural disasters such as the Hurricane Katrina of 2005 a disaster management structure organizer will face significant problems of emergency services and evacuation. In several disasters, the disaster area requests residents to be evacuated of the area and need to be moved to safe places as fast as possible, leading to a sudden and great surge of demands for emergency services.

Humanitarian relief organizations and NGO's are mostly non-profit organizations with the idea of providing critical services to the public in order to minimize the pain and sufferings after a natural disaster. According to UN Office for Humanitarian Affairs, there is increasing human vulnerability in natural disasters, 244.7 million affected in 2011, and in complex emergencies 54 million in need of life-saving assistance in 2011. Furthermore, emergency management involves preparing for disaster before it happens, responding to disasters immediately, as well as supporting, and rebuilding societies after the natural or human-made disasters have occurred. It is essential to have comprehensive emergency plans and evaluate and improve the plans continuously.

Immediately after the disaster, there is a huge surge of demand of relief materials with a short notice and the humanitarian relief organizations often face significant problems of emergency logistics management such as

Yousef Abu Nahleh is with the School of Aerospace, Mechanical andManufacturing Eng., RMIT University, Melbourne, VIC3000, Australia (phone: +61399256226; e-mail: s3319062@student.rmit.edu.au).

Arun Kumar is with the School of Aerospace, Mechanical and Manufacturing Eng., RMIT University, Melbourne, VIC3000, Australia (phone: +61 3 9925 4328; e-mail: a.kumar@rmit.edu.au).

Fugen Daver is with the School of Aerospace, Mechanical and Manufacturing Eng., RMIT University, Melbourne, VIC3000, Australia (phone: +61 3 9925 6008; e-mail: fugen.daver@rmit.edu.au).

transporting large amounts of many different commodities including food, clothing, medicine, medical supplies, machinery, and personnel from several origins to several destinations inside the disaster area. The transportation of supplies and relief personnel must be done quickly and efficiently to maximize the survival rate of the affected population and minimize the cost of such operations. The demands in the relief chain occur in irregular amounts and at irregular intervals and occur suddenly, such that the locations are often completely unknown until the demand occurs.

In large-scale disasters such as earthquakes or hurricanes and biological attacks, facilities cannot satisfy the demand in the disaster area by the simple point that if the region is damaged, then the facilities placed near the disaster area will be damaged as well. For instance, in the 2008 earthquake in Sichuan region of China, Wenchuan, destroyed an area about 66km long and 20km wide, was called as "very terrible" [2]. Majority of local health facilities had been damaged and their personnel killed or injured. After the earthquake in Haiti (January 2010), we saw from the media that almost all help came only from international organizations due to the total damage of local facilities. The logistics for humanitarian relief still suffered even five days after the main shock. These facts give space to an important network problem to study: where to locate facilities that minimize the maximum weighted distance to provide service under the condition that the facility located at a given node on the network cannot provide service to the population residing in the same node. The location model in this paper is motivated by arrange the flow of relief material from the main warehouse and further to continent warehouse to regional warehouse to the disaster area. This makes the relief organization always ready to deal with the disaster situation as soon as possible. The main purpose of this paper is merge the concept of just in time and the campaign system in emergency supply chain, so that when the disaster happens the affected country will request help from the nearest regional warehouse, which will supply the relief material and the required stuff to help the victim in the disaster area.

II. Literature Review

One of the earliest studies for logistics management in relief operations was addressed by [3], for the increasing refugee population in Somalia. Subsequently, [4] addressed the need of logistics management in relief operations for the 1985 Mexico City earthquake. Some specific features of the emergency logistics problem were studied in the routing literature by [5], [6]; however, the general logistics problem involving relief supplies distribution characteristics received far less attention. Further, [7], [8] addressed the mathematical formulations for commodities transportation in emergency. Reference [9] extended the commodity logistics model to integrate the wounded evacuation and emergency medical centre location problems, and the logistics operations are illustrated by a concrete application on earthquake scenario. Further, [10] present a meta-heuristic of Ant Colony Optimization (ACO) for solving the logistics problem arising in disaster relief activities. The logistics planning involves dispatching commodities to distribution centers in the affected areas and evacuating the wounded people to medical centers. Furthermore, [11] proposed a model to determine the number and location of distribution centers to be used in relief operations.

Humanitarian logistics, also called relief supply chain management, have gained attention due to an increasing number of natural and man-made disasters and the recognition of the central role of logistics in responding to these [12]. The needs are expected to increase another five-fold over the next fifty years' [13]. However, the literature in the area of humanitarian logistics is largely focused on handbooks and general procedures [14]. Reference [15] has reviewed the literature on disaster operations management, resulting in only 109 academic articles published in operations management related journals, indicating needs for more research on the subject. The analytical techniques used in the field of operations research and management include mainly simulation, optimization and statistics. They concluded that most of the disaster management research was related to social sciences and humanities literature. References [16] and [17] discuss the need for speed and better coordination between those involved in the humanitarian logistics network. Logistics in humanitarian aid operations are highly dynamic, innovative and characterized by complexity of operational conditions and often politically volatile climate, high level of uncertainties in terms of demand and supplies, pressure of time and high staff turnover [18], [19]. Some studies such as [20], [21], [13], [19], and [22], emphasized that some supply chain concepts share similarities to emergency logistics and therefore can be successfully adapted in emergency response logistics. Reference [23] discussed the food security and humanitarian assistance among displaced Iraqi populations in Jordan and Syria. In a recent study, [24] highlighted pre-storm emergency supplies inventory planning. More research is needed to develop new models or new variants of old ones, especially in preparedness, response and recovery stages of the disaster management.

Although the literature in logistics management is extensive, the particular problem on the reliability of supply chains in emergency logistics planning has received little attention. Reference [25] studied the supply chain system reliability based on Markov process for normal business supply chains. Huang evaluated the reliability of railway emergency supply chain in China. Reference [26] proposed the GO methodology to analyze the transportation network reliability for emergency logistics; [27] recently studied the supply chain reliability in emergency situations in China. However, none of these studies provide an in-depth analysis of reliability of supply chains under natural disasters and vulnerability. Moreover, to my best knowledge, there is no research dealing with these two aspects of humanitarian and commercial logistics in an integrated manner which is the subject of this study, though such plan can significantly enhance the system-wide operational efficiency.

Reference [28] mentioned five reasons why the research in this area is very important. The first reason, [29] emphasized that the current method is not enough and that something has to be done to improve the emergency supply chain. Second, the cost in terms of both economic impact and human suffering is still growing. Third, there are many different organizations donating money and resource for the humanitarian / disaster relief event, so we have to find the best way to spend this money [30]. The fourth reason, how emergency supply chain systems can be organized to deal with uncertainty. Finally, by studying emergency supply chain we can deal with outcome rather than cost such as time because the time is very important in relief process specially the first 72 hours.

For years, Operations Research methods have been used to a huge variety of problems to define the best geographical locations for facilities [31]-[34] for new surveys on facility location research). Facility location problems develop their importance from two reasons: their direct effect on the system's timeliness of response to the demand and functional cost [35]. While the objective of facility location models addressing Commercial sector problems is commonly to maximize profit or reduce cost, the models addressing community and emergency services instead focus on response time and user accessibility [36], [37].

Models with coverage-type objectives are generally used in facility location study and applications, mainly when response time is the main act principle [38], [39]. In covering-type facility location models, a source of demand is defined as covered if it is located inside a definite response distance or response time from a facility. The regular covering models look to select facilities between a finite set of candidate places such that all demand are covered with a least number of facilities. In disaster relief operation, this would mean that each possible demand point necessity be within a definite target response time of a facility in the relief organization.

In this study, we will find the facility location for the relief organization network. In this paper we will present three levels of inventory warehouses. These warehouses are main warehouse, which distributes the relief material just for the continent warehouses. The continent warehouses distribute the relief material mainly for the regional warehouses. The regional warehouses distribute to affected area.

III. Methodology

A. Center-of-Gravity Technique

In general, transportation costs are a function of time, distance, and weight. Also, the relief operation is a function of time, distance, and availability of recue materials. The center-of-gravity method is a numerical technique for a facility location such as a warehouse at the middle of movement in a geographic area based on distance and weight. This method identifies a set of coordinates designating a central location on a map relative to all other locations [40].

The coordinates for the location of the new facility are calculated using the following formulas:

$$x = \frac{\sum_{i=1}^{n} x_i * W_i}{\sum_{i=1}^{n} W_i}, \; y = \frac{\sum_{i=1}^{n} y_i * W_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

where

x, y = coordinates of the new facility at center of gravity.

x_i, y_i = coordinates of existing facility i.

W_i = annual weight shipped from facility i.

IV. Results and Discussion

The coordinates for each country has been found from the nation master website [41]. Also, the disaster data for each country has been collected from the Centre for Research on the Epidemiology of Disasters (CRED)'s EM-DAT worldwide database for natural disasters. This has been sponsored by the United States Agency for International Development's Office of Foreign Disaster Assistance (USAID/OFDA). It contains data from year 1900 to 2011. CRED has compiled the data from numerous sources including UN agencies, NGOs, insurance companies and research institutes [42]. Systematic collection and analysis of these data provides invaluable information to governments and relief agencies in charge of relief and recovery activities. EM-DAT provides an objective basis for vulnerability assessment and rational decision making in disaster situations. In addition to providing information on the human impact of disasters, such as the number of people killed, injured or affected, EM-DAT provides disaster-related economic damage estimates and disaster-specific international aid contributions.

We assume that the number of disasters affecting the country is Wi., so this number has been calculated by using the data available from the Centre for Research on the Epidemiology of Disasters (CRED)'s EM-DAT worldwide database for natural disasters.

A. The Regional Warehouse

Assumption has been made that there are 18 regions in the world. For example Central Asia, Eastern Asia, South-Eastern Asia, Western Africa and so on.

Equation (1) has been applied to each region to find the coordinates for each regional warehouse.

For example, Eastern Asia, the following table shows the coordinates and the number of disasters for each country in the Eastern Asia region.

TABLE I
COUNTRIES IN THE EASTERN ASIA REGION DATA

Country	Capital	Latitude	Longitude	Number of disaster
China	Beijing	39.91	116.4	57
Hong Kong	Hong Kong	22.28	114.15	6
Japan	Tokyo	35.67	139.78	16
Macao	Macao	22.2	113.55	0
Mongolia	Ulan Bator	47.92	106.92	1
North Korea	Pyongyang	39.02	125.75	1
South Korea	Seoul	37.57	127	7
Taiwan	Taipei	25.04	121.53	6

After applying (1) as shown in Table II:

TABLE II
COUNTRIES IN THE EASTERN ASIA REGION RESULTS

Country	Capital	Latitude	Longitude	Number of disaster
China	Beijing	2274.87	6634.80	57
Hong Kong	Hong Kong	133.68	684.90	6
Japan	Tokyo	570.72	2236.48	16
Macao	Macao	0.00	0.00	0
Mongolia	Ulan Bator	47.92	106.92	1
North Korea	Pyongyang	39.02	125.75	1
South Korea	Seoul	262.99	889.00	7
Taiwan	Taipei	150.24	729.18	6
Total		3479.44	11407.03	94
The warehouse coordinate		37.02	121.35	

We applied the same process to all the regional warehouses; Table III shows the coordinates for all the warehouses.

TABLE III
THE REGIONAL WAREHOUSE LOCATION

Continent	Region	Country	Latitude	Longitude
Asia	Central Asia	Kazakhstan	42.41	69.56
Asia	Eastern Asia	China	37.02	121.35
Asia	South-Eastern Asia	Philippines	7.46	110.01
Asia	Southern Asia	Pakistan	25.14	67.93
Asia	Western Asia	Iraq	33.56	40.45
Africa	Western Africa	Burkina Faso	11.61	-4.01
Africa	Eastern Africa	Tanzania	-8.77	37.96
Africa	Middle Africa	Cameroon	4.69	13.76
Africa	Northern Africa	Libya	30.67	16.65
Europe	Eastern Europe	Ukraine	50.16	28.79
Europe	Northern Europe	Denmark	55.48	4.80
Europe	Southern Europe	Spain	39.89	3.94
Europe	Western Europe	France	49.39	6.46
Americas	Caribbean	Dominican Republic	18.30	-71.09
Americas	Central America	Mexico	15.95	-92.32
Americas	Northern America	United States(Maryland)	39.48	-76.92
Americas	South America	Bolivia	-11.36	-68.89
Oceania	Oceania	Australia	-22.36	124.75

B. The Continent Warehouses

By applying the same equation for each continent, Table IV shows the coordinates for each continent warehouse.

TABLE IV
THE CONTINENT WAREHOUSE LOCATION

Continent	Country Name	Latitude	Longitude
Africa	Sudan	20.26	32.31
Asia	Burma	25.83	95.93
Europe	Austria	47.98	13.08
Americas	Jamaica	18.25	-77.50
Oceania	Australia	-22.36	124.75

C. Main Warehouse Calculation

By applying (1) the coordinates for the main warehouse have been found (20.7,-10.7) and these coordinates correspond to Sudan.

V. CONCLUSION

In disaster response actions, the survival rate among affected people depends on the effectiveness of search and rescue operations and this requires, in turn, a good pre-disaster planning. Facility location is one of the most important problems that can affect the relief operations. By considering three levels of warehouses and merging the concept of just in time and the campaign system in emergency supply chain, the approach leads to better coordination of search and rescue activities and efficient evacuation of injured people. Furthermore, overall health conditions of everyone in the affected area depend on the timely availability of commodities such as food shelter and medicine. Moreover, it decreases the number of people suffering from the disaster and improves the response time. Fig. 1 summarizes all the facility locations in the world.

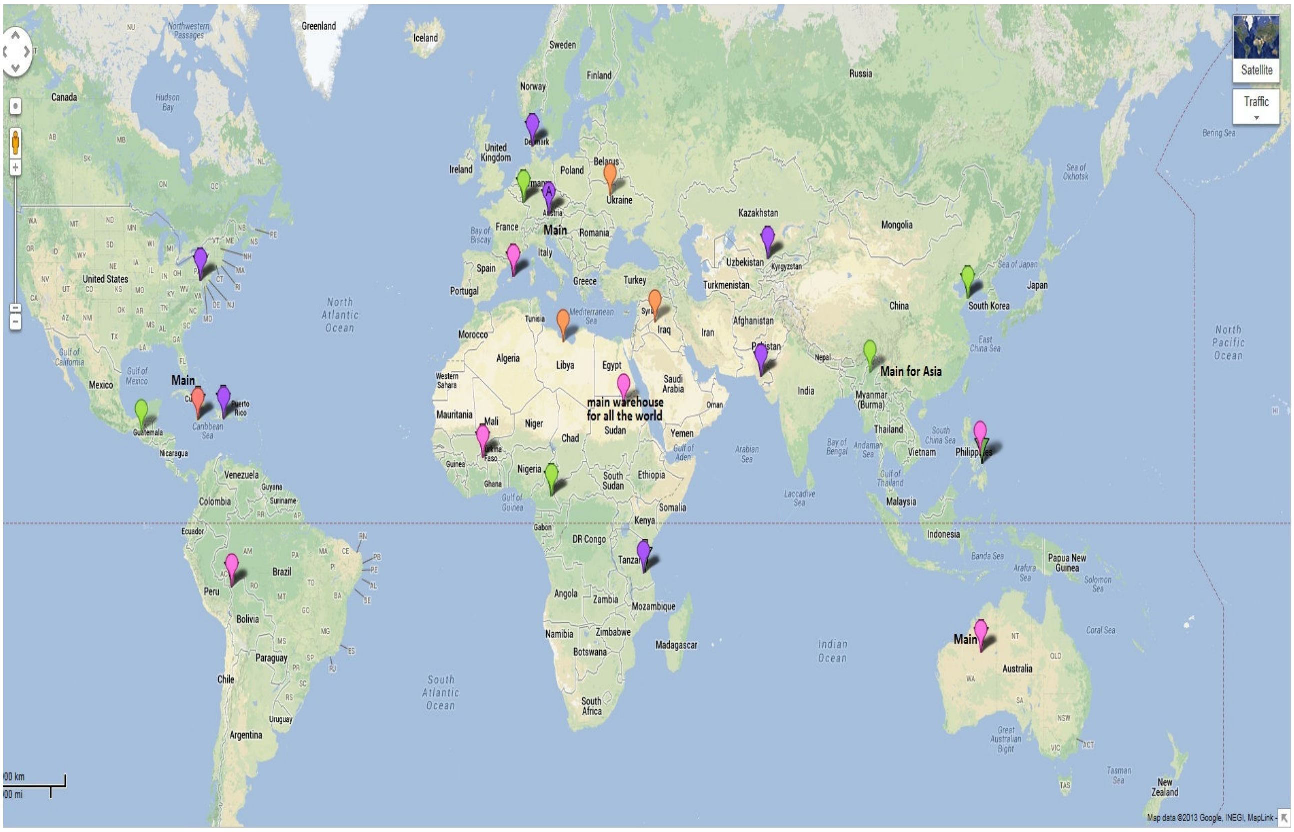

Fig. 1 All the warehouses in the world map

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