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The concept of applying Failure Mode and Effects Analysis (FMEA) to evaluate the risk in the field of maritime security of the State – the case study for Poland

Koncepcja zastosowania metody FMEA do oceny ryzyk i zagrożeń w obszarze bezpieczeństwa morskiego państwa – studium przypadku dla Polski

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Abstract. Presented below, the article is of interdisciplinary nature, as it combines problems related to security sciences and methods and tools applied in management and quality sciences. The aim of the study is to present a concept of applying FMEA for evaluation of risks in the field of maritime security of the State. The solution to the research problem involves the implementation of the FMEA method as a procedure that allows for the assessment of risks posed to maritime security in the indicated aspects and for the definition of necessary corrective and preventive actions eliminating these risks. During the research, it has been possible to verify a hypothesis stating that the accurate evaluation of risks posed to maritime security in the discussed aspects is viable due to the application of FMEA and the determination of the values of the suitable measures and indicators resulting from that analysis. This modus operandi allows the Author to fill in a research gap with the use of an interdisciplinary approach toward the problem in question. The results of the particular stages of the study come as the results of the Author's own scientific research discussed on the example of Poland. Consequently, the set of activities recommended to eliminate the risks identified in the area under research is established.
Keywords: analysis, risk, maritime security, management and quality, naval forces

Abstrakt. Opracowanie ma charakter interdyscyplinarny, łącząc zagadnienia z zakresu nauk o bezpieczeństwie z metodami i narzędziami stosowanymi w naukach o zarządzaniu i jakości. Celem opracowania jest zaprezentowanie zastosowania metody Failure Mode and Effects Analysis (FMEA), wykorzystywanej w wyżej wymienionych naukach, do oceny ryzyka w obszarze bezpieczeństwa morskiego państwa. Rozwiązanie problemu badawczego polegało na implementacji Failure Mode and Effects Analysis, jako procedury umożliwiającej ocenę występujących lub potencjalnych ryzyk dla bezpieczeństwa morskiego we wskazanych aspektach oraz

zdefiniowanie koniecznych działań naprawczych i prewencyjnych. W postępowaniu badawczym dokonano weryfikacji hipotezy, iż trafna ocena ryzyk dla bezpieczeństwa morskiego we wskazanych aspektach, możliwa jest dzięki zastosowaniu metody FMEA oraz określeniu wartości, wynikających z tej analizy mierników / wskaźników poziomu tego bezpieczeństwa. Proponowane rozwiązanie pozwala na wypełnienie pewnej niszy badawczej związanej z wykorzystaniem przedmiotowej metody do oceny ryzyk i zagrożeń w obszarze bezpieczeństwa morskiego. Rezultaty poszczególnych etapów opracowania są wynikiem badań własnych autora. Przedstawione rozwiązanie pozwala na zdefiniowanie zespołu rekomendowanych działań zorientowanych na neutralizację ryzyk i zagrożeń w badanym obszarze.
Słowa kluczowe: analiza, ryzyko, bezpieczeństwo morskie, zarządzanie i jakość, siły morskieD

Introduction

Requiring some particular recommendations and directives at a strategic level, maritime security of the State comes as an undertaking implemented in military and non-military aspects. Evaluating the level of maritime security of the State is inseparably related to the capability of identifying and assessing the level of threats in this field. The risks occurring in the field of maritime security can be identified in various aspects, for example, political, economic, military, social, information or ecological ones. The measurement of the discussed phenomenon identified in the area of security sciences is possible due to the application of methods and tools typical of management and quality sciences. Therefore, it has been decided to apply FMEA (Failure Mode and Effects Analysis) (see: Hu – Chen et al., 2019 pp. 881-897; Zhongyi et al., 2021 pp. 1409-1436), which – when properly adjusted – offers a possibility to evaluate risks and to define relevant security measures and indicators.

Hence, the aim of the study is to present a concept of applying FMEA in order to evaluate risks in the field of maritime security of the State. The research problem that should be solved is to provide an answer to the following question: *How should FMEA be applied as a procedure to evaluate risks in the field of maritime security so that it can allow for determining necessary corrective and preventive actions.*

The research hypothesis to be verified has been formulated as follows: *An accurate evaluation of risks posed to maritime security in the discussed aspects is possible due to the application of FMEA and determination of values of the suitable measures and indicators resulting from that analysis.*

A basic limitation to the discussed research process is the assumption of some indicated aspects of maritime security, for which the sets of risks have been identified, including those that can occur during the time of peace, crisis and war (political and geographical, economic and technological, military and social aspects; the information and ecological aspects have been omitted due to the recommended publication size).

Failure Mode and Effects Analysis

In management and quality sciences, FMEA is applied to identify potential and actual flaws/risks that occur in a particular process or product, with their reasons and consequences (Mascia et al., 2020 pp. 311-321; Hu-Chen et al., 2019, pp. 881-897). During the application of this method, the ultimate aim is to determine actions that can prevent or correct any possible flaws and to monitor the efficiency of their implementation in practice. The procedure of applying FMEA is presented in Fig. 1.

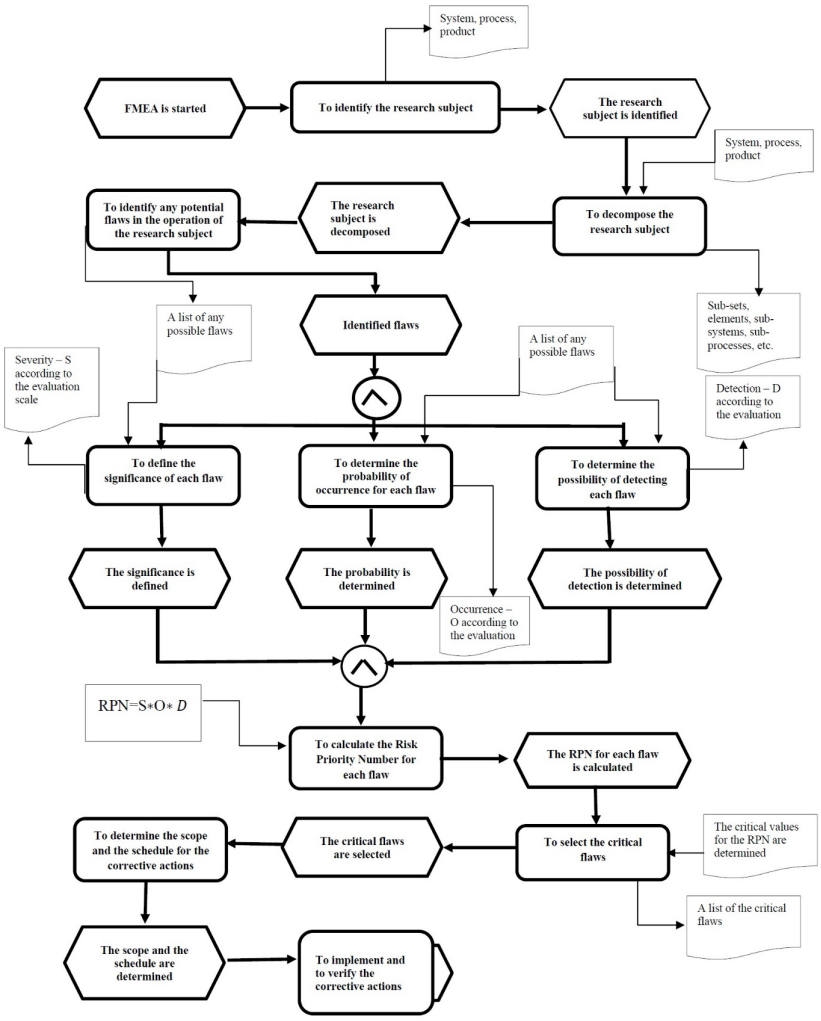

Fig. 1. A FMEA scheme

Source: Own elaboration based on: Mascia et al., 2020; Stamatis, 2019; Van der Last et al., 2002

In this method, a set of identified flaws is evaluated in terms of their severity/ significance (S), occurrence (O) and detection (D). The product of those factors determines the value of the RPN measure (Risk Priority Number), which is a basis for determining the particular flaw as critical, considering the assumed preference scale (Cf.: Mascia et al., 2020, p.314). Then, a plan or a schedule for corrective actions is developed for the critical flaws and it is periodically verified after its implementation (see: *AIAG Potential Failure* **…**2019). The discussed method is applied in the fields where reliability affects the safety of users. Hence, it can be also applied in the field referring to the security of an organisation.

Application of FMEA in the field of maritime security of the State

Maritime security of the State is understood as protection of the land and maritime territory of the State, including its infrastructure, economy, environment and human resources against any challenges and threats coming from the sea. It also refers to the execution of the current national and international legal regulations and maintenance of the territorial integrity of the State. It provides conditions allowing for the use of the areas considered to be vital for the existence of the State, according to its will and national interest (Cf.: BBN, 2017, p. 73). Considered from the perspective of management and quality sciences, the systems approach to maritime security is presented in Fig. 2.

While analysing the scheme presented in Fig. 2, it should be noted that:

- the system input includes the occurrences that appear during the time of peace and emergency (in time of crisis and on a war footing) with the related risks that can be observed in the area of maritime security and that result from the actual deficiencies of capabilities and resources of the State and possible external threats in this field;
- the system output displays the status of the functioning of the State in the maritime environment, where the basic criterion is the level of maritime security that is conditioned by neutralisation or the lack of neutralisation of identified risks;
- the system transformation unit uses the national resources, the adequate procedures, and possible support provided by the allied parties that can be used for the neutralisation of risks;
- the system control unit collects information about the occurrences and any related risks, the efficiency of the implemented resources, procedures and support provided by the allied parties. Based on that, some decisions are made to apply relevant resources and procedures or possibly to use the support provided by the allied parties to neutralise the risks.

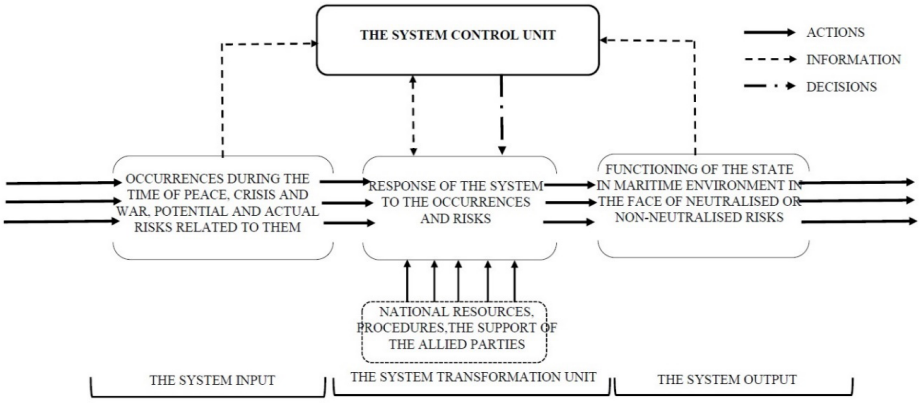

Fig. 2. Maritime security of the State presented in the systems approach
Source: Own elaboration

The application of FMEA to evaluate risks in the field of maritime security comes as a process that is composed of several stages (Fig. 3). The discussed concept assumes the following order of actions:

- defining the field of the research, namely the area of the analysis. The first step is to identify the key success factors in selected aspects of maritime security that have been assumed for the case of Poland: political and geographical, economic and technological, military and social (Fig.4).

Based on that identification, a list of the occurring risks has been formulated (Fig. 5). In strategic analysis, the key success factors are the elements that are used for the evaluation of the capabilities of one's own organisation (Köseoglu et al., 2020; Janjić et al., 2019, pp. 98 – 106; Zanoni, 2021). In this particular case, the organisation is the State and the element to be defined in the four assumed aspects is the level of its maritime security. The particular aspects (A_i), namely: political and geographical aspect (A_1), economic and technological aspect (A_2), military aspect (A_3) and social aspect (A_4) have been assigned with relevant success factors (F_{ij}) that are the features defining capabilities of the organisation (Cf.: Pac, 2022, pp. 74-75). In order to systemise risks resulting from the insufficient capabilities of the organisation and external threats, the causal Ishikawa diagram (see: Goetsh, Davis, 2014, pp. 261-262) comes as a base (Fig. 5), where the particular risks (R_{ij}) result in a decrease in the level of maritime security in the assumed aspects. Defined in such a way, the list of risks becomes a starting point for FMEA.

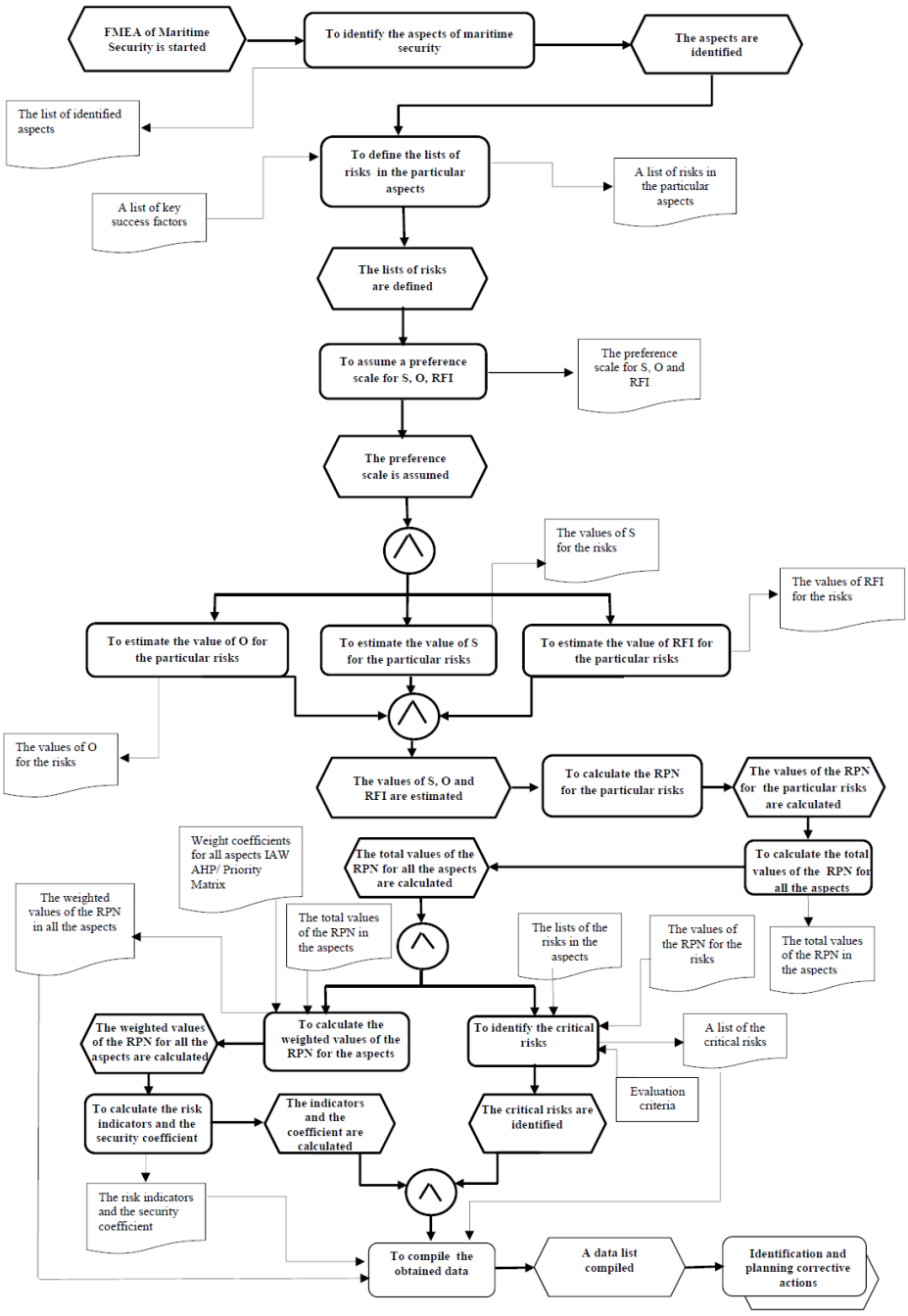

Fig. 3. FMEA in the field of maritime security

Source: Own elaboration based on: Hu – Chen et al., 2019; Stamatis, 2019; Van der Last et al., 2002

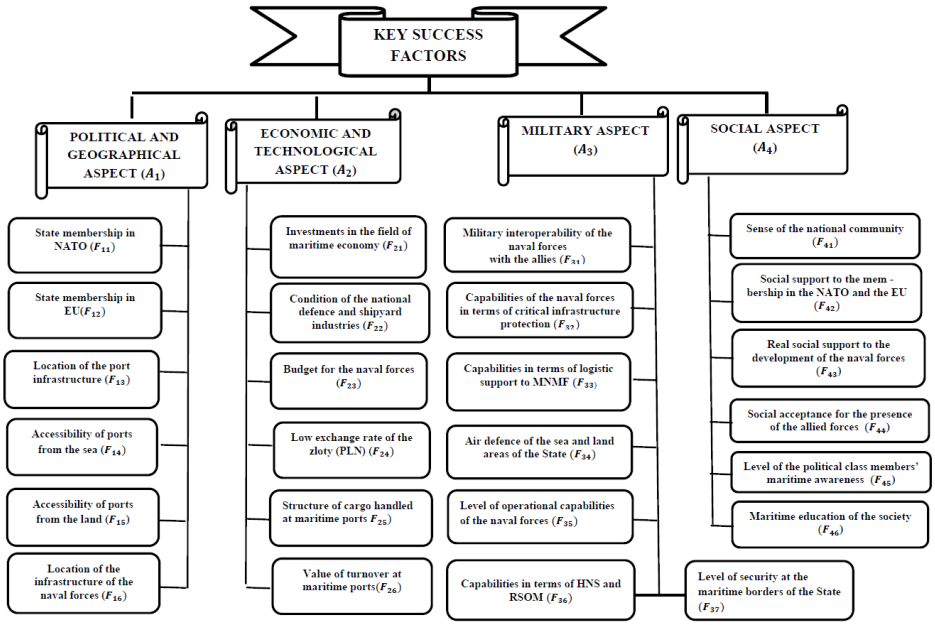

Fig. 4. The field of the analysis – the key success factors (the case study for Poland)
Source: Own elaboration based on: Pac, 2022

- calculating the Risk Priority Number for the particular risks occurring in the discussed aspects comes as the next step:

$$RPN_{ij} = S_{ij} O_{ij} RFI_{ij} \tag{1}$$

where: RPN_{ij} – the value of the Risk Priority Number for the j[th] risk assigned to the i[th] aspect, where: i=$\overline{1.4}$; S_{ij} – Severity of the j[th] risk assigned to the i[th] aspect; O_{ij} – Occurrence (the probability of the occurrence) for the j[th] risk assigned to the i[th] aspect; RFI_{ij} - Room for Improvement (a possibility to improve the situation based on one's own resources) for the j[th] risk assigned to the i[th] aspect.

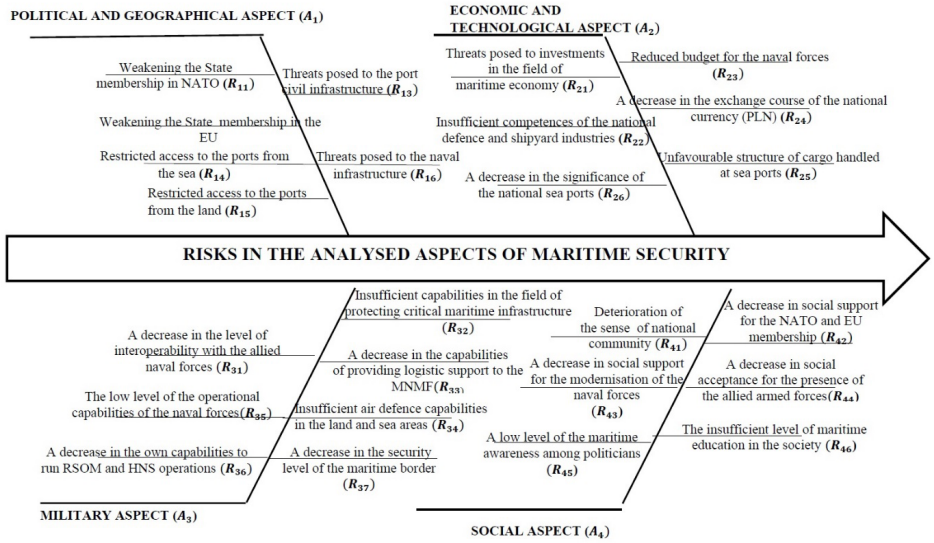

Fig. 5. A list of risks observed in the assumed aspects of maritime security
Source: Own elaboration.

Calculating the RPN_{ij} values for the subsequent risks requires assuming a particular preference scale that refers to the evaluation of the values of the particular factors that make up the total value of the particular risk (Table 1).

Table 1. The preference scale for evaluating the values of the factors

No.	Severity	Occurrence	Room for Improvement
1	1 – insignificant	1 – incidental	1 – very high
2	2 - low	2 – low	2 – high
3	3 – moderate	3 – moderate	3 – moderate
4	4 – high	4 – high	4 – low
5	5 – very high	5 – very high	5 - minimum

Source: Own elaboration based on: Stamatis, 2019

- -calculating the total values of RPN_i for the discussed aspects, according to the following equation:

$$RPN_i = \sum_{j=1}^{m} RPN_{ij} \tag{2}$$

where: RPN_i – the total value of the Risk Priority Number for the risks assigned to the ith aspect; $\sum_{j=1}^{m} RPN_{ij}$ – the sum of the values of the risks assigned to the ith

aspect, where m – is the number of risks in the i[th] aspect;

- calculating the weighted values of the Risk Priority Number for each aspect;

$$RPN_i^{WV} = w_i \ RPN_i \tag{3}$$

where RPN_i^{WV} – the weighted value of RPN_i in the i[th] aspect; w_i – the weight coefficient for the i[th] aspect that is determined based on the AHP method or the Priority Matrix;

- calculating the maximum weighted values of the Risk Priority Number for each i[th] aspect, according to the following equation:

$$RPN_{imax}^{WV} = w_i \ RPN_{imax} \tag{4}$$

considering that: $$RPN_{imax} = \sum_{j=1}^{m} S_{ij}^{max} O_{ij}^{max} RFI_{ij}^{max} \tag{5}$$

where: $S_{ij}^{max}, O_{ij}^{max}, RFI_{ij}^{max}$ take the maximum values from Table 1, namely the value = 5;

- calculating the risk indicator (MOR_i) for the i[th] aspect, according to the following equation:

$$MOR_i = \frac{RPN_i^{WV}}{RPN_{imax}^{WV}} \tag{6}$$

where: $MOR_i \in (0;1$

- calculating the coefficient of maritime security of the State (MMS), according to the following equation:

$$MMS = (1 - \frac{\sum_{i=1}^{n} MOR_i}{n}) \tag{7}$$

where n=4 – the number of the aspects of maritime security that have been analysed in the research;

- identifying the most significant risks in terms of the RPN_{ij} critical values. For the requirements of the research, it has been assumed that a particular risk is considered as critical if it meets the following conditions:

$$\begin{cases} RPN_{ijcr} \geq \overline{RPN_{ij}} \\ RPN_{ijcr} \in A \end{cases} \tag{8}$$

where: $\overline{RPN_{ij}}$ – the arithmetic mean value of the (RPN_{ij}) risk assigned to the i[th] aspect; A – the risks in the A group, according to the Pareto principle (see: Goetsh, Davis, 2014, pp. 258-260).

- collating the key data, namely: the critical risks (based on RPN_{ijcr}), the values of the MOR_i indicators and the values of the MMS coefficient for identifying and planning preventive and corrective actions;
- identifying and planning preventive and corrective measures.

The results of the application – the case study for Poland

The application of the discussed solution on the example of Poland, has been performed in accordance with the following order:

- as presented in Fig. 2, the first step involves identifying the aspects of maritime security (A_i), that are presented in Fig. 4 and Fig. 5;
- each of the four analysed aspects has been assigned with their characteristic risks (R_{ij}) (Fig. 5) that are presented in Table 2 with the identification of their reasons;
- evaluating the particular risks assigned to the aspects with the calculation of the RPN_{ij} values for each of them, according to the equation (1). The values of the particular factors (S, O and RFI), which are the components of the Risk Priority Number for each of the risks, have been assumed based on the Author's own analysis and evaluation (see Table 2);
- calculating the total $\underline{RPN_i}$ values for the analysed aspects, according to the equation (2) and the $\overline{RPN_{ij}}$ values, namely the arithmetic mean values of the risks in the particular aspects (Table 2).

Table 2. The list and evaluation of the risks for the particular aspects of maritime security.

ASPECT A_i	RISK (R_{ij})	REASONS	S_{ij}	O_{ij}	RFI_{ij}	RPN_{ij}
1	2	3	4	5	6	7
POLITICAL AND GEOGRAPHICAL ASPECT - A_1	Weakening the Polish membership in NATO – R_{11}	Information warfare and diplomatic activities of the adversary	5	2	3	30
	Weakening the Polish membership in the EU – R_{12}	Information warfare and diplomatic activities of the adversary, internal conflicts among the EU member countries	5	3	3	45
	Restricted access to the Polish ports from the sea - R_{13}	Close vicinity of the military installations of the Baltic Fleet and its combat capabilities. Potential hybrid activities undertaken by the Armed Forces of the Russian Federation in the Pomeranian and West Pomeranian Provinces. The dispute over the approach fairway to the Port of Świnoujście with Germany.	4	4	4	64
	Restricted access to the Polish ports from the land - R_{14}		4	4	4	64
	Threats posed to the port civil infrastructure - R_{15}		5	4	4	80
	Threats posed to the own naval infrastructure - R_{16}		5	4	3	60
			$RPN_1 = \sum_{j=1}^{6} RPN_{ij}$ =343			
		$\overline{RPN_{1j}}$ =57				
1	2	3	4	5	6	7

cd. tab. 2

ECONOMIC AND TECHNOLOGICAL ASPECT - A_2	Threats posed to investments in the field of maritime economy - R_{21}	Economic and financial crisis. Activities undertaken by the neighbouring countries (Germany) and local governments to block the construction of a container terminal in Świnoujście.	4	4	3	48
	Insufficient competences of the national defence and shipyard industries - R_{22}	Insufficient capabilities of the industry to absorb the offset, deterioration of the defence and shipyard industries over the recent decades	3	4	3	36
	Reduced budget for the naval forces - R_{23}	Economic and financial crisis. The modernisation priority to the land and air forces	4	4	3	48
	A decrease in the exchange course of the national currency - R_{24}	Economic crisis, progressive inflation	3	4	3	36
	Unfavourable structure of cargo handled at sea ports - R_{25}	Activities undertaken by the competitors	4	2	3	24
	A decrease in the significance of the national sea ports - R_{26}	Activities undertaken by the competitors - unfavourable decisions referring to the liquidation of ocean services to the Baltic Hub in Gdańsk made by Maersk and Hapag-Lloyd.	4	2	3	24
			$RPN_2 = \sum_{j=1}^{6} RPN_{ij}$ =216			
	$\overline{RPN_{2j}}$ =36					
1	2	3	4	5	6	7

cd. tab. 2

MILITARY ASPECT - A_3	A decrease in the level of interoperability with the allied naval forces - R_{31}	The shortcomings of the naval forces in the field of the interoperability with the allied forces in terms of operational, technical and administrative standards	5	3	3	45
	Insufficient capabilities in the field of protecting critical maritime infrastructure - R_{32}	The lack of advanced systems and resources in the field of protection provided to critical maritime infrastructure	5	4	4	80
	A decrease in the capabilities of logistic support to the MNMF (see: NATO, 2017-2018) - R_{33}	Insufficient competences of the national logistic (technical, material and infrastructural) base.	4	3	4	48
	Insufficient air defence capabilities of the land and sea areas - R_{34}	The lack of advanced air defence systems	5	5	5	125
	The low level of the operational capabilities (see: NATO, 2010) of the naval forces - R_{35}	Deterioration of the capabilities of the naval forces over the recent decades	5	4	4	80
	A decrease in the capabilities to run RSOM&I and HNS operations - R_{36}	Economic crisis. Potential hybrid and war combat activities undertaken by the adversary (the Russian Federation)	4	3	4	48
	A decrease in the security level of the maritime border - R_{37}	Insufficient operational capabilities of the Border Guard	3	3	3	27
			$RPN_3 = \sum_{j=1}^{7} RPN_{3j}$ =453			

cd. tab. 2

	$\overline{RPN_{3j}}$ =65					
1	2	3	4	5	6	7
SOCIAL ASPECT - A_4	Deterioration of the sense of national community - R_{41}	Increasing political fractures inside the society	5	4	4	80
	A decrease in social support for the NATO and EU membership - R_{42}	The sense of a war threat	2	1	1	2
	A decrease in social support for the development of the naval forces - R_{43}	Economic crisis, the lack of maritime culture and awareness in the society	3	4	4	48
	A decrease in social acceptance for the presence of the allied armed forces - R_{44}	The sense of a war threat, conflicts between the local communities and the allied armed forces	2	2	3	12
	A low level of the maritime awareness among politicians - R_{45}	The lack of understanding for maritime problems among politicians	4	4	4	64
	The insufficient level of maritime education in the society - R_{46}	The insufficient level of maritime education and awareness resulting from decreased significance of maritime economy	4	3	3	36
			$RPN_4 = \sum_{j=1}^{6} RPN_{4j}$ =242			
	$\overline{RPN_{4j}}$ =40					

Source: Own elaboration

calculating the risk indicators for the discussed aspects - $MORi$ – the (6) equation and the coefficient of maritime security of the State (MMS) – the (7) equation. The weight coefficients w_i for the particular aspects of maritime security are calculated with the use of the AHP (Analytic Hierarchy Process) method (Kulakowski, Raton, 2020) (see: Table 3);

Table 3. The risk indicators and the value taken by the coefficient of maritime security of the State

	A_1	A_2	A_3	A_4
w_i (IAW AHP)	w_1 =0.3659	w_2 =0.2326	w_3 =0.2778	w_4 =0.1237
RPN_i	RPN_1 = 343	RPN_2=216	RPN_3 = 453	RPN_4 =242
RPN_i^{WV}=$w_i RPN_i$	RPN_1^{WV} =125	RPN_2^{WV} =50	RPN_3^{WV} =126	RPN_4^{WV} =30
RPN_{imax}= $\sum_{j=1}^{m} S_{ij}^{max}\, OOC_{ij}^{max} RFI_{ij}^{max}$	RPN_{1max} = 750 /100%	RPN_{2max} = 750 / 100%	RPN_{3max}= 875/100%	RPN_{4max} = 750/100%
RPN_{imax}^{WV}= w_i RPN_{imax}	RPN_{1max}^{WV} = 274	RPN_{2max}^{WV} =174	RPN_{3max}^{WV} =243	RPN_{4max}^{WV} =93
MOR_i= $\frac{RPN_i^{WV}}{RPN_{imax}^{WV}}$	MOR_1 =0.456	MOR_2 =0.287	MOR_3 = 0.518	MOR_4 =0.322
$MMS = (1 - \frac{\sum_{i=1}^{n} MOR_i}{n})$	$MMS = (1 - \frac{(MOR_1+MOR_2+MOR_3+MOR_4}{4})$= 0.604			

Source: Own elaboration based on: Kulakowski, Raton, 2020

- identifying the critical risks, according to the (8) formula (see: Table 4).

As presented in Table 4, 12 critical risks have been identified (highlighted in grey) that meet the criteria of the (8) formula. In the next stage of the research, some corrective and preventive actions are defined for these areas.

Table 4. Identification of the critical risks in the field of maritime security.

No.	Risk according to RPN_{ij} in descending order	RPN_{ij}	RPN_{ij} accumulated	Accumulated share in %	The risk class	$RPN_{ijcr} \geq \overline{RPN_{ij}}$	Meeting the conditions of the critical risk
1	R_{34}	125	125	**81.8**	**A**	**Yes**	**Yes**
2	R_{35}	80	205		**A**	**Yes**	**Yes**
3	R_{32}	80	285		**A**	**Yes**	**Yes**
4	R_{15}	80	365		**A**	**Yes**	**Yes**
5	R_{41}	80	445		**A**	**Yes**	**Yes**
6	R_{13}	64	509		**A**	**Yes**	**Yes**
7	R_{14}	64	573		**A**	**Yes**	**Yes**
8	R_{45}	64	637		**A**	**Yes**	**Yes**
9	R_{16}	60	697		**A**	**Yes**	**Yes**
10	R_{21}	48	745		**A**	**Yes**	**Yes**
11	R_{23}	48	793		**A**	**Yes**	**Yes**
12	R_{33}	48	841		**A**	No	No
13	R_{36}	48	889		**A**	No	No
14	R_{43}	48	937		**A**	**Yes**	**Yes**
15	R_{12}	45	982		**A**	No	No
16	R_{31}	45	1027		**A**	No	No
17	R_{22}	36	1063	**95.05%**	**B**	Yes	No
18	R_{24}	36	1099		**B**	Yes	No
19	R_{46}	36	1135		**B**	No	No
20	R_{11}	30	1165		**B**	No	No
21	R_{37}	27	1192		**B**	No	No
22	R_{25}	24	1216	**100%**	**C**	No	No
23	R_{26}	24	1240		**C**	No	No
24	R_{44}	12	1252		**C**	No	No
25	R_{42}	2	1254		**C**	No	No

Source: Own elaboration

The scope of corrective and preventive actions, the monitoring of the maritime security level

Determining the scope of corrective and preventive actions (see: Table 5) refers to the critical risks because these factors should be treated as the priorities, considering the criteria listed in the (8) formula.

Table 5. The potential corrective and preventive actions

No.	Critical risk	Corrective/preventive actions
R_{13}	Restricted access to the ports from the sea	Providing security to Sea Lines of Communication (SLOC) to the national sea ports on the Baltic Sea in cooperation with the allied forces. Modernising the naval forces oriented toward the development of assets providing capabilities to run operations of this type. Constructing a new approach fairway to the sea port of Świnoujście.
R_{14}	Restricted access to the ports from the land	Continuing the modernisation of transport infrastructure in the areas of the Pomeranian and West Pomeranian Provinces that connects this region with the other parts of the country and with the EU transport network. Developing military capabilities to secure the northern part of the country against combat and hybrid operations run from the Kaliningrad Oblast.
R_{15}	Threats posed to the port civil infrastructure	Implementing programmes oriented toward antiterrorist actions and protection of the critical infrastructure. Developing alternative port facilities outside the area of the Gulf of Gdańsk (e.g.: modernisation of the sea port of Ustka, construction of a container terminal in Świnoujście).
R_{16}	Threats posed to the naval infrastructure	Developing alternative port facilities outside the area of the Gulf of Gdańsk (e.g.: modernisation of the sea port of Ustka). Relocating the naval forces command centre outside the area of Tricity. Implementing modernisation programmes oriented toward antiterrorist actions and protection of the maritime critical infrastructure.
R_{21}	Threats posed to investments in the field of maritime economy	Moving some key investments in the field of maritime economy towards the central and western coast. Implementing educational programmes among local government representatives to promote such investments. Implementing diplomatic activities in order to promote investments (modernisation of the sea port of Ustka, construction of a container terminal in Świnoujście) in the European Union and NATO to acquire EU and NSIP (NATO Security Investment Program) funds and to neutralise activities undertaken by the neighbouring countries (Germany) aimed at blocking such investments.
R_{23}	Reduced budget for the naval forces	Guaranteeing funds for the implementation of the key modernisation programmes, regardless of the situation related to the MOD (the Ministry of Defence) budget.
R_{32}	Insufficient capabilities in the field of protecting critical maritime infrastructure	Approving and implementing the modernisation programmes oriented toward antiterrorist actions and protection of maritime critical infrastructure.

cd. tab. 5

R_{34}	Insufficient air defence capabilities of the land and sea areas	Integrating the programmes of the naval forces modernisation with the programme of developing the air defence system at the State level. Engaging the air defence capabilities of the allied forces located permanently or rotationally at the Eastern Flank of NATO in the Polish airspace defence over the Baltic Sea.
R_{35}	The low level of the operational capabilities of the naval forces	Implementing consistent and reasonable modernisation of the naval forces oriented toward developing capabilities to run operations under the 5th Article, protection of the State interests at sea and cooperation with the allied forces.
R_{41}	Deterioration of the sense of national community	Undertaking political actions at the State level in order to mitigate political disputes among national political parties to maintain the continuity of the undertakings implemented in the field of the State security, including maritime security, regardless of the election outcomes.
R_{43}	A decrease in social support for the development of the naval forces	Education of the public in the field of maritime security.
R_{45}	A low level of the maritime awareness among politicians	Education of politicians in the field of maritime affaires.

Source: Own elaboration

While analysing the activities presented in Table 5, it should be noted that neutralising 9 out of 12 defined critical risks involves the programme of naval forces modernisation and activities undertaken in the field of (maritime and land) logistic infrastructure. Hence, providing more details to the actions presented in Table 5, the modernisation programme should include:

- consistent continuation of the programmes implemented in relation to the frigate-class / Multi-Role Ships (see: NATO, 2004) (Miecznik/Swordfish programme) and the mine hunter -class / Naval Mine Warfare Units (see: NATO, 2004) (Kormoran/Cormorant programme). Both programmes are oriented toward the construction of vessels capable of operating under the standing NATO maritime units and of implementing tasks in the fields of protection and defence of maritime interests of the State and running operations under the 5th Article (see: Table 5 / R_{13}, R_{35});
- implementation of the Delfin/Dolphin programme involving construction of new SIGINT vessels (see: Table 5 / R_{13}, R_{35});
- consistent improvement in the capabilities of the Naval Missile Unit in terms of the quantity of munition and acquisition of necessary reconnaissance

and guidance means to improve the actual range of the missiles to their nominal range level (see: Table 5 / R_{13} , R_{35});

- implementation of modernisation programmes in the field of acquiring resources necessary to protect civil and military maritime infrastructure (the Ostryga/Oyster programme), to provide anti-terrorist defence to vessels at ports, roadsteads and anchorages (an equivalent to the Krill programme) and unmanned maritime vehicles used for running reconnaissance, surveillance and minesweeping operations (including anti-sabotage and anti-terrorist defence provided to the offshore wind farms that are planned to be constructed in the Słupsk Bank and the Baltic Pipe installations) (see: Table 5 / R_{13} , R_{15} , R_{16} , R_{32}); (Cf.: Pac, Pączek, 2023, p. 131-132)
- integration of the air defence systems on the newly constructed vessels with the national air defence system that is now being under development (see: Table 5 / R_{34}, R_{35});
- reconstruction of the Fortified Zone of Hel that would be an additional base for the air defence units and coastal missile regiments; efficient reconnaissance and surveillance of air and maritime areas (see: Table 5 / R_{16} , R_{34}, R_{35});
- acquisition of air forces detachments , operating for the benefit of naval forces, that would be capable of neutralising military installations of the adversary and providing defence against air raids (see: Table 5 / R_{34}, R_{35});
- extension of the programme acquiring helicopters for the naval forces that would be capable of mine warfare, early warning operations, anti-surface warfare, VERTREP (Cf.: NATO, 2017-2018 p. V-2); (see: Table 5 / R_{13}, R_{34}, R_{35})
- development of the anti-landing and anti- sabotage defence detachments under the units of the Territorial Defence Forces (see: Table 5 / R_{14}, R_{15}, R_{16});
- development of capabilities in the field of laying offensive minefields (see: Table 5 / R_{35});
- perspective acquisition of motherships for the unmanned maritime vehicles through adapting the SIGINT vessels, which are still in service (see: Table 5 / R_{15} , R_{16} , R_{32} , R_{35}). After commissioning the new SIGINT vessels under the Delfin/Dolphin programme, the vessels conducting SIGINT operations so far, could still implement training tasks of midshipmen;
- if possible, inclusion of the sea ports located on the Polish coast into the anti-missile and air defence system located in the base of the US Armed Forces in Redzikowo (see: Table 5 / R_{34}, R_{35});
- continuation of the presence of the NATO naval forces characterised by the required operational capabilities in the zone under the responsibility of our own naval forces until they acquire the intended assets/resources

and rebuild the necessary operational capabilities, in accordance with the requirements of the allied forces (NATO, 2010). (See: Table 5 / R_{13}, R_{35})

The particular undertakings in the field of broadly understood logistic infrastructure include the following (Cf.: Pac, 2022, p. 89):

- -modernisation of the sea port of Ustka to upgrade it to the standards of deep-water ports to provide the complementarity of its facilities with the other sea ports located in the Gulf of Gdańsk and to expand the basing system of the naval forces, considering the close and dangerous vicinity of the military installations of the Baltic Fleet and its combat capabilities (see: Table 5 / $R_{16}, R_{21;} R_{35}$) ;
- construction of a container terminal in the sea port of Świnoujście expanding capabilities in the field of the RSOM&I (NATO, 2018, p. 4-2) and HNS (see: NATO, 2021, p. 64) operations for the allied response and reinforcement forces, complementarity with other container terminals located in the Gulf of Gdańsk (see: Table 5 / $R_{15}, R_{21;} R_{35}$) ;
- completion of the modernisation work related to the land transport infrastructure in the Pomeranian and West Pomeranian Provinces, connecting these regions with the rest of the country and Mecklenburg-Vorpommern and Brandenburg areas, which in the case of an armed conflict may become Rear Area (RA) (NATO, 2021, p. 109) (see: Table 5 / $R_{14}; R_{35}$) ;
- relocation of the naval forces command centre to the area of the central or western coast (e.g.: Ustka, Koszalin, the area of Szczecin Lagoon), considering the close vicinity of the Kaliningrad Oblast (see: Table 5 / R_{32}, R_{35}) ;
- modernisation work necessary for enabling the operation of the LBH (Land-Based Helicopters), PMA (Patrol Maritime Aircraft) and ITAL (Intra – theatre Airlift) run from the air base in Darłowo (see: Table 5 / R_{34}, R_{35});
- construction of a new approach fairway to the north of the sea port of Świnoujście (see: Table 5 / R_{13}) ;
- education activities among the members of local government referring to the necessity of expanding the facilities of port infrastructure (see: Table 5 / R_{21}, R_{43}, R_{45}).

Another problem is the monitoring of the maritime security level, with the periodic analysis of the changes in the values indicated by the risk indicators in the particular aspects of maritime security (MOR_i) and the coefficient of maritime security of the State (MMS). In order to achieve this aim, a strategic trajectory has been proposed to follow the changes in the above-mentioned factors in the function of time (see: Fig. 6).

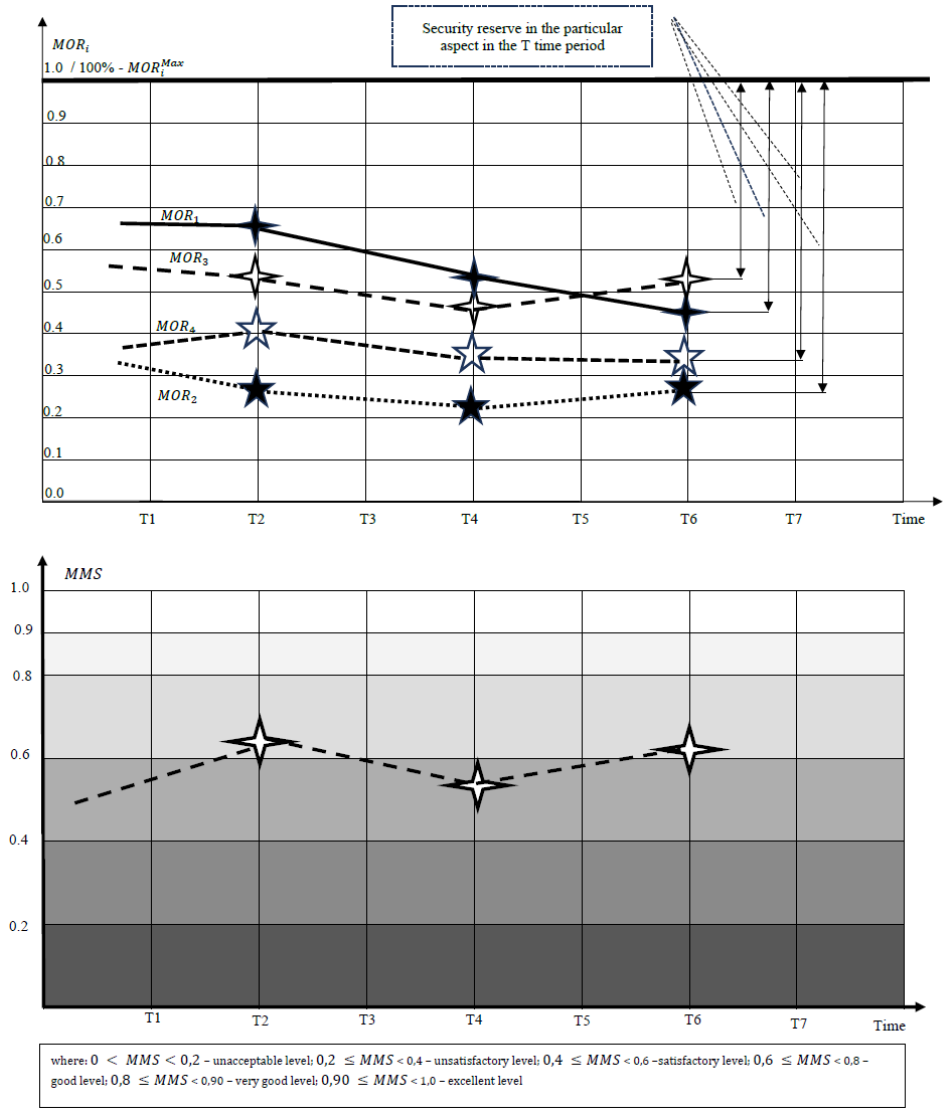

Fig.6. An example of a trajectory of the changes in the maritime security indicators.
Source: Own elaboration

The upper part of Fig. 6 presents an example of a trajectory of the changes in the MOR_i indicators in the analysed periods of time, which also indicate the current security reserves in the particular aspects in reference to the current values of the indicators to their possible maximum values, namely: MOR_i^{Max} =1 (100%).

The lower part of Fig. 6 allows for the identification of the security level expressed by the maritime security coefficient, according to the assumed scale of maritime security.

Trajectories shown in Fig. 6 may allow for periodic checks of the risk and security levels, including the summary evaluation of the efficiency of corrective and preventive actions that have been implemented. The results obtained after calculating the MMS security coefficient in Table 3 indicate that the maritime security level of the State has reached the line between satisfactory and good (see: lower part of Fig. 6). The results obtained by the risk indicators MOR_i (see: Table 3) indicate that the lowest security reserve is observed in the political and geographical and military aspects (the highest values of RPN_1, RPN_3 and MOR_1, MOR_3 – Table 3).

While referring the results obtained after the discussed application to the current situation, it is possible to conclude that the situation comes as a result of years of negligence in the field of naval forces development and the location of the Baltic Fleet's assets that is unfavourable to the Polish Naval Forces. Although the geo-strategic situation has been significantly improved after the accession of Sweden and Finland to NATO, in the case of an armed conflict, the high probability of invading the Baltic countries by the adversary still remains and it would provide an opportunity to extend the basing system of the Baltic Fleet.

Conclusions

Summing up the analysed research process, it should be noted that the presented solution makes it possible to evaluate the level of maritime security of the State in terms of the discussed critical risks. FMEA has allowed the Author to determine the level of the particular risks occurring in the analysed aspects of maritime security. This evaluation comes as a basis for defining critical risks (see: Table 2 and Table 4) and calculating the relevant RPN_i, MOR_i and MMS indicators (see: Table 3), that define the level of maritime security in a holistic way. The current values of risk indicators (RPN_i and MOR_i) allow to point out the (political and geographical) and A_3 (military) aspects as the most important problems to be solved. These aspects contain the largest number of critical risks and involve the majority of projects related to corrective / preventive actions. However, other aspects cannot be neglected due to the necessity of a comprehensive approach to the issue of maritime security.

When analysed periodically, the discussed measures should allow not only for a systematic assessment of individual risks (pointing out the critical ones – Table 4) but also for an evaluation of the efficiency and accuracy of preventive and corrective actions undertaken within the assumed aspects of maritime security using a strategic trajectory (see: Table 5 and Fig. 6). This gives us an opportunity to improve the corrective and preventive actions carried out in the case of unsatisfactory results to date.

Considering the scope of corrective and preventive actions presented in the article, it is possible to note that in the time of the armed conflict between the Russian Federation and Ukraine the main actions refer to the modernisation programmes, relocation of the naval forces and implementation of new infrastructural investments in the field of maritime economy in the Pomeranian region. Some of the implemented or intended modernisation programmes for the naval forces (Swordfish / Cormorant / Dolphin) are coherent with the results of the analysis presented in the article, however, the activities undertaken in the field of infrastructure and those related to the relocation of the naval forces have not been assigned with the right priority or they still remain to be intentions.

To sum up the procedures presented in the article, it should be emphasized that the solution comes only as a concept that has got its shortcomings. A precise evaluation of the RPN indicators for the particular risks requires a panel of competent experts that would be composed of full-time employees of the Naval Forces staff (the Polish Naval Academy, the Naval Operations Centre – Naval Component Command), specialists who deal with the problem of the national security in a holistic way (e.g.: the National Security Bureau, the Ministry of Defence) and experts in the field of maritime economy, especially its infrastructure (the Maritime Office). Additionally, in some more advanced research, it could be possible to extend the scope of the discussed maritime security aspects by information warfare (including problems in the field of cybersecurity) and ecological (a programme for constructing vessels to fight chemical and ecological disasters and threats) aspects.

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