How to increase emergency responsiveness of a disrupted healthcare network in a large-scale disaster by locating Mobile Care Centers?

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This study focuses on strategically pre-positioning mobile care centers, determining their optimal capacity and locations, to reinforce the existing healthcare network and facilitate an efficient and reliable emergency response. The objective is to minimize congestion and maintain control over waiting times within the care network. This includes considering various uncertainties and probabilistic disruptions in infrastructure that may occur during a disaster. As a case study, we center our attention on Istanbul, Turkey, a city bracing for a potentially destructive earthquake in the foreseeable future.

Key words: Mobile Care Centers; Healthcare Network; Emergency; Large-scale disaster; Location Allocation; Stochastic Programming; Data

1. Introduction

This paper concerns the study of a natural disaster (specifically an earthquake) and seeks to devise a methodology for the selection and placement of temporary care centers, such as mobile units or tents, in response to such crises. Large-scale disasters can profoundly affect societal well-being and disrupt humanitarian relief networks. In the aftermath of such disasters, there is a surge in demand for healthcare services, resulting in overloaded hospitals. Moreover, the disaster may damage critical infrastructure, rendering hospitals, roads, bridges, and airports partially or completely nonfunctional. The confluence of increased demand and disrupted healthcare networks inevitably leads to significant congestion and prolonged waiting times in operational and accessible hospitals, substantially diminishing service quality at a time when urgent care is crucial (Pouraliakbari-Mamaghani et al. (2023)).

Our work aims to strategically pre-positioning mobile care centers, determining their optimal capacity and locations, to reinforce the existing healthcare network and facilitate an efficient and reliable emergency response. The objective is to minimize congestion and maintain control over waiting times within the care network by strategically locating temporary care centers in the disaster zone. This necessiates considering various uncertainties and probabilistic disruptions in infrastructure that may occur during a disaster.

2. The Scientific Challenges and Proposed Methodology

2.1. The Study Case and Data Analysis

This project centers its attention on Istanbul, Turkey, a city bracing for a potentially destructive earthquake in the foreseeable future. Istanbul's dense population of 16 million residents raises significant concerns about its readiness for such seismic events. Acknowledging this vulnerability, a comprehensive disaster prevention and mitigation plan was collaboratively devised in 2002 by the Istanbul Metropolitan Municipality (IMM) and the Japan International Cooperation Agency JICA (2002). A subsequent study (IMM and DEZIM (2019)) delves into an extensive analysis of earthquake damage and loss estimates for urban superstructures and infrastructure across Istanbul.

Current projections from the IMM suggest that a seismic event with a magnitude of 7.5 could potentially result in the destruction of approximately 90,000 buildings in the city, with an additional 260,000 buildings facing significant damage. Various studies in the literature, including those Parsons et al. (2000), Acar and Kaya (2019), further contribute to discussions on the likelihood and effects of a potential earthquake in Istanbul.

The initial phase of this project involves conducting a comprehensive analysis of existing data, sourced from the aforementioned references, to formulate input scenarios encompassing healthcare demand and structural damage. Istanbul comprises districts with varying degrees of vulnerability. We possess data outlining the quantity, type, and age of buildings, population statistics, and risk of damage for each district. Additionally, we have extensive data and analyses on potential earthquake scenarios and their impact on the city. The challenge lies in effectively harnessing all this information to model healthcare demand. Hence, the primary objective of the data analysis phase is to predict the behavior of the demandx for diverse healthcare services across different districts of Istanbul following a seismic event. This will depend on several variables, including earthquake specifics, district vulnerability, and structural integrity. Given the inherent uncertainties associated with earthquakes, including magnitude, epicenter, time, and their impact on vulnerable areas and city infrastructure, careful data analysis becomes imperative.

2.2. Positioning mobile care centers

The idea of locating mobile hospitals was first suggested by Blackwell and Bosse (2007). Recently, Acar and Kaya (2019) considered the location and re-location decisions of emergency medical centers (EMC) with various earthquake scenarios. Their model is a combination of pre-disaster and post-disaster location models. They introduced a network design problem to determine the number and capacities of EMCs that need to be acquired before the disaster, the re-location, and allocation decisions in post-disaster situations considering the travel times, expected waiting times, and possible facility damages in the post-disaster environment. The authors proposed a two-stage stochastic programming model for this purpose. Several scientific challenges motivate us to further address a similar problem of locating mobile hospitals in a large-scale disaster.

1. Timely response is crucial in saving lives and impacts the survival rates in a disaster situation. In conventional disaster logistics literature, emphasis is typically placed on travel times between demand sites and selected facility locations, with waiting times often overlooked. This oversight stems from the fact that disaster logistics literature traditionally prioritizes the location of the relief distribution centers, where waiting at the facility is not a primary concern compared to travel times. However, Acar and Kaya (2019) innovatively incorporated waiting times into their model by integrating each Emergency Medical Center as an M/M/1 queuing model, effectively addressing the waiting time factor within their mathematical framework to achieve targeted expected waiting times.

We believe that in such strategic level decisions, it is important to ensure that each emergency facility has enough capacity to accommodate its demand. Thus, it is reasonable to adopt a loss system approach when determining the location and capacity of these emergency facilities, as commonly assumed in the literature when dealing with urgent patients requiring immediate medical attention (Pehlivan et al. (2014)). To address this, we propose to model each mobile care center as a loss queuing system M/G/c/c from which the analytical relationship between service capacity and patient acceptance rate can be obtained by Erlang Loss formula. By working with rejection probabilities (Erlang loss probability), we aim to strategically locate and plan the capacity of emergency medical facilities to ensure a specified maximum rejection probability across the network, thereby optimizing disaster response efforts.

2. Disrupted network: We consider probabilistic damages to the critical urban structures (including the existing hospital network, the roads, bridges, etc.) by assigning a survival probability according to the risk level of the district under an expected disaster scenario. Our goal is to develop a methodology to assess the vulnerability of the existing network and design a robust and resilient network by strategically locating mobile care centers effectively.

3. Robustness: In addressing the challenge of uncertainty, two-stage stochastic programming is a widely adopted approach in humanitarian relief logistics literature. However, two-stage stochastic optimization primarily focuses on expectations of uncertainties, often overlooking variabilities. To address this limitation, we intend to test the robustness of our results using a digital twin model. This will allow us to assess the resilience and reliability of our strategies under various scenarios, providing valuable insights into the effectiveness of our disaster planning.

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