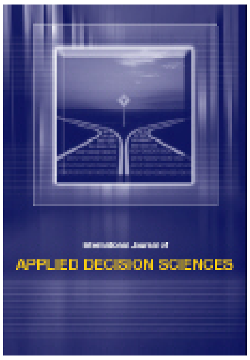

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An optimisation model to design a maritime search and rescue system under uncertainty

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Abstract: Unfavourable weather conditions, disruptions in equipment, and human error are the factors that lead to maritime accidents. In such cases, delays in providing relief may lead to catastrophic events. Hence, this paper presents a bi-objective mixed-integer linear programming (MILP) model for marine search and rescue under uncertainty. The purpose of the proposed model is to minimise total costs and the completion time of operations, simultaneously. Helicopters and ships equipped with rescue and relief equipment are applied for maximum coverage. We use a stochastic scenario-based approach to cope the uncertain response time. A fuzzy solution approach is developed to deal with the uncertainty and solve the proposed bi-objective model. Finally, an algorithm is presented to generate data using probabilistic distribution functions, and the performance of the proposed model is evaluated by eight simulated problems. The results obtained for the simulated problems and the sensitivity analysis of the coefficients of the objective functions show the effectiveness of the proposed model.

Keywords: maritime search and rescue; mathematical programming; location problem; fuzzy theory; stochastic programming.

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1 Introduction

Maritime search and rescue (MSAR) mainly aim at searching for and rescuing the items or individuals that are missing or at risk in a shipwreck. One of the important targets of maritime SAR is timeliness, which is deeply affected by the SAR equipment items such as helicopters and ships in allocation plans (Yang et al., 2020; Agbissoh OTOTE et al., 2019). Due to the unpredictability of time and location of the future accidents and the necessity of determining allocation plan of SAR equipment items beforehand, it has become a cumbersome task to develop a proper allocation plan for SAR equipment. In reality, the starting point of maritime SAR is the sending of a distress call to the maritime SAR centre (Cai et al., 2020). At first, decision makers start searching all SAR equipment items considering the place, occurrence time, type, and duration of the accident. Whenever the distance of the accident from the activated maritime SAR station is far more than the operating range of SAR equipment, it is possible that some SAR equipment items may not be taken into consideration (Baber et al., 2013). Next, decision makers embark on estimating the time that the intended maritime SAR equipment takes to arrive at the accident scene. Afterwards, they start sorting all the alternative equipment items. Here, the equipment will be selected that has the capability to initiate the maritime SAR work in the shortest possible time. In this step, decision makers may select the following alternative SAR equipment item, in the case that the intended SAR equipment performs other emergent maritime SAR tasks, as well (Siljander et al., 2015). In this situation, if there is no maritime SAR equipment to perform the intended mission, it must wat in the que for the SAR equipment to become available. As a result, it seems necessary for decision makers in the area of maritime SAR develop and implement some effective tools for decision support to go for easier decision making. This is so while only few studies have provided a quantitative decision methodology/mathematical programming model to tackle this issue. It is evident that the application of mathematical programming models can assist individuals to make educated decisions (Zhen et al., 2017, 2016).

In this paper, a bi-objective mixed-integer linear programming (MILP) model is developed with the aim of minimising total costs and completion time of operations for MSAR under uncertainty. For maximum coverage, helicopters and ships equipped with rescue equipment are used. In general, the contributions of this paper can be stated as follows:

- Formulating a novel MILP model for MSAR operations under uncertainty

- Applying a scenario-based approach to deal with uncertain response time
- Using a fuzzy multi-objective solution approach to solve the multi-objective model under uncertainty
- proposing a data simulation algorithm to generate data, and validate the proposed model and solution approach using simulated data.

The rest of this paper is organised as follows. Section 2 presents a relevant review of the literature followed by the proposed mathematical model in Section 3. The solution approach and experimental results are presented in Sections 4 and 5, respectively. Finally, the conclusion is presented in Section 6.

2 Literature review

Since MSAR deals with human lives, the use of appropriate marine equipment such as ships, helicopters, etc., are more important, and the cost of using this equipment is placed in the next priorities (Chen et al., 2022a). In order for rescue operations to take place in the best way, equipment must be used optimally (Gudmestad, 2022). Recently, researchers such as Chen et al. (2022b), Dobie (2022), and Yu et al. (2022) have focused on types of marine equipment and the knowledge of using this equipment. In addition, some researches in the field of MSAR have been drawn towards rescue and the type of rescue (Olgac and Toz, 2022; Rani et al. 2022). One of the tools used in this field is the mathematical programming tool, which is used to optimise strategic and operational decisions. Some researchers such as Zhang et al. (2020), Morin et al. (2022), and Zhou (2022) have used mathematical programming model for this purpose.

The issue of location-allocation is very important in the field of MSAR; because it has a significant effect on reducing rescue time and optimal use of equipment, and this leads to a reduction in casualties (Jin et al., 2021). The location-allocation problem in the field of MSAR in the articles presented by Hornberger et al. (2022), Lee and Teixeira (2022), and Sun et al. (2022) has been used. Uncertainty is an integral part of the models presented in the SAR field; because accurate information about the type of incident, time and place of its occurrence is not available (Christodoulou et al., 2022). Therefore, the use of uncertainty approaches is a suitable solution to deal with it, which has been considered in some researches (Smith, 2017; Drew, 2021; Malyszko, 2021).

In terms of the research already conducted on rescue allocation, one can refer to Karatas (2021), who has provided a multi-objective location-routing model for SAR. In this regard, Geng et al. (2021) have also raised the location-routing of rescue warehouses. From among the other works carried out in this area, one may refer to the pieces of research undertaken by Wang et al. (2021) and Jin et al. (2021) focusing on location-routing problems.

Maritime accidents can originate from various factors, including human factors (Fan et al., 2020a), technical factors and equipment failure (Du et al., 2020), weather conditions (Uddin and Awal, 2017), maritime piracy and robbery (Hribernik, 2013), and sea collisions (Fan et al., 2020b).

Hu et al. (2021) embarked on the assessment of a method for helicopter SAR under uncertainty conditions wherein they believed that helicopters play an important role in marine SAR and that it is a platform for responding to marine accidents. The most important issue at play when it comes to MSAR is the issue of higher uncertainty than drought, in which numerous factors are involved. According to them, a rescue can be successful when the required operations are fully accomplished. They also believe that when it comes to uncertainty, these uncertainties should be taken into account as much as possible until a successful MSAR is achieved. Using Montcarlo's method, they have devised their comprehensive framework for the probability distribution and robustness responsible plan.

Xing (2021) has proposed a model of search equipment selection for joint air-sea operations. According to him, joint air-sea operations have the greatest impact on sea rescue. When rescue operations at sea are carried out jointly by sea-air forces, the search area expands and the speed of finding and reaching the scene of the accident increases sharply; however, the complexity of coordination of operations also increases significantly. If the location of the accident is not known, the search option comes into play and the related costs and potential risks are raised, which may affect the entire rescue operations. His research has addressed the selection of the optimal equipment for rescue operations at sea.

When it comes to rescue, one of the most important factors is the response time, which has been considered by Kurniawan and Mahara (2021). In fact, they have gone through the conduct of a survival analysis based on the average response time in MSAR operations where they have made use of two methods, namely Kaplan-Meier and log-Rank in their analysis. They have examined their work in light of the maritime incidents that took place on the Indonesian peninsula. The classification of accidents in their work falls within three categories, including low, medium, and high, and the importance of the issue is prioritised on the basis of the response time and the probability of survival in the accident.

The development of the SAR framework for maritime freight shipping in the Arctic is a title that is raised by Benz et al. (2021) when it comes to maritime rescue. They maintained that since the Arctic routes are gaining more attention for maritime transport these days, it is spoken of capacity bottlenecks along the route, such as the Suez Canal, the Straits of Malacca, and the Panama Canal. Owing to the climate change, the melting of polar ice caps, and rising northern water levels; the North, Northeast and Northwest sea lanes have become competitive and crowded routes. When the routes increase in traffic, then the probability of an accident also increases in these routes at the same time. Thus, it is necessary to encounter these accidents with full preparation. The subject of their discussion is the development of a rescue framework in these waters based on the infrastructure dimensions of seaports, communication equipment, navigation equipment, maritime transport standards, and cooperation among fleets.

Xiao et al. (2010) designed a marine rescue simulation system where they believe that maritime rescue is an important human activity that should be assigned credit. However, this issue becomes highly complex when it comes to coordination between rescue units in the sea. Given that using real rescue equipment for such preparation is very costly and risky, they performed this operation by means of a marine rescue simulator. In the face of a risk, this simulator provides the necessary preparation for rescue forces, which, in turn, leads to the reduction of the operating costs.

The number of casualties in maritime accidents is on the rise; therefore, the authorities have resorted to using unmanned aerial vehicles to reduce the area of search environment.

Cho et al. (2021) proposed a two-phase method to solve the coverage path problem where they analysed the area based on the network in the first phase, which aimed at minimising the decomposed area based on the length of the edges. In the second phase, they presented an MILP model to minimise the coverage time of the decomposed area. Due to the complexity of the large-scale MILP problem, they used an extended randomised search heuristic algorithm and then validated their algorithm by numerical experiments, which performed the optimisation task with a desired approximation.

Ai et al. (2021) proposed a system based on the shortest time and priority of covering high-risk areas. They believed that search planning in SAR problems has a direct impact on the effectiveness of the SAR and stated that traditional decision-making systems have poor flexibility in SAR conditions to select the search path, which results in the low efficiency of the existing models. First, they used real marine data and, then, used these data to propose a model for learning and prediction that can have the most coverage points.

Helicopter maritime search area planning based on a minimum bounding rectangle and K-means clustering is the title of the research conducted by Xiong et al. (2021). Given the importance of using helicopters in the SAR issue, they have addressed it. They believed that successful SAR operations require careful planning and the possibility of predicting accident hotspots increases due to scientific advances in climate planning and forecasting. Accordingly, they developed a method for predicting maritime accident hotspots for helicopter rescue in these hotspots. Using the k-means clustering system, they embarked on predicting the accident hotspots to reduce casualties.

Cai et al. (2020) developed a bi-level intelligent model for maritime rescue issues. Their model has been proposed in a certain fashion and has been developed with the objective minimisation functions, the number of marine rescue stations, and deviation from the standard response time to maritime accidents. They proposed their model assuming the size of the rescue equipment at sea and the type of rescue equipment (i.e., both sea and air equipment). To solve their model, they used marine data from the east coast of China and, then, solved the model using meta-heuristic algorithms.

3 Proposed model

In the real world, accidents at sea have a variety of causes, including human error, adverse weather conditions, equipment failure, and other factors. The possibility of occurring each of these factors has been mentioned in a variety of scenarios. After an accident, people contact the SAR centres and expect help in the shortest possible time. Based on the location of the accident scene, the arrival time to the accident, the conduct of rescue operations from active SAR stations, and the type of equipment that should reach the accident site, the help and rescue operations may be different depending on the type of vehicle (helicopter or different ships).

In this section, a bi-objective MILP model is proposed based on the coverage of all the search area, the time required for response, and equipment related to the type of accident. The first objective of this model is to minimise the costs and its second one is to reduce the time of rescue operations. This model is suitable for responding to different events under different scenarios.

3.1 Assumptions

- The entire search area should be covered.
- For each accident, the related equipment should be used.
- The time required to respond to each accident has been considered to be uncertain.
- There is the possibility of setting up stations for helicopters and ships with different capacities.
- Some accidents can only be responded to by helicopter/ ship, but some can be responded to by both of them.
- Ships and helicopters can be deployed simultaneously at any potential station.

3.2 Mathematical model

Indices	
$j \in \{1, 2, \ldots, J\}$	Potential stations
$k \in \{1, 2, \ldots, K\}$	Type of accident
$f \in \{1, 2, \ldots, F\}$	Equipment
$n \in \{1, 2, \ldots, N\}$	Capacity level
$s \in \{1, 2, \ldots, S\}$	Scenario
Parameters	
$\lambda_f \begin{cases} 1 \\ 0 \end{cases}$	If equipment *f* belongs to the ship If equipment *f* belongs to the helicopter
$\theta_{fk} \begin{cases} 1 \\ 0 \end{cases}$	If equipment *f* is suitable for responding to accident Otherwise
P_s	The probability of occurring scenario *s*
α_{kj}	Distance of the accident site from station *j*
w_f	Average speed of the ship/helicopter having equipment *f*
U_{jn}	Maximum capacity of station *j* at capacity level *n*
GT_{ks}	Critical time to respond to accident *k* under scenario *s*
ξ_f	Length of ship/helicopter having equipment *f*
CF_j	Cost of setting up station *j*
CV_{jfh}	Cost of equipping station *j* with equipment *f* under capacity level *n*
ST_{kf}	Duration of doing the operations to respond to accident by equipment *f*
Variables	
$x_j \begin{cases} 1 \\ 0 \end{cases}$	If station *j* is set up Otherwise
$y_{jfn} \begin{cases} 1 \\ 0 \end{cases}$	If the ship/helicopter having equipment *f* is set up at station *j* with capacity level *n* Otherwise
$\delta_{kfs} \begin{cases} 1 \\ 0 \end{cases}$	If the ship/helicopter equipped with equipment *f* is allocated to respond to accident *j* under scenario *n* Otherwise
CT_{ks}	Completion time of the operation to respond to accident *k*

3.3 Objective functions

$$Min\, Z_1 = \sum_{j} CF_j \times x_j + \sum_{j,f,n} CV_{jfn} \times y_{jfn} \tag{1}$$

- First objective function: This objective function minimises total costs, including the cost of setting up stations and the cost of equipment used in stations.

$$Min\, Z_2 = \sum_{k,s} CT_{ks} \times p_s \tag{2}$$

- Second objective function: This objective function minimises completion time of operations.

$$s.t.$$

$$y_{jfn} \le x_j \quad \forall j, f, n \tag{3}$$

Equation (3): If the station is not set up, no equipment should be allocated to it.

$$\sum_{k} \delta_{kfs} \le \sum_{j,n} y_{jfn} \times bigM \quad \forall f, s \tag{4}$$

Equation (4): Those ships/helicopters that have been set up at stations are allowed to respond to accidents.

$$\sum_{f} \delta_{kfs} \times \lambda_f \times \theta_{fk} + \sum_{f} \delta_{kfs} \times (1-\lambda_f) \times \theta_{fk} = 1 \quad \forall k, s \tag{5}$$

Equation (5): Each incident must be assigned a piece of equipment.

$$\sum_{f,n} y_{jfn} \times \lambda_f \le 1 \quad \forall j \tag{6}$$

$$\sum_{f,n} y_{jfn} \times (1-\lambda_f) \le 1 \quad \forall j \tag{7}$$

Equation (6) and (7): We are allowed to use a maximum of one capacity level in each station.

$$\sum_{f} y_{jfn} \times \lambda_f \times \xi_f + \sum_{f} y_{jfn} \times (1-\lambda_f) \times \xi_f \le U_{jn} \quad \forall j, n \tag{8}$$

Equation (8): Determining the capacity level of stations.

$$CT_{ks} = \sum_{j,f} \frac{\delta_{kfs} \times \alpha_{kj}}{w_f} + \sum_{f} ST_{kf} \times \delta_{kfs} \quad \forall k, s \tag{9}$$

Equation (9): Calculating the completion time of operations.

$$CT_{ks} \le GT_{ks} \quad \forall k, s \tag{10}$$

Equation (10): Not exceeding the critical time.

4 Solution approach

There are many methods such as goal programming (Zandkarimkhani et al., 2020), LP-metric (Mardan et al., 2019), weighted fuzzy approach (Tavana et al., 2020), and so on for transforming a multi-objective model to single-objective one, each of which is used according to the nature of the problem under study. In this study, it is attempted to make the proposed model a single-objective one using a fuzzy method proposed by Torabi and Hassini (2008). This method allows users to weight each objective function as s/he intends and also solves the problem under uncertainty conditions. The method used here is as follows:

$$\begin{aligned} & Max\ \varpi x_0 + (1-\varpi)\times\sum_l \tau_l \times \psi_l \\ & St: \\ & x_0 \le \psi_l \\ & System\ constraints \end{aligned} \tag{11}$$

where x_0 indicates the minimum degree of satisfaction of objective functions; ψ_l and τ_l also represent the degree of satisfaction of the l^{th} objective function; and ϖ denotes the weight of the minimum degree of satisfaction of the objective functions. The ψ_l has also been given below for the minimisation and maximisation objective functions:

- For minimisation objective functions:

$$\psi_l(x) = \begin{cases} 1 & Z_l(x) > Z_l^+ \\ 0 & Z_l(x) < Z_l^- \\ f_{\psi_l} = \dfrac{Z_l^+ - Z_l(x)}{Z_l^+ - Z_l^-}, & Z_l^- \le Z_l(x) \le Z_l^+ \end{cases} \tag{12}$$

- For maximisation objective functions

$$\psi_l(x) = \begin{cases} 1 & Z_l(x) > Z_l^+ \\ 0 & Z_l(x) < Z_l^- \\ f_{\psi_l} = \dfrac{Z_l(x) - Z_l^-}{Z_l^+ - Z_l^-}, & Z_l^- \le Z_l(x) \le Z_l^+ \end{cases} \tag{13}$$

Therefore, the proposed single-objective model will be as follows:

$$Max\ \varpi \times x_0 + (1-\varpi)\times(\tau_1 \times \psi_1 + \tau_2 \times \psi_2) \tag{14}$$

$s.t.$

$$\psi_1 = \frac{Z_1^+ - Z_1}{Z_1^+ - Z_1^-} \tag{15}$$

$$\psi_2 = \frac{Z_2^+ - Z_2}{Z_2^+ - Z_2^-} \tag{16}$$

$$x_0 \le \psi_1 \tag{17}$$

$$x_0 \le \psi_2 \tag{18}$$

$$Z_1 = \sum_{J} CF_j \times x_j \sum_{j,f,n} CV_{jfn} \times y_{jfn} \tag{19}$$

$$Z_2 = \sum_{k,s} CT_{ks} \times p_s \tag{20}$$

5 Results

In this section, the performance of the proposed model and solution approach is evaluated using the simulated data. For this purpose, a simulation algorithm is proposed using probabilistic distribution functions to generate data in desired sizes. This algorithm is given in Table 1.

Table 1 Data simulation algorithm

Indices/parameters	*Distribution function*
j, k, f, n, s	Optional values
λ_f	$Round(Uniform(0,1.5))$
θ_{jk}	$Round(Uniform(0,1.5))$
P_s	$Uniform(0,1)\ and \sum_s p_s = 1$
α_{kj}	$Round(Uniform(15,50))$
w_f	$Round(Uniform(60,90))$
U_{jn}	$Round(Uniform(100,150))$
GT_{ks}	$Round(Uniform(200,300))$
ξ_j	$Round(Uniform(20,25))$
CF_j	$Round(Uniform(1500000,2250000))$
CV_{jfn}	$Round(Uniform(30000,50000))$
ST_{kf}	$Round(Uniform(40,80))$

Now, using the proposed simulation algorithm, eight problems are generated in different dimensions and the performance of the proposed model is assessed for each of the simulated problems. The sizes for the simulated problems are given in Table 2.

To solve the proposed model, the proposed bi-objective model should be converted into a single-objective one using the fuzzy method proposed by Torabi and Hassini (2008). To this end, the lower and upper bounds of each objective function should be determined. The lexicographic method is used to determine the lower and upper bounds of the objective functions. In Table 3, the lower and upper bounds of each objective function are shown.

Table 2 The sizes of simulated problem

Instance	*j*	*k*	*f*	*n*	*s*
1	5	2	4	2	7
2	6	3	4	2	8
3	7	3	5	3	9
4	8	4	6	3	10
5	9	4	6	4	11
6	9	5	6	5	12
7	10	5	7	5	13
8	11	6	7	6	14

Table 3 The lower and upper bounds of objective functions

Instance	*Objective function 1*		*Objective function 2*	
	Lower bound	*Upper bound*	*Lower bound*	*Upper bound*
1	1554752	3154367	95	115.65
2	1541292	3151916	177.48	201.85
3	1548019	1582946	163.63	190.75
4	1623509	3338689	199.15	227.08
5	1550519	3184577	211.24	218.11
6	1567413	5143367	251.86	508.17
7	1597332	3391725	250.93	422.97
8	1582170	1583291	326.19	650.03

Since both objective functions are of the minimisation type, equation (12) is used to calculate their membership functions. In Table 4, the membership functions of objective functions are presented for each problem.

Table 4 Membership function for each objective function

Instance	*Membership function*	
	Objective function 1	*Objective function 2*
1	$\frac{3154367-Z_1}{3154367-1554752}$	$\frac{115.65-Z_2}{115.65-95}$
2	$\frac{3151916-Z_1}{3151916-1541292}$	$\frac{201.85-Z_2}{201.85-177.48}$
3	$\frac{1582946-Z_1}{1582946-1548019}$	$\frac{190.75-Z_2}{190.75-163.63}$
4	$\frac{3338689-Z_1}{3338689-1623509}$	$\frac{227.08-Z_2}{227.08-199.15}$

Table 4 Membership function for each objective function (continued)

Instance	*Membership function*	
	Objective function 1	*Objective function 2*
5	$\frac{3184577 - Z_1}{3184577 - 1550519}$	$\frac{218.11 - Z_2}{218.11 - 211.24}$
6	$\frac{5143367 - Z_1}{5143367 - 1567413}$	$\frac{508.17 - Z_2}{508.17 - 251.86}$
7	$\frac{3391725 - Z_1}{3391725 - 1597332}$	$\frac{422.97 - Z_2}{422.97 - 250.93}$
8	$\frac{1583291 - Z_1}{1583291 - 1582170}$	$\frac{650.03 - Z_2}{650.03 - 326.19}$

Now, equations (21) to (27) are used to convert the proposed bi-objective model into a single-objective model. For example, the single-objective model for Instance 6 (for $\tau_1 = 0.6$, $\tau_2 = 0.4$ and $\varpi = 0.3$) would be as follows:

$$Max\ 0.3 \times x_0 + 0.7 \times (0.6 \times \psi_1 + 0.4 \times \psi_2) \tag{21}$$

S.t.

$$\psi_1 = \frac{5143367 - Z_1}{5143367 - 1567413} \tag{22}$$

$$\psi_2 = \frac{298.17 - Z_2}{298.17 - 251.86} \tag{23}$$

$$x_0 \le \psi_1 \tag{24}$$

$$x_0 \le \psi_2 \tag{25}$$

$$Z_1 = \sum_{J} CF_j \times x_j + \sum_{j,f,n} CV_{jfn} \times y_{jfn} \tag{26}$$

$$Z_2 = \sum_{k,s} CT_{ks} \times p_s \tag{27}$$

By running this model in GAMS software using BARON solver, the optimal values of objective functions and decision variables for Instance 6 are obtained. This process is run for all instances. In Table 5, the optimal values of objective functions are shown for all instances.

As it was mentioned earlier, the optimal values given in Table 5 have been obtained for $\tau_1 = 0.6$, $\tau_2 = 0.4$ and $\varpi = 0.3$. By making a change into these values, the optimal values of the objective functions will also change. In other words, by changing these values, a set of Pareto solutions is obtained and this possibility is provided for the decision-maker to select the intended optimal solution from the available optimal solutions. Afterwards, the results obtained from the sensitivity analysis of these values are examined. In Table 6, the optimal values of the objective functions of Instance 6 have been shown for changes into the values of τ_1, τ_2, ϖ. The results of the sensitivity analysis process have been illustrated in Figures 1 and 2 for $\varpi = 0.2$ and 0.3, respectively.

Table 5 The optimal value of objective functions

Instance	*Optimal value of*	
	Objective function 1	*Objective function 2*
1	1629786	105.02
2	1716147	195.31
3	1581964	186.24
4	1960562	209.76
5	1852739	216.78
6	3698703	419.92
7	1969889	397.62
8	1582170	577.15

Table 6 Results of sensitivity analysis for parameters τ_1, τ_2, ϖ

(τ_1, τ_2)	$\varpi = 0.2$		$\varpi = 0.3$	
	Objective function 1	*Objective function 2*	*Objective function 1*	*Objective function 2*
(0, 1)	4343367	251.86	3405892	355.1
(0.2, 0.8)	3395885	359.30	3394610	367.26
(0.4, 0.6)	3374312	380.19	3388773	379.69
(0.6, 0.4)	3210509	404.92	3298703	401.92
(0.8, 0.2)	3103532	478.63	3153768	469.19
(1, 0)	1567413	493.17	1693467	508.17

Figure 1 Results of sensitivity analysis for coefficients of objective functions per $\varpi = 0.2$ (see online version for colours)

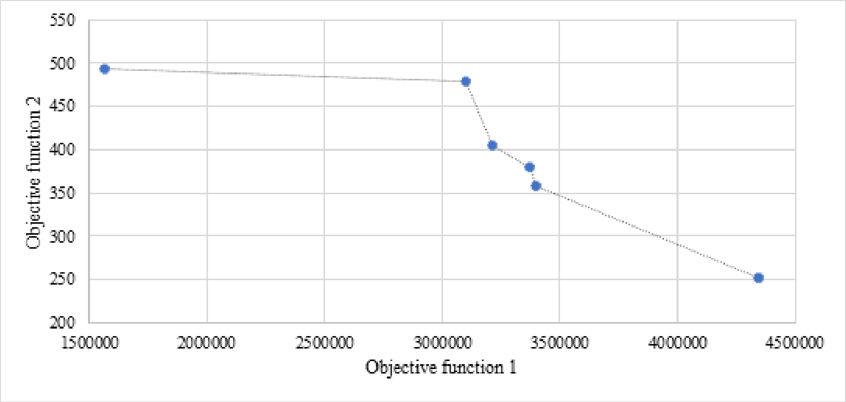
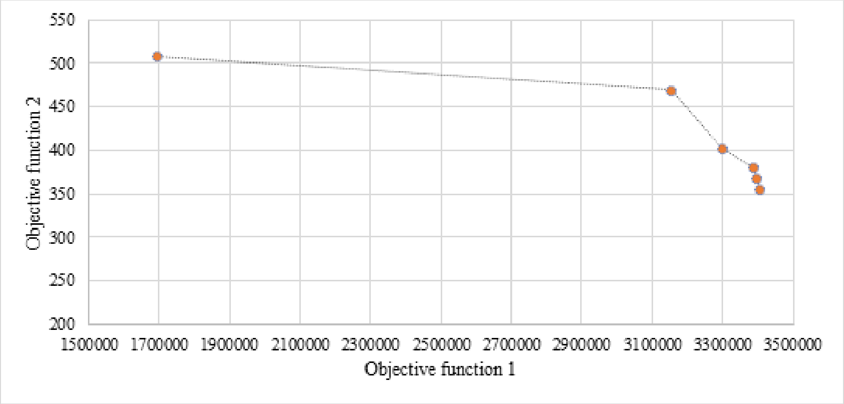


Figure 2 Results of sensitivity analysis for coefficients of objective functions per $\varpi = 0.3$ (see online version for colours)



As it can be observed in Table 6 and Figures 1 and 2, all the obtained responses are acceptable because no optimal solution is dominated by other optimal solutions. Therefore, decision-makers can select the optimal response that is closer to their conditions in accordance with the available budget and other constraints.

6 Conclusions

In this paper, a novel bi-objective MILP model was presented to manage maritime catastrophe. The proposed model is structured based on the search and rescue problem. Its purpose is to optimally locate naval rescue stations to deploy helicopters and ships so that operations time and total costs are minimised at the same time. In addition, we have used a fuzzy solution approach to convert the proposed bi-objective model to a single-objective one. The efficiency of the proposed model and fuzzy solution method was measured by eight simulated problems in small and medium sizes, and finally the accuracy of the proposed model behaviour was confirmed by the sensitivity analysis process. The location-routing problem considered in this study is an NP-hard problem. We suggest developing an efficient heuristic or meta-heuristic algorithm to solve large-size instances of this problem since GAMS software is incapable of solving them.

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