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Facility location optimization model for emergency humanitarian logistics

Chawis Boonmee, Mikiharu Arimura*, Takumi Asada

Division of Sustainable and Environmental Engineering, Muroran Institute of Technology, Muroran, Hokkaido, Japan

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ABSTRACT

Since the 1950s, the number of natural and man-made disasters has increased exponentially and the facility location problem has become the preferred approach for dealing with emergency humanitarian logistical problems. To deal with this challenge, an exact algorithm and a heuristic algorithm have been combined as the main approach to solving this problem. Owing to the importance that an exact algorithm holds with regard to enhancing emergency humanitarian logistical facility location problems, this paper aims to conduct a survey on the facility location problems that are related to emergency humanitarian logistics based on both data modeling types and problem types and to examine the pre- and post-disaster situations with respect to facility location, such as the location of distribution centers, warehouses, shelters, debris removal sites and medical centers. The survey will examine the four main problems highlighted in the literature review: deterministic facility location problems, dynamic facility location problems, stochastic facility location problems, and robust facility location problems. For each problem, facility location type, data modeling type, disaster type, decisions, objectives, constraints, and solution methods will be evaluated and real-world applications and case studies will then be presented. Finally, research gaps will be identified and be addressed in further research studies to develop more effective disaster relief operations.

1. Introduction

Since the 1950s, both the number and magnitude of disasters have been continuously increasing, with the number of affected people having increased in proportion (about 235 million people per annum on average since the 1990s). In 2014, 324 natural disasters were recorded, with economic damages estimated to be US$ 99.2 billion [1]. According to the International Disaster Database, Asia and the Americas have been the continents most affected by disasters such as floods, earthquakes, storms, and landslides [2]. Disaster is any occurrence that causes damage, destruction, ecological disruption, loss of human life, human suffering, or the deterioration of health and health services on a scale sufficient to warrant an extraordinary response from outside the affected community or area [3]. Such situations may include natural disasters such as drought, earthquakes, floods or storms, and epidemics, or man-made disruptions such as nuclear or chemical explosions [4–6]. According to an increasing number of disasters, many academicians have paid a great deal of attention to “Disaster Management (DM)” for the purposes of helping at-risk persons to avoid or recover from the effects of a disaster [7]. DM activities are conducted across four consecutive stages: mitigation, preparation, response, and recovery. Coppola [8] defined mitigation as reducing the probability of disaster occurrence and decreasing the degree of the hazard; furthermore, he defined preparation as planning activities to be conducted following disaster occurrence that increase chances of survival and minimize financial and other losses. Response was defined as reducing the impact of disasters during their aftermath to prevent additional suffering, financial loss, or other losses. Finally, recovery was defined as restoring the affected area back to a normal situation after the disaster. Disaster situations can be divided into two stages: a pre-disaster or proactive (mitigation and preparation) stage and a post-disaster or reactive (response and recovery) stage. Humanitarian logistics is one of the operations that are involved in following the three stages of the DM activities: preparation, response, and recovery. Humanitarian logistics (HL) is the process of evacuating people from disaster stricken areas to safe places and planning, implementing and controlling the efficient, cost effective flow and storage of goods and materials, while collecting information from the point of origin to the point of consumption for the purposes of relieving the suffering of vulnerable people [9,10].

Because of the increasing severity of recent disasters, research has paid more attention to DM in dealing with humanitarian logistics, with optimization, decision making, and simulation being proposed as the main approaches. Disaster research has tended to employ modeling and optimization to solve emergency humanitarian logistics problems. Labib and Read [11] proposed a hybrid model for learning from

* Corresponding author.
E-mail address: arimura@mmm.muroran-it.ac.jp (M. Arimura).

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failures that examined the multifaceted nature of disaster research and the hybrid modeling approaches within this domain and tested a reliability framework and multiple-criteria decision analysis techniques on the 2005 Hurricane Katrina disaster. Verma and Gaukler [12] proposed a deterministic and stochastic model for the pre-positioning of disaster response facilities at safe locations and demonstrated its usefulness with a case study on a Californian earthquake. Scott [13], Kongsomsaksakul et al. [14], Mete and Zabinsky [15], Salman and Yücel [16], Bayram et al. [17], Marcelin et al. [18] and Jabbarzadeh et al. [19] also studied emergency humanitarian logistics' facility location problems.

Recent research has also included surveys on effective DM. Altay and Green [20] reviewed the disaster operation management (DOM) by which this article has employed to focus on the life-cycle phase. Galindo and Batt [21] then extended the article of Altay and Green [20] with new advancements and presented an original evaluation based on the most common assumptions in OR/MS research in DOM. Caunhye et al. [22] reviewed an optimization model for emergency logistics that was classified into three main categories: (1) facility location, (2) relief distribution and casualty transportation and (3) other operations. Each piece of published literature has been analyzed and structured based on relevant goals, constraints, data modeling types, and decisions. Safeer et al. [23] surveyed the modeling parameters for the objective functions and constraints associated with humanitarian logistics distribution that were classified into two groups: casualty transportation and evacuation and relief distribution. Özdamar and Ertem [2] presented a survey that focused on the response and recovery planning phases of the disaster life-cycle. This article examined the vehicle/network representation structures and their functionally. The review structure is based on objectives, constraints, structures of available mathematical models and solution methods. Furthermore, information systems in humanitarian logistics have also been presented. Anaya-Arenas et al. [24] proposed a systematic review of contributions related to the relief distribution networks in response to disasters by categorizing them according to location and network design, transportation, location and transportation, and other important topics. Zheng et al. [25] studied research advances in evolutionary algorithms for disaster relief operations. The research study was classified into five categories (General transportation planning problems, Facility location problems, Routing problems, Roadway repair problems, and Integrated problems) and represents a summary of related papers on evolutionary algorithms for solving specific problems. Habib et al. [9] reviewed the mathematical model in humanitarian logistics by covering all the phases of a disaster, and provided a summary of modeling techniques and solution methodologies.

Facility location models involving the location and selection of distribution centers, warehouses, shelters, medical centers, and other locations are an important approach in DM. Facility location modeling is an approach of strategic planning design for pre- and post-disaster operations and is important for effective and efficient DM planning. In recent research, as has been noted above, emergency humanitarian logistics optimization models have been emphasized as an important element of disaster facility location problems. To overcome these challenges, two approaches can be used to solve this problem; (1) a heuristic algorithm and (2) an exact algorithm. Normally, the emergency humanitarian logistics' facility location problems are NP-hard and most research studies have usually addressed this by using a heuristic algorithm because it requires less time to employ and can solve complicated problems, but the results of this approach are of poor quality when compared with the exact algorithm. Although the first approach can overcome the second approach, the second approach is necessary because it can be used to check the heuristic algorithm, and, moreover, in some real cases, an exact algorithm can also be used to solve the problem. Hence, the use of an exact algorithm is important and unavoidable.

Following on from the previous research studies, a lack of any literature review that has been based on data modeling types and problem types as a basic element of the exact algorithm employed to enhance or develop the emergency humanitarian logistics' facility location problems has been observed. Therefore, we aim to propose a survey of research work on the emergency humanitarian logistical facility location optimization model based on data modeling types and problem types. This will be done not only to conduct this research study, but also to simultaneously present the basic mathematical models associated with this discipline to other individuals to whom they may be of interest. Moreover, each piece of published literature has been analyzed and structured based on the relevant objectives, conditions, disaster types, facility location types, data modeling types, applications, solution methods, categories, and case studies. Finally, any research gaps and future research possibilities will then be identified.

The remainder of this paper is organized as follows: Section 2 presents the scope of the literature review. In Section 3, facility location models are classified into four categories: deterministic, stochastic, dynamic, and robust. Section 4 presents an application and case study. In Section 5 future research that illuminates the research gaps is presented along with a framework analysis. Finally, a conclusion is given in Section 6.

2. Scope of literature review

In this paper, emergency humanitarian logistics' facility location optimization models are examined. To develop the literature database, emergency humanitarian logistics' facility location optimization models were searched for in journals, books, and conference proceedings and then classified according to the facility location problem and optimization method categories: deterministic, stochastic, dynamic, and robust. Finally, applications and case studies were reviewed. As the objective of this paper focuses on the exact algorithm or mathematical modeling techniques in emergency humanitarian logistics' facility location optimization problems, only those papers are included which proposed any type of exact algorithm of mathematical technique. Journal search engines such as the transport research board publication database, the IEEE database standard, Science direct, and the Springer journal database were interrogated using "disaster," "facility location," "humanitarian logistics," "optimization model," and "emergency" as the key search strings. Further, the references in each paper, including books and conference proceedings, were scrutinized to reveal any additional relevant papers. Most articles identified in the literature search came from a range of journals: Social-Economic Planning Science, European Journal of Operations Research, Computers & Industrial Engineering, Applied Soft Computing, Expert Systems with Applications, Transportation Research Part B and Part E, Computer & Operation Research, Int. J. Production Economics, Journal of Cleaner Production, the Journal of Risk Research, International Journal of Disaster Risk Reduction and the Journal of the Eastern Asia Society for Transportation Studies.

3. Literature breakdown and analysis

From a general viewpoint, Arabani and Farahani [26] found that facility location problems could be defined across the two elements of space and time, in which space was "a planning area where facilities are located," and time was "the time the location is identified" (developing a new facility or revising an existing facility). Essentially, however, space and time should be analyzed concurrently. Emergency humanitarian logistics' facility location problems included the identification of locations such as fire stations, emergency shelters, distribution centers, warehouses, debris removal sites and medical centers. Potential facilities were identified based on the geography of the respective areas and divided into two: continuing facility location problems (facilities