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Reliability analysis for disaster waste management systems

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ABSTRACT

The management of disaster waste is one of the most critical tasks associated with recovery after a disaster. Having a general idea of the required capacity, cost and target clean-up time while considering the uncertainties involved in the system before the detailed plan of a disaster waste clean-up system is significant. Reliability analysis is a method to judge the performance of a system and deal with uncertainties in the system. Evaluating the reliability of the system, which can indicate the possibility to complete the clean-up within the target time and cost, and optimising the system to maximise the reliability to provide information to decision-makers regarding the capacity, cost and time required to finish the clean-up is the purpose of this paper. A mathematical model is developed applying the First Order Reliability Method (FORM) to address the problem. Additionally, a non-linear optimisation model is developed to improve the reliability of the disaster waste clean-up system with consideration of the total cost and clean-up time constraints, and solved using a Genetic Algorithm. The proposed models are implemented to solve a case study in Queensland, Australia. It is shown that the models have the capability of maximising the reliability and minimising the total clean-up costs by optimising the arrangement of vehicles during the clean-up process.

1. Introduction

A large quantity of waste is produced when a natural disaster occurs, regardless of whether it is a bush-fire, flood, or an earthquake (McCreanor, 1999). For example, after 2008 Wenchuan earthquake in China, the total amount of building waste generated in the disaster area was approximately 380 million tonnes (Xiao et al., 2012). During the Great East Japan Earthquake in 2011, there were about 28 million tonnes of disaster waste produced in the three severely affected prefectures (Tabata et al., 2016).

The management of waste generated from disasters is always a difficult, time-consuming, and expensive operation (Swan, 2000). A significant amount of waste generated after disasters leads to both environmental and operational risks. Rescue and emergency services routes can be impeded. Lifeline support may also be inhibited. Disaster waste can also pose public and environmental health hazards. The clean-up of disaster waste from road networks is the first step in both emergency response and disaster recovery (Özdamar et al., 2014). It is not possible to start full-scale reconstruction work until the waste has been removed (Lauritzen, 1998). Poor management of a clean-up effort can result in a slow and costly recovery which is potentially risky to the public and environmental health in both the short and long-term (Brown et al., 2011a). In the short-term, the clean-up of waste is required to facilitate the recovery of the affected region. In the long run, proper methods to finally dispose of the waste should be identified carefully to make sure that its management (e.g., landfill) would not cause a future threat to human health or the environment (Luther, 2006).

The modelling of disaster waste management can improve the system to a certain extent. Hu and Sheu (2013) regarded disaster waste clean-up as a reverse logistics system and formulated it as a multi-objective linear programming model, in which psychological cost and the aggregate reverse logistics costs were both considered. Also, Özdamar et al. (2014) implemented mathematical modelling to generate roadside waste clean-up plans for a limited quantity of equipment in road recovery planning problem. Moreover, Markov decision process model was applied in stochastic waste clean-up problem under limited information (Çelik et al., 2015). Besides, Lorca et al. (2015) proposed analytical models to assist disaster and waste management officials with decisions regarding the collection, transportation, reduction, recycling, and disposal of debris. The tool enables optimising and balancing of financial and environmental costs, duration of the collection and disposal operations, landfill usage, and the number of recycled materials. In Lorca et al. (2017), a case study was conducted to illustrate the applicability and effectiveness of the tool with a

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disaster scenario based on Hurricane Andrew. Furthermore, Çelik (2016) summarised the models related to disaster debris management. All the models mentioned above focused on the decision on operations of detailed waste clean-up. However, not one addresses the problem regarding how much capacity should be prepared and what the possibility of finishing the clean-up within a target time and cost before the detailed plan of the clean-up operations considering the uncertainty is involved in the system. Furthermore, there is no consideration of the vehicles involved in the system.

Uncertainties are inevitable in disaster waste clean-up. The type of disasters will affect both waste characteristics and quantity (Lauritzen, 1998). For example, bush-fires leave burnt personal property, burnt metals, charred wood, ash, asbestos, and other hazardous waste. Waste from an earthquake consists of damaged personal property, structural building materials, charred materials, concrete, and asphalt. Soil, gravel, rock, and some construction materials contribute most to the waste produced from floods (FEMA, 2007). Also, the availability of local resources to manage disaster waste, the preferred waste management strategy, the public information dissemination strategy, and funding issues can add further uncertainties to the system (Swan, 2000).

Vehicles are direct tools used to collect and transport debris after disasters. For example, 600 trucks were involved in the waste management after the 2009 Back Saturday Bushfires in Victoria, Australia (Brown et al., 2011b). Each type of vehicle has a different fuel consumption rate and, hence, a different transportation cost per distance travelled (Serper and Alumur, 2016; Yang et al., 2016). Therefore, the optimisation of vehicles allocation can improve the performance of a system. For example, (Serper and Alumur, 2016) considered determining the optimal number of different types of vehicles in the hub network design to achieve economies of scale and decrease unit transportation cost.

The reliability analysis is a method to consider uncertainties and risk involved in a system. In disaster waste management, reliability analysis can provide information regarding the possibility to finish the clean-up in a target clean-up time and capacity (Cheng et al., 2018). Besides, it can facilitate to estimate the total cost of the clean-up to maintain reliability to a certain level. Thus, the subject of this paper is to develop a methodology to evaluate the reliability of a disaster waste clean-up system and an optimisation model considering the allocation of different types of vehicles to improve the reliability of the system to help the decision-maker to understand the capacity and total time required to have a reliable system.

In the present research, the aim is to determine the capacity and total time required to build a reliable disaster waste management system instead of considering the detailed operation design for the system. Readers who are interested in the detailed operation design of the system are referred to Çelik (2016), Çelik et al. (2015), Lorca et al. (2015), Lorca et al. (2017), and Fetter and Rakes (2012). The first-order reliability method (FORM) is applied to evaluate the reliability of a waste clean-up system. To improve the reliability of the system, an optimisation model to identify the best allocation of vehicles is developed. The remainder of this paper is structured as follows. Section 2 summarises the impact factors of a disaster waste clean-up system. Section 3 presents a methodology for applying the FORM method and the optimisation model. Section 4 provides the pseudo-code of the two algorithms. The next section introduces a case study and an analysis of the results. The last section presents the conclusions.

2. Disaster waste clean-up impact factors

The two variables which have a major influence on the reliability of a waste clean-up system are the capacity of the system and the total amount of waste generated from the disaster. Fig. 1 provides a summary of the factors that have an impact on a disaster waste clean-up system.

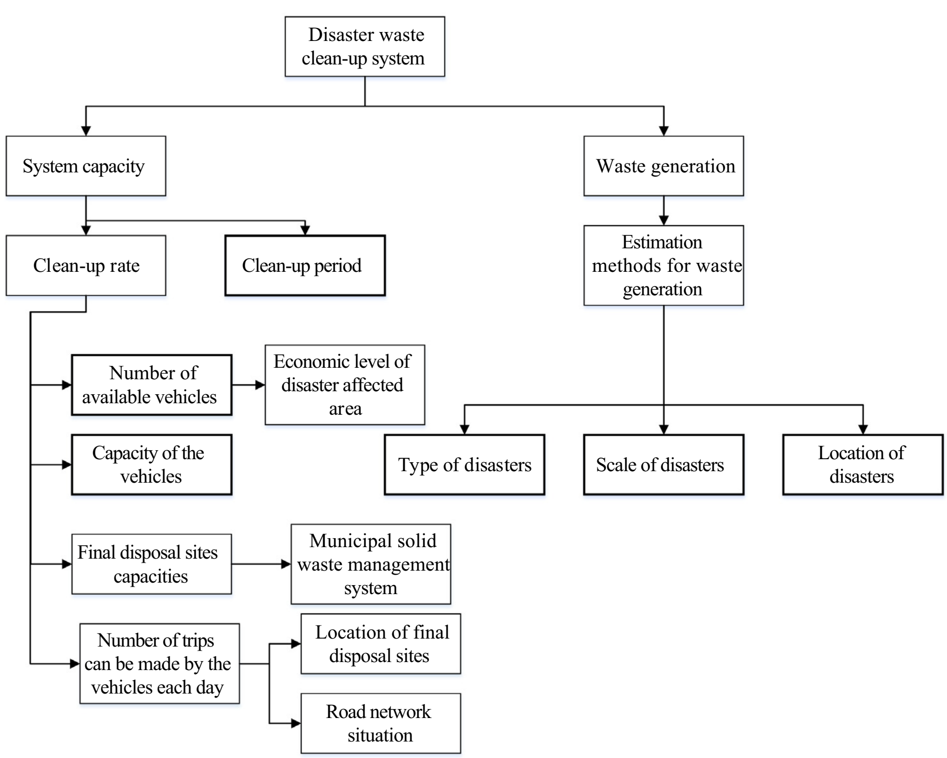

Fig. 1. Impact factors of a disaster waste clean-up system.