



Review

Network restoration and recovery in humanitarian operations: Framework, literature review, and research directions



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A B S T R A C T

In the aftermath of large-scale events requiring humanitarian action, critical infrastructure networks in the affected areas, such as electrical power, transportation, telecommunications, water supply, and waste water networks, may be disrupted by the devastating impact of the event. In the short and long term following the event, activities to return these networks to the pre-disaster working state include debris clearance and disposal, infrastructure repair, network reconstruction, road repair and rehabilitation, and snow removal. The costly and complicated nature of these activities has led to an increased level of interest regarding this field in the OR/MS literature over the recent years. In this study, we present the results of a comprehensive overview of the literature on network restoration and recovery in humanitarian operations, and provide a framework to consider this body of literature. We classify the studies in terms of the problems addressed, main decisions, objectives, models, and solution methods for these problems. Based on ongoing work, we also underline potential directions for future research by pointing to the gaps between the needs in the field and the existing body of literature.

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1. Introduction

Infrastructure networks play an important role in providing a lifeline for everyday activities of communities. Among these, road networks help businesses establish connectivity among various levels of the supply chains of their products and services, as

well as facilitating the mobility of people and accessibility to critical facilities and resources in times of need. Similarly, power and telecommunication systems are crucial in supplying the energy and establishing connectivity among various entities of the community, whereas maintenance and cleanliness of water supply networks are important so as to maintain the health and well-being of the people using them.

In cases of events requiring humanitarian action, such as natural and human-inflicted disasters (e.g., earthquakes, hurricanes,

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floods, terrorist attacks) or long-term humanitarian issues (e.g., armed conflicts), restoration and recovery of infrastructure networks become increasingly important due to mainly two reasons. In the short term, these networks provide the baseline for performing response activities such as evacuation, search-and-rescue, relief distribution, and establishing communication among the various stakeholders responding to the event. Hence, within the first few days or weeks following the event, the main goal is to bring these networks to at least minimal working conditions so that response activities can be performed. In the long term, the restoration and repair of infrastructure networks is an important factor in stabilizing the community and restoring at least some level of normalcy after the event. Consequently, timely recovery of these networks is of concern.

The recent trends in the occurrences of catastrophic events show that while the number of recorded events has increased (mainly due to better information systems, growth in global population and population density, and human-inflicted causes such as global warming), the number of casualties from such events is on the decline. For the period 1965–2015, the average annual number of deaths from disasters is around 100,000, whereas when the interval between 2000 and 2015 is considered, the death toll decreases to around 41,000 per year. On the other hand, an opposite effect is observed on the economic impacts of disasters; the estimated economic damages for these two periods are US\$11 billion and US\$30 billion per year, respectively [1]. The main reasons for the latter trend lie not only in the increase in population density and economic activity, but also in the increased investments in infrastructure networks, which generally incur substantial amounts of damage in cases of large-scale events.

Damages to infrastructure networks in the aftermath of large-scale catastrophic events can be in many different forms, including collapse of road networks and bridges, generation of debris, failure of power and telecommunication systems, damages on critical facilities, and build up of large amounts of snow. In any of these cases, the restoration and recovery activities are generally costly and complicated, and may significantly hamper the necessary response operations. For instance, Hurricane Katrina (2005) generated more than 100 million cubic yards of debris, the cleanup of which accounted for an estimated 27% of all disaster-related costs [2]. Similarly, Hurricane Sandy (2012) caused significant damage on the infrastructure systems, resulting in an estimated cost of US\$33 billion for repair and cleanup in the aftermath [3]. Following the Haiti earthquake (2010), despite the abundance of relief supplies, the damage in the road infrastructure resulted in transportation of these to people in need to be impossible [4]. The response activities to Typhoon Haiyan (2013) in the Philippines were severely exacerbated by the damage and debris on the road network; it took about six hours to make the 22 km journey from the airport to Tacloban City center, which resulted in the loss of vital time for search-and-rescue activities [5]. Altogether, the experience from these events underlines the significance of the need for timely, efficient, and effective network restoration and recovery activities in the aftermath of large-scale events, so that both short-term and long-term needs for the infrastructure networks can be satisfied.

The increase in the number of and awareness for events requiring humanitarian action, as well as the importance of the effectiveness and efficiency of logistics (to which more than 80% of all disaster relief efforts can be attributed [6]) in determining the performance of humanitarian relief operations have led to substantial amount of research addressing humanitarian logistics in the last decade. Consequently, a number of survey papers have been published, which either present an overall view of the studies in this field or focus on a specific set of decisions. Among these, Altay and Green [7] present an extensive review on research in the OR/MS field regarding disasters until 2006. Apte [8] focuses on

logistics decisions and discusses the unique characteristics and challenges of humanitarian supply chains. In Caunhye et al. [9], the emphasis is on the optimization models for emergency logistics, whereas de la Torre et al. [10] provide a review on disaster relief routing. Çelik et al. [11] take a broader perspective on humanitarian logistics in general, and classify the problems in this field based on the disaster life cycle addressed or the specific long-term humanitarian issue considered. Galindo and Batta [12] build upon Altay and Green [7] and update the findings in the latter study by reviewing the OR/MS papers regarding disaster management in the last decade. Anaya-Arenas et al. [13] provide a framework and a literature review on problems in relief distribution networks, whereas Faturechi and Miller-Hooks [14] discuss the performance assessment of transportation infrastructures in disasters, while providing an extensive literature review. Özdamar and Ertem [15] consider the models developed for the post-disaster stage and put additional emphasis on the information systems needs and applications in humanitarian logistics.

As also observed by Faturechi and Miller-Hooks [14], while there exists a vast body of literature in the performance assessment of infrastructure networks to cope with large-scale catastrophic events, the literature on the management strategies for these systems is more limited, but growing. In this paper, we aim to provide an extensive review on this growing field of literature, focusing on the restoration and recovery activities in the aftermath of large-scale catastrophic events.

The main contributions of this paper are three-fold. (1) To the best of our knowledge, this is the first paper that extensively reviews the recent literature on infrastructure network restoration and recovery in humanitarian operations. Thus, it also serves as a catalogue of research areas for those not familiar with this area of research. (2) It provides a framework for classifying the body of literature in this field by analyzing the problem types, main decisions, objectives, modeling techniques and solution methods. (3) It underlines the potential gaps between theory and practice, and proposes further research directions based on ongoing work.

The remainder of this paper is organized as follows: Section 2 describes the scope of this paper, the search method, and the main findings of the literature search in detail. A classification of problem types, along with decisions, objectives, models, and solution methods is presented in Section 3. Section 4 describes a number of potential further research directions and concludes the paper.

2. Scope of the study, search method, and main findings

As evidenced by the number of review papers that were described in Section 1, a vast amount of studies have been carried out on decision making in humanitarian operations. Thus, we begin this section by defining the scope of our study in order to specify the criteria for papers in this area to be included. This is followed by the systematic search procedure applied to determine the list of papers to review. We also discuss the main findings of our review, such as the number of studies over 5-year intervals, number of publications by journal, and the number of common papers with the aforementioned reviews in Section 1.

2.1. Scope of the study

The main emphasis of our work is on network restoration and recovery, for which the practical applications lie in the field of humanitarian logistics. Borrowing from Çelik et al. [11], we define humanitarian logistics as the set of “logistics activities related to preventing, reducing, preparing for, responding to, or recovering from human suffering and environmental and financial effects due to a disaster or a long-term humanitarian issue”. Key to this

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