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Analysis of the parameters influencing the suitability of a surface unit for search and rescue operations at sea

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Abstract

Research studies have discussed the correct selection and choice of the optimal units for a specific type of search and rescue task. This article has described the characteristics and properties of merchant vessels that determine their potential for SAR (Search and Rescue) operation. An attempt was made to estimate the suitability of a craft according to its effectiveness and risk. This research may have an impact on improving the organization and coordination of search and rescue operations at sea. The authors have proposed criteria for evaluating merchant units during selection for planned SAR actions. A model for evaluating the suitability of a unit has been presented. It is a mathematical model with elements of expert knowledge. The model classifies attributes, taking into account the lower and upper risk limits and introducing a risk sensitivity factor. The article contains tables and graphs.

Introduction

The planning, organisation and coordination of search and rescue operations at sea, especially in the case of vessels that do not conduct rescue operations on a daily basis – cargo ships, passenger ships, fishing vessels and small leisure crafts – is connected with the rarely required but very important decisions, which may have a significant impact on the course and effectiveness of the action. In the present day, with the clear specialisation of officers for certain types of ships, it is natural that the officer or Captain of a large or medium bulk carrier will not know all the specific characteristics of the container ship; its operational limitations and manoeuvrability. Even less knowledge and experience can be expected in the case of small fishing vessels and leisure craft crew. A similar problem will be encountered by MRCC (Maritime Rescue Coordination Centre) and MRSC (Maritime Rescue Sub-Centre) employees with less experience and working in the face of the selection of multiple units of different sizes and types. The aim of the action will always be to operate efficiently and make optimal use of the selected units. This study has been an attempt to determine the principles of correct selection and choice of the optimal units for a specific type of search and rescue action. This research has been an essential element in creating an automatic decision support system for captains and coordinators during the execution of complex tasks related to the organization and coordination of search and rescue operations at sea.

Search parameters

The coordinator should take into account the assessment of a ship's utility when selecting units for participation in a search or search and rescue operation. Selecting the appropriate ships will improve the conduct of the action and reduce its costs. The usefulness of a unit refers to the relationship between their effectiveness and risk. Every search and rescue operation should seek to maximise the effectiveness of its operations, while minimising risk.

An action's effectiveness is the factor that characterises the action's result. In the case of a search operation, one can speak of a fully effective action when the object of the search has been found; a partially effective action, if only certain objects have been located; and of an ineffective action, if unsuccessful at all under the assumption that the search area and object were reliable. A reliable area means that the search area boundaries have been correctly calculated and a reliable object means that it is present in this area.

The effectiveness of the search unit is characterized by its operational and technical parameters and the current situation in which it finds itself. The most important parameters include the following attributes. The presented set is not a closed list and updates are possible.

Vector $\mathbf{A_i}$ is the *i*-th attribute vector with six coordinates (description of the attributes: maximum category, category, weight, ratio, result).

Each attribute will be qualitatively evaluated by assigning it a category. Attributes are evaluated with division into two to four categories. Attributes receive weightings assigned by the expert method. The unit's effectiveness is the sum of the values obtained for each attribute class; however the seaworthiness shall be a negative sign (1).

$$S = \sum_{i=1}^{n} W(\mathbf{A_i}) \tag{1}$$

where:

$W(\mathbf{A_i})$ – result of the *i*-th attribute – last $\mathbf{A_i}$ vector coordinate ($i = 1, 2..., n$);

n – number of attributes.

The basic characteristics of the attributes have been presented below.

1. Time of arrival (t_a) – the unit's transit time to the reference point (datum) or search area. This parameter is directly related to the unit's speed, but it also strongly depends on the navigational situation of the unit. A vessel with a high maximum speed may be at anchorage, between obstacles to navigation or may be engaged in work, the termination of which may take a long time. In this case, despite a hypothetically short transit time between the present position and the position of survivors, the total arrival time can be much longer. Other vessels that are in immediate readiness to sail towards the survivor's position, despite a lower maximum speed or a greater distance away, could be able to reach the required position faster and therefore (t_a) will be smaller (2).

$$t_a = t_t + t_g \tag{2}$$

where:

t_a – time of arrival,

t_t – minimum transit time between two points,

t_g – stand by (readiness) time.

2. Maximum speed (v) – the speed at which the unit will be able to search the area. In the case of surface craft, this is usually between 15 and 45 km/h (8–25 knots on average). It will be two or three times faster when using a WIG craft (Wing-In-Ground Effect Craft), or up to several times faster when using airborne craft such as planes or helicopters. However those units are not the subject of this research work.
3. Elevation of observer's eye (h_o) – a point above the surface of the water from which the observer can see. In the case of non-professional rescue vessels (fishing boats, leisure crafts, passenger and cargo vessels) the elevation of observation varies from a few meters to several dozen meters. This value is important for the quality of the search operation, observation range and sweep width, which influences the search effort. Especially in heavy weather conditions causing high seas, a low-located observer has poor scanning capabilities, which may affect the effectiveness of the search of selected search sectors.
4. Autonomy of the unit (a) – the ability to stand ready for action at sea, without the need to replenish supplies. Some vessels may have restrictions related to e.g. domestic, coastal, sheltered or harbour shipping.
5. Manoeuvrability (m) – ability of the unit to perform individual manoeuvres during the search pattern, in particular the turn radius (or tactical diameter of circulation) and the ability to move sideways to a wave. Manoeuvrability is also related to the maritime seaworthiness, safety and the ability to follow an assumed route in given hydro-meteorological conditions (the main problem may be the direction and speed of the wind, and the direction and height of the waves). Low freeboard vessels may not be able to maintain the required course during search patterns. Vessels requiring a large turn radius when making turns may not be able to effectively search certain sectors.
6. Personnel (p_s) – the vast majority of ships have qualified maritime personnel (e.g. STCW (Standards of Training, Certification and Watchkeeping)

requirements), thanks to the unification of training standards, these people are able to organize and coordinate actions on scene and, above all, are able to cooperate with other units and the SAR mission coordinator. Although they do not carry out these tasks on a daily basis, they are familiar with the appropriate procedures. For vessels where the level of training may be limited (e.g. leisure crafts, fishing vessels) the ability to effectively carry out the SAR task is uncertain. Professional rescue ship crews are a distinct group due to them providing a rescue service on a daily basis.

7. Communication skills (p_j) – despite the same training standards, language skills have an impact on the possibility of effective verbal communication in different maritime areas. English is accepted as the standard working language, which can be used at dissimilar levels by ships' crew. The influence of native language and accent has a great impact on the quality of English pronunciation.
8. Draught (z_t) – the possibility of safe access to the search area and safe navigation, taking into account the relation of the ship's draft to the depth of the water area and the likelihood of the occurrence of shallows or navigation hazards. In some areas there may be sandbanks, nets, underwater rocks or wrecks that make safe navigation impossible for large vessels in particular.
9. Recovery (r) – the capability of the vessel to pick up a survivor after locating them. The search action is terminated as soon as the object has been detected, the rescue action starts from the moment the object is detected. Many ships are able to carry out a rescue operation once the object has been located. Difficulties may arise if there is: a high freeboard, a lack of lifting equipment or there are heavy weather conditions. Some units may not be able to stop in the vicinity of survivors (WIGs, aircrafts) but they may provide means of rescue, e.g. life rafts.
10. Number of survivors (r_n) – the attribute essential for mass evacuation; vessels, depending on their size, are able to take on board anywhere from a few to several hundred people. Airplanes, helicopters and WIGs are usually able to take on board only a few people.
11. Detection capability (d_i) – the unit may only have an observer or be additionally equipped with navigation radar, thermal detection cameras and/or distress signal direction finders.
12. Radio communication equipment (l_i) – depending on the trading area, communication equipment may be limited to UHF, VHF, MF or there maybe equipment with unlimited range for HF and satellite communications.
13. Seaworthiness (s_w) – limitation of the vessel's shipping due to the sea state.

Table 1 has presented an analysis of the performance of an exemplary merchant ship.

The classification of units in terms of their search-performance parameters is the first step in the selection of search and rescue units that may be involved in the operation. In addition to the search potential, an important factor is the current situation of the unit and verification on an ongoing basis of the degree of risk it may be burdened with. A vessel with a high effectiveness but high risk may therefore

Table 1. List of performance attributes of an exemplary merchant ship

Attribute	Attribute symbol	Maximum category	Allocated category	Weight	Factor	Result $W(\mathbf{A_i})$
A_1	t_a	3	3	0.175	0.0583	0.1750
A_2	v	4	2	0.175	0.0875	0.0875
A_3	h_o	4	3	0.12	0.0400	0.0900
A_4	d_i	4	2	0.13	0.0650	0.0650
A_5	l_i	4	4	0.06	0.0150	0.0600
A_6	a	2	2	0.09	0.0450	0.0900
A_7	m	3	1	0.05	0.0500	0.0167
A_8	p_s	3	2	0.04	0.0200	0.0267
A_9	r	2	2	0.07	0.0350	0.0700
A_{10}	r_n	3	3	0.01	0.0033	0.0100
A_1	z_t	2	2	0.03	0.0150	0.0300
A_{12}	p_j	2	2	0.05	0.0250	0.0500
A_{13}	s_w	4	1	−0.1	0.0025	−0.0025
					Effectiveness	0.7683

be less useful for action than a unit with a lower effectiveness factor but a small risk. The suitability of a vessel will consider both factors for the particular situation.

Risk of the unit

There is a risk in maritime transport, and this will always exist. The activities carried out by international organisations have a significant impact on the reduction of accidents and damage (Gucma, 2009). The same is true for the need to carry out search and rescue operations, often reaching a large scale (Koopman, 1980; IMO, 2002).

Each maritime craft is exposed to some risk and its involvement in the role of rescuer may change this level of risk. When selecting the units that may potentially be used in action, the coordinator has to take into account the current state of the unit's risk and monitor changes on an ongoing basis (Burciu & Starosta, 2008; Burciu, 2012).

In the event of multiple factors that may result in a loss of risk, all components are aggregated. One element of the SAR operation risk is the unit's risk (Burciu 2011).

The authors have focused on the situation of non-professional rescue crafts, and their usefulness, i.e. search effectiveness and the risk of their use. In the authors' opinion, the key problems that are universal for all SAR operations are the following:

1) Weather risks – deterioration of hydro meteorological conditions
   a) threat of loss/damage of the unit – capsizing, breakage, hull cracking from a wave, bad weather conditions and its unexpected change, with a well-known weather forecast (9 days is highly verifiable);
   b) wave resonance – when conducting search patterns, large and frequent alterations of a vessel's course resulting in changes of the wave angle to the vessel's axis;
   c) threat of loss or damage to the cargo – shift or overturning of cargo in bad weather conditions;
   d) risk to life of the crew.
2) Navigational risk – rapid change of the navigation route, route planning errors
   a) collision/contact hazard – poor coordination of multiple units during a SAR operation:
      - searching,
      - towage,
      - refloating of grounded ships,
      - others.
   b) the threat of grounding;
   c) environmental pollution danger (generally resulting from the above mentioned factors).
3) Action risk (rescue task) – when performing a rescue operation (lack of experience in such actions)
   a) the risk of ineffective performance of the task:
      - self planning, if needed;
      - the coordinator's instructions are not executed correctly (e.g. imprecisely following the search pattern, death of the survivors being searched for);
      - lack of experience in manoeuvring, the provision and fixing of a towing line, approaching other ships, winding of the towing line onto the propeller, danger to the life of the crew at mooring stations, breaking/loss of the towing line, rubbing the towing lines;
      - uncertainty of the data;
      - incorrect decisions of the coordinator;
      - inaccurate communication.
   b) risks of unit selection, poor assessment of the effectiveness and suitability of particular non-rescue units;
   c) time risk – stress in planning and taking decisions, reduced chances of persons in the water surviving;
   d) procedural risks – ignorance of procedures, unfit for current situation standard procedure, need for adjustment and modification, poor assessment of the evacuation sequence in relation to the ship and life-saving appliances and persons in the water;
   e) loss of own rescue boats and crew due to wrongly assessed sea conditions;
   f) fire spreading to own ship when extinguishing another.
4) Business risk (ship owner's) – change of vessel's route, stoppage of the voyage/deviation from route:
   a) risk of delay in the performance of the carriage contract (harbour costs, costs of consignees of cargo);
   b) threat of loss/damage to the cargo (especially sensitive cargoes);
   c) chartering risk (loss of another lucrative contract, logistical risks, delay or absence on laydays for the next contract).
5) Operational risk:
   a) exhaustion of fuel and fresh water stores;
   b) fuel consumption costs;
   c) overload/overheating of the engine during towing (Małyszko & Wielgosz, 2016a; 2016b; 2016c).

Qualitative risk assessment is a subjective evaluation based on experience and the principles of good seamanship practice. An expert method has been adopted to determine the degree of risk the ship may be exposed to. A unit may be as useful to the operation as its effectiveness ratio indicates, under the condition that it can deal well with the higher risk. A unit will be defined as less useful if it is more risk-sensitive.

Suitability of the unit

Selection of a search unit depends on its search potential, i.e. how quickly it is able to undertake an action, its search effectiveness, whether it is able to satisfactorily follow the planned route, shows correct communication skills, what risk level the ship will be exposed to, etc. Systematizing these factors and giving them weight will allow for the use of mathematical modelling leading to optimization of this selection and choice (definition of the unit's suitability class for a specific task in the SAR operation). That usefulness of the SAR unit will therefore be a determinant to facilitate the selection and choice of units when organizing SAR action (Billingsley, 1987). Let the family of functions be given (3) and called p_t:

$$\begin{aligned} p_t &: R \times S \to [0,1] \\ (r,s) &\mapsto s \cdot (1-r)^t \end{aligned} \tag{3}$$

where:

R, S – range [0, 1] of the values determining, in turn, the risk and effectiveness;
r, s – elements belonging to the set R, S;
t – factor determining the sensitivity to risk of a particular ship's type.

The p_t function is called the suitability of a SAR unit with t-factor, which transforms the value of risk and effectiveness into a coefficient belonging to the range [0, 1].

For each type of ship, the usability function (3) can be adjusted with the optimum coefficient (t). For this purpose, baseline data on the effectiveness and risk identified by experts are needed. To make it easier to assess the suitability of a particular vessel, usefulness classes can be introduced, e.g. Classes I, II, III and IV, which represent respectively the values in ranges e.g. ⟨1–0.78⟩, ⟨0.77–0.56⟩, ⟨0.55–0.34⟩ and ⟨0.33–0⟩. The expert defines risk limits for 4 discrete values, instead of any real values in the range ⟨0.1⟩. Optimising the selection of the suitability function is based on determining the sensitivity factor (t) in such a way that the value of the sum of the squares of the suitability function value deviation from the expert values is the smallest possible value. The sum calculated shall be in the form (4):

$$\begin{gathered} \sum_{i=1}^{n}\sum_{j=1}^{4}\int_{lu_{ij}}^{ll_{ij}}\left(m_{ij} - ef_i \cdot (1-r)^t\right)^2 \mathrm{d}\,r = \sum_{i=1}^{n}\sum_{j=1}^{4} A + B - C \\ A = m_{ij}^2\left(lu_{ij} - ll_{ij}\right) \\ B = 2m_{ij}ef_i\left(\frac{\left(1-lu_{ij}\right)^{t+1}}{t+1} - \frac{\left(1-ll_{ij}\right)^{t+1}}{t+1}\right) \\ C = ef_i^2\left(\frac{\left(1-lu_{ij}\right)^{2t+1}}{2t+1} - \frac{\left(1-ll_{ij}\right)^{2t+1}}{2t+1}\right) \end{gathered} \tag{4}$$

where:

n – number of units evaluated by experts,
i – the index of the rated unit,
j – suitability class number,
$lu(ll)$ – upper (lower) risk class for the i-th unit and j-th class of suitability,
m – centre value of the j-th class of suitability for the i-th unit,
ef – effectiveness of the i-th unit,
t – risk-sensitivity factor,
$A+B-C$ – partial error for *i-th* unit and *j-th* utility class.

For a certain fixed type of units (cargo ship, container vessel, low Gross Tonnage) the suitability function was selected (p_t). Based on the risk assessment of three sample vessels of the indicated type, their usefulness classes were determined. Then, on the basis of expert data and unit effectiveness, a non-linear parameter (t) of the usefulness function was optimized (p_t). The sensitivity factor analysis (t) showed that the lowest value of the sum of the partial errors of 0.0365 was assigned to the coefficient t = 0.85. The table 2 shows the data needed to optimize the $P_{0.85}$ suitability function.

The resulting $P_{0.85}$ function is therefore a tool to assess the suitability of a unit of a particular type in relation to the risk identified by the coordinator and the established effectiveness. A person who compares the usefulness of multiple units is only required to identify the risk of an individual unit. The risk assessment may be subjective or structured in accordance with the scheme. Determination of the risk value according to the assessment sheet shall be carried out by indicating the presence of certain features concerning the unit and the weather conditions. Each feature may have a certain weighting to

Table 2. Effectiveness, risk and suitability usefulness class of selected units

Ship name	Effectiveness	Risk		Usefulness class	Partial error
		From	To		$A + B - C$
Alfa	0.725	0	0	1	0
Alfa	0.725	0	50	2	0.009476826
Alfa	0.725	50	70	3	0.003022124
Alfa	0.725	70	100	4	0.001847351
Bravo	0.7700833	0	0	1	0
Bravo	0.7700833	0	40	2	0.002875981
Bravo	0.7700833	40	60	3	0.000449422
Bravo	0.7700833	60	100	4	0.00416307
Charlie	0.82958	0	10	1	0.0095902
Charlie	0.82958	10	30	2	0.000406693
Charlie	0.82958	30	50	3	0.001923185
Charlie	0.82958	50	100	4	0.011454059

Table 3. Ship's risk in terms of weight of example features

No.	Feature	Weight
1	Good weather forecasts	4
2	Well secured (stable) cargo	4
3	Good technical condition, no hidden defects	2
4	Confidence of own engine room	3
5	Experience of the crew	5
6	Acceptable dangers	5
7	Communication capability	5
8	Communication capability	3
9	Good, correct stability	5
10	Specific features of the cargo	4
11	Crew's physical condition, personal safety	5
12	No damage suspected	5
13	Business and economic impact	1

determine the level at which its presence or absence affects the unit's perceived risk.

The risk value can then be determined from the formula (5):

$$1-\frac{\sum_{i=1}^{13} c_i \cdot w_i}{\sum_{i=1}^{13} w_i} \tag{5}$$

where:
i – feature number;
c_i – logical value (0 or 1), of occurrence of the i-th feature;
w_i – weight of the i-th feature.

This study has examined the suitability of a medium-sized cargo vessel carrying cargo in containers. For this purpose, a set of data has been developed for three similar units in three situations with variable risk levels, with a total of nine cases. For each unit, the level of search effectiveness was determined and on the basis of the above mathematical relationships the suitability of the unit was determined, depending on its degree of risk. A chart (Figure 1) was developed for the type of cargo vessels researched. From the graph one can read the level of a unit's usefulness depending on its effectiveness and risk.

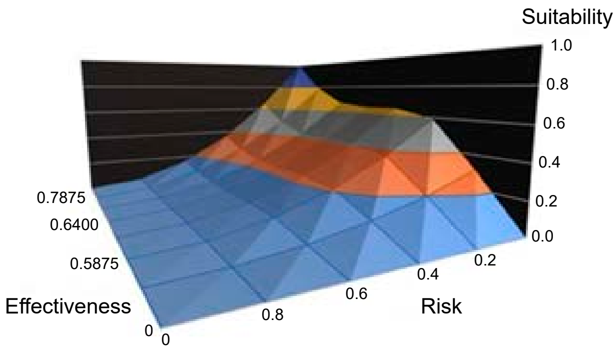

Figure 1. Characteristics of suitability for the search operation for the selected ship type

Conclusions

The ability to classify objects in terms of their potential in a conducted search action, or one being prepared, can be a valuable determinant for the coordinator, whose task is to organise and plan the action in an efficient and cost effective way. The method presented in this article defined the effectiveness, risk and suitability of a ship that can potentially be used in a SAR operation. This method, based on the preliminary expert assessment of the parameters mentioned above, supported by advanced mathematical analysis, may be an element of the decision support system in emergency situations on the ship or in the coordination centre, because it accelerates the initial selection of units and provides reliable determinants for a person planning a search, or search and rescue, operation. According to the authors, further work is required on the description of these coefficients and the extension of the study to a more diversified group of units that can be used for SAR actions, including airborne units and WIGs.

References

1. Billingsley, P. (1987) *Prawdopodobieństwo i miara*. Warszawa: Państwowe Wydawnictwo Naukowe (in Polish).
2. Burciu, Z. (2011) *Bezpieczeństwo w transporcie morskim i zarządzanie w akcji ratowniczej*. Gdynia: Wydawnicywo Akademii Morskiej w Gdyni (in Polish).
3. Burciu, Z. (2012) *Niezawodność akcji ratowniczej w transporcie morskim*. Warszawa: Oficyna wydawnicza Poliechniki Warszawskiej (in Polish)
4. Burciu, Z. & Starosta, A. (2008) SAR action effectiveness measures. *Journal of KONBIN* 3(6), pp. 137–144.
5. Gucma, L. (2009) *Wytyczne do zarządzania ryzykiem w transporcie morskim.* Szczecin: Wydawnictwo Naukowe Akademii Morskiej (in Polish)
6. IMO (2002) MSC/Circ.1023, MEPC/Circ.392, Guidelines for formal safety assessment (FSA) for use in the IMO rule-making process, 5 April 2002.
7. Koopman, B.O. (1980) *Search and Screening*. Alexandria: Military Operations Research Society.
8. Małyszko, M. & Wielgosz, M. (2016a) Analiza procesu decyzyjnego SAR DSS na przykładzie statku na mieliźnie. *Autobusy* 4 (in Polish).
9. Małyszko, M. & Wielgosz, M. (2016b) Decision support systems in search, rescue and salvage operations at sea. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 45(117), pp. 191–195.
10. Małyszko, M. & Wielgosz, M. (2016c) Wykorzystanie metody drzew decyzyjnych w systemie wspomagania decyzji kapitana statku w sytuacjach awaryjnych. *Autobusy* 12 (in Polish).