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Reliability and uncertainty in determining search area during Search-and Rescue action

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ABSTRACT

Sea accident occurring far away from the base of rescue ships generates – for SAR action coordinator - problem of determining search areas on the basis of information which sometimes may be incomplete and uncertain, e.g. an unknown number of launched life rafts and persons in water (PIW), as well as that of sending, to the area, a non-rescue ship nearest to place of occurrence of the accident. Variety of operational states of life rafts (number of persons on raft, drift anchor etc) produces different wind leeways as a result of which search areas for the objects would be in a different distance from the last known position (LKP), e.g.:
- search areas for life rafts without drift anchor, with an unknown number of castaways on board,
-search areas for life rafts with drift anchor, with an unknown number of castaways on board, and
- search area for the PIW.
To sweep determined search areas the coordinator makes use of a ship nearest to place of danger.
In this paper has been made an attempt to determine measures which would make SAR action coordinator capable of deciding which area should be searched first by using a ship nearest to place of the action.

Keywords: life raft; uncertainty; reliability; belief; probability; PIW (Person In Water); search; rescue; search area; SAR

AREAS DEPENDENT ON RELIABILITY OF OBJECTS AND UNCERTAINTY

Decision made in uncertainty conditions is that whose occurrence probability of consequences of a given decision is unknown. According to [8], risk is a random event of known distribution of its occurrence probability, whereas uncertainty constitutes such kind of randomness whose probability distribution is unknown.

An uncertainty condition may be a decision of unknown future consequences and probability of their occurrence or hazard - this is occurrence probability of losses resulting from a single undesirable event occurring in a given aeronautical system [6].

Along with increasing uncertainty level decisions are made often by people than machines [9]. Hence the more uncertain information the greater probability that the SAR action coordinator (team of experts) will take part in solving a decision problem.

Risk constitutes uncertainty associated with future events or results of decisions made by the coordinator. Results of decisions lead to occurrence of an unexpected loss or reaching success of performed SAR action.

Risk assessment is a process undertaken to calculate or determine risk for an organism, population, subpopulation or ecosystem, which results from its exposure to a given factor. Risk assessment takes into account identification of accompanying uncertainties, qualities of a factor as well as features of an exposed organism, population or ecosystem [7]

Knowledge of reliability characteristics of life-saving appliances, gained by SAR action coordinator [3, 4, 5], would make it possible to increase SAR action effectiveness by making decision as to sweeping the determined area first.

COORDINATOR'S DECISION BASED ON RELIABILITY OF AN ENDANGERED OBJECT

Sea accidents which still happen, make the SAR action coordinator facing the task of determination of search areas and sweeping them as fast as possible. Lack of knowledge in which operational state a given life raft is (different leeways), results in that many such areas may appear, e.g.:

- search area of a life raft without drift anchor and an unknown number of castaways,
- search area of a life raft with drift anchor and an unknown number of castaways,

Safety function – the life raft reliability R_{tr} can be expressed as follows[4, 5]:

$$R(x) = P(Z_{tr} > x) = 1 - \int_0^x f_Z(z)dz =$$

$$= 1 - \frac{\lambda_1^{\alpha_1}\lambda_2^{\alpha_2}}{3^{\alpha_1}2^{\alpha_2}B(\alpha_1, \alpha_2)}\int_0^x \frac{z^{\alpha_2 - 1}}{(\frac{\lambda_1}{3} + \frac{\lambda_2}{2}z)^{\alpha_1+\alpha_2}}dz \quad z > 0 \tag{1}$$

where:

R(x) – life raft reliability, safety function

Z_{tr} – maximum value of life raft speed (wind leeway)

x – wind speed

y – numerically expressed life raft speed

a, b – mean values of the independent non-negative random variables A, B

A – random variable of the gamma distribution G (α_1, λ_1)

B – random variable of the gamma distribution G (α_2, λ_2).

20-person life raft

Example:

Realization of a SAR action – the searching of 20-person life rafts with accounting for reliability: the life raft performance reliability determined for 48-knot wind speed (9°B), 5 h period of action and 10°C temperature of water.

Tab. 1. *Safety function, reliability values for selected 20-person life rafts [4]*

Type of object		Reliability R(48)
20-person life raft with drift anchor, 20 persons on board	–	0.7368
20-person life raft with drift anchor, 2 persons on board	–	0.5234
20-person life raft without drift anchor, 20 persons on board	–	0.7275
20-person life raft without drift anchor, 2 persons on board	–	0.5234
PIW (castaway in water)	–	0.4800

As results from the above presented reliability data, the 20-person life rafts with 2 persons on board are less safe (their reliability is lower) than those with 20 persons on board, excluding the PIW.

6-person life raft

Example:

Realization of a SAR action – the searching of 6-person life rafts with accounting for reliability: the life raft performance reliability determined for 52-knot wind speed (10°B), 5 h period of action and 10°C temperature of water.

Tab. 2. *Safety function, reliability values for selected 6-person life rafts [4]*

Type of object		Reliability R(48)
6-person life raft without drift anchor, 1 person on board	–	0.7785
6-person life raft without drift anchor, 6 persons on board	–	0.9962
6-person life raft with drift anchor, 1 person on board	–	0.7122
6-person life raft with drift anchor, 6 persons on board	–	0.9943
PIW (castaway in water)	–	0.480

As results from the above presented reliability data, the 6-person life rafts with 2 persons on board are less safe (their reliability is lower) than those with 20 persons on board, excluding the PIW.

UNCERTAIN INFERENCE IN SAR ACTION

As real situation – threat to life at sea, sea accident situation – never can be described in detail therefore information dealing with a danger at sea are usually unprecise, incomplete or uncertain. A way of inference depends on a kind of information at our disposal. Hence the following classification of inference methods was assumed [1, 2, 10]:

- methods of uncertain information processing,
- methods of incomplete information processing.

The classification is obviously conventional and working, and methods of both the groups can be used jointly. Among the methods of the first group prevails the numerical approach in which a.o. multi-value, fuzzy, probabilistic schemes, Dempster-Shafer (DS) theory called also belief function or mathematical theory of evidence, can be distinguished.

The DS theory is applied in the following cases:

- incomplete knowledge,
- belief updating,
- evidence composing.

One of the most important problems in incertainty processing is differentiation between uncertainty and lack of knowledge. The differentiation between the two things is just the aim of the DS theory in which are determined probabilities with which given hypotheses can be proved on the basis of information being at disposal. It shows one of the ways of mathematical probability application to subjective assessment [1, 2, 10], e.g. that made by SAR action coordinator.

The DS theory[1)] makes it possible to prove a given hypothesis on the basis of information at disposal:

- it allows to combine different pieces of evidence of information gained by SAR action coordinator – knowledge updating,
- new subsets of hypotheses, new probability values, are formed,
- realization – knowledge updating lasts as long as new pieces of evidence i.e. information achieved by SAR action coordinator are acquired.

$$Bel(A) \leq P(A) \leq Pl(A)$$

The association of two values: the belief Bel(A) and the likelihood Pl(A), forms the upper and lower limit of belief and likelihood of the hypothesis A.

As time is running the obtained new pieces of evidence, i.e. information achieved by SAR action coordinator, make the interval between the upper and lower limit, Bel(A) and Pl(A) narrower and narrower, causing uncertainty of information smaller.

The measure m is constrained by the conditions:

$$m(\emptyset) = 0$$

$$\sum_{A \subseteq \Theta} m(A) = 1$$

The function m is called the basic assignment of probability (differentiating frame) for the set of all hypotheses, Θ.

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1) Dempster-Shafer theory is widely described in literature and internet sources.

The belief function is:

$$\mathrm{Bel}(A) = \sum_{B \subseteq A} m(B)$$

for every $A \subseteq \Theta$.

The likelihood function is:

$$\mathrm{Pl}(A) = \sum_{B \cap A \neq \emptyset} m(B)$$

for every $A \subseteq \Theta$.

The synthesis of knowledge, i.e. the combining of knowledge achieved from various sources, can be expressed as follows:

$$m(A) = \frac{\sum_{A_i \cap B_j = A} m_1(A_i) m_2(B_j)}{1 - \sum_{A_i \cap B_j = \emptyset} m_1(A_i) m_2(B_j)}$$

Application of DS theory which makes it possible to combine (integrate) information achieved from different sources and concerning identification of hazard to life at sea, constitutes an element of SAR action planning and managing.

Search areas loaded with uncertain information

SAR action planning by its coordinator will met initially a lack of sufficient information which may be imprecise, incomplete or uncertain.

The basic question for the coordinator is: who is searched and whether a castaway (- s) are in water or placed on life saving appliances and which ones. The DS theory application makes it possible e.g. to determine priorities of sweeping sequence of the determined search areas.

The example scenarios of the DS theory application, which make it possible to account for information flowing to SAR action coordinator, i.e. pieces of evidence of information reaching him and updating his knowledge (computer aided), are as follows:

- Information on reception a SOS signal.
- Additional information on:
  - an object calling for help,
  - life saving appliances (rules, knowledge, practice, coordinator's experience).

<u>Differentiating frame, result</u>

1. kind of object facing danger at sea:
   a. merchant ship,
   b. fishing ship,
   c. yacht – sporting boat,
   d. ferry.

The largest probability value was obtained for merchant ship: $P_{(SH)} = 0.9760$ [4]

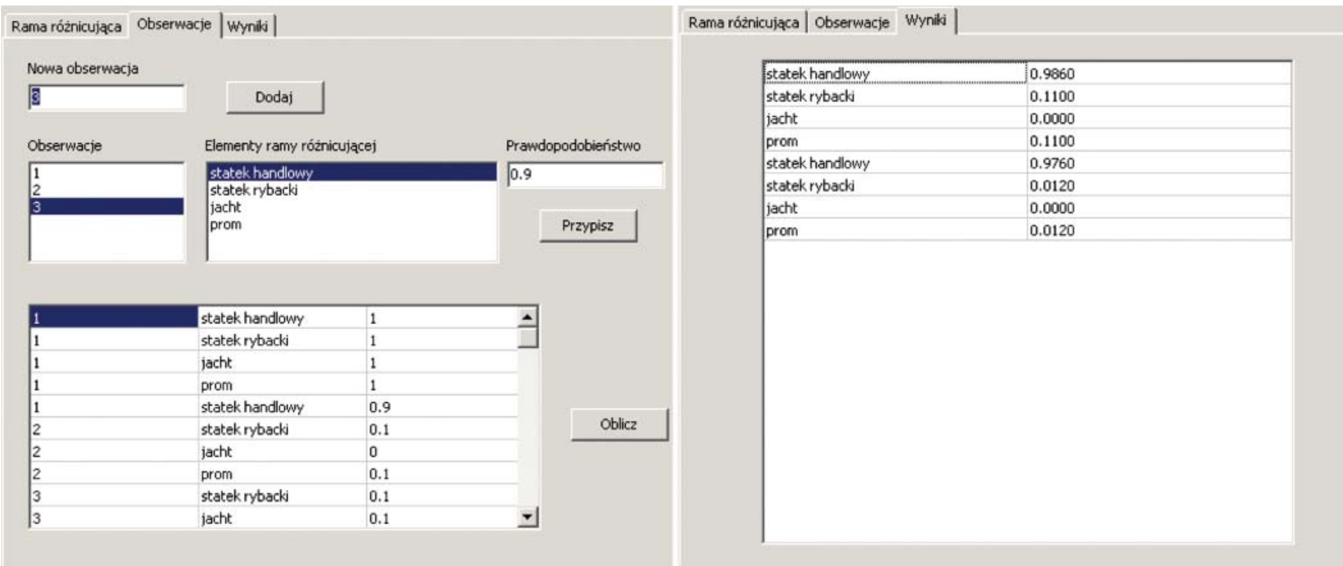
<u>Differentiating frame, result</u>

2. Sea accident (of merchant ship), castaways and life rafts in water:
   a. 6-person life raft,
   b. 10-person life raft,
   c. 20-person life raft,
   d. the PIW.

The largest probability value was obtained for 20-person life raft: $P_{(tr\ 20)} = 0.4240$, and, $P_{(PIW)} = 0.4240$.

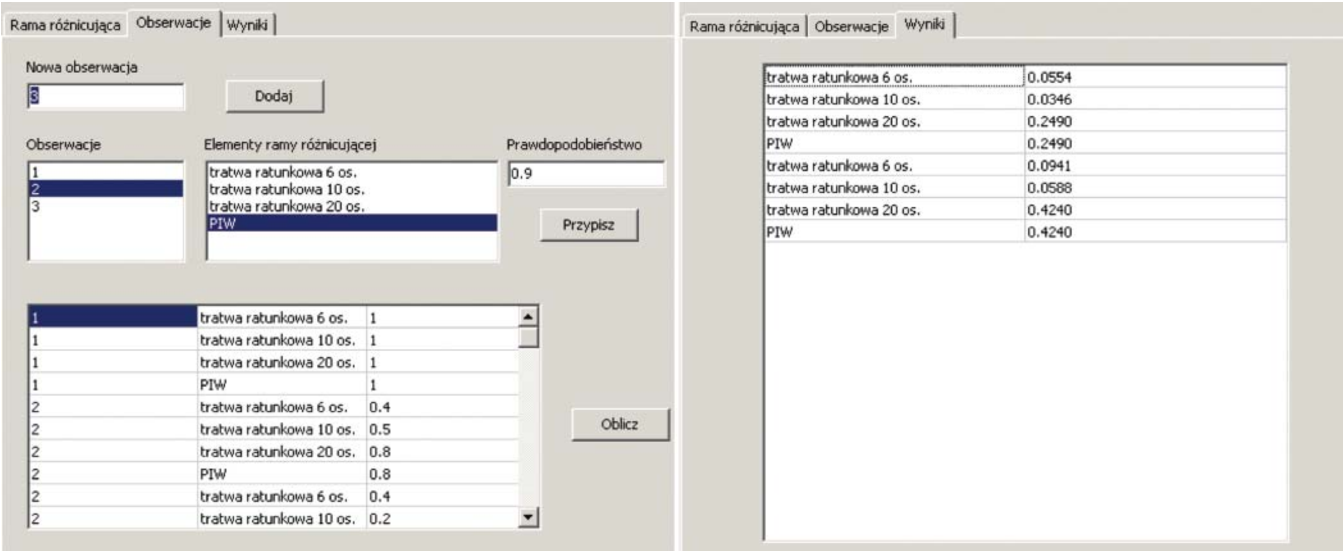
<u>Differentiating frame, result</u>

3. Castaways and 20-person life rafts in water:
   a. 20-person life raft with drift anchor – 20 persons on board,
   b. 20-person life raft with drift anchor – 2 persons on board,
   c. 20-person life raft without drift anchor – 20 persons on board,
   d. 20-person life raft without drift anchor – 2 persons on board,
   e. a castaway in water, PIW.



Translation:
Rama różnicująca - Differentiating frame, **Obserwacje** - Observations, **Wyniki** - Results;
Nowa obserwacja - New observation, **Dodaj** - Introduce;
Obserwacje - Observations, **Elementy ramy różnicującej** - Elements of differentiating frame, **Prawdopodobieństwo** - Probability;
Przypisz - Attribute;
statek handlowy - merchant ship, **statek rybacki** - fishing ship, **jacht** - yacht, **prom** - ferry;
Oblicz - Calculate

Fig. 1. *Differentiating frame for a kind of object facing danger at sea*



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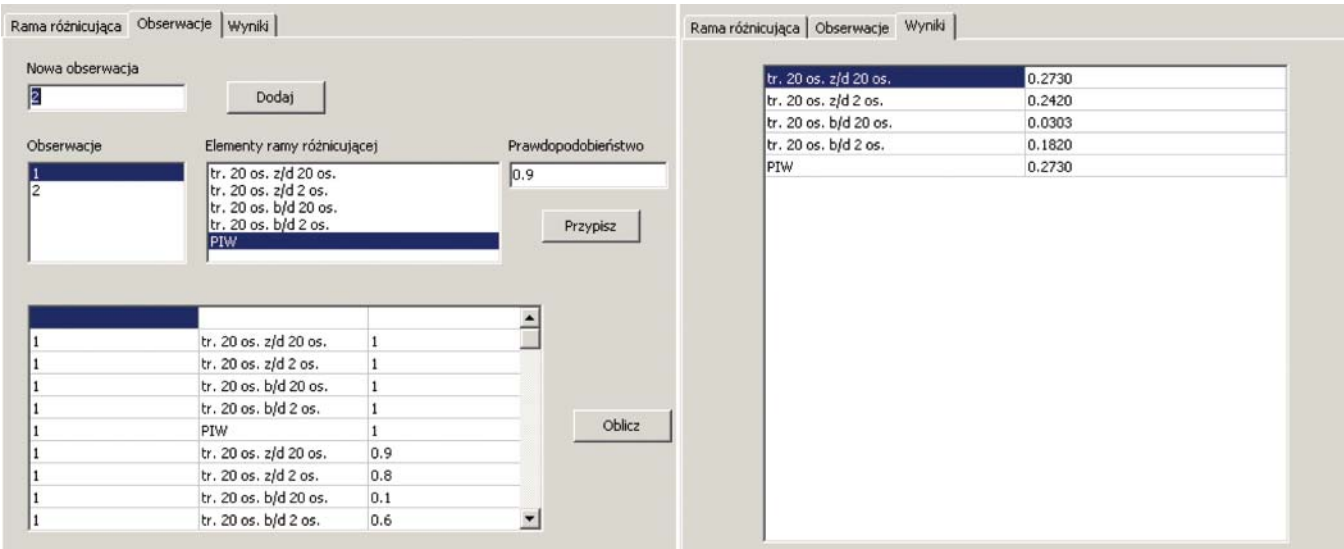
Przypisz - Attribute;
tratwa ratunkowa 6 os. - 6-person life raft, **tratwa ratunkowa 10 os.** - 10-person life raft, **tratwa ratunkowa 20 os.** - 20-personlife raft, **PIW** - the PIW (person in water);
Oblicz - Calculate

Fig. 2. *Differentiating frame for a sea accident – castaways and life rafts in water [4]*



Translation:
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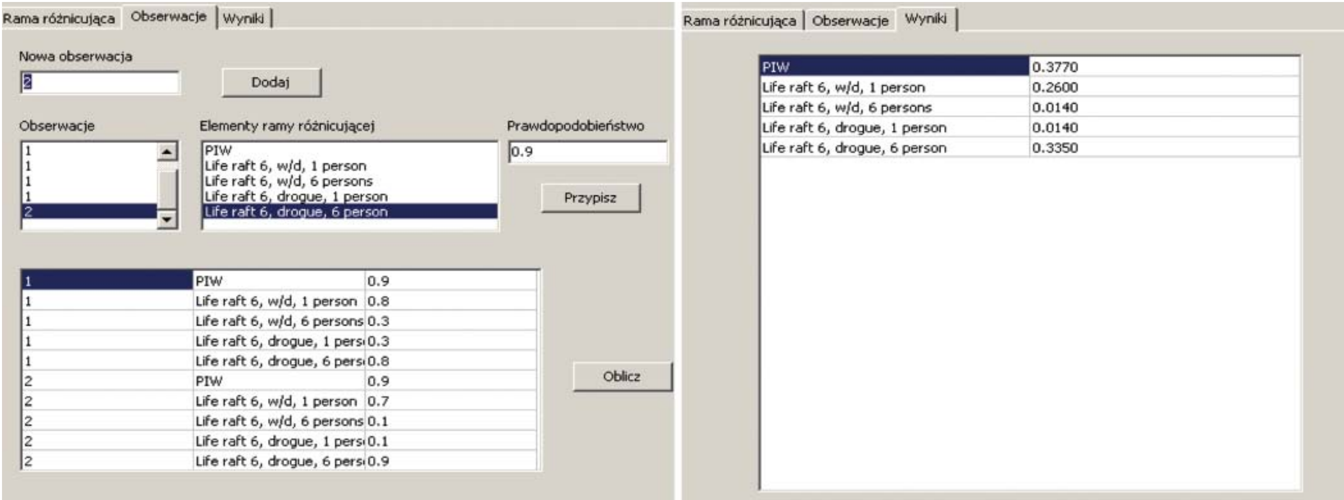
Nowa obserwacja - New observation, **Dodaj** - Introduce;
Obserwacje - Observations, **Elementy ramy różnicującej** - Elements of differentiating frame, **Prawdopodobieństwo** - Probability;
Przypisz - Attribute;
tr. 20 os. z/d 20 os. - 20-person life raft with drift anchor - 20 persons on board, **tr. 20 os. z/d 2 os.** - 20-person life raft with drift anchor - 2 persons on board, **tr. 20 os. b/d 20 os.** - 20-person life raft without drift anchor - 20 persons on board, **tr. 20 os. b/d 2 os.** - 20-person life raft without drift anchor - 2 persons on board, **PIW** - the PIW (person in water);
Oblicz - Calculate

Fig. 3. *Differentiating frame for 20-person life raft and castaways in water [4]*

Tab. 3. *The calculated values of the probability m for the example situation: 20-person life raft and a castaway in water*

Kind of object		**Probability** [m]
20-person life raft with drift anchor – 20 persons on board	–	0.2730
20-person life raft with drift anchor – 2 persons on board	–	0.2420
20-person life raft without drift anchor – 20 persons on board	–	0.1820
20-person life raft without drift anchor – 2 persons on board	–	0.0303
PIW – a castaway in water	–	0.2730



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Nowa obserwacja - New observation, **Dodaj** - Introduce;
Obserwacje - Observations, **Elementy ramy różnicującej** - Elements of differentiating frame, **Prawdopodobieństwo** - Probability;
Przypisz - Attribute;
Oblicz - Calculate

Fig. 4. *Differentiating frame for 6-person life raft [4]*

Tab. 4. *The calculated values of the probability m for the example of 6-person life raft and a castaway in water (PIW)*

Kind of object		**Probability** [m]
6-person life raft without drift anchor – 1 person	–	0.260
6-person life raft without drift anchor – 6 persons	–	0.014
6-person life raft with drift anchor – 1 person	–	0.014
6-person life raft with drift anchor – 6 persons	–	0.335
PIW – a castaway in water	–	0.377

The obtained results show importance and sweeping sequence of the search areas. The areas were determined by using the author's method for the following data: a castaway in water (PIW) and 20-person life raft.

For the SAR action coordinator it may serve as an indication as to sequence in which a given search area should be swept. The sweeping should start from the PIW's area (P = 0.273), next should be swept the areas of the life rafts with drift anchor, both fully (100%) manned (P = 0.273) and with 2 persons on board (P = 0.242), and then the areas of the life rafts without drift anchor, both with 2 persons on board (P = 0.182) and fully manned (P = 0.0303).

Example:

6-person life raft; the PIW;
52 kn wind speed; 5 h search period.

The presented method is one of many which make SAR action coordinator capable of deciding which search area should be swept in the first place.

As during SAR action an uncertainty of information and unreliability of life saving appliances take place a measure has been proposed to account for the parameters. The measure of uncertainty and unreliability of a searched object, M_{nz}, is as follows [4]:

$$M_{nz} = m \cdot (1 - R_o)$$

where:
M_{nz} – measure of uncertainty and unreliability,
m_{tr} – life raft uncertainty measure,
R_o – object reliability (of life raft or PIW)
$1 - R_o$ – object unreliability.

In Tab. 5 is presented the decision matrix for 20-person life raft and PIW, which makes it possible to make decision as to choice of area sweeping sequence, depending on R, m, R · m, $M_{nz} = m \cdot (1 - R_o)$, and in Tab. 6 – the same for 6-person life raft and PIW.

Tab. 5. *The decision matrix for 20-person life raft and PIW [3, 4]*

For: - 48 kn wind speed (10°B), - 5 h period of action, - 10°C temperature of water			**Reliability R**	**1 - R**	**Uncertainty [m]**	**R · m**	**(1-R) · m**	**Decision - making sequence on sweeping search area depending on parameters**			
								R	**m**	**R · m**	**M_{nz} = (1-R_o) · m**
Person in water (PIW)			0.4800	0.520	0.2730	0.131	**0.142**	1	1	1	**1**
20-person life raft	with drift anchor	10%	0.5234	0.4766	0.2420	0.127	**0.115**	2	3	3	**2**
		100%	0.7275	0.2725	0.2730	0.199	**0.074**	4	2	2	**4**
	without drift anchor	10%	0.5234	0.4766	0.1820	0.095	**0.087**	2	4	4	**3**
		100%	0.7368	0.2632	0.0303	0.022	**0.008**	3	5	5	**5**

__Tab. 6.__ The decision matrix for 6-person life raft and PIW [3, 4]

For: - 52 kn wind speed (10°B), - 5 h period of action, - 10°C temperature of water			Reliability R	1 - R	Uncertainty [m]	R · m	(1-R) · m	Decision - making sequence on sweeping search area depending on parameters			
								R	m	R · m	$M_{nz} = (1-R_o) \cdot m$
Person in water (PIW)			0.4800	0.520	0.377	0.181	**0.196**	1	1	1	**1**
6-person life raft	with drift anchor	10%	0.7122	0.288	0.014	0.01	**0.011**	2	4	5	**3**
		100%	0.9943	0.006	0.335	0.333	**0.002**	3	2	1	**4**
	without drift anchor	10%	0.7785	0.221	0.260	0.202	**0.057**	2	3	2	**2**
		100%	0.9962	0.004	0.014	0.014	**0.00006**	4	4	4	**5**

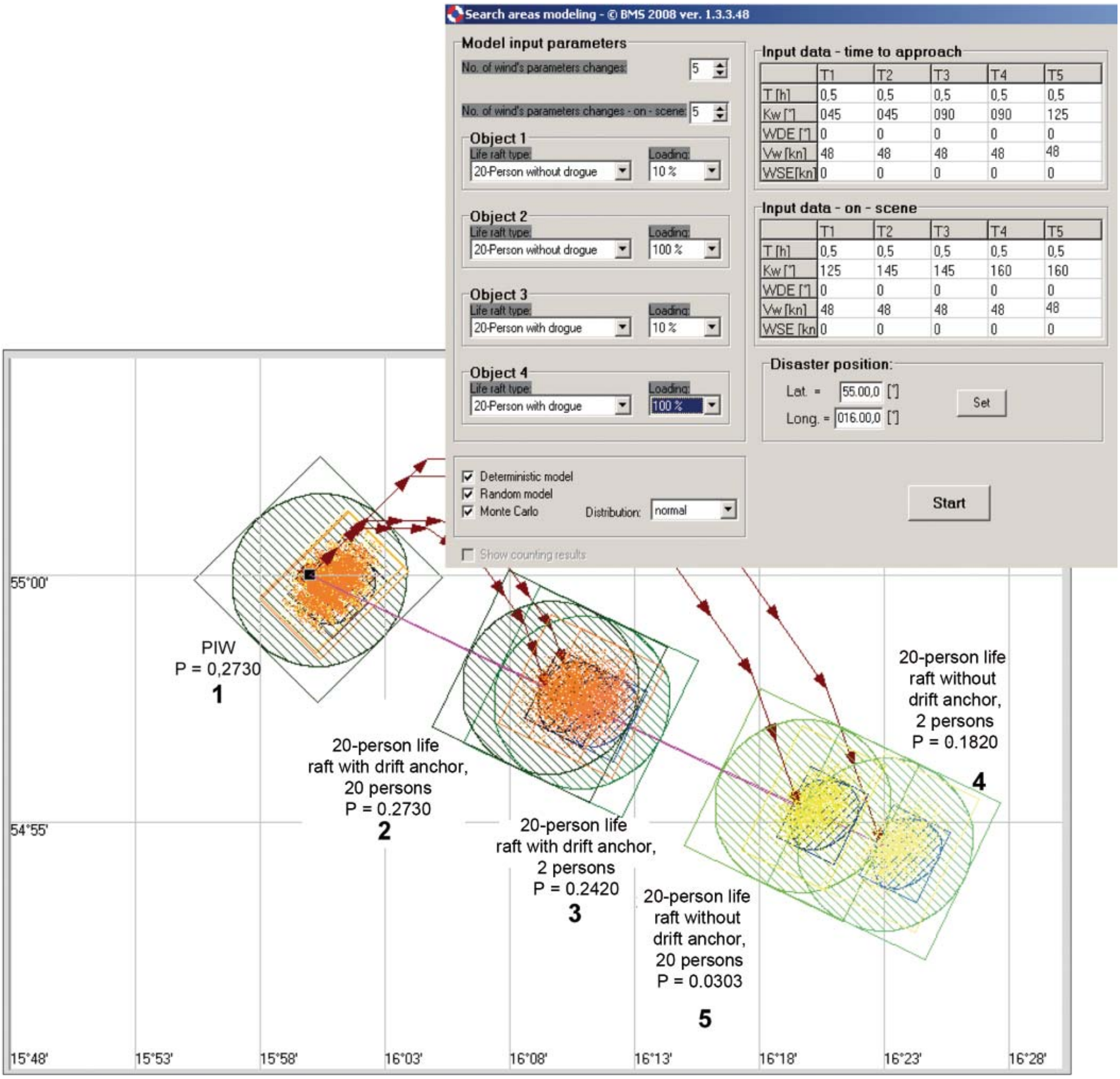

__Fig. 5.__ The determined search areas for 20-person life raft both with drift anchor and without it as well as for a castaway in water[2]), with assigned numbers of sweeping sequence and values of the occurrence probability m [4]

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2) The Search and Rescue Computer Aided Sysytem SARCAS 2000 for supporting life saving action at sea, Research project No. 2288/C.T12-9/98 sponsored by KBN (State Committee for Scientific Research). Project manager: Z. Burciu.

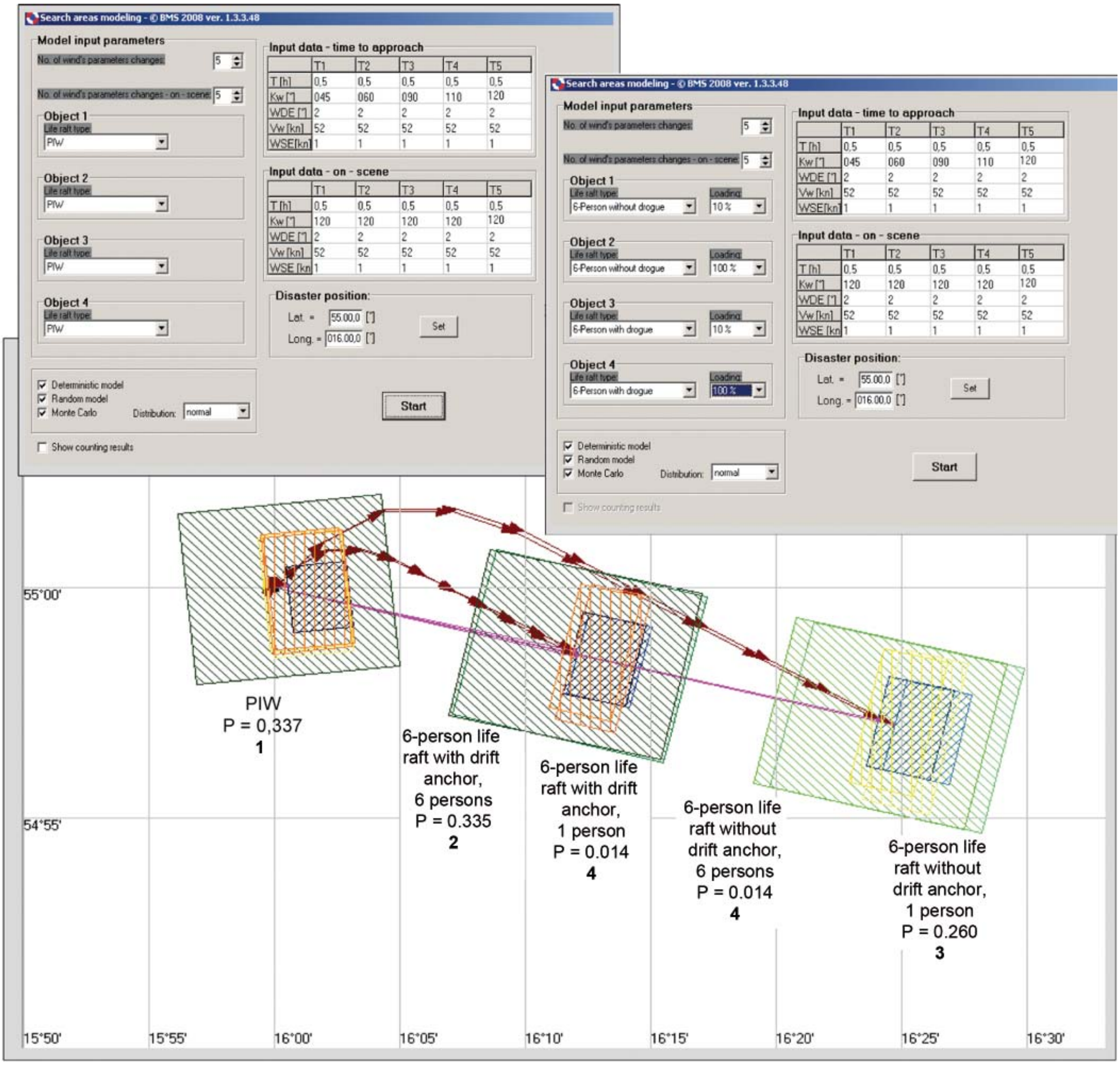


Fig. 6. The determined search areas for 6-person life raft both with drift anchor and without it as well as for a castaway in water[3]), with assigned numbers of sweeping sequence and values of the occurrence probability m [4]

Tab. 7. The decision matrix for 6-person life raft and PIW [3, 4]

For: - 52 kn wind speed (10°B), - 5 h period of action, - 10°C temperature of water			Decision - making sequence on sweeping search area depending on parameters			
			R	**m**	**R · m**	$M_{nz} = (1-R_o) \cdot m$
Person in water (PIW)			**1**	1	1	**1**
6-person life raft	with drift anchor	10%	**2**	4	5	**3**
		100%	**3**	2	1	**4**
	without drift anchor	10%	**2**	3	2	**2**
		100%	**4**	4	4	**5**

3) The Search and Rescue Computer Aided Sysytem SARCAS 2000 for supporting life saving action at sea, Research project No. 2288/C.T12-9/98 sponsored by KBN (State Committee for Scientific Research). Project manager: Z. Burciu.

Tab. 8. The decision matrix for 20-person life raft and PIW, where wind speed was accounted for.Sweeping sequence of the determined search areas

For: - 48 kn wind speed (10°B), - 5 h period of action, - 10°C temperature of water			Decision - making sequence on sweeping search area depending on parameters			
			R	m	R · m	$M_{nz} = (1-R_o) \cdot m$
Person in water (PIW)			1	1	1	1
6-person life raft	with drift anchor	10%	2	3	3	2
		100%	4	2	2	4
	without drift anchor	10%	2	4	4	3
		100%	3	5	5	5

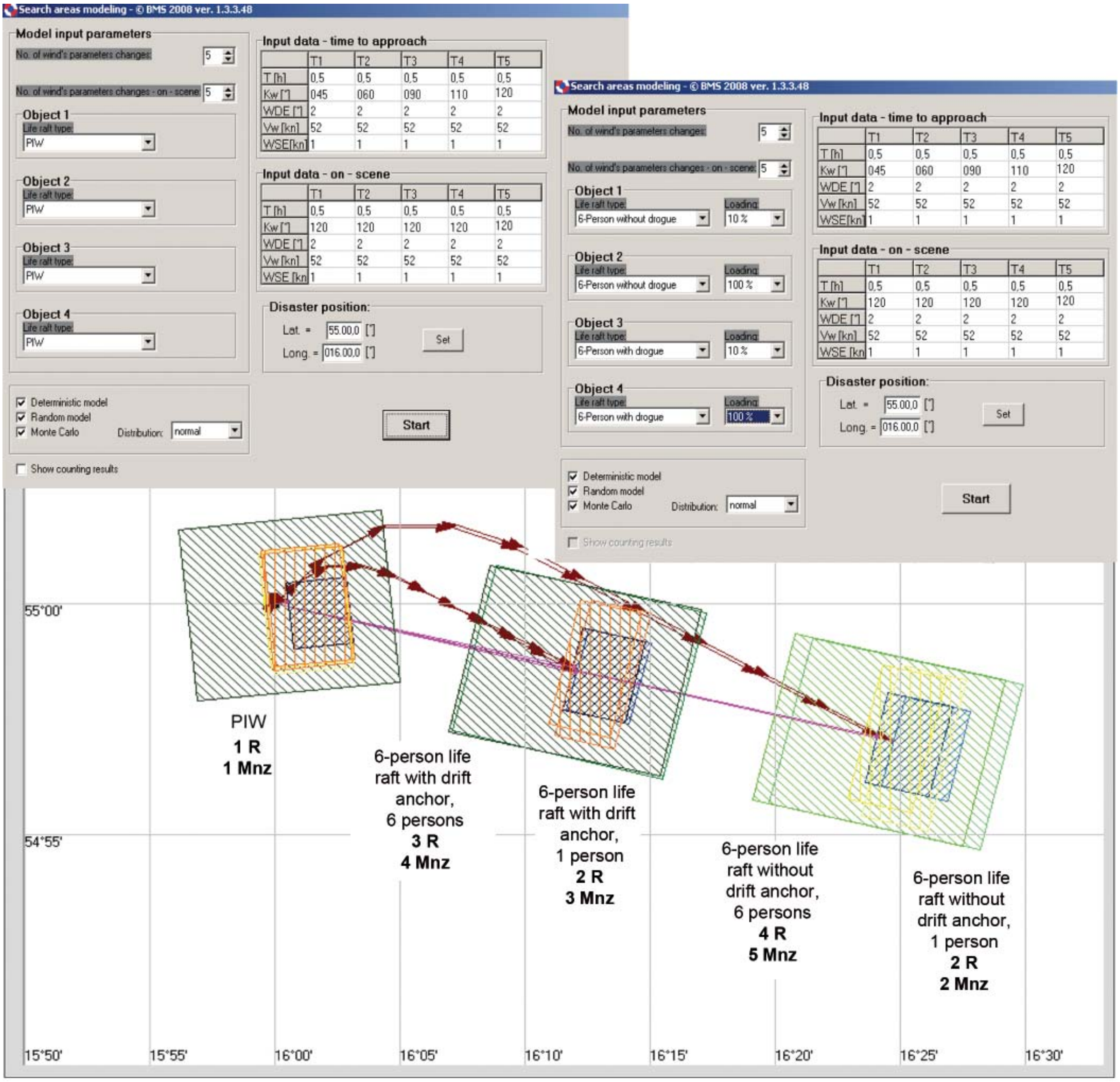
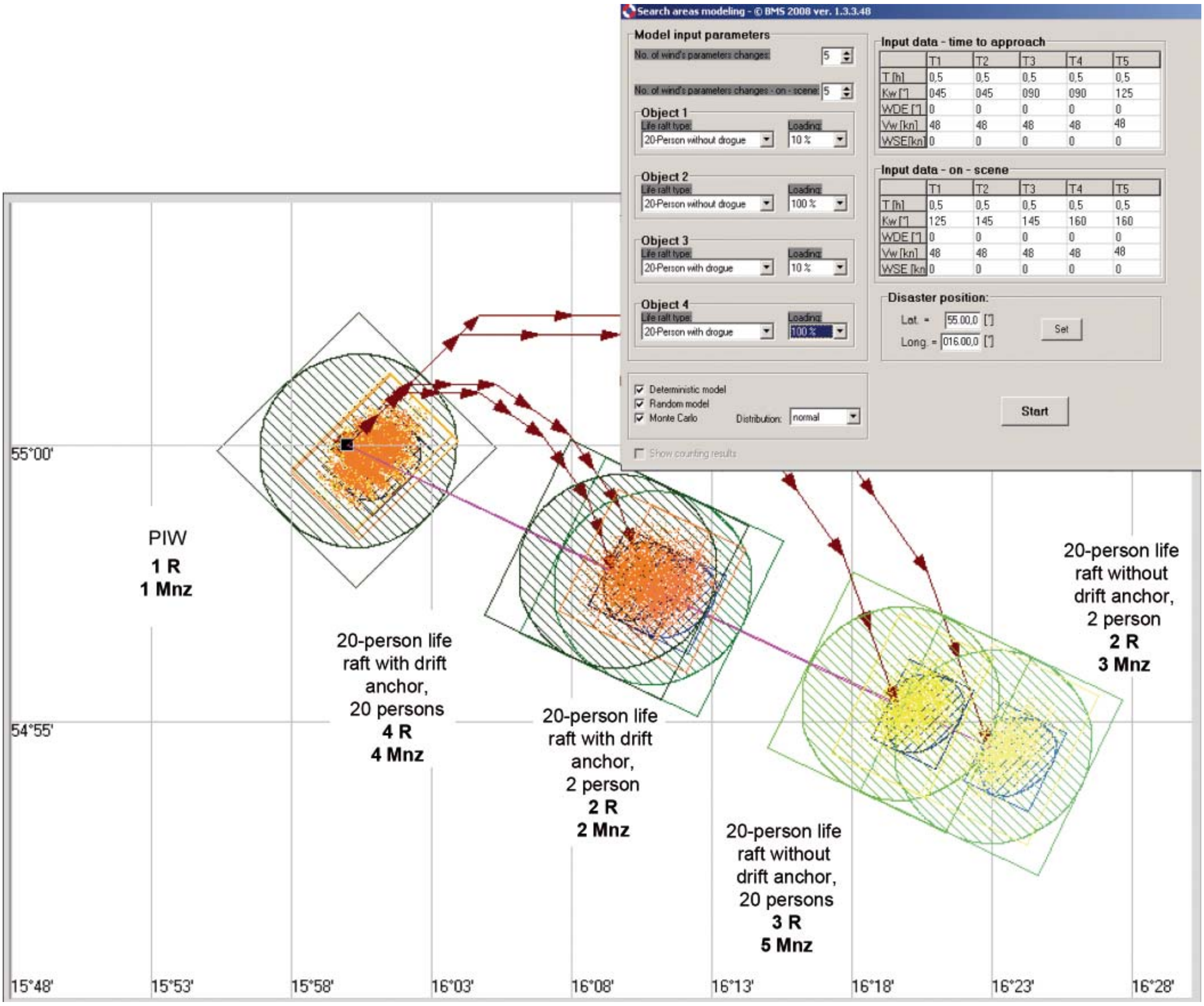


Fig. 7. The search areas determined for 6-person life raft both with drift anchor and without it as well as for a castaway in water[4]. Sweeping sequence of the determined areas depending on R, M_{nz}

[4] The Search and Rescue Computer Aided Sysytem SARCAS 2000 for supporting life saving action at sea, Research project No. 2288/C.T12-9/98 sponsored by KBN (State Committee for Scientific Research). Project manager: Z. Burciu.



Input data - time to approach:

	T1	T2	T3	T4	T5
T [h]	0,5	0,5	0,5	0,5	0,5
Kw [°]	045	045	090	090	125
WDE [°]	0	0	0	0	0
Vw [kn]	48	48	48	48	48
WSE [kn]	0	0	0	0	0

Input data - on - scene:

	T1	T2	T3	T4	T5
T [h]	0,5	0,5	0,5	0,5	0,5
Kw [°]	125	145	145	160	160
WDE [°]	0	0	0	0	0
Vw [kn]	48	48	48	48	48
WSE [kn]	0	0	0	0	0

Fig. 8. *The search areas determined for 20-person life raft both with drift anchor and without it as well as for a castaway in water*[5]*. Sweeping sequence of the determined areas depending on R,* M_{nz}

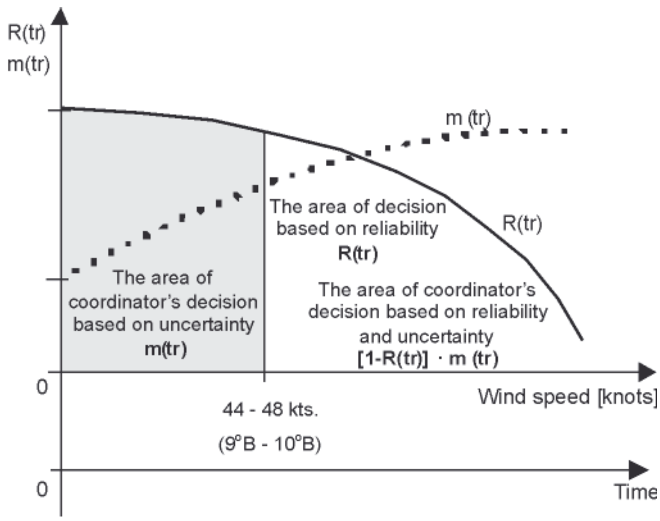


Fig. 9. *Areas of decision – making based on uncertain information and reliability of life raft [4]*

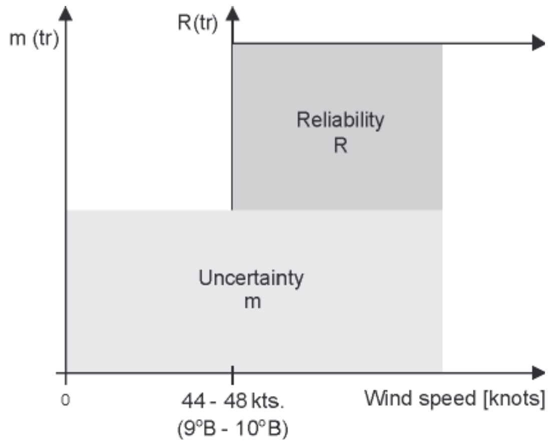


Fig. 10. *Areas of uncertainty and reliability measures for the presented example [4]*

5) The Search and Rescue Computer Aided Sysytem SARCAS 2000 for supporting life saving action at sea, Research project No. 2288/C.T12-9/98 sponsored by KBN (State Committee for Scientific Research). Project manager: Z. Burciu.

The areas of decision - making by SAR action coordinator:

- in the case of wind speed lower than 48 knots the information uncertainty m_{tr} should serve as the decison measure.
- in the case of SAR action planning at the wind speed greater than 48 knots the coordinator should take into account both the reliability of life saving appliances and the measure of uncertainty and unreliability, $M_{nz} = m \cdot (1 - R_o)$.

The reliability of person in water, $S_p(t)$, depends on time and water temperature [3, 4].

CONCLUSIONS

Both the above presented solution in which the reliability model – functions of searched object, was used, and that of Dempster and Shafer, make the coordinator capable of taking decision on sweeping first a search area in which an object of a low reliability is located (safety function) and when it is simultaneously quite sure that it is placed just in the area.

BIBLIOGRAPHY

1. Biernacki M., Tarnowski A., Truszczyński O.: *Risk in aeronautical operations and a method of its optimization* (in Polish). [in:] *Psychology of hazardous behaviour. Concepts, research, practice* (in Polish) by Goszczyńska M., Studenski R. (Ed.), Wydawnictwo Akademickie „Żak" („Żak" academic publishing house),Warsaw, 2006.
2. Bolc L., Brodziewicz W., Wójcik M.: *Fundamentals of processing uncertain and incomplete information* (in Polish), PWN (State scientific publishing house), Warsaw, 1991.
3. Burciu Z.: *Bayesian methods in reliability of search and rescue action*. Polish Maritime Research, No. 4(67), Vol 17, Gdańsk, 2010
4. Burciu Z., *Safety in shipping by sea - Search and Rescue (SAR)*. A monograph (to be published)
5. Burciu Z., Grabski F.: *The experimental and theoretical study on the reliability of life rafts.* Submitted for publication in Reliability Engineering & System Safety, Elsevier
6. Makarowski R.: *Risk limits. Psychological paradigm* (in Polish). Oficyna Wydawnicza „Impuls" („Impuls" Publishing House). Cracow, 2006
7. Seńczuk W.: *Contemporary toxicology* (in Polish). PZWL (Medical publishing house), Warsaw, 2005
8. Sikora W.: *Operational research* (in Polish). Polskie Wydawnictwo Ekonomiczne. (Polish economic publishing house) Warsaw, 2008
9. Syska E.: *Cash-Flow sources from using informatic systems* (in Polish). Gazeta IT, e-czasopisma (e-publications) 22.05.2003
10. Tołwiński M.: *Inferencing in uncertainty conditions*. *Dempster-Shafer theory.* (in Polish). Electronic script: aragorn. pb.bialystok.pl/~radev/ai/sosn/tolwinski.doc 25.03.2010.

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