ARTICLE IN PRESS

Surveys in Operations Research and Management Science ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Surveys in Operations Research and Management Science

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

Review

Optimization models for large scale network evacuation planning and management: A literature review

Vedat Bayram

Department of Management Sciences, Faculty of Engineering, University of Waterloo, 200 University Ave. West, Waterloo, Ontario, N2L 3G1, Canada

HIGHLIGHTS

- We review network-based large scale emergency evacuation planning/management studies.
- Relevant literature in urban transportation and human behavior science is covered.
- Static/dynamic, and deterministic/stochastic/robust modeling approaches are covered.
- Effective supply and demand management strategies are specified.
- Optimization-based solution methodologies are reviewed, research gaps are identified.

ABSTRACT

This study presents a comprehensive review of network-based large scale emergency evacuation planning and management literature. Evacuation planning and management approaches are mostly based on traffic assignment approaches. For that reason, for a complete grasp of the ideas in evacuation planning and management, the relevant literature in urban transportation is covered including traffic assignment approaches, travel time modeling to represent congestion and traffic flow propagation approaches. Correct estimation of evacuation response rates and demand distributions by human behavior studies covered in this review contribute to an efficient evacuation planning and management at a large extent. Since it is not cost effective to design the evacuation network from scratch for rare disasters, the existing road network must be efficiently used for avoiding congestion to enable the evacuation of the disaster area in a timely manner. We present studies that propose effective supply and demand management strategies that aim to achieve this. We focus on macroscopic approaches in static/dynamic, deterministic/stochastic/robust evacuation modeling that consider different evacuee behavior assumptions, traffic assignment methodologies and supply and demand management strategies. We review the optimization-based solution methodologies so as to identify research gaps and limitations and suggest future research directions.

Contents

E-mail address: vbayram@uwaterloo.ca.

http://dx.doi.org/10.1016/j.sorms.2016.11.001
1876-7354/

Please cite this article in press as: V. Bayram, Optimization models for large scale network evacuation planning and management: A literature review, Surveys in Operations Research and Management Science (2016), http://dx.doi.org/10.1016/j.sorms.2016.11.001

1. Introduction

The 2004 Indian Ocean tsunami, the 2010 Haiti earthquake, and the triple disaster that hit the Tohoku region of Japan in 2011 [1] imposed tremendous operational challenges on the humanitarian agencies and governments, killing thousands of people, dislocating millions of them and causing a massive level of destruction. Disasters have never ceased to be a threat to humanity and a great concern to humanitarian agencies. On the contrary, the increasing number of disasters and the catastrophic damages they continue to cause [2] illustrate the importance of an effective disaster management program.

International Federation of Red Cross and Red Crescent Societies (IFRC) [3] defines a disaster as a natural or man-made phenomenon such as a hurricane, earthquake, flood, nuclear accident and terrorist attack which disrupts the functioning of a community in such a way that the widespread losses incurred exceed the community's capacity to cope with it. IFRC [3] defines disaster management as the organization and management of resources and responsibilities for dealing with all humanitarian aspects of emergencies, in particular preparedness, response and recovery in order to lessen the impact of disasters. There are four phases of an adequate disaster management program: mitigation, preparedness, response and recovery [4–7]. FEMA [5], Bullock and Haddow [6], Altay and Green [8] and Bumgarner [7] list the typical activities involved in these phases and Caunhye et al. [9] summarize the framework for the emergency logistics activities.

To protect people from the possible impact of a disaster, the foremost used strategy is the evacuation of the disaster region [10]. Evacuation planning and management are included in the preparedness and response phases of disaster management activities respectively. In accordance with the US Federal Emergency Management Agency (FEMA) reports, the number of disasters that require an evacuation annually is about 45–75 [11]. An effective traffic management is listed among the core capabilities that must be achieved for the mass evacuation of people in the National Response Framework [12]. Evacuation traffic management is critical [13] as people's lives are at risk and if it is not planned and conducted effectively, the surge in traffic demand which is far beyond the capacity of the transportation network [14], can cause congestion and may leave the evacuees in harm's way possibly resulting in further losses. In 1999 hurricane Floyd [15], and in 2005 hurricanes Katrina and Rita [11] required millions of people to evacuate creating largest traffic jams in the US history. Successful evacuation management not only saves lives but also contributes to the community's regaining functionality in a fast and smooth way [16].

In the first part of a two-part study, Wolshon et al. [17] review policies and practices for evacuation planning, preparedness, and response focusing on command and control strategies, and implementation and enforcement criteria. In the second part, Wolshon et al. [18] summarize evacuation management operations concentrating on contraflow operations and the use of intelligent transportation systems.

Evacuation models are categorized mainly into two groups: macroscopic models and microscopic ones. If an evacuation model represents traffic as flows, then it is a macro-level model. These models generally attempt to answer how long it takes to evacuate an area and they are generally used for large scale evacuations. Transportation engineering approaches on the other hand consider traffic at more detailed levels and focus on individual entities (vehicles). These kind of models are classified as microscopic models. Mesoscopic models have characteristics of both macroscopic and microscopic models [19] and are obtained by disaggregating segments of macroscopic models into smaller segments [20].

Southworth [21] and Tüydeş [22] outline components of a general evacuation study in a similar fashion. Hazard analysis focuses on the disaster type, where and when it might take place, and the damages it can cause based on the available forecasting methodologies. In vulnerability analysis, the population under risk and possible damage to infrastructure and transportation network is specified. Shelter analysis deals with determining the safe locations, where and how many shelters to open and with how much capacity. Behavior analysis investigates the response of the population to an evacuation order and determines the evacuation participation rates, mobilization times and destination choices of the evacuees. Traffic management during an evacuation is studied by means of a transportation analysis. This analysis includes the assignment of traffic demand specified by hazard, vulnerability and behavioral analysis into evacuation routes.

The evacuation planning and management approaches by Southworth [21] and Tüydeş [22] are divided into three steps: trip generation, trip distribution and trip assignment. Evacuation trip generation starts with the determination of the region from where evacuees at risk are to be evacuated in accordance with results of the hazard analysis. Wilmot and Meduri [23] propose a procedure to guide establishment of hurricane evacuation zones, which are defined as the areas in which inhabitants are at risk due to flooding or strong winds caused by a hurricane. Evacuation zones are not only used for estimation of the evacuation demand but also as a way to reduce traffic congestion by evacuating only those at risk. Combining the evacuation zones with the information derived from the vulnerability analysis, a population and vehicle use estimation for each zone is made. Once the number of evacuation trips for each zone is specified and grouped into destinations, the capacity of shelters are considered while assigning trips to these destinations. The destination assignment can also be included in the trip assignment process and solved for optimality. And finally evacuation trip assignment is the step that assigns evacuation trips to evacuation routes.

Since it is not cost effective to design the evacuation network from scratch for rare disasters, the existing road network must be efficiently used to avoid congestion and enable the evacuation of the disaster area in a timely manner. This can be achieved through effective supply and demand management strategies. Supply management strategies try to manage/modify the roadway infrastructure such as reverse capacity or contraflow corridors, modifying traffic flows at selected intersections, etc. to make it

Please cite this article in press as: V. Bayram, Optimization models for large scale network evacuation planning and management: A literature review, Surveys in Operations Research and Management Science (2016), http://dx.doi.org/10.1016/j.sorms.2016.11.001