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A strategic planning model for the railway system accident rescue problem

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ABSTRACT

The present study examines the location of emergency rescue problems for urban ambulance and railway emergency systems. The proposed model considers probabilistic rescue demand, independent busy fractions of ambulances, and the corresponding risk levels in railway segments. We formulate the proposed model using fuzzy multi-objective programming and solve it using a generic algorithm and a non-dominated sorting genetic algorithm-II. Computation results are analyzed by applying the model to a real-world Taiwan railway system. Analytical results demonstrate that a proper adjustment of the rescue resource location improves rescue effectiveness for railway rescue and urban medical service demand.

1. Introduction

Rail transportation is increasingly becoming an important mode of transport, because of the advantages it offers, such as great reliability, high energy utilization efficiency, and unaffected by bad weather and heavy traffic conditions (Tuzkaya and Önüt, 2008). However, deaths or severe injuries may result from railway accidents (Hambeck and Pueschel, 1981; Smiley, 1990; Evans, 1994; Høj and Kroeger, 2002; Diamantidis et al., 2000).

Emergency medical service (EMS) provides immediate medical service when accidents occur, but EMS location decisions are not specifically designed for railway accident rescue. Under limited resources, a well-designed emergency depot location planning strategy is crucial for both urban medical service and railway emergency rescue when a railway line is being set down. Previous studies have revealed that efficient and instantaneous rescue activities indeed reduce accident fatality rates and economic losses (Brotcorne et al., 2003; Goldberg, 2004). Considering rescue response time characteristics, Wu and Wang (2011) demonstrated an injury survival rate of 10%, 40%, and 80% when first aid is given within 90, 60, and 30 min of a traffic accident, respectively. Several public objectives, such as fairness and efficiency issues, must be considered simultaneously to develop a comprehensive planning model for public resource locations (Araz et al., 2007; Iannoni and Morabito 2007; Tzeng et al., 2007; Yang et al., 2007; Zhou et al., 2010). Multi-objective optimization problems are very important research topics, because of the multi-objective nature of most real-world decisions made on accident rescue (Saadatseresht et al., 2009).

In an ambulance location problem, providing maximum coverage ensures efficiency, whereas considering the same response time of various areas ensures fairness. However, the nature of public resource allocation problems leads to conflicts between different objectives. Therefore, we address the railway rescue problem by using the fuzzy multi-objective program-

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ming (FMOP) approach. The utilization of a max–min operator for multi-objective linear programming simplifies the solution to difficult and complicated issues (Araz et al., 2007; Tzeng et al., 2007; Yang et al., 2007), but the disadvantage of the max–min operator is the reduction in solution efficiency (Li et al., 2006). Therefore, an appropriate approach for addressing the railway system accident rescue problem is urgently needed.

Most earlier models targeted the static and deterministic location problem and are used at the planning stage; such models also ignored stochastic considerations (Brotcorne et al., 2003; Hogan and ReVelle, 1986; Kolesar and Walker, 1974; Gendreaua et al., 2001). Ambulances may be unavailable throughout the day, and certain demand points may not be covered (Schmid and Donrner, 2010). The benefit of considering different rescue call demand patterns is having alternative ways to account for the shifting ambulance location scheduling (Rajagopalan et al., 2008). Therefore, EMS can avoid idle ambulances and achieve higher operational efficiency. The appropriate utilization of rescue resources with regard to various rescue demand fluctuations and the availability of ambulance service warrant further discussion.

Railway systems pass through both urban and rural areas, and accidents may occur in either area. Determining how to utilize resources efficiently and fairly so as to maximize the population coverage for urban ambulance systems and the risk coverage for railway emergency systems is a critical issue, because of medical resource constraints. The links of the network with a higher risk should be prioritized (Berman et al., 2007). The risk level can determine the relative significance of providing emergency response coverage to each road link, because of the different levels of transport risks for specific railway transport links (Erkut and Verter, 1998). Risk coverage implies that at least one ambulance should be located within a predetermined travel time to high-risk railway locations, allowing this ambulance to bring any victim to the closest medical center within a pre-specified time. Higher risk coverage implies that an ambulance can cover higher risks within a predetermined travel time (Erdemir et al., 2010).

At the planning stage, a railway system operation agency must consider beforehand how rescue problems for different railway accident types would be addressed. Previous studies have adopted the travel distance between a rescue service depot and a potential accident site as the risk classification index, but the severity of specific accident types is neglected in such an approach (Yang et al., 2007; Tzeng and Chen, 1999). Previous EMS planning studies considered the accident risk levels of various areas to be identical (Sorensen and Church, 2010; Iannoni et al., 2009; Pal and Bose, 2009), which is not a realistic assumption. The accident risk levels of various areas can be calculated by the accident occurrence probability multiplied by the accident's severity.

Risk assessment is considered an essential aspect of qualitative and quantitative analyses for assisting decision makers to understand the consequence of a potential accident that must be prevented before it occurs. Risk assessment also helps decision makers to identify suitable preventive measures (RSSB, 2009). The United Kingdom Railway Safety Standard Board (RSSB) provided a formula for estimating the risk assessment for hazardous events. Therefore, we introduce the risk assessment approach to reflect different risk levels on various railway segments in order to derive corresponding ambulance allocation improvement strategies. The risk assessment approach can be performed by evaluating the corresponding occurrence frequency and the expected number of injuries in a railway accident. Thus, we multiply the corresponding occurrence frequency with the expected number of injuries in a railway accident to derive the potential railway accident risk (Muttram, 2002).

A fundamental concern as to why accessibility is considered in a rescue scenario is for providing immediate medical service to a railway accident location. Donnges and Foley (2003) indicated that the accessibility problem is the degree of difficulty that people or communities have to access locations. A railway accident can be located in various sections of the railway line, such as viaducts, tunnels, and planes, causing diverse levels of rescue difficulties. A number of accidents that occur in rural areas with insufficient rescue resource coverage may cause severe rescue difficulty in terms of accident response arrival (Vuilleumier et al., 2002). Therefore, determining how to evaluate the effects in low accessibility areas with limited resources is an important issue.

This research develops a multi-objective strategic planning model to address the location of emergency rescue units for both urban ambulance and railway emergency systems. The proposed model aims to maximize the ambulance coverage in a population within a predetermined time threshold and for various railway segments so as to maximize the risk covered on the railway line. In addition, fairness issues are also examined. This model aims to improve current urban ambulance system resource optimization to provide additional assistance during railway medical emergencies. The proposed model incorporates the probabilistic demand nature along a period, the independent busy fractions of ambulances, the risk level in railway segments, and the different railway accident types. The model is solved by meta-heuristics, such as the FMOP/genetic algorithm (GA) approach and the non-dominated sorting genetic algorithm-II (NSGA-II). Computation results are analyzed by applying the model to a real-world railway system.

The following sections are organized to investigate railway system accident rescue planning issues. The first section describes the central problems and objective of the present study. Section 2 provides an overall review of previous emergency planning and operational models and also reviews relevant topics, such as the probabilistic model, risk assessment issue, and rescue logistics theme of transportation accidents. Section 3 formulates the mathematical model by means of the FMOP approach and introduces probabilistic medical demand characteristics along a period and busy fractions of ambulances into the proposed model. The present study applies a meta-heuristic algorithm to solve this NP-hard problem. Section 4 conducts an empirical study and compares the result of the proposed model with the real case. Finally, we present the conclusions and discuss the managerial implications in Section 5.