European Journal of Operational Research 254 (2016) 279–293

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Innovative Applications of O.R.

# A multi-objective model for locating search and rescue boats

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ARTICLE INFO

*Article history:*
Received 26 November 2015
Accepted 15 March 2016
Available online 24 March 2016

*Keywords:*
Integer programming
Resource allocation
Search and rescue

ABSTRACT

We present the Incident Based-Boat Allocation Model (IB-BAM), a multi-objective model designed to allocate search and rescue resources. The decision of where to locate search and rescue boats depends upon a set of criteria that are unique to a given problem such as the density and types of incidents responded in the area of interest, resource capabilities, geographical factors and governments' business rules. Thus, traditional models that incorporate only political decisions are no longer appropriate. IB-BAM considers all these criteria and determines optimal boat allocation plans with the objectives of minimizing response time to incidents, fleet operating cost and the mismatch between boats' workload and operation capacity hours.

IB-BAM methodology includes three major steps: In step-1, the model ranks and assigns a weight to each incident type according to its severity, using Analytical Hierarchy Process technique. In step-2, considering historical incident data, a Zonal Distribution Model generates aggregated weighted demand locations. In step-3, a multi-objective mixed integer program determines locations and responsibility zones of search and rescue boats. We demonstrate the effectiveness of the proposed model with respect to the Aegean Sea responsibility area of the Turkish Coast Guard boats. The results show that IB-BAM implementation led to a more effective utilization of boats considering the three objectives of the model.


## 1. Introduction

Each year the Turkish Coast Guard (TurCG) receives hundreds of distress signals and calls from the vessels in danger. Immediate response to these signals is crucial for both victim survival and damage prevention. Moreover, in a Search and Rescue (SAR) operation, the difference between life and death can sometimes be measured in minutes. Additionally, a SAR operation consumes considerable amounts of time, effort and money. Thus, emergency response actions should be well-planned and neatly organized. A distinguished review by Green and Colesar (2004) analyzed details of the research about emergency response systems and development of OR/MS applications in the area. They argued that, despite many challenges, OR/MS applications play an important role in minimizing the impact of emergencies. This observation is particularly applicable to SAR operations conducted by TurCG.

According to the national SAR plan, TurCG has the responsibility for coordinating and conducting SAR activities/operations in the Turkish Maritime SAR Zone, which is divided into four sub-responsibility areas as follows: the Black Sea, the Sea of Marmara and Adjacent Straits, the Aegean Sea and the Mediterranean Sea. Among these sub-areas, the Aegean Sea has the heaviest marine traffic due to maritime transportation from and to the Black Sea, shipping, cruise tours, yachting, windsurfing and enormous illegal-border crossing activities. The heavy traffic on narrow waters, among 3000 islands of various sizes, increases the risk and hence the ratio of maritime incidents to traffic levels and risk in maritime safety (Goerlandt & Kujala, 2011). Miliou et al. (2012) studied characteristics of marine traffic and high risk traffic conditions for the Aegean Sea and reported that the number of vessels passing through the region more than doubled from November 2009 to October 2011. Furthermore, the risk in the area increases with the number of ships carrying hazardous cargo and the lack of designated shipping lanes, together with narrow and dangerous routes. According to their research, of the 72,919 vessels that crossed the Aegean Sea (via three channels, Mykonos-Ikaria, Ikaria-Samos and Evia-Andros) between 2009 and 2011, 65 percent were cargo ships, 21 percent were tankers, 5 percent were passenger ships and 9 percent were others.

Soares and Teixeira (2001)'s analysis of the world-wide marine incident databases suggests that fire, grounding and collision are the most common accident types. However, the incident statistics for the Aegean Sea in Fig. 1 represent a significantly different ranking, mainly because of its unique political and physical

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http://dx.doi.org/10.1016/j.ejor.2016.03.026
0377-2217/

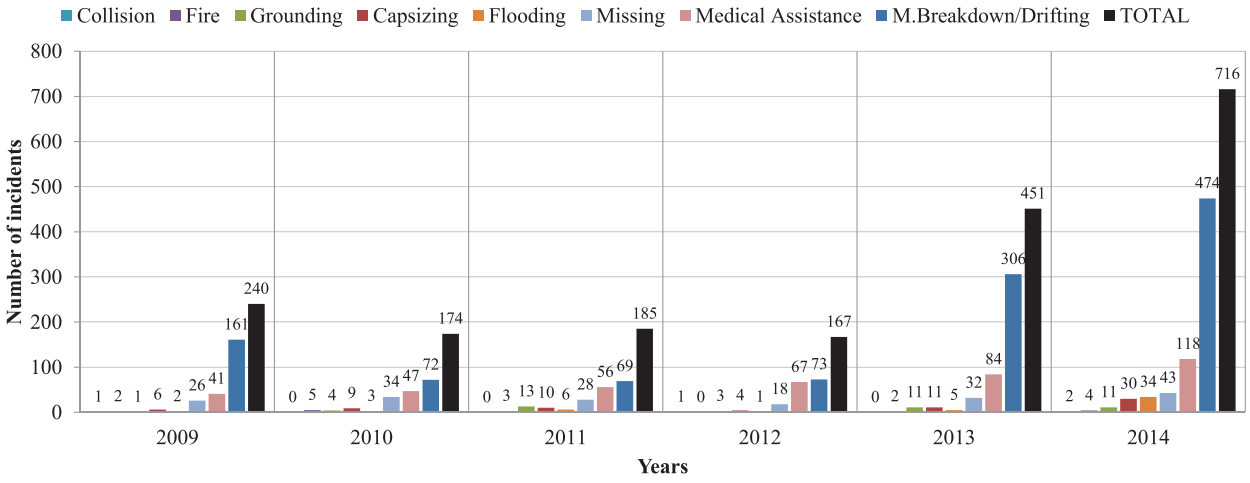


**Fig. 1.** Number of incidents between years 2009 and 2014 in the Aegean Sea responsibility area.

geographical features. Yearly incident data provided by TurCG reveals that, of the recorded 1933 incidents that occurred in the Aegean Sea between 2009 and 2014, 60 percent were drifting/machinery breakdown notably associated with illegal-border crossing and yachting/surfing activities, 21 percent were medical assistance, 9 percent were missing, 4 percent were capsizing, 3 percent were flooding, 2 percent were grounding, 0.8 percent were fire and 0.2 percent were collision. Despite the reduction in the number of incidents from 2009 until 2012, the analysis displays a marked increase starting from 2012. The main reason for this increase can be explained with the turmoil in Syria and Iraq, which caused a respectable increase in the number of refugees and migrants crossing the Eastern Mediterranean since 2013 (UNHCR Global Appeal, 2015). The Aegean Sea is such a main route for immigrants to illegally cross EU borders that the number of migrants caught along the route has tripled in 2014 from 2863 to 10,445 (Giuliani, 2015). In 2014 alone, TurCG conducted 842 operations, 716 of which were in the Aegean Sea. TurCG incident data reveals that during those operations, 12,901 victims were saved, 190 boats were recovered undamaged and 154 lives were lost, while 62 percent of all operations were related to illegal-border crossing activities.

As a consequence, the risk stemming from the increasing traffic density has accentuated the problem of establishing well-planned SAR organizations in the region. Discussions with TurCG representatives have revealed that this question has not been sufficiently investigated with regard to the incidents observed in the area. Currently, resource deployment decisions are not carried out according to scientific criteria but rather political decisions. Thus, this study concerns the tactical aspect of the emergency incident response problem, i.e., determining locations of SAR resources. Concerning the importance of immediate response to catastrophic casualties and high costs associated with the boat operations, we proposed an optimal allocation plan for SAR resources in the Aegean Sea sub-area.

TurCG executes SAR operations with three types of platforms: (1) SAR ship (single type) with a length of more than 85 meters, (2) SAR boats (12 different types) under 45 meters in length, and (3) aircraft (airplanes and helicopters). Since surface units are the primary platforms used to respond maritime incidents, we focus on surface units and their allocations among the available ports. Although aircrafts are also accepted as effective SAR platforms, the problem of their optimal allocation is out of our scope. We are specifically devoted to allocate 9 types of surface units; namely the SAR ship and 8 types of SAR boats (the ones that can operate in the confined and shallow waters of Aegean Sea), to 25 different pre-determined candidate ports along the coast of the Aegean Sea in accordance with SAR missions and historical incident data.

SAR missions carried out in the Aegean Sea include cases of drifting, capsizing, grounding, fire, collision, flooding, missing, and medical assistance. Each type of incident requires an individual operation with specific types of boats. For example, in case of a fire incident, decision makers must assign a boat with fire-fighting capability, while it is that of a high speed boat in the case of medical assistance. In our problem, the operation duration of an incident represents a demand (in hours) based on the incident's location and allocated annual operation hours of a boat represents supply (in hours). A SAR plan is accepted as 'successful' if it has the following properties: (1) appropriate and sufficient number of boat assignments to incidents, (2) short response time, (3) low fleet operating cost, (4) balanced workload distribution among the boats, and (5) successfully implemented business and technical rules. Therefore, a tool that can help us develop a successful SAR plan can be very useful for decision makers. Accordingly, this paper explains IB-BAM (Incident Based Boat Allocation Model), the tool that we have developed for determining optimal SAR allocation plans.

The paper is organized as follows: a literature research of various resource allocation models is presented in Section 2. Our main technical contribution is the development of IB-BAM, a structured resource allocation model in Section 3. In our model, we first use the Analytical Hierarchy Process (AHP)-a widely-used Multi Criteria Decision Making (MCDM) technique-to generate weights for incident types. We obtain concentrated demands, called "*superincidents*", by applying a weighted *k*-clustering algorithm on a historical dataset of incidents. Considering the criteria mentioned above for a successful SAR plan, we develop a Multi-Objective Mixed Integer Program (mo-MIP) that enables determining locations of SAR resources and workload distribution among boats. We illustrate our proposed approach and results with respect to the Aegean Sea sub-area in Section 4. Finally, in Section 5, we present a summary and conclusion of our work.

## 2. Related work

Planning an effective SAR organization is a sub-class of resource allocation problems. Below, we first review studies that address general resource allocation problems and then the relevant literature on military and SAR resource allocation problems.

Studies on resource allocation problems in the literature generally comprise common models such as *p*-median problems