Operations Research for Health Care 4 (2015) 36–43

Contents lists available at ScienceDirect

Operations Research for Health Care

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

Modeling and simulation of a hospital evacuation before a forecasted flood

Wanying Chen [a], Alain Guinet [a], Angel Ruiz [b,*]

[a] INSA de Lyon, DISP (laboratoire de Décision et d'Information des Systèmes de Production), Bât. Jules Verne, 19 av. Jean Capelle, 69621 Villeurbanne, France
[b] Faculté des sciences de l'administration and CIRRELT, Université LAVAL, 2325 rue de la Terrasse, Québec (Québec), G1V 0A6, Canada

ARTICLE INFO

Article history:
Received 2 June 2014
Accepted 10 February 2015
Available online 25 February 2015

Keywords:
Emergency management plan
Modeling
Dimensioning
Linear programming
Simulation

ABSTRACT

As high level emergencies can have serious consequences on hospital activities, an emergency management plan to face a crisis situation must be specified and assessed. Even though more and more research is devoted to this area, most studies are based on academic assumptions and the proposed improvement methods are difficult to apply in the real world. This paper deals with a hospital evacuation plan facing a flood based on a real life scenario. We modeled the evacuation process and identified its different activities. We then used SIMIO – a commercial simulation software – to translate our conceptual model into a dynamic model. Numerical experiments were conducted to determine the best way to assign the resources. We also propose two organizational improvements to the current, as-is, evacuation process. By simulating these changes, we were able to show that, if implemented together, they should be able to reduce the evacuation time by 1 h and 18 min, an improvement of 23.8% with respect to the current average evacuation time.

1. Introduction

Hydrological disasters, triggered by flood or wet mass movement (mudslides), bring about heavy loss of life and property damage. For instance, in March 2011, Japan's tsunami and earthquake, accounted for the biggest amount of money distributed for disasters in Japan ($210 billion), as well as the most casualties (15,500 deaths with 7300 still counted as missing). After Japan, the costliest disaster was the flood from December 2010 to January 2011, in Australia, which caused a $7.3 billion loss. In the Asian continent in 2010, hydrological disasters were responsible for 92.9% of disaster victims, the highest number since the 1980s. Extensive floods and landslides, following heavy monsoonal rains in Southern China affected 134 million people. Floods and flash floods in Pakistan brought about another 20.4 million victims. Hydrological disasters are among the most serious disasters worldwide. Moreover, the impact of those catastrophic floods in Pakistan in July 2010 showed how disaster-risk and poverty are closely interlinked (Guha-Sapir et al. [7]). An effective way to tackle the serious hydrological disaster consequences is to establish a prudent and comprehensive emergency management plan.

A hospital evacuation occurs when the patients in one hospital must be transported to other safe places in emergency situations. In France, the Extended White Plan (Ministère de la Santé et des Solidarités [13]) provides a legal framework to hospital evacuation, including a set of directives concerning both affected hospitals as well as the ones that will receive the evacuees. Given that most of the patients require acute and continuous cares, and since hospital evacuation concerns both patients and personals, evacuation of a hospital present challenges different from the ones in traditional emergency evacuation and therefore should be studied separately. However, the research in this field is really limited.

This work studies the evacuation of a medium-sized hospital before a forecasted flood with the aim of modeling, formalizing and improving the evacuation process. Therefore, this work is a part of the French Extended White Plan (FEWP) and, in several aspects, extends it by addressing operational issues far beyond its present scope. In particular, our work seeks at optimize two main aspects: the resource dimensioning and the evacuation time. To this end, we elaborated an accurate simulation model representing the most important activities within the evacuation process. We elected and executed a factorial experiment design in order to

* Corresponding author.
E-mail addresses: wanying.chen@insa-lyon.fr (W. Chen), alain.guinet@insa-lyon.fr (A. Guinet), angel.ruiz@fsa.ulaval.ca (A. Ruiz).

http://dx.doi.org/10.1016/j.orhc.2015.02.001
2211-6923/

assess the sensibility of the evacuation time with respect to the amount of resources (number of ambulances, number of nurses, number of stretchers, number of coordinators) devoted to the evacuation activities. Finally, we propose organizational improvements to the current evacuation process.By simulating these changes, we were able to show that, if implemented together, they should be able to reduce the evacuation time by more than 1 h and a quarter, an improvement of more than 23% with respect to the current average evacuation time.

The remaining part of this paper is organized as follows. Section 2 reviews briefly the related literature. Section 3 describes the evacuation problem, including the context and the vested interest actors. Section 4 describes the activities in the evacuation process and sketches the proposed simulation model. Section 5 is devoted to numerical experiments and results analysis. It also proposes and evaluates two organizational changes leading to important improvements on the total evacuation time. Conclusion and some limitations to this research complete the paper.

2. Literature review

This part is a brief review of the related papers in terms of the research content and the approach. Optimization models and computer simulation seem to be the two most popular research approaches to study evacuation problems. Sheffi et al. [17] used computer simulation for simulating the traffic situation during an emergency evacuation. This simulation could estimate the time used to clear the traffic surrounding nuclear power site. Filippoupolitis and Gelenbe [6] presented a distributed decision support system which consisted of a number of decision nodes modeling how to help evacuees to find the best available outlet in a disaster. A multi-agent simulation platform for building evacuation was developed to evaluate the proposed system in various emergency scenarios. Su et al. [22] built a discrete-event computer simulation model for assessing evacuation programs and provided a comprehensive idea of evacuation plans for hospital buildings in the event of a possible bomb threat. Wu et al. [23] proposed a dynamic discrete disaster decision simulation system, which combined the ARENA simulation model with a geographic information system and an SQL Server database to simulate generic evacuation process and resource deployment. Russo and Vitetta [15] implemented a formulation of the general evacuation problem in the standard simulation context of a 'what if' approach with the consideration of the transportation system in nominal conditions.

The research studying the evacuation problem with optimization tools always combine the evacuation problem with the 'facility location problem' or 'relief distribution problem'. All location-evacuation models built for large-scale emergency situations seek to minimize total evacuation time. Kongsomsaksakul et al. [11] proposed a bi-level program based on the Stackelberg game to find the optimal shelter locations for flood evacuation planning. The upper level problem is a location model which solves the shelter location. The lower level problem is a combined distribution and assignment model that deals with the evacuee route choices. Sherali et al. [18] established a location-allocation model in the event of hurricanes. This model selects the candidate shelters among a given set of admissible alternatives and prescribes an evacuation plan which minimizes the total congestion-related evacuation time. As the evacuees can be regarded as a vehicle or a commodity, it is understandable that some researchers study the relief distribution and the evacuation together using the vehicle routing. This methodology simplifies the model and the solution, but it is not practical in the real world. Different evacuees have different situations and disruptions (transportation congestion) are likely to happen to patients during an evacuation trip. Adding a probability of disruption parameter may be a solution. Yi and Özdamar [24] proposed a mixed integer multi-commodity network flow model that co-ordinates logistics support and evacuation activities while maintaining equilibrium among service rates of medical facilities. Both wounded people and commodities are categorized into a priority hierarchy, where different types of vehicles are utilized to serve priority transportation needs. The model is based on a network flow formulation. Song et al. [20] formulated a location-routing model with uncertain demands. This model identifies the optimal serving areas and transit vehicle routings to move evacuees from the affected zone to safe destinations.

From 2012 to 2013, more and more researchers paid attention to this area. Kaisar et al. [10] evaluated different evacuation procedures for special needs populations from large urban areas using a linear optimization model. Special needs populations include, but are not limited to, people with physical disabilities, older adults, non-English-speaking populations, residents and employees without vehicles, and tourists. A linear optimization model was developed to find the optimum locations for evacuation bus stops for the case study area. Özdamar and Demir [14] described a hierarchical cluster and route procedure for coordinating vehicle routing in large-scale post-disaster distribution and evacuation activities. He used a multi-level clustering algorithm that groups demand nodes into smaller clusters, enabling the optimal solution of cluster routing problems. Desmet and Gelenbe [5] established a mathematical model based on the graph theory and the queuing theory to improve the planning of the emergency evacuation. The graph theory offers insight into the critical areas and the queuing theory is useful in estimating the evacuation times and points of congestions. Similar to [11,9] proposed a bi-level programming model to combine the shelter location problem and the evacuation trip distribution problem. The upper level solves the shelter location problem and the lower level aims to determine the trip distribution from the result of shelter location problem.

To sum up, from a view of the content, it can be found that the papers studying emergency evacuation are abundant, but the papers focusing on hospital evacuation are few. From a methodological point of view, optimization models and computer simulation are the more popular approaches in this field. However, most of the research on the evacuation was not based on real scenarios, which led to two drawbacks: the first is to fail to respect the hospital's rules and its best practices, and the second is to ignore the detail of the real case. Moreover, most of the models had not been checked and verified effectively. These problems make the existing plans and the improvement methods difficult to put into practice. These gaps have been our main drive: to study the Extended White Plan deployment by using a simulation approach on a real scenario.

3. Problem description

3.1. The context

The evacuation situation we intend to study is provoked by the natural or artificial damage to a dam, located in Commune Cernon (Jura, France), which, if damaged could trigger a disaster. The dam is about 103 m tall and 36 000 m long. Its water volume is about 600 million m^3. Following a dam breaking, the speed of the flood is estimated at 20 km/h and the height of the water wave is between 1 and 8 m. The Hospital Saint-Joseph/Saint-Luc is located in the passage of the potential flood, which would arrive in Lyon in 5 or 6 h and at the Hospital Saint-Joseph/Saint-Luc in 8 or 9 h. Water in the hospital would rise between 6 and 9 m. The whole situation would last approximately for 24 h and its overall impact is difficult to estimate. The flood would affect telecommunication networks, transportation networks and so on. Therefore, the evacuation of all the patients in the Hospital Saint-Joseph/Saint-Luc to other unaffected