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Maritime safety in the approach of L. von Bertalanffy's general system theory;

Bezpieczeństwo morskie w ujęciu ogólnej teorii systemów L. von Bertalanffy`ego

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Abstract. The paper presents an original concept of maritime safety modeling using the tool apparatus of L. von Bertalanffy's general systems theory. In the introduction, the methodological assumptions of the general systems theory were formulated, which was used to build a formalized model of the maritime security system, including all the basic structures of the system topology, i.e. separated components, basic relations between these elements and the specification of the system environment. Using the tool apparatus of the general systems theory by L. von Bertalanffy in the modeled Maritime Security System, the basic elements of the system approach were distinguished, i.e. the concept of a set, structural elements, system relations, external environment and system inputs and outputs. The main research thesis is that maritime security, which is a kind of open system, can be interpreted on the basis of general systems theory, which provides effective research tools for a broader look at the application side of maritime safety. The basis of this thesis is the assumption that maritime security can be interpreted as a praxeological system of action that functions in a specific holistic environment, constantly exchanging information, energy and matter with it, thanks to which the entropy (disorder) of the system remains in a certain (safe) equilibrium. Finally,

a brief analysis of the controversy surrounding a universal systems approach with regard to application in the social sciences and humanities was conducted.
Keywords: system, elements, relationships, maritime safety, external environment

Abstrakt. W artykule przedstawiono autorską koncepcję modelowania bezpieczeństwa morskiego z wykorzystaniem aparatury ogólnej teorii systemów L. von Bertalanffy'ego. We wstępie sformułowano założenia metodologiczne ogólnej teorii systemów, które posłużyły do zbudowania sformalizowanego modelu systemu bezpieczeństwa morskiego, uwzględniającego wszystkie podstawowe struktury topologii systemu, tj. specyfikację środowiska systemowego. Wykorzystując aparat narzędziowy ogólnej teorii systemów L. von Bertalanffy'ego w modelowanym Systemie Bezpieczeństwa Morskiego wyróżniono podstawowe elementy podejścia systemowego, tj. pojęcie zbioru, elementy strukturalne, relacje systemowe, otoczenie zewnętrzne i wejścia systemowe oraz wyjścia. Główną tezą badawczą jest to, że bezpieczeństwo morskie, które jest swego rodzaju systemem otwartym, może być interpretowane w oparciu o ogólną teorię systemów, która dostarcza skutecznych narzędzi badawczych dla szerszego spojrzenia na aplikacyjną stronę bezpieczeństwa morskiego. Podstawą tej tezy jest założenie, iż bezpieczeństwo morskie można interpretować jako prakseologiczny system działania funkcjonujący w określonym holistycznym środowisku, stale wymieniający z nim informacje, energię i materię, dzięki czemu entropia (nieporządek) systemu pozostaje w pewnej (bezpiecznej) równowadze. Na koniec dokonano krótkiej analizy kontrowersji wokół uniwersalnego podejścia systemowego w odniesieniu do zastosowań w naukach społecznych i humanistycznych.
Słowa kluczowe: system, elementy, relacje, bezpieczeństwo morskie, środowisko zewnętrzne

Introduction

The category of maritime safety typologically belongs to the area of national security, and semantically it is classified as object safety. Taking into account the utilitarian dimension of maritime security, it can be regarded as a praxeological system of efficient operation, the main goal of which is to guarantee a certain level of safety in a given category. It is about the safety of all subjects and objects operating in the area of maritime safety. Safety understood in this way is normative in nature and requires the construction of a praxeological systems structure that meets the required evaluation criteria or other qualitative or quantitative indicators. In social practice, these functions are carried out by a variety of utilitarian systems, characterized by appropriate effectiveness and efficiency of operation. Thus, the theory of maritime safety should be reduced to the praxeological level of a system with the required utility; in this case it will be the maritime security system. Most often, methods and tools of systemic analysis, which offers proven procedures with high utilitarian potential, are used for such a transformation.

Systemic analysis by A. Koźmiński (Koźmiński, 1976, p. 35) defines it as: «a systemic way of analyzing complex problems aimed at ensuring the achievement of broader goals and more effective than if the individual parts of the system were analyzed in isolation.» P. Sienkiewicz (Sienkiewicz, 1994, p. 37) strongly emphasizes the tool nature of systemic analysis, defining it as: «a set of analytical, evaluation and decision-making methods and techniques for the rational solution of systemic decision-making situations» (Sienkiewicz, 1994, p. 37). Systemic analysis uses various types of models and modeling, using, among other things, formalized models built, for example, in the convention of logical-mathematical models according to the assumptions of general systems theory (Rawson et al, 2021, p. 3). The designed maritime safety system belongs to the category of complex systems, which Z. Gomółka (Gomółka, 2000, p. 13) defines as: "open systems, the integral part of which is a human being, providing conscious and purposive operation of this isolated entity from the environment." (Gomółka, 2000, p. 13). Human participation in a complex system makes it an open system with conscious and purposive action.

Using the tool apparatus of L. von Bertalanffy's (1984) general systems theory, the modeled Maritime Security System isolated the essential elements of the systems approach, i.e. the concept of a set, structural elements, system relations, external environment, and system inputs and outputs. The systemic analysis of the modeled Maritime Security System was carried out on the basis of two classical cybernetic models built on the concept of black box and white box cybernetics. The essence of the model based on the cybernetic black box is the analysis of the input/output relation of the studied maritime security system, i.e. the input threat spectrum and the output security stream. In this case, the internal structure of the studied system is less important and is not analyzed. The model using the cybernetic white box concept focuses on the internal organizational and functional structure of the system under study and the detailed relations occurring between the isolated system elements. It enables a more thorough analysis of the role and function of individual components in the structure of the system under study and their impact on the output vector of maritime safety.

The concepts of cybernetic black box and white box were used to organize the essential input/output streams and synthetically define the entire internal and external environment of the open Maritime Security System. According to the principles of cybernetics, the Maritime Security System thus defined is susceptible to control interactions through appropriate internal and external relations, and thus to the fulfillment of utilitarian requirements that guarantee, for example, the required level of maritime security. The result is a praxeological Maritime Security System adequate to the identified organizational and functional environment, which can be purposively managed by means of appropriate information and decision-making streams.

Outline of general systems theory

General systems theory, whose undisputed father is Austrian biologist and philosopher Ludwig von Bertalanffy (1901-1972) is an interdisciplinary science that relativizes the achievements of many generations of researchers, including representatives of the humanities, natural sciences and social sciences, and paves new paths for the development of many disciplines in both theoretical and applied sciences.

Its basic paradigm is a holistic, comprehensive understanding of the world around us, full of various systems, subsystems and supersystems, both animate (natural) and inanimate (artificial) (Bertalanffy, 1984, p. 68). A systems approach is, in other words, «a certain methodological attitude emphasizing the absence of disciplinary barriers, the freedom to apply knowledge and techniques accumulated in one field to problems occurring in another field, or to recognize that two different fields are in fact one contact field» (Bertalanffy, 1984, p. 68).

Formally, the foundations of the general systems theory were not promulgated by L. von Bertalanffy until 1930, defining such concepts as totality, sum, elements, differentiation, centralization, hierarchy, purposiveness, etc. In order to generalize L. von Bertalanffy›s considerations, his preferred notion of «organism» had to be replaced by a new, more universal concept, such as «organized whole» or «system», in order to use this theory directly as the foundation of a general systems theory. Due to the vitalistic criterion and the hierarchy of information processing, these systems can be divided into two disjoint classes: animate and inanimate systems. Inanimate systems include static structures (Frameworks), dynamic structures (Clockworks) and cybernetic structures (Thermostats). Animate systems include: self-maintaining biological cells, organisms with low information processing capabilities, e.g., plankton, organisms with developed information processing capabilities, e.g., animals, organisms characterized by reflexivity, intelligence and a developed behavioral system, as well as complex social systems or transcedent systems currently beyond the capacity of any analysis. It should be noted that general systems theory deals with all types of systems (Weinberg, 1979, p. 306).

The concept of «system» that is key for the general systems theory is treated as «organized complexity» in which information and information entropy are central problems. Information refers to the intangible medium through which open systems contact the outside world and exchange control-adaptive and stabilizing signals. According to the *Dictionary of Information Technology*, information is "a message concerning a fragment of reality or replacing it, a physical factor causing such a message, fixable and susceptible to processing" (Płoski, 2003, 1976). *The Lexicon of Science and Technology*, on the other hand, defines the concept of information as: "any factor by means of which an object receiving it (a human being, a living organism, an organization, an automatic device) can improve its knowledge of its surroundings and carry out a purposive activity more efficiently" (Lexicon ..., 1984, p. 306).

Information entropy according to the *Little Cybernetic Dictionary* is: "a measure of the indeterminacy of events that are sources of information under a certain state of ignorance about these phenomena" (Kempisty, 1973, p. 105). In general, "entropy is a measure of missing information" (Gościński, 1968, p. 105) and symbolizes systemic disorder that can be changed with additional information taken from the environment. It is closely related to the amount of information contained in the received message. Following the father of cybernetics N. Wiener (Wiener, 1971, p. 18), the concept of information can most simply be defined as: "the content taken from the external world in the process of our adaptation to it." (Wiener, 1971, p. 18). Information is a prerequisite for the existence and praxeological functionality of any system. According to N. Wiener (Wiener, 1971, p. 206), every organism maintains unity of action by virtue of the fact that it has the means to receive and transmit information.

The cognitive goal of the general systems theory is to study, analyze and synthesize primary animate (natural) systems with a view to improving and perfecting secondary, artificial inanimate systems. The utilitarian goal is the design and construction of artificial systems that fulfill specific tasks and functions in modern civilization. An example of such an application could be maritime security, considered as a purposively designed and organized system of effective operation, open to wide cooperation.

Concept and attributes of a system

Of cardinal importance for the general systems theory is the concept of "system", which in the world of science and practice is very universal and interdisciplinary, and, above all, occurs massively and universally, implying a huge multiplicity of different definitional concepts. In traditional mechanistic systemic analysis, a system is either organized simplicity or unorganized complexity, and the central problem is mass, force and energy. According to D.J. Klir, "a general system is essentially an abstract model of some already existing system (material or conceptual), in which are reflected (to the extent we wish) all the main or basic features of the original" (Klir, 1976, p. 73).

One of the simplest definitions of a system was proposed by L. von Bertalanffy: "A system is a collection of elements in mutual relations" (Bertalanffy, 1984, p. 68). In the opinion of S. Mynarski, 1) "a system is a purposively defined set of elements and the relations occurring between these elements and their properties." 2) "a system is any purposively isolated collection of elements linked by dependencies or interactions" (Mynarski, 1981, p. 23). In turn, P. Sienkiewicz defines the concept of system as: "any complex object distinguished from the studied reality constituting a whole, formed by a set of elementary objects (elements) and connections (relations) between them" (Sienkiewicz, 1983, p. 27). An adequate definition of the system for the current of system studies is formulated by Z. Bubnicki: "a system is a certain whole in which isolated components interact, and the functioning of the system depends on the functions of the components and the relationships between them, while the connections of the components determine the structure of the system" (Bubnicki, 1993, p. 38). More formally, the concept of a system [*S*] is defined in two basic ways – as a topological structure or as a cybernetic system (Ficoń, 2007, p. 25):

$$S = \langle E, R \rangle = \langle E, E \times E \rangle \tag{1}$$

where: E – the set of elements that make up the system
R – the set of relations isolated between elements E
whereby:

$$E = \left\{ E_i;\ i = \overline{1,I} \right\} = \{1, 2, 3, \ldots, K\} \tag{2}$$

$$R = \left\{ R_j;\ j = \overline{1,I} \right\} = \{1, 2, 3, \ldots, L\},\ \ L = 2, 3, \ldots, 2^{2K} \tag{3}$$

On the grounds of cybernetics theory, a system can be defined as a decision-driven [D] transformation of input signals [X] into output signals [Y]:

$$S \subseteq X \times D \times Y \tag{4}$$

where: $X = \left\{ X_i; i = \overline{1,I} \right\}$ – set of system inputs (forcings, needs),
$Y = \left\{ Y_j; j = \overline{1,J} \right\}$ – set of system outputs (reactions, opportunities),
$D = \left\{ D_k; k = \overline{1,K}; K \subseteq I \times J \right\}$ – set of decisions of purposive action.

According to praxeological principles – the science of efficient and effective action, the system [4] being a system of purposive action must meet at least two boundary conditions:

$$W_1:\ \ X \times D \to Y[C] \tag{5}$$

$$W_2:\ \ D \times Y \to F^{+}[min / max] \tag{6}$$

Condition W_1 as a necessary condition determines the efficiency of the system's operation S, i.e. the ability to realize the intended goal C to the intended degree. On the other hand, condition W_2 as a sufficient condition determines the efficiency of the system's operation, i.e. the realization of the intended purpose in a rational, most efficient manner [F^+]. In the case of security systems, efficiency should not be expressed in typical economic terms, therefore one can take, for example, the rate of minimization of the risk of threats and their negative consequences as a measure of efficiency. Many other additional conditions are imposed on actual security systems, representing mainly time and space requirements, including ecological ones (Hao M., Nie Y., 2022, p. 4).

Any system is a certain whole which is formed by a set of elements (essential objects) and a set of relations (couplings) between these elements. The definitions presented have common features such as: "an organized whole, a set of elements, couplings (relations) between these elements, information input and output channels, mutual conditions, as well as purposiveness and efficiency of operation" (Bojarski, 1984, p. 48).

The maritime security system studied below is a praxeological system of purposive action, the elements of which co-contribute to the achievement of the desired states of the whole, i.e. the goal of the system, while meeting a certain efficiency criterion. As P. Sienkiewicz writes, "A security system is such a system of purposive action, the purpose of which is to secure (defend) a specific system (object) from the action of undesirable phenomena (processes) and their negative effects (consequences) (Sienkiewicz, 2015, p. 11). In operational terms, the goal of the security system is most often to minimize the risk of real threats harming the safety of a particular subject/object and to reduce undesirable consequences and repercussions.

Formalization of the Maritime Security System

The maritime security system is a praxeological system of purposive action, which, on the basis of the security theory, can be formally expressed as follows:

$$MSS: \ \Pi \times \Omega \times \Psi \times \Gamma \overset{Æ}{\rightarrow} \Sigma \nearrow \max \quad (7)$$

where: MSS – Maritime Security System,
Π – set of security subjects,
Ω – set of security objects,
Ψ – formal and legal basis,
Γ – operational capability for security operations,
Z – set of potential challenges and real threats,
Σ – target safety state.

The systemic subject whose safety will be protected by the studied system MSS is the human being, his health and life or, generally speaking: professional groups performing a specific task in the wider maritime environment:

$$\Pi = \{\Pi_1, \Pi_2, \ldots, \Pi_n\} \quad (8)$$

where: Π_1 – person and its personal safety,
Π_2 – professional groups and their social safety.

The object of safety is all material, energy and natural objects that function in the maritime environment. Particularly protected are man-made artifacts, which are most generally divided into static and dynamic objects that condition the performance of useful functions in the maritime environment:

$$\Omega = \left\{ \Omega_1, \Omega_2, \ldots, \Omega_n \right\} \tag{9}$$

where: Ω_1 – static, infrastructural objects,
Ω_2 – dynamic objects, ships and maritime vehicles,
Ω_3 – natural resources – animate and inanimate.

Natural resources, especially animate resources that determine the identity and biodiversity of this environment, are protected separately. The main purpose is the safety of the global maritime ecosystem, whose importance for life on planet Earth has been absolutely crucial from the very beginning.

The universal criterion for the functioning of the maritime security system is international and national formal and legal regulations, which are global in nature, as a result of the worldwide importance of the seas and the world ocean:

$$\Psi = \left\{ \Psi_1, \Psi_2, \ldots, \Psi_n \right\} \tag{10}$$

where: Ψ_1 – international conventions, codes and treaties,
Ψ_2 – internal regulations and national laws.

Each security system achieves its mission through an adequate operational capability, which illustrates the actual capacity to act in protecting the subject/object and shaping the desired safety standards. The operational potential should guarantee an effective response to the identified threats in order to maintain the required safety standards of the subject/object. The response process is implemented in three stages as [Fig. 1]:

$$\Gamma = \left\langle \Gamma_1 \prec \Gamma_2 \prec \Gamma_3 \right\rangle \tag{11}$$

where: Γ_1 – identification of the emerging challenges,
Γ_2 – estimation of the risk of transformation of challenges to the state of threats,
Γ_3 – determination of potential and real threats.

Response [11] is the security system's response to identified real threats, directly harming the safety of the subject/object. It involves the use of available forces and means of operational capabilities to effectively combat identified real threats.

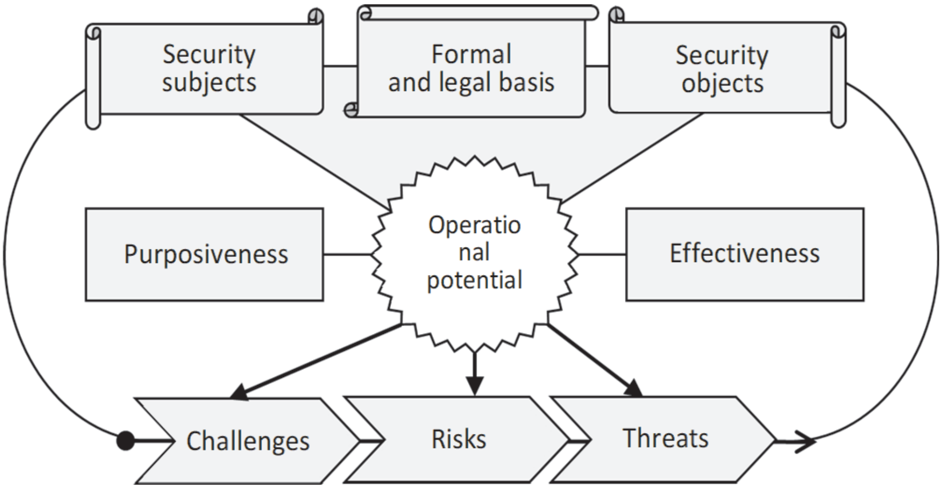

Fig. 1. Model structure of the security system
Source: Own elaboration

In organizational and functional terms, we can define the maritime security system as: a purposively organized, on the basis of relevant international and national formal and legal regulations and delegated tangible and intangible resources, complex organizational and functional system whose task is to guarantee the safety of life, health, property and the environment in the field of maritime shipping, the exploitation of maritime resources and all human economic activities on the world's seas and oceans:

$$MSS: \; A_C \times A_M \times A_S \xrightarrow{\S \times \mathcal{M}} B_Z \times B_E \times B_G \qquad (12)$$

where: A_C – safety of life, health,
A_M – safety of property,
A_S – safety of the maritime environment,
B_Z – safety of maritime shipping,
B_E – safety of maritime resource exploitation,
B_G – safety of economic activities,
$\S$ – international legal regulations,
$\mathcal{M}$ – world seas and oceans.

The Maritime Security System defined by expression [12] takes into account only non-military aspects of human activities at sea and does not include deliberate destructive actions that accompany military operations or warfare. The studied set of potential safety threats was limited to the classic non-military domains including natural, social, technical and other random threats, such as maritime terrorism.

An extremely important functional characteristic of any praxeological system is the actual purposiveness and efficiency of its operation. In the case of system MSS, the fundamental purpose of its operation [C[MSS]] is to guarantee the safety of isolated subjects [6] and objects [7] at a certain level:

$$C\left(MSS\right):\ PB\left(A_C, A_M, A_S, B_Z, B_E, B_G\right) \geq PB^* \tag{13}$$

$C(MSS)$ – the purpose of the MSS system,
PB^* – the MSS system's guaranteed state of safety for subjects and objects.

We will relate the effectiveness of the security system $\left[E\left(MSS\right)\right]$ to the degree of compliance with normative requirements in terms of applicable maritime conventions and codes, such as:

$$\begin{gathered} E\left(MSS\right)]:\left[MAR \geq MAR^*\right] \cup \left[SOL \geq SOL^*\right] \cup \left[COL \geq COL^*\right] \cap \\ \cap \left[STC \geq STC^*\right] \cup \left[ISP \geq IPS^*\right] \cup \left[VTM \geq VTM^*\right] \end{gathered} \tag{14}$$

where: MAR^* – the desired level of compliance with MARPOL requirements,
SOL^* – the desired level of compliance with SOLAS requirements,
COL^* – the desired level of compliance with the COLREG Convention requirements,
STC^* – the desired level of compliance with the STCW Convention requirements,
ISP^* – the desired level of compliance with the ISPS Code requirements,
VTM^* – the desired level of utilization of the VTMIS system.

Formally, the MSS system should guarantee the highest possible standards of safety of life and work at sea, an important element of which is economic activity aimed at conducting a global maritime economy (Ficoń, 2009). In economic terms, it is about obtaining the maximum effect of multiple economic activities at sea, the main fields of which are shipping, port and cargo turnover, exploitation of maritime resources (animate and inanimate), as well as extensive economic spheres related to sea cultivation, sea tourism, extractive industries and research of the sea as a global ecosystem. The most pressing safety needs today include ecological threats to the maritime environment, which is reflected in a self-contained category – ecological safety of the maritime environment.

Maritime Security System as a cybernetic black box

In terms of the general systems theory closely related to the tool apparatus of cybernetics, any praxeological system, especially the Maritime Security System, can be defined either in the form of a so-called black box [Figure 2] or a white box [Figure 3]. According to the *Little Cybernetics Dictionary*, a black box is: "a system of unknown structure of which all our knowledge is acquired through analyzing the relationship of observed responses to the observed stimulus" (Kempisty, 1973, p. 66). The *Lexicon of Science and Technology* defines a black box as: "a device whose structure is unknown, only the states of its inputs and outputs are known" (Lexicon..., 1984, p. 119). In both cases, we are interested only in open systems that are relatively isolated, i.e. that exchange information, energy and matter with the system environment, which, according to the law of entropy, guarantees their stability and ability to self-realize.

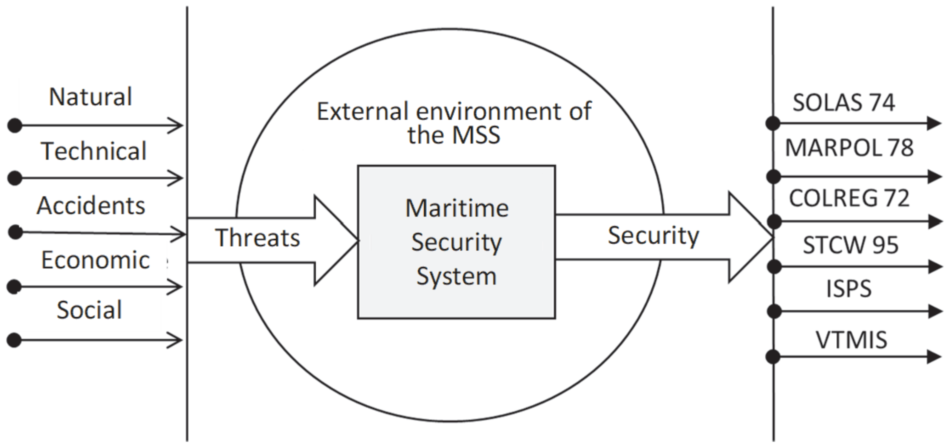

Fig. 2. Maritime Security System as a cybernetic black box
Source: Own elaboration

In the case of a cybernetic black box, we are only interested in the input signals flowing into the system and the output signals leaving the system. The transformation of input to output is performed by the black box, whose organizational and functional structure is temporarily irrelevant (Ficon, 2009). In the black box convention, at the input to the system MSS there is a threat stream, while at its output we have a safety stream, determined, for example, by the standards of international maritime conventions and codes. Formally, the operation of the MSS black box can be written as:

$$MSS: \quad \overrightarrow{ZG} \times CS\left[MSS\right] \rightarrow \overrightarrow{BP} \tag{15}$$

where: $\overrightarrow{ZG}$ – threats vector,
CS [*MSS*] – cybernetic black box,
$\overrightarrow{BP}$ – security vector.

Threats vector $\overrightarrow{ZG}$ is a multidimensional vector containing the following components:

$$\overrightarrow{ZG} = \left\{\overrightarrow{ZG}_N, \overrightarrow{ZG}_T, \overrightarrow{ZG}_G, \overrightarrow{ZG}_S, \overrightarrow{ZG}_W\right\} \tag{16}$$

where: $\overrightarrow{ZG}_N$ – natural threats vector,
$\overrightarrow{ZG}_T$ – technical threats vector,
$\overrightarrow{ZG}_G$ – economic threats vector,
$\overrightarrow{ZG}_S$ – social threats vector,
$\overrightarrow{ZG}_W$ – vector of maritime incidents and accidents.

Each of the above vectors $\overrightarrow{ZG}_m \in \overrightarrow{ZG}$ is divided into a number of generic threats, the list of which will virtually never be exhaustive:

$$\overrightarrow{ZG}_m = \left\{\overrightarrow{ZG}_{mi},\ m = 1, 2, 3, 4;\ \ i = \overline{1, I}\right\} \tag{17}$$

For example, the maritime accidents category $\left[\overrightarrow{ZG}_W\right]$ is divided into:

$$\overrightarrow{ZG}_W = \left\{\overrightarrow{ZG}_{Wi};\ \ i = \overline{1, 7}\right\} \tag{18}$$

where: $\overrightarrow{ZG}_{W1}$ – maritime collisions,
$\overrightarrow{ZG}_{W2}$ – contact with obstacle,
$\overrightarrow{ZG}_{W3}$ – ship sinking,
$\overrightarrow{ZG}_{W4}$ – fire, explosion,
$\overrightarrow{ZG}_{W5}$ – taking ground,
$\overrightarrow{ZG}_{W6}$ – power plant failure,
$\overrightarrow{ZG}_{W7}$ – accidents involving humans.

The output security vector [TEKST4] is also a multivariate vector, containing, for example, the following components:

$$\overrightarrow{BP} = \left\{ \overrightarrow{PB}_S, \overrightarrow{BP}_M, \overrightarrow{BP}_C, \overrightarrow{BP}_W, \overrightarrow{BP}_I, \overrightarrow{BP}_V \right\} \quad (19)$$

where: $\overrightarrow{PB}_S$ – SOLAS'74 Convention,
$\overrightarrow{BP}_M$ – MARPOL'78 Convention,
$\overrightarrow{BP}_C$ – COLREG'72 Convention,
$\overrightarrow{BP}_W$ – STCW'75 Convention,
$\overrightarrow{BP}_I$ – ISPS Code,
$\overrightarrow{BP}_V$ – VTMIS system.

We will refer the fulfillment of safety conditions to the fulfillment of the rules contained in the relevant conventions and maritime codes [19]. These conventions are the result of years of experience of numerous generations of seafarers and are a prerequisite for maintaining sound standards while working and serving at sea. Adherence to established conventions and maritime codes makes it possible to minimize the risk of critical and undesirable events, thereby maintaining the required level of maritime safety in all its dimensions.

Maritime Security System as a cybernetic white box

In the case of a cybernetic white box, the object of special interest is its interior, through which the input-output transformation mechanism, i.e. the purposiveness and functionality of a given system, is illustrated. We will refer to the concepts of the interior of the *MSS* system as the isolated components of this system, which we will most generally divide into three basic categories including:

$$MSS = MSS_Z \cup MSS_N \cup MSS_R \quad (20)$$

where: MSS_Z – management elements (subsystems),
MSS_N – normative elements (subsystems),
MSS_R – working elements (subsystems).

The set of key (working) elements of the *MSS* system can be divided into two main groups:

$$MSS_R = MSS_{RA} \cup MSS_{RB} \quad (21)$$

comprising respectively:

$$MSS_{RA} = \{A_{CZ}, A_{MS}, A_{SR}\} \tag{22}$$

where: MSS_A – subject systems, being the protected security subject,
A_{CZ} – life and health security system,
A_{MS}– ship, property and cargo security system,
A_{SR} – maritime environment security system.

$$MSS_{RB} = \{B_{ZM}, B_{EK}, B_{GO}\} \tag{23}$$

where: MSS_B – object systems, generating various hazards,
B_{ZM} – maritime shipping security system,
B_{EK} – security system for maritime resource exploitation,
B_{GO} – security system for maritime economic activities.

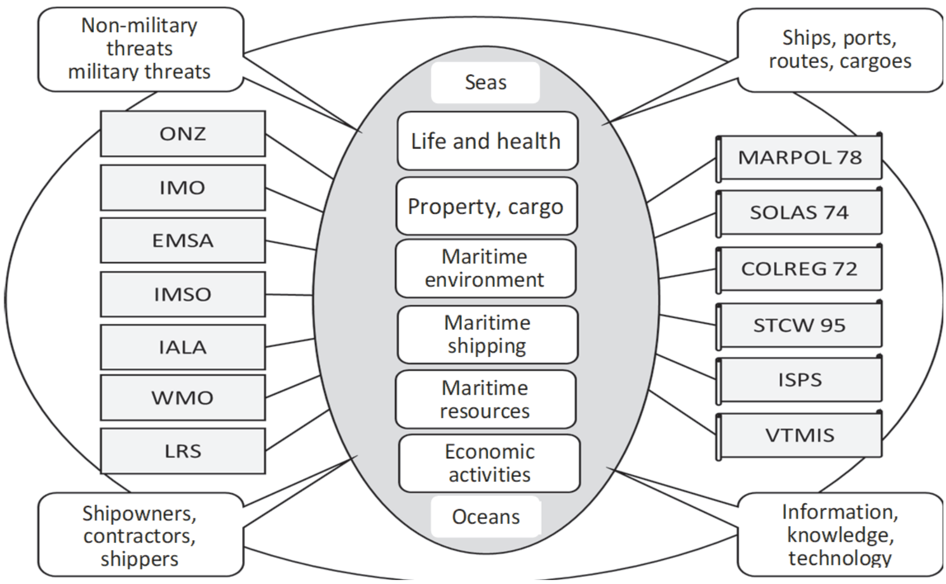

Fig. 3. Maritime Security System as a cybernetic white box
Source: Own elaboration

Between the various subject [MSS_{RA}] and object [MSS_{RB}] security systems, there are various internal relations depicting their organizational and functional interrelations, determining the safety of these subjects and objects:

$$MSS_R : \; A_{CZ} \times A_{MS} \times A_{SR} \times B_{ZM} \times B_{EK} \times B_{GO} \rightarrow \overrightarrow{BP} \tag{24}$$

As can be seen from equation [24], the set of internal relations is very extensive, which demonstrates the great complexity and enormous responsibility of the working elements of the MSS system in the process of shaping various aspects of maritime safety $\overrightarrow{BP}$.

In addition to the aforementioned working elements that perform key executive functions [MSS_{RA}, MSS_{RB}] in the MSS system, there are active elements that stimulate safety – the management system [MSS_Z] and the normative system [MSS_N]:

$$MSS = \left\{ MSS_A, MSS_B, MSS_Z, MSS_N \right\} \tag{25}$$

where: MSS_Z – maritime security management system [organizations],
MSS_N – normative system offering legal and international tools to protect maritime safety.

The model maritime security management system MSS_Z includes the following international organizations and structures:

$$MSS_Z = \left\{ MSS_{Zi};\; i = \overline{1, I} \right\} \tag{26}$$

where: $MSS_{Z1} = ONZ$ – United Nations,
$MSS_{Z2} = IMO$ – International Maritime Organization,
$MSS_{Z3} = EMSA$ – European Maritime Safety Agency,
$MSS_{Z4} = IMSO$ – International Mobile Satellite Organization,
$MSS_{Z5} = IALA$ – International Association of Lighthouse Authorities,
$MSS_{Z6} = WMO$ – World Meteorological Organization,
$MSS_{Z7} = LRS$ – Lloyd's Register of Shipping.

An exemplary collection of international conventions and codes governing maritime safety includes the following types:

$$MSS_K = \left\{ MSS_{Ki};\;\; i = \overline{1, I} \right\} \tag{27}$$

where: $MSS_{N1} = MAR$ – Maritime Pollution Convention (MARPOL],
$MSS_{N2} = SOL$ – Convention for the Safety of Life at Sea (SOLAS],

$MSS_{N3} = COL$ – International Regulations for Preventing Collisions at Sea (COLREG],
$MSS_{N4} = STC$ – International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW),
$MSS_{N5} = ISP$ – International Ship and Port Facility Security Code (ISPS),
$MSS_{N6} = VTM$ – Vessel Traffic Monitoring and Information System (VTMIS).

The management systems $\left[MSS_Z \in MSS\right]$ organize and coordinate the activities of the working systems $\left[MSS_{A,B} \in MSS\right]$ with the use of state acts of international law $\left[MSS_N \in MSS\right]$. Working systems $\left[MSS_{A,B} \in MSS\right]$ realize the main mission of the system MSS_R – working elements (subsystems), in maintaining the safety of all system subjects and objects at the required level.

According to the concept of general systems theory and the principle of hierarchical decomposition, each relatively isolated component element (subsystem) of a given system can be recursively considered as a separate system possessing all the attributes of the systemic definition. For example, the maritime shipping system $[B_{ZM}]$ can be decomposed into the following components:

$$B_{ZM} = \left\{B_{ZMi};\ i = \overline{1,I}\right\} \tag{28}$$

where: B_{ZM1} – seagoing vessels as means of transport,
B_{ZM2} – sea lanes as waterways,
B_{ZM3} – seaports as distribution centers,
B_{ZM4} – shipping rates and tariffs, as elements of the market game,
B_{ZM5} – production and repair yards,
B_{ZM6} – port services,
B_{ZM7} – maritime personnel and agencies,
B_{ZM8} – insurance companies.

The above elements $B_{ZMi} \in B_Z M$ remain in mutual systemic relations $[R_{ZM}]$ that guarantee the effective performance of the basic functions of the shipping system:

$$R_{ZM} \subseteq B_{ZM1} \times B_{ZM2} \times B_{ZM3} \times B_{ZM4} \times B_{ZM5} \times B_{ZM6} \times B_{ZM7} \times B_{ZM8} \tag{29}$$

where: R_{ZM} – set of organizational and functional relations in the maritime shipping system.

The maritime shipping security system $[B_{ZM}]$, like any praxeological system, is an open system in which input $\left[B_{ZM}^{We} \right]$ and output $\left[B_{ZM}^{Wy} \right]$ streams can be distinguished, such as, for example:

$$B_{ZM}^{We} = \left\{ B_{ZM}^{We1}, B_{ZM}^{We2}, B_{ZM}^{We3}, B_{ZM}^{We4}, B_{ZM}^{We5} \right\} \tag{30}$$

where: B_{ZM}^{We1} – stream of maritime shipping threats,
B_{ZM}^{We2} – stream of market shipping needs,
B_{ZM}^{We3} – stream of reservations of port berths,
B_{ZM}^{We4} – stream of reservations of port maintenance services,
B_{ZM}^{We5} – stream of insurance orders.

$$B_{ZM}^{Wy} = \left\{ B_{ZM}^{Wy1}, B_{ZM}^{Wy2}, B_{ZM}^{Wy3}, B_{ZM}^{Wy4}, B_{ZM}^{Wy5} \right\} \tag{31}$$

where: B_{ZM}^{Wy1} – stream of completed shipping contracts,
B_{ZM}^{Wy2} – stream of completed sea voyages,
B_{ZM}^{Wy3} – stream of visited sea ports,
B_{ZM}^{Wy4} – stream of completed transhipment work,
B_{ZM}^{Wy5} – stream of completed port handling and servicing.

For example, the selected maritime shipping security system $[B_{ZM}]$ can also be described using a black box and white box cybernetics, analogous to the overarching Maritime Security System. In a similar convention, all other elements (subsystems) of the MSS system can be presented, which is due to the property of hierarchization of systems – superordinate (supersystems) and subordinate (subsystems).

Relations in the Maritime Security System

Of fundamental importance for achieving the desired purposiveness and functionality of a given system are the relations between the isolated elements of the system, the so-called intra-system relations, which in general can be of a material, energetic and informational nature. Particularly useful in further deliberation appears to be the definition of H. Białyszewski, defining a system as: "an ordered arrangement of identifiable elements. This order consists in the fact that the place of a given element in the system is not accidental. Each element is related by certain relations (forces) to the other elements of the system, and the arrangement of these relations (forces) determines the place of each element in the system and determines its state. A change in the place or state of an element in the system causes a change in the arrangement of relations (forces], which is more or less reflected in the system as a whole, as well as in its other elements." (Białyszewski, 1972, p. 180). This definition strongly emphasizes the importance of relations and couplings in creating the detailed properties and functionality of any praxeological system.

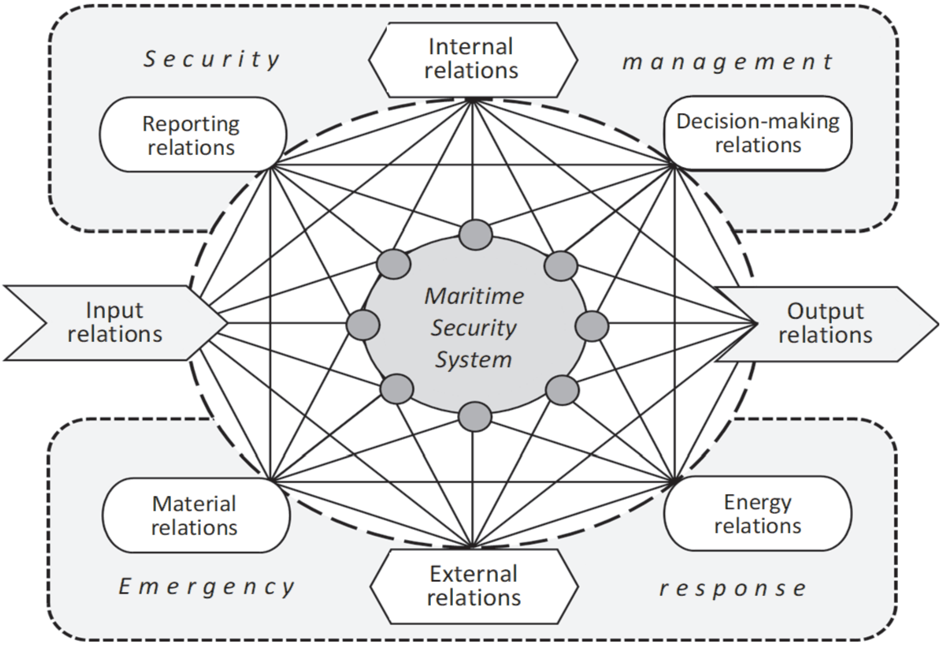

Fig. 4. Categories of relations in the Maritime Security System
Source: Own elaboration

The functional structure of a system is formed by the network of couplings and system relations that exist between all its elements. The denser this network is, the greater the efficiency and quality of functioning of a given system is, since it covers as comprehensively as possible all system attributes. It is the system relations (couplings) occurring between the various elements of the system, and not the constituent elements, that determine the functionality of a given system, and they play a system-forming role. In complex systems, containing subjects of a social nature, relations take the form of multipartite relations, directed in arbitrary directions and repeatedly connecting any elements of the system with each other. In general, system relations are divided into intra-system relations and external relations connecting the open system with the system environment. Due to the medium and carrier of these relations, they are divided into informational, material and kinetic relations. Due to the direction vector, input and output relations were isolated. Exceptionally, due to their causality and consequences, information relations have been divided into reporting and decision (executive) relations.

The great diversity and complexity of the set of relations R will be symbolically written with the following expression:

$$R: \quad R_{IM} \times R_{ID} \times R_M \times R_E \rightarrow R_{Wy} \times R_{We} \times R_Z \times R_W \tag{32}$$

where: R – set of system relations,
R_{IM} – reporting information relations,
R_{ID} – decision information relations,
R_M – material relations,
R_E – energy relations,
R_{Wy} – input relations,
R_{We} – output relations,
R_W – intra-system relations,
R_Z – extra-system relations.

The primary role in creating the functionality of the system is played by information relations for managing all properties and attributes of the system. For the sake of management efficiency, they have been divided into reporting streams and decision-making streams, for reporting information is the basis for developing and making decisions to executive material or energy actions for individual subjects and objects of the maritime security system.

Information ties are a prerequisite for the existence and purposive functioning of a given system, since, according to N. Wiener, «every organism maintains unity of action by virtue of the fact that it has the means to receive and transmit information» (Wiener, 1971, p. 206). In systems theory, information as a symbolic medium materializes in the form of signals and control couplings. Material forms of information transmission in the form of signs and symbols enable human communication with the world of systems. In the case of security systems, we are dealing mainly with non-material, informational relations that carry decisions and commands to executive (working) systems, which in turn carry out material or energy actions, such as in the emergency response stage.

External environment of the Maritime Security System

Any large system such as, e.g., the Maritime Security System operates in a certain system environment, which in this case is the global political-economic-social environment of the world's shipping and maritime economy, additionally taking into account the hydrometeorological conditions and the temporal-spatial dispersion of all stakeholders interested in relevant maritime safety. According to A. Hall, "the system's environment is the set of all objects that do not belong to the system, whose properties interact with the system and at the same time are themselves changed by the action of the system" (Hall, 1968, p. 94).

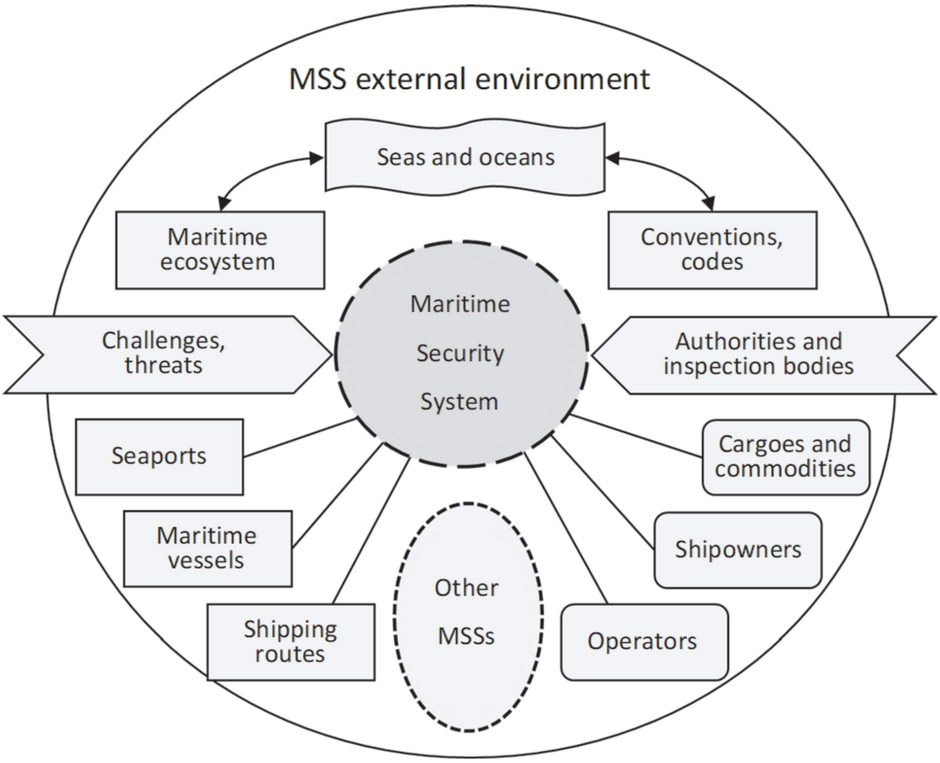

Fig. 5. Elements of the external environment of the Maritime Security System
Source: Own elaboration

The Maritime Security System, as a cybernetic system of relative isolation, functions in a global environment that integrates the economic, social and political interests of individual states and nations and the international community as a whole. It uses the universal common good of the seas and oceans, as well as their animate and inanimate resources, which belong to the global ecosystem. All these elements can be categorized as the external environment of the MSS system, which can be most broadly divided into:

$$MSS^{OZ} = \left\{ MSS_i^{OZ}; \;\; i = \overline{1, I} \right\} \tag{33}$$

where: MSS^{OZ} – external environment of the system MSS,

MSS_1^{OZ} – the global maritime ecosystem,

MSS_2^{OZ} – the world's seas and oceans,

MSS_3^{OZ} – external threats to maritime safety,

MSS_4^{OZ} – maritime operators,

MSS_5^{OZ} – cargo, goods, passengers,

MSS_6^{OZ} – means of sea transport,

MSS_7^{OZ} – ports and port infrastructure,

MSS_8^{OZ} – sea lanes and shipping channels,

MSS_9^{OZ} – international and national regulations,

MSS_{10}^{OZ} – national and international regulatory bodies and entities.

Every isolated element (system, subsystem) of the external environment is most often a complex organizational and functional system and in itself represents a huge system diversity. Accordingly, it can be structurally decomposed into component subsystems, guaranteeing its specialized functioning in a specific field. For example, in the set of offshore business operators $\left[MSS_4^{OZ} \right]$, the following elements can be distinguished:

$$MSS_4^{OZ} = \left\{ MSS_{4j}^{OZ}; \;\; j = \overline{1, J} \right\} \tag{34}$$

where: MSS_{41}^{OZ} – shipowners and shipping companies,

MSS_{42}^{OZ} – shippers and brokers,

MSS_{43}^{OZ} – shippers and contractors,

MSS_{44}^{OZ} – brokers and intermediaries,

MSS_{45}^{OZ} – insurers and banks,

MSS_{46}^{OZ} – goods handling agencies,

MSS_{47}^{OZ} – maritime agencies,

MSS_{48}^{OZ} – maritime services.

The isolated components of the external environment $\left[MSS_{ij}^{OZ} \in MSS^{OZ} \right]$ of the MSS system remain in mutual information, energy, kinetic, as well as formal-legal, business and natural (ecological) relations and conditions, which makes them constantly interact with each other and remain in numerous realities of cooperative or confrontational nature.

$$MSS: \quad MSS_{i}^{OZ} \times MSS_{i+1}^{OZ} \rightarrow RZ^{MSS} = \left\{ RZ_{ij}^{OZ};\ i = \overline{1, I};\ \ j = \overline{1, J} \right\} \tag{35}$$

where: RZ^{MSS} – set of relations connecting the elements of the external environment $\left[MSS_{ij}^{OZ} \right]$ with the studied system MSS.

The set of relations [35] determines the identity and specificity of the external environment of the MSS and interts with the internal relations occurring in the MSS system. The myriad relations and interdependencies present in the external environment determine the degree of openness of the MSS system, and thus its ability to self-regulate and flexibly adapt to the changing challenges emanating from this environment. According to general systems theory, the openness and susceptibility of a system to external stimuli determines its identity, systemic vitality and praxeological utility.

Conclusions

Proposed in 1930 by L. von Bertalanffy, the universal systems approach, like any novel and original scientific idea, received both a positive and critical response from researchers. While in the natural or technical sciences it has been absorbed almost uncritically, especially in the social sciences and humanities it poses a variety of methodological problems and doubts. The construction of universal systems with the participation of man, in view of the enormous complexity of its intellectual personality and various manifestations of rational action, has proven to be a task far more difficult than analyzing and creating primate biological or natural systems, not to mention the entirely determinate technical or cybernetic systems.

According to Z. Pietraś, the application of the systems approach in the social sciences brings with it a number of problematic paradoxes. For example, the paradox of purposiveness is that one cannot define the characteristics of a social system as the sum of the characteristics of its individual elements and infer the behavior of the system on this basis (Pietraś, 1986, p. 115). Another paradox of hierarchicality has it that such concepts as system, subsystem or supersystem are relative and can be intertwined. In view of this, it is possible to treat a system as an element of a certain subsystem, that is, to consider it as a component of another system.

The interpretation of the very concept of a system and the systems approach is an individual and highly subjective matter for each researcher. According to popular opinion, there is still a lack of a precise definition and interpretation of the system itself, which makes it possible to define almost anything with this concept. Huge problems arise in determining the boundary of the system and separating its distinctiveness from the surrounding reality. The issue of the boundaries of the system is very strongly connected with the division into open and closed systems, which, according to many researchers, is an eminently theoretical division. The proposed division into partially open and partially closed systems is de facto the concept of an open and transparent system (Maracz, 1983, p. 277).

The surrounding world of systems, especially social systems, is a world of open systems that enter, especially in the information society era, into strong interactions with the entire environment – social, political, economic, cultural and civilizational in general, and, above all, natural. Cross-border technologies of the information society have led to virtually complete transparency of all borders and barriers, especially in the intangible world of information, ideas, thoughts and knowledge. Thanks to the mobile technologies of the IT sector, almost all closed systems are disappearing before our eyes, and their place is taken by a global open system, whose carriers today include the technologies of Internet, mobile telephony, or cloud computing, big data and the turbulently forming internet of things. Therefore, a contemporary systems approach must take into account scientific and technological progress, developments in technology that are changing not only the face of science, but also the image of human civilization and the limits of human cognition (Wang et al., 2022, p. 3).

In response to the criticisms of the classical systems approach in science presented above, a new theory emerged in the 1970s representing the so-called situational approach, whose main theses are relativism, flexibility and research pragmatism. The essence of the situational approach is: «to determine what method in a given situation, given conditions and at a given moment will best contribute to the achievement of goals» (Stoner, Wankel, 1994, p. 67). Proponents of the situational approach oppose the search for and implementation of universal principles and laws (dogmas) for all scientific theories.

In civilized countries, all aspects and dimensions of safety are the responsibility, under the highest national and international laws, of the public administration and professional bodies established for this purpose. The activities of these bodies are based mainly on situational analyses of the current level of threats and projected safety states. The implementation of these tasks is based firstly on the necessary formal and legal regulations (the Law on Crisis Management) and secondly on the systemic technology of crisis management in critical situations, which in Polish conditions operates at all levels of territorial public administration, such as: crisis management at the central (government), provincial, district, municipal levels, as well as departmental, environmental, individual plants, etc. All of these applications operate in a unified organizational and functional structure, as respective crisis management systems, meeting, on the one hand, the conditions of systemic coherence, openness, hierarchy and interdependence, while on the other hand, the situational approach, which directly attaches the level of threats and the state of safety to the current conditions of the crisis situation.

Despite the controversies cited in the conclusion, it should be stated that the real contribution of general systems theory to the development of safety science is primarily due to the mutual interdisciplinarity, universality and complementarity of the two theories. The universalist systems approach has contributed to the significant development of modern security theory, which uses a flexible systems apparatus with great vigor, fulfilling the hopes of developers of the general systems theory. It should also be emphasized that the mature systems theory of safety must be given credit for the high level of modern utilitarian solutions found in almost all fields of social activity, such as the most diverse applied systems of safety and crisis management.

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