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Logistic Aspects in the Methodology of Efficiency Evaluation of Transport System on the Example of Air SAR Service

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The article presents the concept of building a transport system model based on the example of maritime aviation SAR service. The applied methodology of efficiency assessment lists the individual elements of the system and then, after applying the mathematical formalization, aims to describe the structure of the system. Both the transport means and the system components necessary for the transport task have been parameterized, with particular emphasis on logistic aspects that support the rescue system.

Keywords: transport system, logistic support, system modelling.

1. INTRODUCTION

The article discusses the methodology of modeling the SAR transport system (Search and Rescue). The effectiveness of the system is measured by the proposed coefficient of the achieved aviation effect. The SAR action aviation effect is a system operation condition that allows the system to be identified as a fit or unfit to performing its dedicated task. A rescue task should be resolved as quickly as possible regardless of the outcome of the action (positive - finding a survivor or survivors, negative - not finding them). The system is effective when it allows, in the shortest possible time without generating unnecessary costs, responding to a rescue task in the aspect of finding and rescuing people, property or obtaining unambiguous confirmation that saving people and property is impossible despite the involvement of maximum forces and resources. The unambiguity of the information obtained from the rescue operation is the achievement of a positive air effect. The article presents a description of rescue operations carried out in the years 1995-2000 in the area of SAR liability. At the same time, further research on reports on rescue operations in subsequent years is continued, taking into account the analyzes carried out so far by both the authors of the article and based on literature analysis of other authors dealing with SAR issues [1], [3], [6], [7], [8], [11].

2. SAR TRANSPORT SYSTEM

The SAR system according to Annex 12 to the International Aeronautical Convention (Chicago 1944) [5] is assigned to provide assistance to crews and passengers of aircrafts that have failed outside the airport by sea or land and to those injured as a result of these accidents. The task of the system is to receive and analyze information on the threat to the safety of crew and passengers of an aircraft, seafarers and to determine the degree of threat; notifying affected institutions about the threat; alarming and directing the system forces and measures, as well as organizing the interaction of these forces during the action; striving to quickly find a place for air, sea and survivors; providing assistance to survivors and persons who have been harmed as a result of an aviation or maritime accident; evacuation of survivors from the scene of the accident. Countries that are signatories to the Convention on maritime security have committed to maintain 24-hour readiness of air and sea rescue services in their territorial waters and high seas. They operate on the basis of such international standards as:

- International Convention on Maritime Search and Rescue in Hamburg on April 27, 1979

(SAR 79, as amended) (Journal of Laws of 1988 No. 27, item 184),

- International Convention for the Safety of Life at Sea, 1974 (SOLAS- 74) (Journal of Laws of 1984 No. 61, item 318 with subsequent amendments, resolutions and protocols), (SOLAS - Safety of life at Sea).

It is the duty of every state with access to the sea to help people in danger at its shores (Fig. 1). The regions of responsibility of SAR are border regions (SSR - Search and Rescue Region) responsible for searching and rescuing the following countries: the Federal Republic of Germany, the Kingdom of Denmark, the Kingdom of Sweden and the Russian Federation.

3. HELICOPTER AS A TRANSPORT VEHICLE IN THE SAR SYSTEM

The basic tool that secures the functioning of the SAR system in the Polish area of responsibility is the helicopter [4], [9], [10]. In Polish aviation, helicopters such as Mi14PŁ/ PS, Mi-8MTW-1/Mi-17, PZL W-3RM Anakonda and Mi-2 are used for marine rescue. The M-28 Skytruck planes are also used, however Mi14PS and W-3RM Anakonda helicopters are the effectiveness of rescue operations (Fig. 2). The helicopter is one of the most important instruments used in modern land and sea rescue. The only limitation in the use of the helicopter are, first and foremost, the factors limiting visibility, but all the time technical solutions are created that enable flights in increasingly difficult weather conditions.

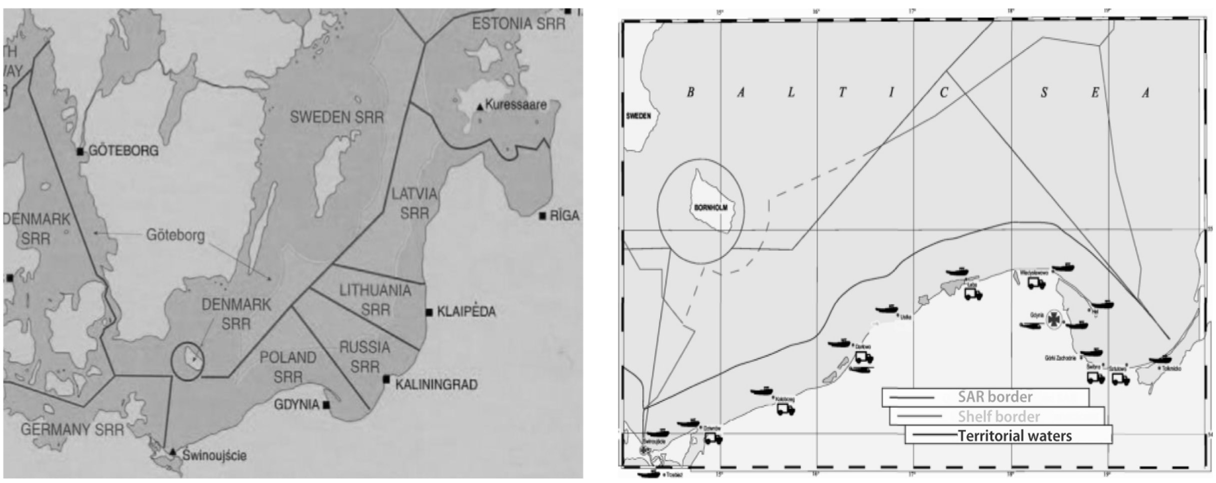

Fig. 1. The figure on the left shows the boundaries of SAR zone responsibility for individual countries. The figure on the right shows the limits of responsibility of the Polish SAR zone [13].

In the Polish SAR zone, it operates on the basis of, such legal acts as:

- Act of 21 March 1991 on the maritime areas of the Republic of Polandand maritime administration (Journal of Laws of 1991 No. 32, item 131 with subsequent amendments),
- Act of 9 November 2000 on maritime safety (Journal of Laws of 2000 No. 109, item 1106 as amended),
- The „Aviation Law" Act of 3 July 2002 (Journal of Laws No. 130, item 1112),
- The Act of 18 September 2001. The Maritime Code (Journal of Laws of 2001 No. 138, item 1545 with subsequent amendments),
- Flight rescue instruction in the land area of the Republic of Poland - OPK 839/80 and OPK - 965/84.

The use of helicopters and planes in rescue operations is one of the most expensive, yet very effective concepts, even in difficult meteorological conditions. Helicopters have great abilities to evacuate survivors on survival assets and to remove survivors from ships in distress. They allow quick evacuation of wounded or sick crew members and provide them with effective help. They are characterized by high speed, as well as the possibility of a good visual search of the reservoir and high sea prowess, as well as the possibility of launching from the water. They also allow for full coordination between SAR and air services of SAR (Search And Rescue) and ASAR (Aeronautical Search And Rescue), which cooperation should guarantee the most effective and efficient operation of emergency services on and over areas of responsibility.

Fig. 2. The figure on the left shows the Mi-14PS helicopter during rescue training, in the drawing on the right W-3RM helicopter "Anakonda" during rescue training.

Helicopters and rescue planes with particular operational and technical features expand considerably the possibility of their use for rescue purposes. Shortening the transport time reduces the threat to the health and lives of survivors who were under adverse hydrometeorological conditions. In addition, crews of rescue aircraft and helicopters can perform other tasks: penetrating the sea to protect the natural environment, identifying damage after storms, patrolling water courses, etc.

4. LOGISTIC ASPECTS OF SAR SYSTEM

Proper and correct functioning of the SAR system requires effective logistic provisioning [12], including in particular:

- organizing material security for action management staffs,
- organizing the reconstruction of the rescue readiness of units returning from the area of operations,
- ensuring supplies of specialist equipment and devices necessary to conduct search and rescue operations,
- arranging short-term repairs and repairs of equipment and units damaged during search and rescue operations,
- organizing rest areas for rescuers,
- organizing, if necessary, exchange of crews of rescue units.

Current logistics is a set of processes treated as a repetitive and determined course of action, oriented towards a potential recipient, defined by the flow of materials and information that permeate the boundaries of individual spheres of activity (Fig. 3). Logistics in the process of aircraft operation should include secure the implementation of aviation tasks. This includes the delivery of material resources of the required quantity, quality, in the right place and at the right time. The implementation of the above mentioned logistic tasks is possible after providing relevant information from the staff preparing the aircraft. With the appropriate tools and software, the aircraft technician (mechanic) can send information about the current state of the aircraft maintenance process in a given system of its operation. The goals set for modern maritime aviation are achieved thanks to technically sophisticated constructions with very high values of reliability coefficients that ensure the highest possible level of flight safety as well as technical and operational readiness.

Each aircraft must pass through three phases: design, manufacture and operation. The longest and the most expensive is the third phase, that is, exploitation. In this phase of an aircraft life, we deal with the organization of operational processes including: people, procedures, methods for maintaining the airworthiness and use of aircraft, and tools.

The concept of helicopter operation covers a very wide range of issues: use, maintenance, repair, spare parts supply, disposable materials (fuel, lubricants, oils, etc.) and storage. The broadly understood concept: logistic security for a sea helicopter, is in fact a dynamic process that creates related cause-time partial processes such as technical operation, airport operation, air transport, distribution of propellants and lubricants, etc. These processes are designed to ensure the assumed helicopter readiness, reliability and safety. They also contain states of technical service, renovation and storage. Generally speaking, the efficiency of logistic security processes is determined by a large number of factors acting on the helicopter during its

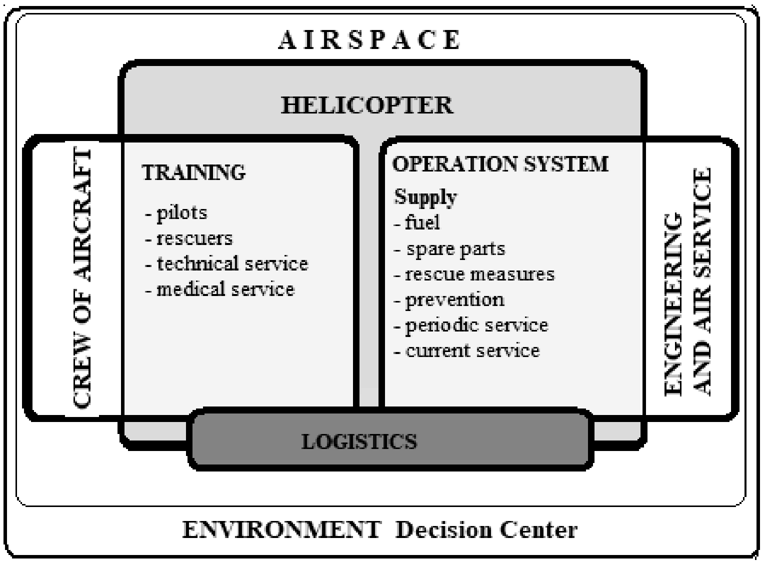

Fig. 3. Chart of the implementation of logistic tasks in the rescue system (interrelationship between groups: crew - helicopter - engineering service).

operation. Logistics in the process of aircraft operation in air rescue should include secure the implementation of aviation tasks. This includes the delivery of material resources of the required quantity, quality, in the right place and at the right time. The implementation of the above mentioned logistic tasks is possible after providing relevant information from the staff preparing the aircraft for rescue operations. With the appropriate tools and software, technical service engineers can send information about the current status of the aircraft maintenance process in a given system of its operation. For safe and functional security of an aircraft it is important to determine the potential of the Engineering and Aviation Service, which secures the correct operation of the operating system. The Engineering and Air Service deals with the issues of ensuring the technical airworthiness of the aircraft, namely current and periodic services, protection of spare parts and materials, their storage, and extremely important problems of the MPS service (propellants and lubricants). An important element from the point of view of the implementation of rescue tasks is the training element. Training is an essential element to increase the level of effectiveness of rescue crews' operations, they are also an element of passive and active safety for crews and people taking part in rescue operations. These trainings include flight training for pilots, engineering and aviation trainings for technical staff, medical services for emergency personnel and doctors. These trainings also require logistic security.

5. SELECTED AREAS OF SAR SYSTEM MODELING

In science, the model is a foundation of reality or its fragment, which is deliberately devoid of many details and traits irrelevant to the modeling goals [2]. The defined model is always a certain approximation of the actual object. In general, we can say that the model is a representation of a real object or only its fragment, which for various reasons can not be directly used in research. The model is defined as a system that sufficiently maps the features of a real object, so that its examination allows obtaining the desired information about this object. The degree of simplification of the model depends on the purpose or objectives of the research and thus many models can be defined for a given object. If the object for the model is a system, then we formulate the system model. The system model in the area of systemic knowledge is very often the basic research tool that facilitates or even allows the system to be recognized. In exact sciences, it has been assumed that the model is a tool enabling the analysis, evaluation and design of any system. description of the system model is made in a mathematical sense, creating a mathematical model of a given system. The mathematical model consists in describing a given system in a formal language in the form of specific mathematical-logical relations. A defined mathematical model is a collection of symbols, mathematical relations and strict rules of operating them, while the symbols and relations adopted in the model are a reflection of specific elements of the modeled real object. It is important for the research that the mathematical model must be unambiguously determined by the numerical values of parameters or characteristics and the conditions and limitations that identify it. Modeling is an action consisting in mapping any object, the real system in the form of an acceptable substitute, called a model and later experimenting with it. The modeling of the SAR system is in fact based on the relationship of a number of important stages that we can as a system of three interrelated stages, i.e.:

- identification of the problem to be solved (stage 1),
- constructing the SAR system model (stage 2),
- verification of the SAR system model (stage 3).

The above stages cannot be treated independently, that is, initiating one of the stages we are forced to take into account the possibility of implementing the remaining stages. At the stage of building the model, one should remember about data availability, measurement capabilities and possible computational algorithms. The methodology for modeling the SAR system in the form of a diagram is shown in Fig.4.

6. MAPPING OF MODEL ELEMENTS OF THE SAR TRANSPORT SYSTEM

Identification of elements of the AR rescue action model:

- organization of a rescue flight with specification of the purpose of the flight, the level of readiness of the rescue operation, weather conditions (hydrometeorological),
- determination and indication of helicopter type used for the action, taking into account its operational capabilities (number of places on board, flight duration),
- helicopter crew with special regard to the level of training (daily, night, IFR, VFR flights), crew composition (presence of a doctor, lifeguard),
- implementation of the task, taking into account the readiness of the helicopter, the crew, the starting place for the action, the course of the action (searching for a person or persons, object), the costs of the action,
- logistics protection of the rescue operation.

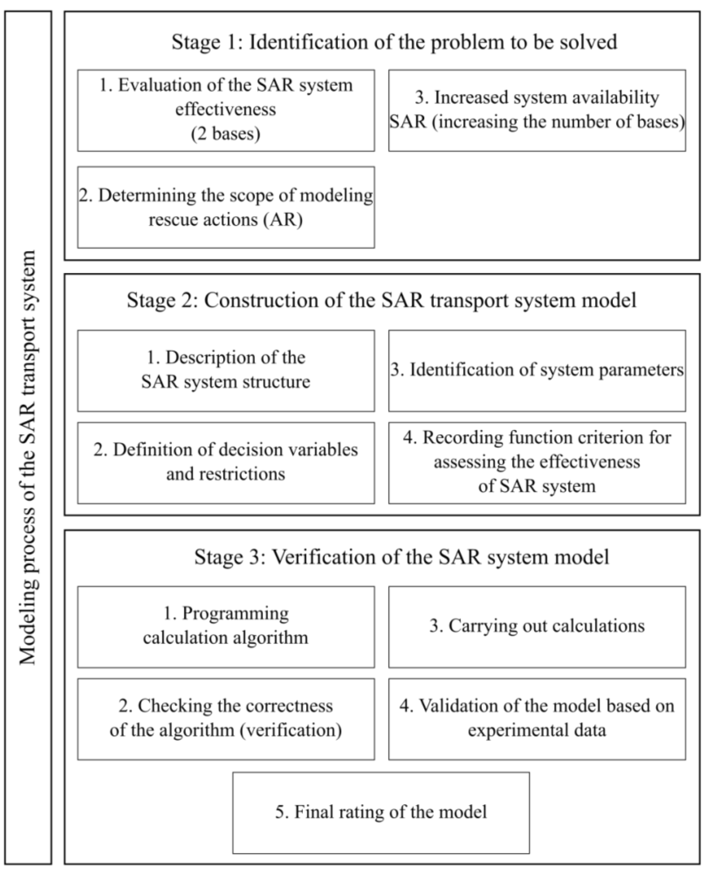

Fig. 4. Methodology for modeling the SAR transport system.

The individual elements of the model are marked with individual symbols and the model of the $\boldsymbol{AR}$ rescue action is presented in the form of an ordered five, ie:

$$\boldsymbol{AR} = \langle \boldsymbol{OL}, \boldsymbol{ST}, \boldsymbol{ZS}, \boldsymbol{RZ}, \boldsymbol{ZLA} \rangle, \quad (1)$$

where:
$\boldsymbol{OL}$ – organization of the rescue flight,
$\boldsymbol{ST}$ – means of transport (helicopters),
$\boldsymbol{ZS}$ – helicopter crew,
$\boldsymbol{RZ}$ – task fulfilment,
$\boldsymbol{ZLA}$ – logistic supply.

To build the SAR transport system model it is necessary to know the organization of the rescue flight, means of transport used for the action, information about the crew of the means of transport (helicopter), knowledge of the components necessary to perform the task.

For modeling purposes, we assume that the organization of an $\boldsymbol{OL}$ flight can be saved in the form of an ordered triple:

$$\boldsymbol{OL} = \langle \boldsymbol{CL}, \boldsymbol{PG}, \boldsymbol{WP} \rangle, \quad (2)$$

where:
$\boldsymbol{CL}$ – flight destination,
$\boldsymbol{PG}$ – readiness level,
$\boldsymbol{WP}$ – hydrometeorogical conditions.

The mapping of the flight order model, the level of readiness of a given rescue operation, weather conditions prevailing during the rescue operation are parameters of the system structure that may decide about the functioning of the system or its non-functioning. In accordance with the adopted assumption, the purpose of the $\boldsymbol{CL}$ rescue flight is the mapping of the structure of the SAR system in the Baltic area and in the designated area of land. For modeling purposes, we assume that the structure of the rescue flight is presented in the form of the SAR system model, i.e.:

$$\boldsymbol{CL} = \langle \boldsymbol{G}, \boldsymbol{F} \rangle, \quad (3)$$

where:
$\boldsymbol{G}$ – graph of SAR system structure based on actions carried out in the past,
$\boldsymbol{F}$ – a set of functions defined on elements of the graph $\boldsymbol{G}$.

Further considerations using graph theory will be the subject of subsequent publications. In this article, it is enough to mention that the SAR rescue system is a complex system in which characteristic subsystems can be extracted. In turn, each subsystem is characterized by a structure described by the transport network of the system (all possible places located in the area of the rescue operation carried out).

For the purpose of modeling rescue operations, we assume that $\boldsymbol{ST}$ transport resources can be saved in the form of an ordered two:

$$\boldsymbol{ST} = \langle \boldsymbol{TS}, \boldsymbol{MO} \rangle, \quad (4)$$

where:
$\boldsymbol{TS}$ – helicopter type,
$\boldsymbol{MO}$ – operational capabilities.

Means of transport are characterized by various technical, operational and economic parameters. Depending on the type of helicopter, its operational capabilities are different. Currently, two types of helicopters participate in rescue operations: Mi-14PS and W-3RM.

For a full description of the model (1) it would also be necessary to distinguish such model mappings as:

- representation of the crew of the $\boldsymbol{ZS}$ helicopter,
- mapping the implementation of the $\boldsymbol{RZ}$ task,
- mapping of logistic security for $\boldsymbol{ZLA}$ shares.

7. SEARCH AND RESCUE ACTIONS

Three types of helicopters, namely Mi-14Ps and W-3RM, were used to perform these tasks in the presented period from 1995 to 2000. Both the adaptation of helicopters to conduct operations in almost all weather conditions as well as the training of crews guaranteed the achievement of high indicators of the effectiveness of rescue operations.

Figure 5 contains a graphical listing of actions carried out in the Baltic Sea basin, including points defined by geographical coordinates. Each of the points are places of rescue operations that were carried out throughout the year between 1995 and 2000. The development of data for this period was based on reports of helicopter crews from rescue operations.

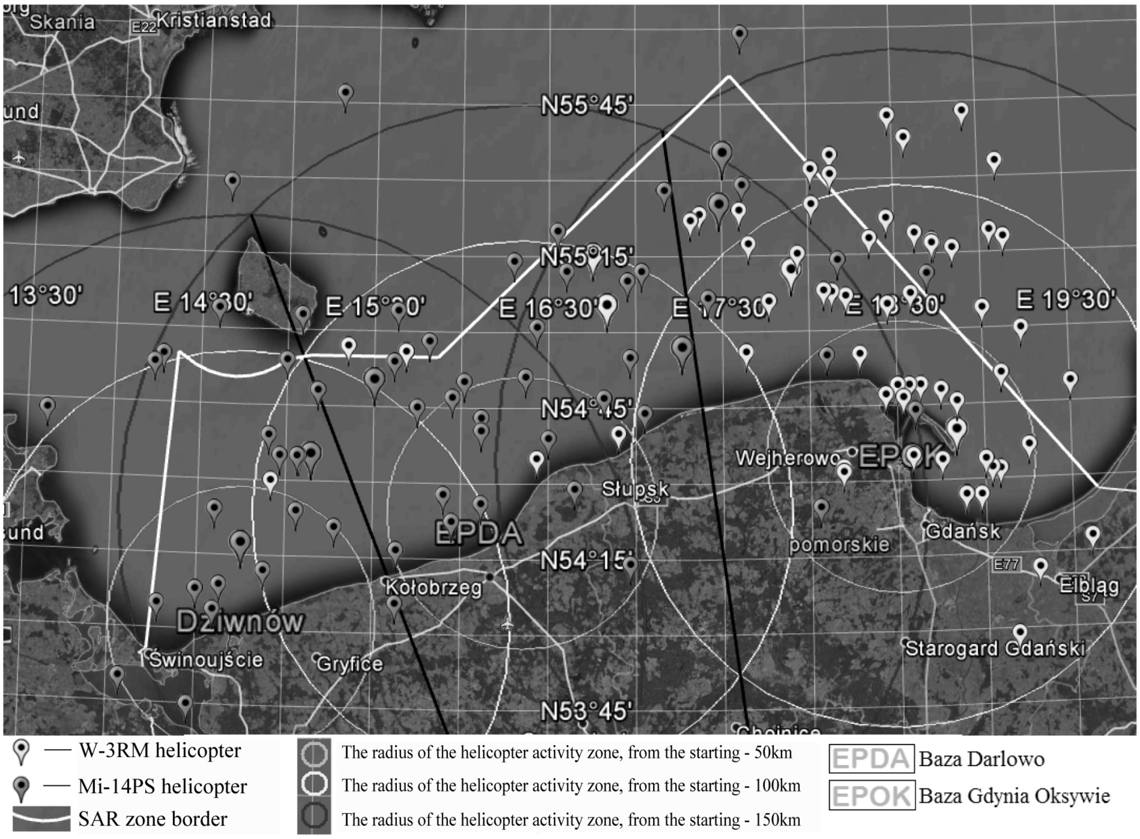

Fig. 5. Display of rescue action locations on the map in the period 1995 – 2000.

The starting place (base) of helicopters has been marked with international codes: EPOK is Gdynia Oksywie, and EPDA is Darłowo. The Dziwnów airfield does not have a code mark. The summary contains the geographical coordinates of 119 actions from that period. Of course, these are not all rescue operations carried out by SAR services at that time, but actions that were directly related to naval vessels. A large number of actions carried out in the eastern part of the Baltic Sea area are noteworthy, apart from the border of the Polish SAR liability zone, because the Polish search and rescue area does not fully coincide with the border of our economic zone. This is due to the fact that the boundaries established in the previous geopolitical period are inconsistent with the rules adopted by the SAR Convention 79 [5]. A particularly noticeable difference is in its north-eastern part, where a relatively large area of the Polish continental shelf lies beyond our boundaries of search and rescue. There is a lot of activity of Polish economic entities on this reservoir (three drilling platforms of PETROBALTIC, Polish fisheries). This is a situation in which these entities are formally outside the scope of functioning of our SAR system. With such division of responsibility zones, in the same sea area, other countries are responsible for environmental protection and navigational aids and others for marine rescue. This causes certain operational consequences, eg sending a Polish rescue measure (a ship, a helicopter) to rescue operations in the area of our drilling platforms should be legally agreed with the MRCK (Maritime Rescue Coordination Center) in Kaliningrad, which is formally responsible for the coordination of actions in this area. Rescue operations carried out by helicopters should be carried out according to the following criteria: minimum implementation costs and minimum implementation time in given conditions. Such actions are nothing more than optimization activities, i.e. those aimed at making the optimal decision, ie the best decision criterion adopted in the given circumstances. SAR rescue helicopters currently operate from two airbases: from Darłowo and Gdynia Oksywie. The landing site in Dziwnów was to become the third SAR base in the future, but until now there are no arguments for making such a decision. This purpose is to be served, *inter alia*, by a study that aims to create a mathematical model that optimizes the existing SAR transport system.

8. CONCLUSIONS

At present, the Navy has two types of SAR helicopters: Mi-14 PS and helicopters W-3 RM „Anaconda".

In the current situation, until the acquisition of a new type of helicopter, it is necessary to ensure effective functioning of the SAR system by optimizing and more efficiently using the available aircraft. This can be achieved by analyzing the issue from the theoretical side, based on a mathematical model. Both the logistic system for increasing the availability of helicopters for use in rescue operations and the SAR system itself can be modeled, which would be more effective if its structures were adapted to the realities of the contemporary division of responsibility zones in the Baltic Sea and in the land zone.

The construction of the mathematical model of the SAR system will also allow for the perception and better understanding of how to optimally use helicopters in rescue operations.

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