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COMPUTER-AIDED SYSTEM FOR HAZARD ZONE IDENTIFICATION IN SHIP POWER PLANTS

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Abstract: *The development of our civilization allows us to produce new machines, installations, and plants, which unfortunately can trigger off any kind of hazards for the community safety. Large means of transport, power and chemical plants are numbered among the most dangerous. From this point of view, specific technical systems are ships with possible types of hazards such as: fires, explosions, accidents, flooding, etc. Moreover, the most dangerous ship spaces are their power plants. One possible solution for increasing their safety is to provide engineers appropriate tools allowing them to take into account the safety issues during the design process, especially at its early stages. For this purpose, we could apply a computer-aided system supporting the design of safe ship power plants. In this paper, assumptions and principles for the development of a hazard zone identification system for ship power plants are presented.*

1. INTRODUCTION

In last years, we have observed growing interest in issues concerning the maritime safety resulting from an increased sense of responsibility for human being and maritime environment protection.
Many international reports show us that the most dangerous ship spaces are their power plants. Moreover, their specificity allows us to assert that their every space can be more or less dangerous for operators carrying out any operations. For this reason, the ship power plants should be well-designed to mitigate possible hazards for their operators. Therefore, Maritime Safety Committee of International Maritime Organization (IMO) has paid attention to this factor by developing guidelines including general principles for design of safe ship power plants [1]. As a rule, they do not have an obligatory character and therefore engineers could ignore them. Today, in order to force engineers to take into account the mentioned guidelines, many maritime design offices have introduced so-called quality control systems to the design process like ISO or TQM. According to these systems, engineers responsible for safety issues have to participate in design reviews. In this approach, they can offer some remarks and suggestions concerning design solutions but after the fact. Acceptance of their suggestions can trigger off the necessity for redesign which, in turn, could entail increasing the design cost and time. Moreover, such procedures require a vast amount of engineering knowledge necessary to design ship power plants, which satisfy all crucial and additional requirements like power, reliability, maintainability, etc.
In our opinion, the complexity of current engine rooms challenges the effectiveness of such design methods. One possible solution for increasing design process effectiveness is to provide appropriate tools allowing engineers to take into account the safety issues during the design process especially at its early stages. For this purpose, we could apply a computer-aided system supporting the design of safe ship power plants. In such a system:

- a design is developed with exchange of information between engineers and a computer,
- an engineer makes proper decisions whereas a computer provides information sets, converts data, and checks correctness of his decisions.

Such a system is being developed in Gdynia Maritime University. It consists of two main modules:

- a system of hazard zone identification for ship power plants on the basis of their preliminary design,
- an expert system aiding design of the most dangerous zones from a safety point of view.

The main task of the first module is to compare selected hazard zones from a danger point of view for operators. Depending on the degree of danger for the considered zone, we can take into account various design strategies, for example: withdrawing operators to more safe places, selecting suitable design features for machines, installations and their layouts, etc. The task of the second module is to propose detailed design solutions decreasing the impact of dangerous and harmful factors for operators.

In many references, safety of a technical system is presented as a function of its unreliability and the possible danger due to this unreliability. Considerations included in [3] show us two main areas of our activities for increasing safety, namely:

– prevention of undesirable situations including improvement of the anthropotechnical system reliability (operator-technical system - environment),
– reduction of actual hazards including mitigation of possible losses.

All these activities can be carried out at the design stage (safety design) and operation stage (safety management).

Due to the anthropotechnical system unreliability two types of danger can appear in the ship power plant:

– for operators operating or maintaining ship machinery (death or human body injury),
– for marine transport or environment (ship accidents or undesirable sea pollution).

In the developed hazard zone identification system for ship power plants, we have taken into account only the first mentioned type of danger.

In recent years, the approach to ship safety issues and a way of developing safety requirements has fundamentally changed [2]. The difference lies in the fact that newly developed regulations are oriented to reach objectives such as considering system safety as the whole. We have observed opinions that design principle of maximum productivity (design for production) should be replaced by another design principle: design for safety. In proposed methods of this approach, it is necessary to assess the safety ('Safety Assessment') or risk ('Risk Assessment'). The second method could be applied in the considered system. Unfortunately, it requires the decomposition of the whole system. In the case of the ship power plant such an approach is very time consuming and costly for the following reasons:

– ship power plants have many installations, junctions, machine parts, etc.,
– all ship power plant components can realize diverse functions,
– operators cannot carry out any operations so that they are not subjected to any danger.

Moreover, risk assessment methods require consideration of the detailed design of a ship power plant. It is very difficulty to introduce any changes to such a design because it has been approved earlier by a classification society. Therefore, we pose the following question: is it possible to design safety issues for the ship power plant only for the most dangerous zones without the necessity to carry out time consuming and costly activities connected with its decomposition and risk analysis?

In our opinion, it is possible if we:

– use, in a proper way, information concerning the functions of ship machinery contained in its preliminary design documentation,
– limit its consideration to zones in which operators could carry out any operations.

Both mentioned actions entail acquiring, collecting, and converting the suitable data. This data could be acquired by means of an expert system being a part of the proposed hazard zone identification system. In such a system a design is developed with exchange of information between engineers and a computer, where:

– engineers provide suitable information based on an analysis of a preliminary design and his knowledge, intuition and experience,
– the computer converts data, and arranges elements of ship hazard zones according to calculated ranks.

2. CONCEPT OF COMPUTER-AIDED SYSTEM FOR HAZARD ZONE IDENTIFICATION

The computer-aided system for hazard zone identification in a ship power plant as every expert system requires development of a appropriate procedure of proceedings. In a general depiction, an idea of such procedure is presented in Fig. 1. Individual steps of this procedure have been formalized and introduced to the computer memory.

In the first step, we decompose a ship power plant into a set of components on the basis of its preliminary design documentation. The result of this step is a set of installations, mechanisms, and units selected according to their complexity. This procedure is performed until a ship power plant will be divided into the elementary *ship machinery components* setting up indivisible 'completeness' from a point of safety view for an operator carrying out any operation activity. In the second step, we perform decomposition of operational tasks. This procedure is carried out on the basis of analyzing a set of operational procedures existing on ship boards or own-developed. The result of this step is a set of *elementary operation activities*. Next, taking into account resultants of the two previous steps we have set up the following dualities: *a ship machinery component – a set of elementary operation activities.* Additionally, we have marked a procedure, which contains these selected activities. These selected dualities, in turn, set up a next set of the *elementary hazard situations*. Finally, for every of the selected *elementary hazard situations,* the system makes a set of function and operation factors (dangerous and harmless factors triggering off hazards for operators) available for its user. Basing on his knowled intuition and experience, he should attribute appropriate values to these factors. After receiving of the introduced values, the system will calculate a rank of potential danger for the considered *elementary haz-*

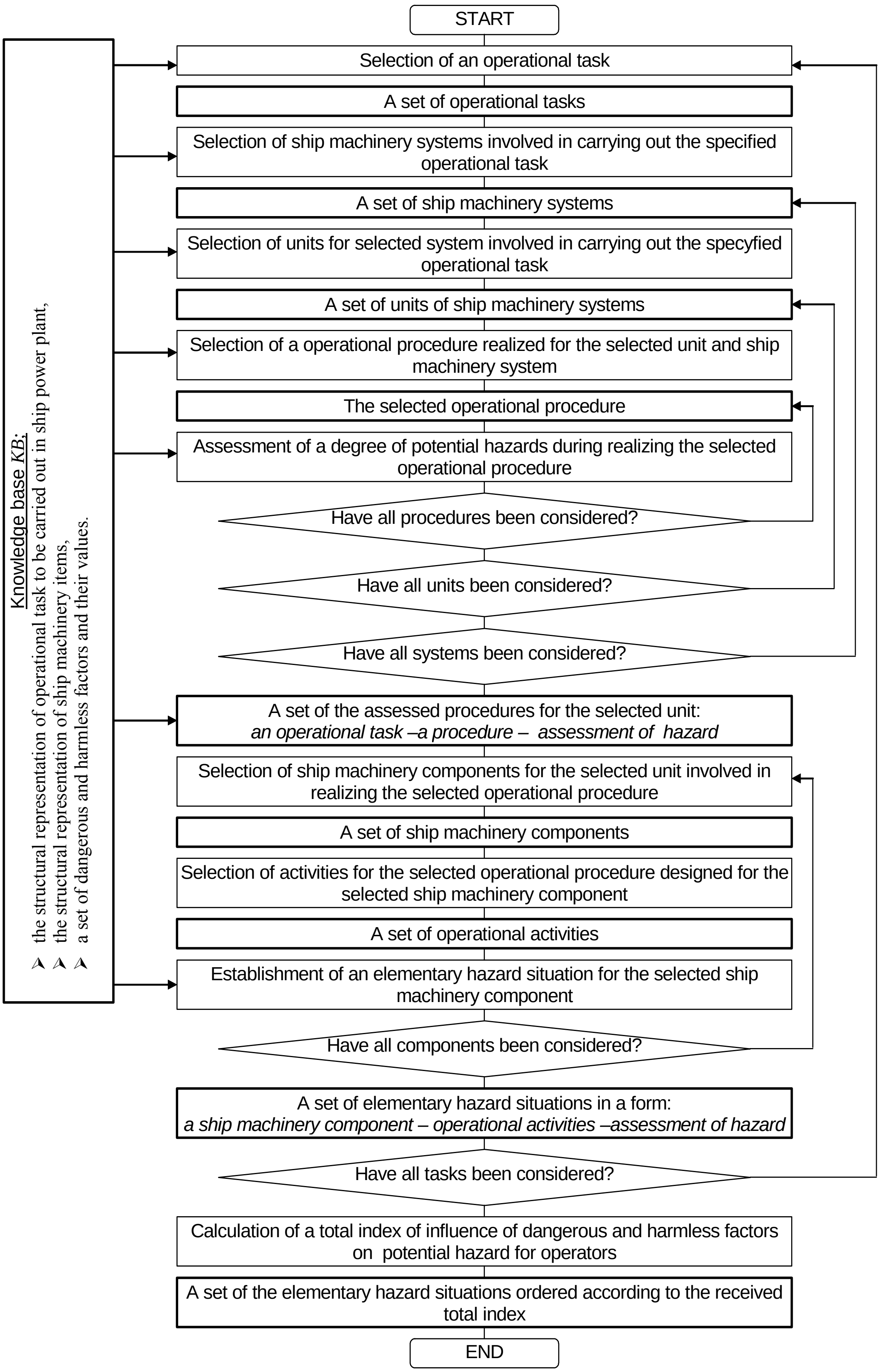

Fig.1. *A procedure of hazard zone identification*

ard situations automatically using the following expression:

$$I_{OZ}^{n} = \sum_{1}^{n} w_i c_i \left(i = 1 \vee 2 \vee 3 \vee 4\right) + \sum_{j=5}^{10} w_j c_j \qquad (1)$$

where:

I_{OZ}^{n} – an index of influence of dangerous and harmless factors on potential hazards for operators for the *n*-th identification task,

n – a number of operation activities appearing in the selected procedures for the given ship machinery component,

w_i – a significance coefficient determining a share of dangerous and harmless factors in triggering off potential hazard for operators,

c_i – a value of the *i*-th factor.

During identification of hazard zones in the ship power plant, every selected *ship machinery component* can appear many times in various operational procedures concerning different ship machinery installations, mechanisms or units. The multiple occurrence of the selected *ship machinery component* can increase the degree of potential hazards for operators. Therefore, the system subsequently aggregates both operation activities performed within various procedures and received ranks for the every selected *ship machinery component* using the following expression:

$$I_{OZ}^{\Sigma} = \sum_{i=1}^{n} I_{OZ}^{n} \qquad (2)$$

This way, we received a new set of *hazard situation elements*. This index expresses a degree of danger for all the specified operational tasks determined by the selected operational procedures. Finally, the system arranges *hazard zone elements* according to their aggregated ranks.

In depend on a value of the received rank, the system proposes a proper strategy of safety design for the selected *hazard situation element*, for example:

– withdrawing operators to more safe places by means of replacing a machinery component together with operations to be involved,
– decreasing hazards for operators by selecting suitable design features of machinery components which can reduce influence of dangerous and harmless factors,
– remaining the considered design solution without any changes.

3. A WORKING PRINCIPLE OF A COMPUTER-AIDED SYSTEM FOR HAZARD ZONE IDENTIFICATION

The degree of danger for operators mainly depends on (Fig.2):

- a kind of ship machinery function,
- operator’s accessibility to workplace,
- a kind of operator’s activity to be carried out, operator’s
- attitude during his activity to be carried out.

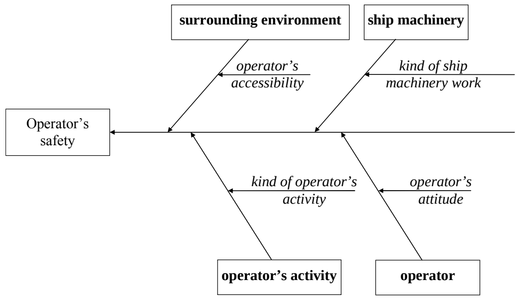

Fig.2. *Factors influencing on operator’s safety*

We have observed that two factors are related to the ship machinery functions and its surrounding environment, and two next are related to a kind of the operational tasks. Therefore, we have divided these sets into two main groups: machinery function and operation factors.

According to our assumptions, information concerning values of design factors can be received on the basis of analyzing the preliminary design documentation of a ship power plant. This documentation includes ship machinery functional structures and a list of ship machinery components with their characteristic data. Nevertheless, such documentation does not contain space layouts of these components. Therefore, it is impossible to assess any hazards connected with space surrounding environment and operator’s attitude.

In order to specify the detailed set of machinery function factors, we have carried out the following actions in sequence:

– performing their classification according to accepted criterions,
– combining these factors into the complete set,
– putting in order of these factors in accordance with their significance determined by experts,
– specifying their possible values.

The description of these procedures can be found in [4]. Basing on these procedures we have selected the following machinery function factors:

- heat energy load hazard,
- fluid energy load hazard,
- thermal hazard,
- chemical hazard,
- dynamical force hazard,
- electrical hazard.

For each factor, we have determined 4 possible appearances.

In order to specify the detailed set of operation factors, we have carried out the following actions in sequence:

- selecting operation stages of a ship,
- selecting operation stages of a ship power plant,
- selecting existing operational procedures,
- developing new operational procedures.

First, we assumed that operation factors should concern any procedure as the whole (preparing the main engine to work, oil change in the auxiliary engine, fuel bunkering, etc.) in contradiction to the elementary operator's activities (valve opening, pump starting up, fuel level checking, etc.), Therefore, these factors depend on:

– a kind of operational tasks (operation use, maintenance, provision or safety level checking procedures),
– interaction between operational tasks (procedures) carried out for any ship machinery component and an operation stage of a ship and its power plant,
– a possibility of dividing up procedures into separate sets, in confines of individual operational tasks, according to their levels of triggering off potential hazards for operators.

Basing on the presented circumstances, we have selected the following operation factors:

– hazard to be triggered off by operation use procedures,
– hazard to be triggered off by maintenance procedures,
– hazard to be triggered off by provision procedures,
– hazard to be triggered off by safety checking procedures.

For each factor we have also determined 4 possible appearances.

In the considered system, components of its knowledge base *KB* have been converted into the computer comprehensible language with using a package LPA- PROLOG for Windows.

Functioning of the considered computer-aided system is presented in the following part of this paper.

In the first step, a user of the computer-aided system for hazard zone identification should specify a proper type of operational tasks (Fig.3). After selecting of the intentional task, for example a maintenance task, a user of this system should determine a ship machinery system and a unit involved in carrying out the selected maintenance task (Fig.4). It means that he determine the maintenance procedure which can be carried out for the determined ship machinery items.

Next, he should assess the selected procedure by attributing the consequence connected with its execution for the ship machinery operation (Fig.4). Each of the possible consequences has the following assigned values: 1,0; 0,75; 0,5;, 0,25. If the selected procedure does not entail any consequence then the system will assign the value 0 automatically.

After that, a user should determine all ship machinery components involved in carrying out of the selected procedure (Fig. 5). It is obvious that the selected components can be located in different ship machinery units and systems but they can take somehow part in realization of the selected procedure. In the next step, the system makes a set of operator's activities available to its user. This set contains all possible operational activities connected with carrying out any operational procedures. The user's task is to select only these activities, which are involved in carrying out the selected procedure realized for the determined ship machinery items. In the presented example (Fig. 5), the ship machinery system 'Electrical system' contains the selected ship machinery component 'Main switchboard'.

In the last step, the system makes dangerous and harmless factors available to assess by the user (Fig. 6). It is obvious that the selected component can be assess only with taking into account operator's activities to be carried out. Similar to a process of assessing a procedure, every hazard consequences have the following values assigned: 1,0; 0,75; 0,5;, 0,25. If the selected activities, for the selected component, do not trigger off any consequence then the system will assign the value 0 automatically as well.

Finally, the system calculates the index of influence of dangerous and harmless factors on potential hazards for operators (Fig. 7) by means of the expression (1).

This way, we have presented only one path of the task of hazard zone identification for a ship power plant. This path allows us to identify the elementary hazard zone. However, the system has the possibility to identify a set of the elementary hazard zones. To perform that, we should repeat the considered procedure, in recurrent way, for the next ship machinery component. Nevertheless, each of the components included in the identified elementary hazard zone can appear in various operational tasks. Therefore, the system has the possibility to analyze recurrently these tasks as well. Finally, the system calculates the total index of influence of dangerous and harmless factors on potential hazard for operators by means of the expression (2). This index is a kind of measure of potential hazards, which can be triggered off by carrying out operational activities realizing with accordance to the selected operational procedures for the selected machinery component. This way, we can identify all hazard zone elements.

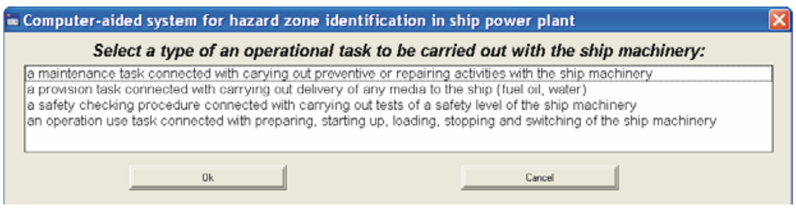

Fig.3. *A screen of selecting the operational tasks*

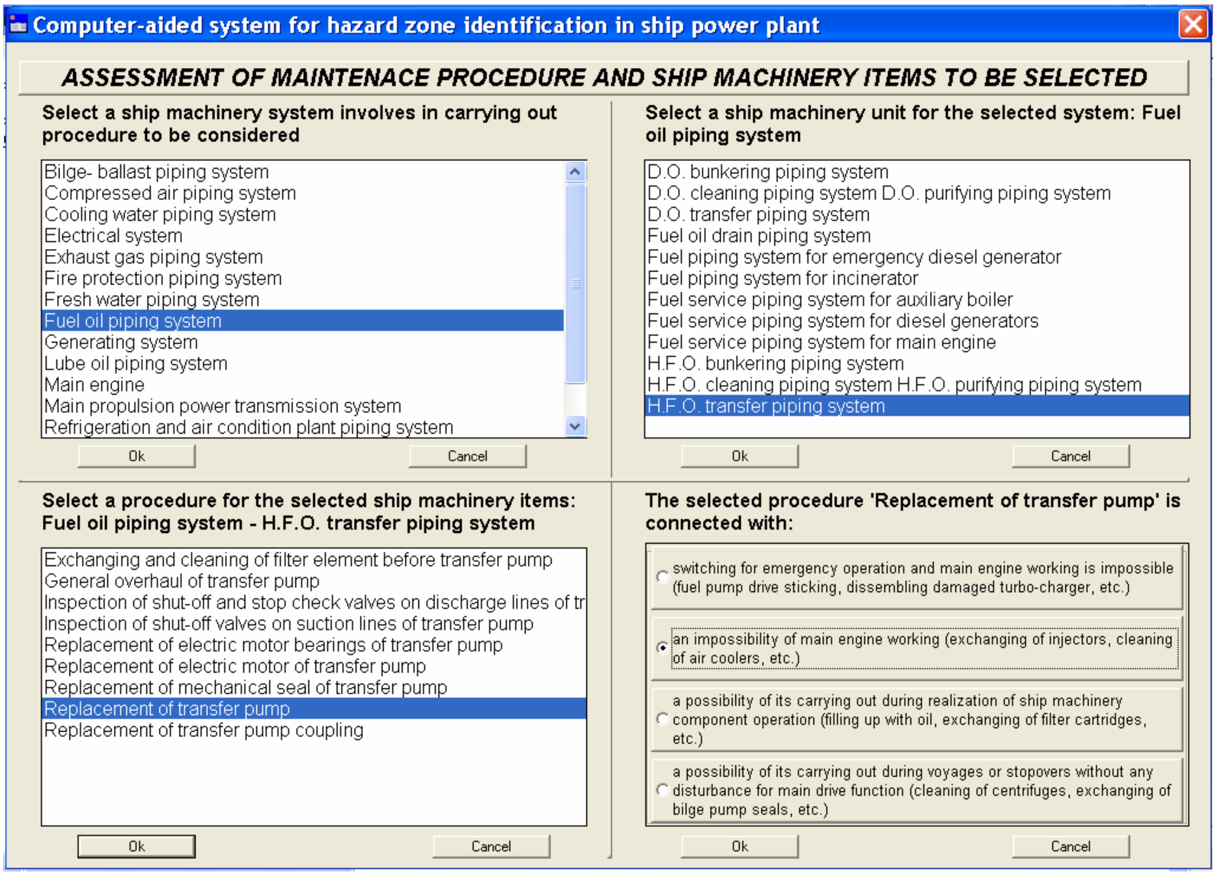

Fig.4. *A screen illustrating selection of ship machinery items and assessment of a procedure*

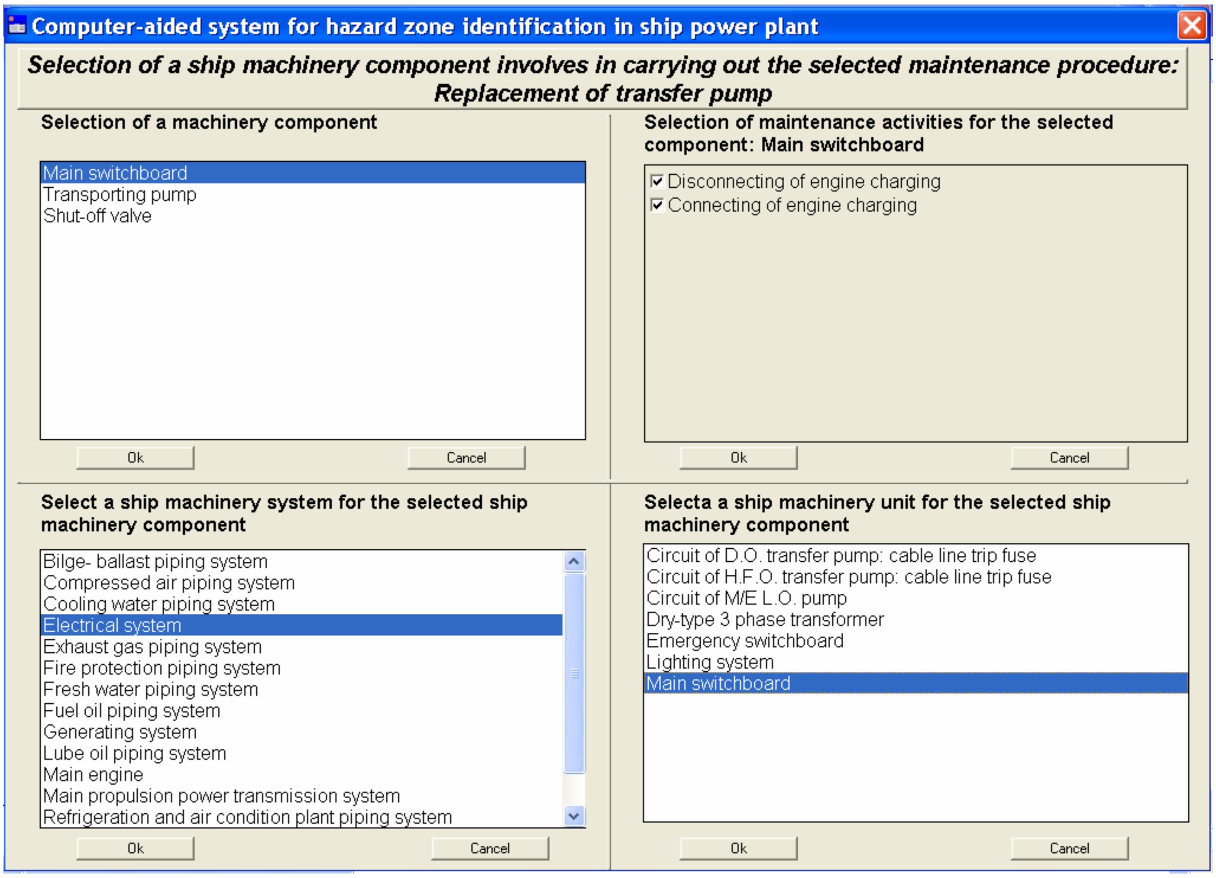

Fig.5. *A screen of selecting ship machinery components and operational / maintenance activities*

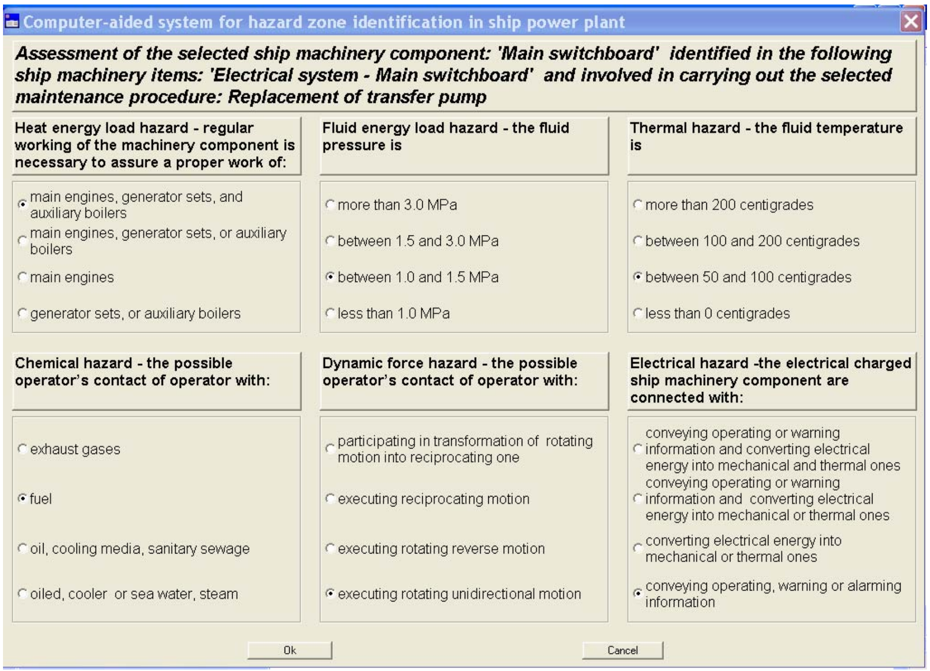

Fig.6. *A screen of assessment of the selected ship machinery component*

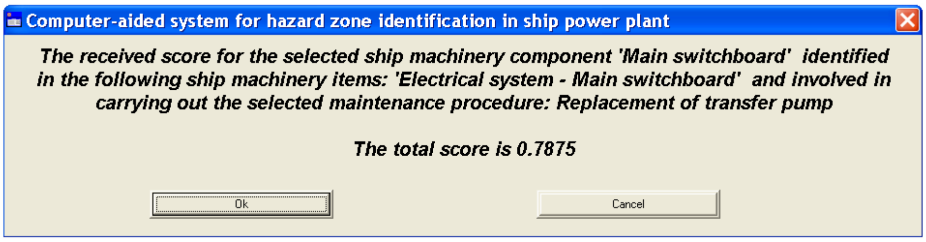

Fig.7. *A value of the total index of influence of dangerous and harmless factors on potential hazard for operators*

4. CONCLUSIONS

Considerations concerning the development process of a computer-aided system for hazard zone identification in ship power plants allows us to formulate the following conclusions:

- hazard zone identification for ship power plants can be performed on the basis of their preliminary design documentation,
- dimension of tasks for hazard zone identification can be decreased by using opinions of experts in the field of design, operation, and maintenance of ship power plants,
- the solution of tasks for hazard zone identification requires use of a computer because of a procedure for generating solutions repeats so many times.

The computer-aided system for hazard zone identification in ship power plants allows designers of ship power plants to:

- determine hazard situations and places in a ship power plant to be designed,
- put in order these determined situations and places according to influence of dangerous and harmless factors on potential hazard for operators,
- receive information, which can be used for choice the appropriate design strategy.

References

[1] *Guidelines for engine room layout, design and arrangement.* International Maritime Organization. London 1998.

[2] Kobyliński L.K. *Maritime transport safety – new philosophy*. Materiały Konferencyjne: 20 Sesja Naukowa Okrętowców – Przemysł Okrętowy 2002. Gdańsk 2002. (in Polish).

[3] Szopa T. *Role of science and government in activities for safety improvement.* Zagadnienia Eksploatacji Maszyn. Nr 4. 1996. (in Polish).

[4] Tarelko W., Hempel L., Podsiadlo A. *Anthropotechnical guidelines for safe techical system design.* Report from research. Zeszyt nr 1. KPT. Akademia Morska w Gdyni. 2004. (in Polish).