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Principles of identifying non-conformities in the safety management system of shipping company while assessing its effectiveness in minimizing errors

Oleksiy Melnyk[1,*], Oleg Onishchenko,[2], Svitlana Onyshchenko,[3], Alla Bondar[4], Svitlana Borovyk[5]

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ABSTRACT

The article outlines a comprehensive strategy for ship safety management in companies. It emphasizes the need for targeted intervention in factors affecting the state of safety, covering technical, social and financial aspects of ship operation. The article proposes a structured approach to the influencing factors, dividing them into internal and external factors. External factors, including mandatory regulations of organizations such as the International Maritime Organization and national authorities, are highlighted as critical determinants of a company's safety management system. The article emphasizes the key role of effective management in connecting the various elements of the safety management system, including personnel, resources, infrastructure and finance. In addition, the article presents a model for assessing the effectiveness and improvement of the safety management that is consistent with the International Safety Management Code's requirements for internal safety audits. The importance of a unified management system based on coordinated control of influencing factors and compliance with external regulatory requirements is emphasized. A systematic approach to modification is proposed to integrate the new standards while minimizing personnel resistance and a model for evaluating safety management processes is proposed to provide a basis for identifying nonconformities and improving safety practices.

1. Introduction.

Numerous studies have addressed aspects of maritime transportation safety. They include the assessment of risks and safety measures in maritime transportation, in particular in the handling of explosives and nuclear substances [1-3]. Some studies focus on specific challenges and opportunities to improve safety in the Arctic maritime sector [4]. In addition, the development of tools and models to enhance safety measures and indicators in this area has been emphasized [5-7]. Furthermore, a comparative study of occupational safety and health conditions on passenger and cargo ships in Norway provides valuable insights into safety protocols in different environments [8]. These studies emphasize the need for continuous improvement in maritime transport safety standards and practices.

The work of [9] focuses on violations related to aviation safety management system components. The paper [10] discusses in detail the safety management system, in particular its evolution towards safety excellence in the oil and gas industry and geosciences. In [11], the authors examine the links between aviation and maritime safety management systems, ex-

[1]PhD (Tech.) Assoc. Prof. at Navigation and Maritime Safety Dept., Odessa National Maritime University, Odessa, Ukraine.
[2]Doctor of Science (Tech.), Professor at Fleet Technical Operation Dept., National University Odessa Maritime academy, Ukraine.
[3]Doctor of Science (Econ.), Professor at Fleet Operation and Shipping Technology Dept., Odessa National Maritime University, Ukraine.
[4]Doctor of Science (Tech.), Professor at Logistics Systems and Projects Management Dept., Odessa National Maritime University, Ukraine.
[5]PhD (Tech.), Assoc. Prof. at Fleet Operation and Shipping Technology Dept., Odessa National Maritime University, Ukraine.
[*]Corresponding author: Oleksiy Melnyk. E-mail Address: m.onmu@ukr.net.

ploring common attributes and ideas related to these critical safety domains. The publication [12] outlines the creation of an Integrated Safety Management System application tailored for workplaces, aiming to enhance safety practices in professional settings. Research [13] addresses safety complexities in dynamic systems-of-systems for flood management, aiming to tackle the intricacies and risks tied to flood-related emergencies and disasters. In [14], the authors explore an Industrial Safety Management System leveraging wireless communication technology. This technology-centric approach to safety management centers on enhancing communication and response protocols.

The papers [15,16] introduce a navigational safety assessment method that employs a Markov model approach, offering a novel way to evaluate safety in maritime navigation, presents a method for evaluating the quality of risk assessments in shipboard operations by incorporating expert reviews, aiming to enhance the effectiveness of risk assessment procedures. In [17] explores the importance of maritime situational awareness as a fundamental factor for ensuring safe ship operations, potentially discussing strategies and technologies to improve situational awareness. Publication [18] provides an overview of ship information security risks and safety concerns in maritime transportation, likely discussing issues related to the security of information on ships. The article [20] examines the flow of information within maritime safety management systems, shedding light on how information is managed to enhance safety in maritime operations. A quantitative analysis to enhance the implementation of safety management systems on ships, potentially assessing the effectiveness of SMS implementation procedures conducted in [21]. The research [22] explores research directions for remotely-controlled merchant ships by revisiting their system-theoretic safety control structures, offering insights into improving safety in remote ship operations. The paper [23] discusses the coordination of the ISM Code and OHSAS procedures to enhance occupational health and safety at sea, likely providing strategies for improving safety practices in maritime environments. Innovative strategy development approach aimed at improving the effective implementation of the ISM Code, potentially offering insights into strategies for ensuring compliance with safety management standards introduced in [24]. A validation study to assess the ongoing effectiveness of the ISM Code by comparing maritime accidents in Korean waters, providing valuable insights into the ISM Code's role in ensuring maritime safety performed in [25]. The articles [26-28] considered the issues of optimizing the energy consumption of an autonomous watercraft by determining the effective modes of operation of propulsion motors and solving the urgent problem of cyber-resistance of ship information systems and strategy for modernizing passenger ships.

While the works studied make a valuable contribution to the field, there is a clear opportunity to further explore the precise criteria and methods for identifying non-conformances in safety management systems. This would involve scrutinizing specific indicators, benchmarks and processes that indicate deviations from established safety standards. In addition, a comparative analysis of different approaches to non-conformance detection can provide valuable insights into best practices.

Thus, although the research conducted has laid a solid foundation, there is an urgent need to further explore the principles of non-conformance identification in safety management systems. Such research can make a significant contribution to efforts to improve maritime safety and minimize operational errors.

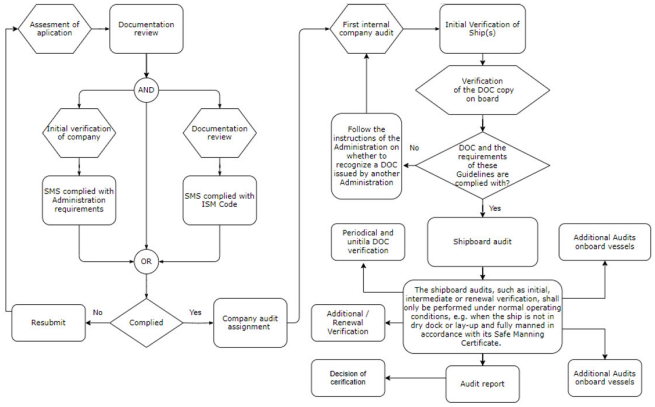
2. Materials and methods.

The International Safety Management Code (ISM Code) is a set of international guidelines and regulations developed by the International Maritime Organization (IMO) for the safe management and operation of ships and the prevention of pollution. The ISM Code is part of a wider system of international maritime safety standards and applies to all ships engaged in international voyages. Its purpose is to ensure the safety of navigation, protect the marine environment and promote the welfare of seafarers. The Code imposes significant obligations on shipowners and operators. These include establishing a safety management system (SMS) on each ship, conducting regular audits and assessments for compliance with the Code, and training and certification of crewmembers.

The ISM Code, which applies to all ships engaged in international voyages, is the cornerstone of maritime crisis prevention, environmental protection and maritime safety. It covers a wide range of aspects, from navigation to ship maintenance, and includes crew management and other aspects.

Conducting SMS audit is a crucial activity in the field of maritime safety. It involves assessing the compliance of the company and the vessel with global safety standards, incorporating the provisions of the ISM Code, as shown in Fig. 1;

Figure 1: Conditional algorithm of SMS audit.

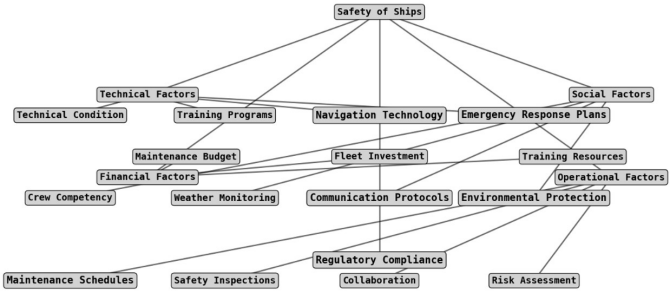


Source: Authors.

In order to manage the state of ship safety in a company, it is necessary to target the factors on which this state depends. For example, in order to manage the condition of a seagoing transport unit (vessel), it is necessary to influence a variety of factors, and such factors as those on which technical, social and financial results of production activities of the company's ship safety management system depend. Such factors (factors

of influence) in relation to the tasks facing the company's SMS can be structured, for example, as follows Fig. 2;

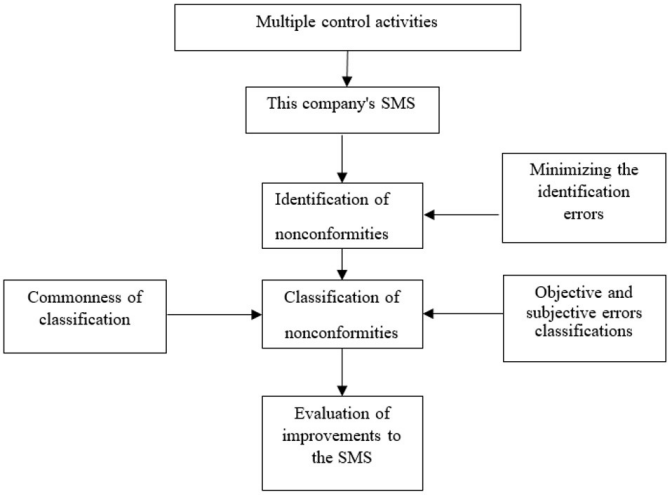
Figure 2: Influencing factors in relation to the company's SMS objectives.



Source: Authors.

It is obvious that the successful functioning of the SMS is impossible without scrupulous periodic analysis of its condition at various stages of its development. To ensure the possibility of self-assessment by shipping and fishing companies, a recognized organization (Classification Society) has developed a model of SMS perfection based on the principles of the International Safety Management Code. Therefore, self-assessment of SMS in a shipping or fishing company is thus a way to compare its safety activities with the SMS excellence model, to determine the level of improvement of its SMS at this stage, to take appropriate management actions to improve the effectiveness of the SMS and to increase the safety of operating vessels. A graphical interpretation of the sequence of actions of personnel in the SMS when conducting self-assessment of their performance can be presented in the figure (Fig. 3).

Figure 3: Graphical interpretation of the sequence of personnel actions in the SMS.



Source: Authors.

The main ideas inherent in the model of SMS perfection allow:

- substantiate methodologies for calculating the quantitative assessment of a company's SMS;
- to be a means (tool) for comparing the effectiveness of the company's SMS at fixed time intervals, as well as among themselves;
- provide an opportunity to compare the effectiveness of the company's SMS with the uniformly established levels of SMS perfection.

Conducting an SMS self-assessment using data from company-operated SMS vessels has a number of advantages:

- allows for an "overall snapshot" of the state of the company's SMS at a given stage;
- gives the right to use a single set of criteria for assessing the effectiveness of SMS;
- realizes a systematic approach to SMS improvement;
- allows obtaining objective assessments based on facts rather than personal perception of managers;
- facilitates an understanding of what the company's SMS, its shore-based units and vessels need to do in key areas of the SMS in a given situation;
- enables changes in the status of the company's SMS to be tracked since the previous self-assessment;
- enables more detailed reviews of the company's SMS activities on ships and shore-based units in accordance with section 12 of the ISM Code.

The model of SMS perfection and the methodology of assessment of SMS improvement based on this model can be used in several situations. First, at the stage of planning any measures aimed at improving the company's SMS. The trained specialists from the personnel of the SMS can estimate to what extent these measures will allow to increase the coefficient of the system ("integral assessment of the SMS perfection") and can choose the amount of resources, which is necessary for realization of the planned measures. In addition, specialists from the SMS personnel can make a more or less justified decision on the expediency of their implementation and the strategy (order) of their implementation.

Another situation in which it is appropriate to use the SMS improvement model and the SMS improvement assessment methodology based on it is to conduct an SMS self-assessment as an activity carried out in fulfillment of the requirement under Section 12.2 of the ISM Code. In particular, this section addresses the requirement for companies to conduct internal audits and safety reviews for compliance with the ISM Code.

This section states that shipping companies should establish and maintain procedures for conducting periodic internal audits to ensure that SMS effectively implemented and that the objectives of the ISM Code are met. These internal audits (Fig.1) are necessary to verify compliance with the ISM Code and to

identify areas where improvements may be required to enhance safety.

In this case, self-assessment of SMS effectiveness in a shipping company is recommended to be carried out in the following sequence: a designated person of the company decides to carry out self-assessment, a leader of the self-assessment process is appointed. As such, a person it is best to appoint a sufficiently trained and authoritative specialist of the company who has a good understanding of its work and computer skills. It would be helpful if the first face of the shipping company (president, director, general or executive officer) can head this work. If there are about twenty or more people working in the company's onshore SMS departments, the self-assessment process can in principle be led by an authorized person of the company and an expert panel appointed.

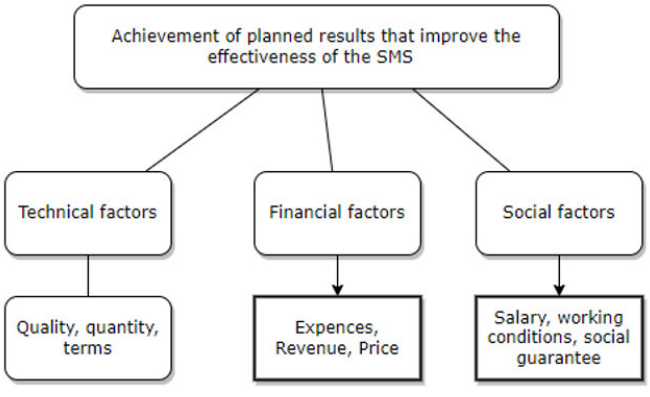
3. Results and discussion.

If the factors of influence are structured, then for successful achievement of the goal set before the company's ship safety management system (SMS) in terms of social factor management it is necessary to draw up the structure of SMS organization, and then, in accordance with this structure, to decompose labor relations, identifying both "functional" (vertical) and "sectoral" (horizontal) subsystems. When singling out vertical and horizontal components of labor relations in an SMS, one should be guided by ratio models:

$$\begin{aligned} W = U \times V = (u, v) \mid u \in U, v \in V \\ (u, v) \in A_1 \leftrightarrow v < u \\ (u, v) \in A_2 \leftrightarrow v \sim u \end{aligned} \tag{1}$$

Where $v < u$, $v \sim u$ – relations defining the signs of vertical and horizontal production relations in the system, respectively;

Figure 4: Influencing factors.



Source: Authors.

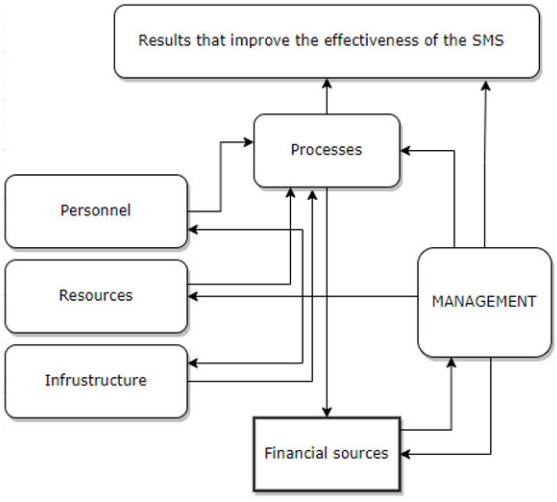
The social factor is the dominating influence factor, because knowledge, experience, qualification, conscientiousness, and, therefore, qualitative, highly effective work of the personnel of the ship operation safety management system, including managers, organizing this work and evaluating it, determine the success of the processes and achievement of all planned improving results.

Achievement of the planned improving results of SMS is impossible without technical and financial resources. Resources can be classified into material, intellectual, own, and those that are purchased and spent while ensuring safety: energy, materials, services, consultations, information, and software products. And the higher the quality of resources, the higher the level of security, but quite often the administration of companies takes into account that the cost of resources is a significant part of the costs and limits these costs from above. A company's operational infrastructure, including financial and material resources, plays an important role in ensuring efficient operations and meeting SMS requirements. It provides the necessary resources to provide transportation services and manufacture products, which in turn contributes to achieving high standards in safety management.

Effective management of the state of safe operation of the company's vessels is one of the influencing factors that is necessary for the successful operation of an SMS. The factor of effective management is as important as the company's infrastructure or the personnel of the SMS. At the same time, it is a specific factor. The management connects the process of managing the state of safety on the company's ships with the personnel of the SMS, resources, infrastructure of this company, its finances (Fig. 5). Only by influencing the above-mentioned factors of influence, it is possible to establish necessary and coordinated requirements to the results of activity and then to ensure their fulfillment. Thus, the management of activity in the SMS is first the management of personnel, resources, infrastructure, and finances.

Note that in process management there are managerial processes, for example, management of planning or management of SMS improvement. Therefore, it is possible and necessary to talk about managerial management (Fig. 5);

Figure 5: Management of activities in SMS.



Source: Authors.

It follows from Fig. 5, that the leading influence factor is processes, as personnel, resources and infrastructure influence the results of the SMS activity only through processes. Financing determines the actual state of all influencing factors, and the objects of management are all factors, including the processes ensuring the state of safety of the company's vessels within the framework of conventional and national requirements.

Influencing factors operate not only within the ship's safety management structure. In addition to internal factors, there are external influencing factors that can also significantly change the performance of the SMS. Such factors are various mandatory requirements set by the International Maritime Organization (IMO), regional international agreements (regional memorandums), national organizations and the company that regulate and define in a certain way the activities of the SMS. These external factors have a direct impact on the requirements for personnel and processes, resources and infrastructure, and the management of the operational status of ships. Compliance is monitored by a whole system of international and national oversight bodies, from the port authority to a recognized organization. The company, through the SMS, has to manage its response to ensure, on the one hand, that the relevant requirements are met and, on the other hand, to minimize the risks generated by failure to meet these requirements. Conscientious fulfillment of mandatory requirements gives certain guarantees in achieving the proper level of safe operation of ships, contributes to good social results and, what is important, protects the company from unreasonable claims from the states in whose ports the company's ships call.

Establishment and sustainment of a unified system of management in the company (the culture of the SMS management) should be a permanent goal of its management. The unified management system should be based on coordinated and balanced management of its results through the management of influencing factors on which they depend, taking into account external regulatory requirements. Implementation of the requirements of international and regional safety standards is more appropriate to implement through modification of the unified management system.

This will allow the company to:

- accommodate the requirements of any newly introduced documents or new management system requirements, without developing new additional systems;
- link in one and the same document the requirements of different standards for the same process or object;
- significantly reduce the number of newly developed documents.

In order to start modification of the unified management system, it is necessary to have its description. It allows to assess its compliance with the requirements of these or those standards and to establish for which requirements such compliance is absent or incomplete. Usually there is no full description of the system, although it can be documented to a greater or lesser extent, but it largely "exists in the heads" of management and employees, based on established relationships and stereotypes of behavior. The question arises, how to identify and describe a unified management system? It is advisable to do this in relation to the management of influencing factors, i.e., for example, safety management and logistics management should be carried out through the management of processes, personnel, resources, finances.

In order to reduce costs and not to cause slowdown and sabotage of work due to too strong psychological rejection of the personnel of the "collapse" innovations, it is advisable to modify not at once, but in stages, depending on the relevance for the company of the introduction of any standards. Consequently, the object of unified and balanced management should be technical, financial and social results of the company's activity. The correct drawing up of goals, development of programs and making any decisions concerning even one result, for example, safety, can be realized only taking into account the influence of this safety on other results of the company's activity.

The basis for the property of systematicity in SMS are the processes Fig. 5, which can be conditionally called the main processes, for example, operation of the company's vessels, procurement of resources to maintain the state of safety on these vessels, etc. Auxiliary or servicing processes: installation, adjustment and repair of equipment, communication, supply, work with crew. The processes ensuring maintenance of the state of safe operation also include management processes, for example, planning, realization, control and selection of corrective management. In this case, the more perfect the technology of processes, the more productive they are, the less labor-intensive they are, the better they are organized, the higher the results, including safety, and the lower the costs.

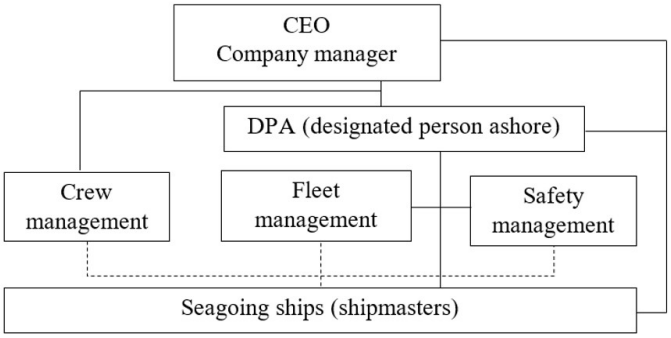
In order to study the peculiarities that may arise in the process of maintaining the state of safe operation of the ship, let us schematize the modern SMS of the company, represent this system in the figure (Fig. 6) and define the structure of the SMS of the company.

On the one hand, the structure of the SMS should meet the requirements of the ninth chapter of the International Convention SOLAS-74 and its Code (ISM code), and on the other hand - the requirements of the FSC concept and national requirements. Formally, such an SMS structure can be defined as follows:

$$\eta = (Y, I, X, R, U, G) \tag{2}$$

where: Y - set of the organizational-technical system, including both onshore divisions of the company and vessels united by information and control links; I - system of actions and relations (SMS management culture), providing a standard state of safety for vessels in the structure; X - set of processes going on in the structure; R - set of management objectives; U - set of purposeful management plans; G - set of management resources, for example, optimal in terms of cost, but selected with agreed constraints;

Figure 6: Schematic structure of a modern company's SMS.



Source: Authors.

Then, within the requirements of a compliance culture, the state assessment of the safety condition management process going on a ship $X_j \in X$, can be defined using an indicator function written as follows:

$$F(X_j) = \begin{cases} 1, \ if \ X_j \subseteq X_0 \ in \text{ safe condition of ship } \eta_0 \\ \text{from SMS structure as whole } \eta; \\ 0, \ if \ X_j \subseteq X_0 \ in \text{ substandard ship condition } \eta_0 \\ \text{from SMS structure as whole } \eta; \end{cases} \tag{3}$$

Where X_j – current status of the process running on the ship, X_0 – standard (reference) safe state of the ship process maintained by system management.

The proposed function allows to transform the process model X_j into a random sequence of zeros and ones that reflects the changing safety state of the ship from standard state to substandard state and vice versa. It should be noted here that the use of the indicator function under fairly general assumptions allows us to identify nonconformities while minimizing the empirical risk.

A set of processes strictly defined within the framework of the structure presented in the form of a schematized description (Fig. 5) is called a metaprocess. From a formal point of view, the most general description of all interactions can be chosen as a model of a metaprocess as the expression written as follows:

$$Y \to \overset{z}{X_0} \tag{4}$$

Conclusions.

The paper emphasizes the importance of a systematic approach to ship safety management in a company. Effective impact on technical, social and financial aspects of safety requires a comprehensive consideration of influencing factors. Particular attention is paid to the social factor as the qualifications; experience and responsibility of the company's personnel and ship crew, as well as the management culture of the company have a direct impact on ship safety. External factors such as the requirements of the International Maritime Organization and national agencies have a significant impact on ship safety management and compliance with these requirements is critical. Management plays a crucial role in linking all aspects affecting the safety status of a ship and includes the management of personnel, resources, infrastructure and finances. The paper also proposes the use of process modeling and analysis to assess the state of the ship's safe operation management system. This will help to identify discrepancies and ensure continuous improvement. The use of metaprocesses and indicator functions to evaluate ship processes appears to be an effective way to improve the management of safety status. To summarize, the article presents important aspects of ship safety management in a company and offers specific recommendations to improve the effectiveness of the management system.

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