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Reliability of Search and Rescue Action

Zbigniew Burciu*

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Abstract

Determination of the reliability of Search and Rescue action system allows the SAR Mission Coordinator to increase the effectiveness of the action through the proper selection of operational characteristics of the system elements, in particular the selection of the rescue units and auxiliary units. The paper presents the example of the influence of water temperature and time of the action on the reliability of search and rescue action in the case of rescuing a survivor in the water.

1. Introduction

The functional integrity consisting of a particular number of elements with precisely defined relations between each another is defined as a system. The number of the essential system elements must be satisfactory to allow the integrity performing the assigned functions [4], [5], [6].

The operational system of SAR action (SOAR) is defined as a functional integrity consisting of the following elements:

– SAR Mission Coordinator,

– search and rescue units (surface units and aviation), assistant units, for example merchant vessels, with people taking part in SAR action, in particular the masters of rescue assistant and units.

The operational system of SAR action (SOAR) together with the search objects, in particular search persons – survivors, in the determined search area forms the SAR system.

The reliability of the system is the ability of this system to fulfil all the requirements necessary to perform the particular tasks for the specified period of time under the specified external conditions (with the particular exciting factors).

* Gdynia Maritime University, Faculty of Navigation, Al. Jana Pawla II 3, 81-345 Gdynia

The quantitative, mathematical description of the reliability of Search and Rescue (SAR) action system requires the determination of the reliability states of the SAR action system and SAR action elements [2], [3].

The set of reliability states of the system S and the sets of reliability states of the system elements S1,. . . , Sn in the simplest expressions are defined as the two-element sets [3]:

$$S=S1=\ldots=Sn=\{0,1\}$$

where:

1 – ability state of the system or the system element,

0 – disability state of the system or the system element.

The proper definition of the reliability states of SOAR and SAR systems elements is a separate difficult problem. For the Search and Rescue action system, consisting among others of the search units and search objects, the system failure is the random event that at least one of the system's characteristics – measurable (c_m) or immeasurable (c_n), do not fulfil the set of requirements, for example the search unit is not able to carry out a search on the recommended search courses [2].

The examples of measurable system characteristics are as follows: speed of search unit in particular hydro-meteorological conditions – maximum speed, minimum speed, boundaries of allowable speed in particular hydro-meteorological conditions.

Immeasurable characteristics are the system characteristics and functions, which can be described in qualitative, subjective way, for example: the search object should survive under the stated hydro-meteorological conditions if the survivor is on board life raft, not in the water, there is a chance to terminate the action with success.

2. Time to Survive of the Search Object in the Water

The Search and Rescue action is terminated with success, if the time to survive of the search objects is not less than the time of search action. The water temperature is the most important factor limiting the object's time to survive which influences the effectiveness of the rescue action [1], [7].

The sinking of „Titanic" in 1912 is a tragic example of the influence of low temperature effect. Partly due to not enough body protection against cooling, lack of life saving appliances and knowledge of rescue procedures 1489 persons drown in the water of zero degrees Celsius temperature before any help had come after one hour and fifty minutes. During the World War II the Royal Navy lost forty five thousand people, thirty thousand among them died due to hypothermia.

The rescue actions show that in the water of temperature below 5 degrees Celsius the dressed up survivors have fifty per cent chances to survive up to three hours [7].

With respect to the data presented by the UK National Immersion Incident Survey eighteen per cent of survivors exposed to the cooling causing loss of conciseness cannot be survived. In the case when the survivors are in the water of temperature from five to fifteen degrees Celsius for not less than thirty minutes, the losses can be even of thirty six per cent [7].

The survivability (reliability) of the search object depends on the kind of life saving appliances used: immersion suit, life raft or life boat. It also depends on the weather conditions: wind, sea state, water and air temperatures, sea currents and individual personal psycho-physical properties of the survivor.

Let S_p to be the random variable which means the time to survive of the search object. We can assume that the survivability function is defined as follows:

$$R_p(t) = P\left(S_p > t\right) = e^{-\lambda t^{\alpha}}, \quad t \geq 0 \tag{1}$$

It means, that the time to survive is of Weibull distribution.

The probability density function of the random variable is expressed as follows [3]:

$$f_p(t) = -R_p'(t) = \lambda \alpha t^{\alpha-1} e^{-\lambda t^{\alpha}}, \quad t \geq 0 \tag{2}$$

The important characteristic of the time to survive of search objects is the hazard rate function expressed as follows:

$$\lambda_p(t) = -\frac{d}{dt}\left[\ln R_p(t)\right] = \frac{f_p(t)}{R_p(t)}, \quad t \geq 0, \quad R_p(t) > 0 \tag{3}$$

The function of risk intensity is often called the risk [3].

We can notice that for $h \to 0$

$$\begin{aligned} P\left(t < T_p \leq t + h | T_p > t\right) &= \frac{P\left(t < T_p \leq t + h\right)}{P\left(T_p > t\right)} = \\ = \frac{F_p(t+h) - F_p(t)}{hR_p(t)} h &= \lambda_p(t) h + o(h) \cong \lambda_p(t) h \end{aligned} \tag{4}$$

It means that $\lambda_p(t) h$ is around the probability that the system state is changing from 1 to 0, in the time periods $(t, t+h)$.

For the survivability function, given by equation (1), the risk is a function expressed by equation (5):

$$\lambda_P(t) = \lambda\, \alpha\, t^{\alpha-1}, \quad t \geq 0 \tag{5}$$

Together with the characteristics expressed in the functions the number characteristics called the survivability (reliability) parameters are used. The important parameter is the expected value of the random variable T_P called the search object mean time to survive. From the definition of the expected value following equation (6) may be obtained.

$$E(T_P) = \int_0^\infty t\, f_P(t)dt \tag{6}$$

3. Reliability of SAR Action

The SAR action will be terminated with success, if the search object's time to survive is not less than the time of SAR action. The reliability of SAR action system is the number defined using the following expression:

$$R_{SAR} = P(S_P \geq T_D) \tag{7}$$

where:

R_{SAR} – reliability of the system of SAR action,
T_D – time of SAR action,
S_P – search objects time to survive.

From the equations (2) and (7) the following equation (8) may be obtained:

$$R_{SAR} = \int_0^\infty F_D(t)f_P(t) = \int_0^\infty [1 - R_D(t)]\lambda\,\alpha\, t^{\alpha-1}e^{-\lambda t^\alpha}dt \tag{8}$$

where:

$$R_D(t) = P(T_D > t) = R_Z(t)R_K(t), \tag{9}$$

is the function of operational reliability of SOAR system,

R_D – reliability of SOAR system (rescue and auxiliary units and coordinator),
R_Z – reliability of sub-system of units involved in action,
R_K – reliability of the coordinator activity,
T_D – time of operation of SOAR system.

Taking into consideration the time to survive of the search object in the water, the reliability of SOAR together with the equations (2), (8), (9) the reliability of the system of SAR action can be obtained:

$$R_{SAR} = \int_0^\infty [1 - R_Z(t)R_K(t)]\lambda\,\alpha\, t^{\alpha-1}e^{-\lambda t^\alpha}\, dt \tag{10}$$

4. The Influence of the Water Temperature for Search Object Survivability and Reliability of SAR Action

The probability that the survivor in the water will be rescued is given by the expression:

$$R_p(t) = P(S_P > t) \tag{11}$$

where:

S_P – time to survive of the survivor (random variable),

t – time counted from the beginning of emergency.

The value of this function means that in the time instant t the search object will stay alive. Following the number of observations, this function can be expressed in the form of equation [1]:

$$R_P(t) = e^{-0.1654 \quad t^{1.3213} e^{-0.071 temp.wody}} \tag{12}$$

This function of survivability (reliability function) determines the Weibull distribution with the following parameters:

$$\lambda = 0,1654 e^{-0,071\, temp.wody}, \alpha = 1.1654 \tag{13}$$

Finally the survivability function may be expressed as follows:

$$R_P(t) = e^{-\ \lambda\ t^{1.3213}} \tag{14}$$

For the water temperatures: five, ten, fifteen and twenty degrees Celsius, the values of the parameter λ and survivability functions are presented in Table 1.

Table 1

Survivability functions

Water temperature	5°C	10°C	15°C	20°C
Parameter λ	0.115974	0.081318	0.057016	0.0399795
Survivability functions $R_P(t) =$	$e^{-0.115974t^{1.3213}}$	$e^{-0.081318t^{1.3213}}$	$e^{-0.057016t^{1.3213}}$	$e^{-0.0399795t^{1.3213}}$

The drawings of the functions given in Table 1 are presented in Figure 1.

From the equations (10) and (14) we can obtain:

$$R_{SAR} = \int_0^\infty [1 - R_Z(t)R_K(t)]\, 1.3213\lambda t^{0.3213} e^{-\lambda t^{1.3213}}\, dt \tag{15}$$

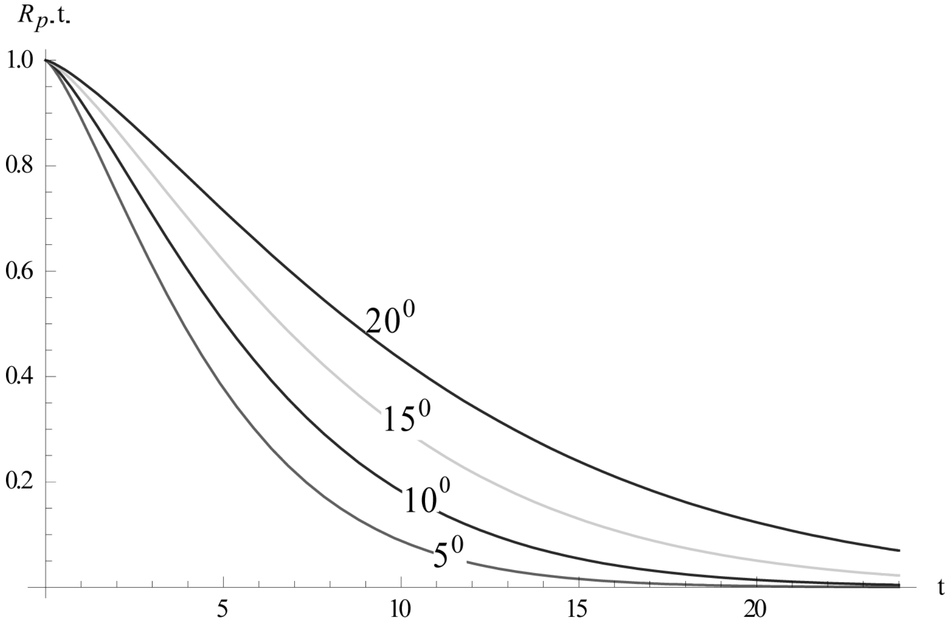

Fig. 1. Survivability functions for the object in the water for the water temperatures: five, ten, fifteen and twenty degrees Celsius

If the fleet of SAR units taking part in the SAR action operates reliably the equation (15) can be expressed in the simpler form:

$$R_{SAR} = \int_0^\infty [1 - R_K(t)]\, 1.3213\lambda t^{0.3213} e^{-\lambda t^{1.3213}}\, dt \tag{16}$$

If the SAR Mission Coordinator, which is acting reliably, makes a decision to terminate the SAR action in the time instant t_K the function of the coordinator's reliability is expressed in the form of equation (17):

$$R_K(t) = \begin{cases} 1 & \text{for} \quad t \le t_K \\ 0 & \text{for} \quad t > t_K \end{cases} \tag{17}$$

The equation (15) can now be expressed as follows:

$$R_{SAR} = \int_{t_K}^\infty 1.3213\lambda t^{0.3213} e^{-\lambda t^{1.3213}}\, dt \tag{18}$$

Based on the equation (18), in the case of rescuing a survivor in the water, assuming that the coordinator's acting and fleet of units involved in the SAR action performance is reliable, the SAR action reliability can be calculated in dependence on the time of action and sea water temperature. The SAR action reliability determined for this case is presented in Table 2.

Table 2

The SAR action reliability in the case of rescuing the survivor in dependence on the time of action and water temperature

Water temperature	5°C	10°C	15°C	20°C
SAR action reliability for t_K =1 hour R_{SAR} =	0.8904	0.9218	0.9440	0.9554
SAR action reliability for t_K =5 hours R_{SAR} =	0.3781	0.5056	0.6193	0.7098
SAR action reliability for t_K =10 hours R_{SAR} =	0.0880	0.1819	0.3021	0.4273
SAR action reliability for t_K =15 hours R_{SAR} =	0.0157	0.0543	0.1292	0.2335

5. Conclusions

The time to survive of the object in the water is the basic element influencing the SAR action reliability. Every SAR action should be carried out reliably by the rescue team and SAR action coordinator. The imprecise realisation of the SAR action by rescue units and lack of coordinators professionalism drastically decrease the SAR action reliability.

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