Transportation Research Part E 83 (2015) 170–188

Contents lists available at ScienceDirect

Transportation Research Part E

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

The optimization model for the location of maritime emergency supplies reserve bases and the configuration of salvage vessels

Yun-fei Ai *, Jing Lu, Li-li Zhang

School of Transportation Management, Dalian Maritime University, Dalian 116026, China

A R T I C L E I N F O

Article history:
Received 18 September 2014
Received in revised form 17 August 2015
Accepted 21 September 2015

Keywords:
Maritime emergency supplies
Location
Configuration
Hybrid heuristic algorithm
Genetic algorithm

A B S T R A C T

This paper studies the location–allocation–configuration problem of emergency resources in a maritime emergency system and it proposes a discrete nonlinear integer-programming model, which integrates the location, allocation and the configuration problem. The model is converted into a two-stage model keeping the calculation logic. It designs a hybrid heuristic algorithm and a genetic algorithm. The test results show that the hybrid heuristic algorithm is more efficient than the genetic algorithm, the sensitivity analysis studies the influence of some parameters to the final solution and the Uncertainty–Sensitivity justification tool is used to evaluate the assumptions.

1. Introduction

Maritime emergencies occur frequently, causing great damage to environment and society. Examples in recent years include the Conocophillips oil spilling in Bohai bay in 2011, Huang Dao petrochemical explosion in 2013, airplane lost event of Malaysia airlines in 2014. When a maritime emergency occurs, immediate response is important in minimizing the damage. There will always have to be a balance between the focus on preventative safety efforts and the extent of emergency preparedness provisions (Koldenhof and Van Der Tak, 2013). To ensure the efficient salvage, emergency resources should be configured during the prevention phase. As the resources are limited and the emergencies have great uncertainty, the reasonable allocation of maritime emergency resources is a significant problem which is important in ensuring the efficient salvage.

In this paper, we consider the problem in a maritime emergency system, which has not been considered in the literatures. In comparison with the traditional emergency system, maritime emergency system has big difference and is more complicated with the influence of maritime natural conditions. There are some papers concerning maritime search and rescue. Li (2006) studied the location model of rescue vessels on the sea based on the large number of data sets acquired from the Canadian Coast Guard Search and Rescue branch. Three coverage location models (maximal covering location problem, maximal expected covering location problem and maximal covering location problem with workload capacity) are applied. He also modified two published models (coverage model with backup service and coverage model with uncovered demand service) to consider response unit (i.e. rescue vessels) capabilities. Azofra et al. (2007) studied the placement of sea rescue resources and they formalized a general methodology based on gravitational models which allowed us to define individual and zonal distribution models. Goerlandt et al. (2012) described recent advances in modeling the sea rescue services using

* Corresponding author. Tel.: +86 18940930018.
E-mail address: fair126aiyf@126.com (Y.-f. Ai).

http://dx.doi.org/10.1016/j.tre.2015.09.006
1366-5545/

discrete-event simulation and the Monte Carlo technique. System performance indicators were identified and analyzed. The simulation logic was in essence a multi-server, multi-customer queuing system, though specific features of the sea rescue system needed to be addressed in this framework. Goerlandt et al. (2014a, 2014b) proposed an account of advances in the construction of a simulation model aimed at evaluating the response characteristics of the maritime voluntary sea rescue system. The simulation model was driven by a historical incident data, augmented with wave data and expert-elicited SRU characteristics. There are some papers concerning oil spilling and response. Montewka et al. (2011) presented a model to analyze the risk of two common marine accidents: collision and grounding. For the assessment of a grounding probability, a new approach was proposed, which utilizes a gravity-like model, where a ship and navigational obstructions are perceived as interacting objects and their repulsion is modeled by a formulation inspired by gravitational force. The considered situation in this case was the movement of oil tankers in the approach channel to an oil terminal at Skoldvik, near Helsinki. Lehikoinen et al. (2013) developed a Bayesian Network to examine the recovery efficiency and optimal disposition of the Finnish oil combating vessels in the Gulf of Finland, Eastern Baltic Sea. Four alternative home harbors, five accident points, and ten oil combating vessels were included in the model to find the optimal disposition policy that would maximize the recovery efficiency.

Based on above literatures, we study the pre-occurrence location–allocation–configuration problem of maritime emergency resources. The problem can be divided into three parts: the location of emergency supplies reserve bases, the allocation of the emergency supplies and the configuration of the salvage vessels (salvage vessel can transport the emergency supplies when emergency occurs).

When and where the emergencies will occur is unknown, so the covering models are widely used in the location problem of emergency facilities. They can consider the entire area or a predefined part to be served. The set covering model which can achieve complete coverage of the area with the minimal construction costs or the minimum number of facilities was first proposed by Toregas et al. (1971). Church and Revelle (1974) proposed the maximal coverage location problem (MCLP) which can achieve the maximum possible part of the demand area with the certain number of facilities. Schilling et al. (1979) extended the MCLP by developing the tandem equipment allocation model that allows for having two different types of service units in the system. Daskin and Stern (1981) modified the original MCLP to maximize the number of demand areas covered more than once which is the backup coverage problem. Gendreau et al. (1997) developed a double standard maximal coverage model that includes two time limits, one for covering the entire demand area and another for covering part of it. In recent years, these models have been extensively used to solve various regular emergency service location problems. Segall (2000) presented the background on the hospital facility location model as a prelude to describing some quantitative methods for determining the optimal capacity and location of emergency medical facilities. Araz et al. (2007) considered the location problem of emergency service vehicles. A multi-objective maximal covering location model was proposed and the model addressed the issue of determining the best base locations for a limited number of vehicles so that the service level objectives were optimized. Geroliminis et al. (2009) developed a model for locating emergency vehicles on urban networks considering both spatial and temporal demand characteristics such as the probability that a server is not available when required. Canbolat and Massow (2011) studied the problem where locations of each demand point were random. Sometimes the probability that a server is not available when required, so it was a practical problem. Verma and Gaukler (2014) provided two location models that explicitly take into consideration the impact a disaster can have on the response facilities and the population centers in surrounding areas. It provided a detailed case study using large-scale emergencies caused by an earthquake in California to demonstrate the performance of these new models. When it comes to the application of covering model in maritime emergency, the coverage radius of maritime emergency supplies reserve base is impacted by the natural conditions, such as wind and water current. Venäläinen (2014) studied the evaluation of emergency response in the Gulf of Finland and studied the influence of water and wind to the speed of rescue vessels. Siljander et al. (2015) presented an approach to evaluate accessibility and response times in a sea area using geographic information system. The presented methodology accounted for the main characteristics of maritime response, namely spatial accessibility, capabilities of search and rescue units (SRUs) and prevailing wave conditions, which affect the attainable SRU speeds.

In general, the location problem of the emergency supplies reserve bases and the configuration problem of rescue vehicles were studied separately. There are a few papers considering the location and allocation as a whole. The location–allocation problem was first raised by Curry and Skeith(1969). Wesolowsky and Truscott (1975) studied the location and distribution problem and bender decomposition method was proposed to solve the distribution center location problem. Marianov and Serra (2002) studied the multi-service center location–allocation problem constrained by the waiting or queuing time. Sheu (2007) presented a hybrid fuzzy clustering-optimization approach to the operation of emergency logistics co-distribution responding to the urgent relief demands in the crucial rescue period. Sha and Huang (2012) studied the location–allocation problem of engineering emergency blood supply systems and proposed a multi-period location–allocation model. Hector et al. (2013) studied the location-dispatching problem of emergency medical services and integrated the location and dispatching decision into a single framework. Zahiri et al. (2014) presented a novel robust programming model for a multi-period location–allocation problem in an organ transplant supply chain under inherent uncertainty of input data. Most of the literatures considered the allocation of emergency resources using all-or-nothing assignment. But emergency event has great uncertainty, the demand allocated to multiple reserves bases can increase the reliability and be more practical, so we use the probabilistic distribution method (Azofra et al., 2007).