A method for determining the decision variables of hazardous zone identification system for ship power plant operator

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ABSTRACT

In this paper a method is presented of determining – on the basis of information available in the preliminary phase of ship power plant design – the set of hazardous and noxious factors for the operator, as well as of converting them into the set of input variables to a hazardous zone identification system. Basing on the choice of values of determined decision variables, the system's user is able to determine potential hazardous zones for the ship power plant operator. Conversions of the determined factors into the set of the system's input variables were performed by using the knowledge achieved from the side of experts in ship power plant designing and operating.

Keywords : ship power plant, safety, operator, hazardous and noxious factors, hazardous zone, task realization procedures, decision variables.

INTRODUCTION

One of the possible ways to increase effectiveness of ship power plant designing, including the designing for safety of its operators, is to create tools for aiding designer's efforts, e.g. in the form of computer - aided expert systems.

A system of the kind is under elaboration in Gdynia Maritime University [1]. It consists of two basic modules :

- the system for identification of hazardous zone for operator realizing his service operations
- the advisory system for aiding the selection of structural form features of machines and devices being in the hazardous zone.

The concept of the system consists in aiding co-operation between designer and computer at the following allocation of tasks :

- the designer provides appropriate information to the system, basing on an analysis of preliminary design of ship power plant, his knowledge, intuition and experience
- the computer processes the introduced data, calculates indices and performs ranking of power plant constructional units from the point of view of their possibility of creating potential hazards for the operator.

Description of the hazardous zone identification system for ship power plant was presented in [1], and its main elements as well as a way of representing the subject-matter knowledge necessary for computer purposes – in [3].

One of the main tasks in building the system in question is the determination of its decision variables by means of which the system's user is capable of determining potentially hazardous zones for the operator. In this paper a method is presented for determining – on the basis of information available in the phase of preliminary design of ship power plant – the set of hazardous and noxious factors for the operator, and for converting them into the set of the system's input variables. Main modules of the elaborated method is presented in the form of block diagram in Fig.1.

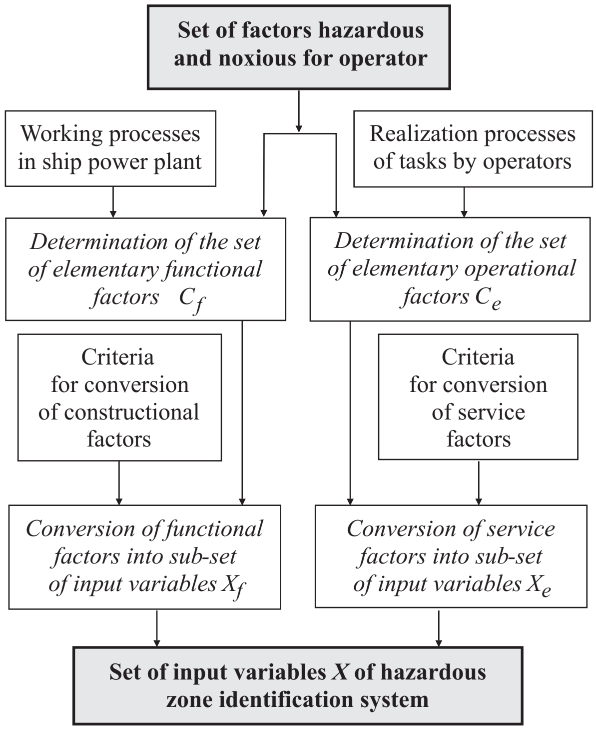

Fig. 1. Main modules of the procedure for determining the input variables of the identification system of hazardous zones in ship power plant .

FACTORS HAZARDOUS AND NOXIOUS FOR THE OPERATOR

The set of input variables of the system in question consists of the factors hazardous and noxious for the operator realizing his service actions, i.e. the factors creating a hazard understood as a state of working environment, capable of causing an accident or illness of the operator. Such factors may result from all elements of the „man - technical object – environment" system, i.e. in the case in question – consisted of the operator, ship power plant machinery and equipment and their environment. Factors which contribute to building a given kind of hazard for the operator may occur in any element as well as any relation between the elements of such system. The elements of the considered system may be as follows :

- **Man** – together with his all abilities and limitations which depend a.o. on his sea service experience, professional knowledge, skill, memory, habits, professional mentality, motivation, accepted system of merits, psycho-physical state, age
- **Machine** – where special role is played by such factors as : serviceability features, reliability characteristics, ergonomic and functional features, allocation of its units
- **Working space environment** – including : physical and chemical conditions in ship machinery room, spatial features of working place
- **Work organisation environment** – including: organisation of work, inter-personal relations
- **„Man - machine" relation** – including : position of control unit, accessibility for maintenance and repair work
- **„Man - working space environment" relation** including: arrangement of machines, man manipulation space
- **„Man - working organisation environment" relation** including: ship owner policy, crew line-up, crew culture, communication means.

In accordance with the assumptions set in [1], the operator will find himself in a potentially hazardous zone only when he performs a service task.

It is additionally assumed that the operator is qualified in accordance with the International Convention on Standards of Training, Certification and Watch-keeping for Seafarers, he is physically and psychologically fit and his deliberately destructive actions are excluded. Moreover it is assumed that physical, chemical and biological conditions (lighting, noise, temperature etc) comply with the relevant standards, e.g. [5] and [7], all devices operate reliably, and that in ship machinery room mainly physical factors are negatively affecting. Among those factors the following can be numbered a.o.: moving machines and transported objects, elements in motion, falling elements, fluids under pressure, slippery and uneven surfaces, limited spaces, situation of working place respective to a base level (work at high altitudes or in recess), hot or cold surfaces, caustic and noxious substances.

At the taken assumptions, the operator's hazard level is a function of the factors resulting from operation of machines and devices, access to work place, position of the operator performing a given operation, as well as its kind. Hence the set of the factors was conventionally divided into the two basic groups :

- the factors C_f associated with the function of technical objects in realizing the demanded operational processes in a given service state of ship
- the factors C_e associated with the kind of operations performed by operators, resulting from realization of demands concerning the service tasks connected with use, maintenance, operation, supply, and safety control.

Obviously, the distinguishment of two groups of factors does not directly make it possible to use them in the computer aided system for identification of hazardous zones in ship machinery room. Therefore they should be converted into the set of input variables X for the system in question, consisted of two sub-sets [4,6] :

⇨ X_f – the set of functional input variables
⇨ X_e – the set of service input variables.

SET OF FUNCTIONAL INPUT VARIABLES

In accordance with the taken assumption, the information available in the phase of preliminary design of power plant, is used in the identification system of zones hazardous for operator in ship machinery room. Such preliminary design mainly concerns functional structure of power plant and makes it possible to identify functions fulfilled by particular constructional units in realising various operational processes. It contains also specification of major machines and devices together with their number and technical characteristics. In this phase, the power plant's functional structure and constructional structure of its major units (machines and devices) is also known. However, the constructional structure of the entire power plant is not yet determined, hence there is not possible to assess hazards associated with its space environment. Such assessment will be possible in the successive phases of elaboration of power plant documentation, namely in the technical (classification) and working design stages.

Taking into account the scope of information contained in preliminary design, one assumed that the information dealing with operational processes carried out in ship power plant makes it possible to determine the set of functional input variables X_f for the hazardous zone identification system. To this end, the operational processes realized in ship power plant were divided into the two groups :

- the main operational processes dealing with conversion of the energy obtained from fuel combustion into mechanical, electrical and heat energy and their transmission to particular consumers
- the auxiliary operational processes realizing the functions of transporting, cleaning, heating, cooling and storing various working media (fresh water, sea water, fuels, oils, air etc.) of determined parameters and quality.

Among the main operational processes
the following should be numbered a.o. :

- the process of conversion of the heat energy obtained from fuel combustion in main engine into mechanical energy for ship propulsion
- the process of transmission of mechanical energy from main engine to propeller
- the process of conversion of heat energy obtained from fuel combustion in main engine into mechanical energy for ship propulsion and electric energy produced by shaft electric generator (hang-up)
- the process of transmission of electric energy from shaft generator to ship electric network
- the process of transmission of heat energy from exhaust gas to waste-heat boiler
- the process of transmission heat energy from the water cooling the cylinder liners and heads to waste-heat utilization systems
- the process of conversion of heat energy obtained from fuel combustion in auxiliary engine (-s) into electric energy produced by generator (-s)
- the process of transmission of electric energy from stationary electric generators to ship electric network

- ❖ the process of conversion of heat energy obtained from fuel combustion in auxiliary boiler into water vapour heat energy
- ❖ the process of conversion of exhaust gas heat energy into water vapour heat energy in waste-heat boiler
- ❖ the processes of transmission of electric energy from ship electric network to its particular consumers (systems)
- ❖ the process of transmission of heat energy (of steam) from boiler (main steam valve) to particular consumers.

Among the auxiliary operational processes the following should be numbered a. o. :

- ☆ the processes supporting operation of the energy system, i.e. main and auxiliary engines, boilers and other devices supporting energy supply (lubricating oil, cooling water, fuel, compressed air, exhaust gas systems etc.)
- ☆ the safety ensuring processes (ballast water, bilge water, fire fighting (water, CO_2, steam etc.) systems
- ☆ the processes for fulfilling the living needs of crew and passengers (sanitary, fresh water, sewage, reefer store and air-conditioning systems, etc.)
- ☆ the processes supporting environmental protection devices (sewage treatment system, bilge water /oil separator, etc.).

Mechanisms of physical state changes of operational processes may be different, but they are always connected with action of several forcing factors.

The forcing factors can be divided into two main groups :

◆ external , ◆ internal.

Among the external forcing factors are numbered such expected and unexpected environmental impacts onto a given object, as ambient temperature changes, vibrations generated by neighbouring objects, changes of voltage or pressure in supply networks, humidity, dust, human actions, etc.

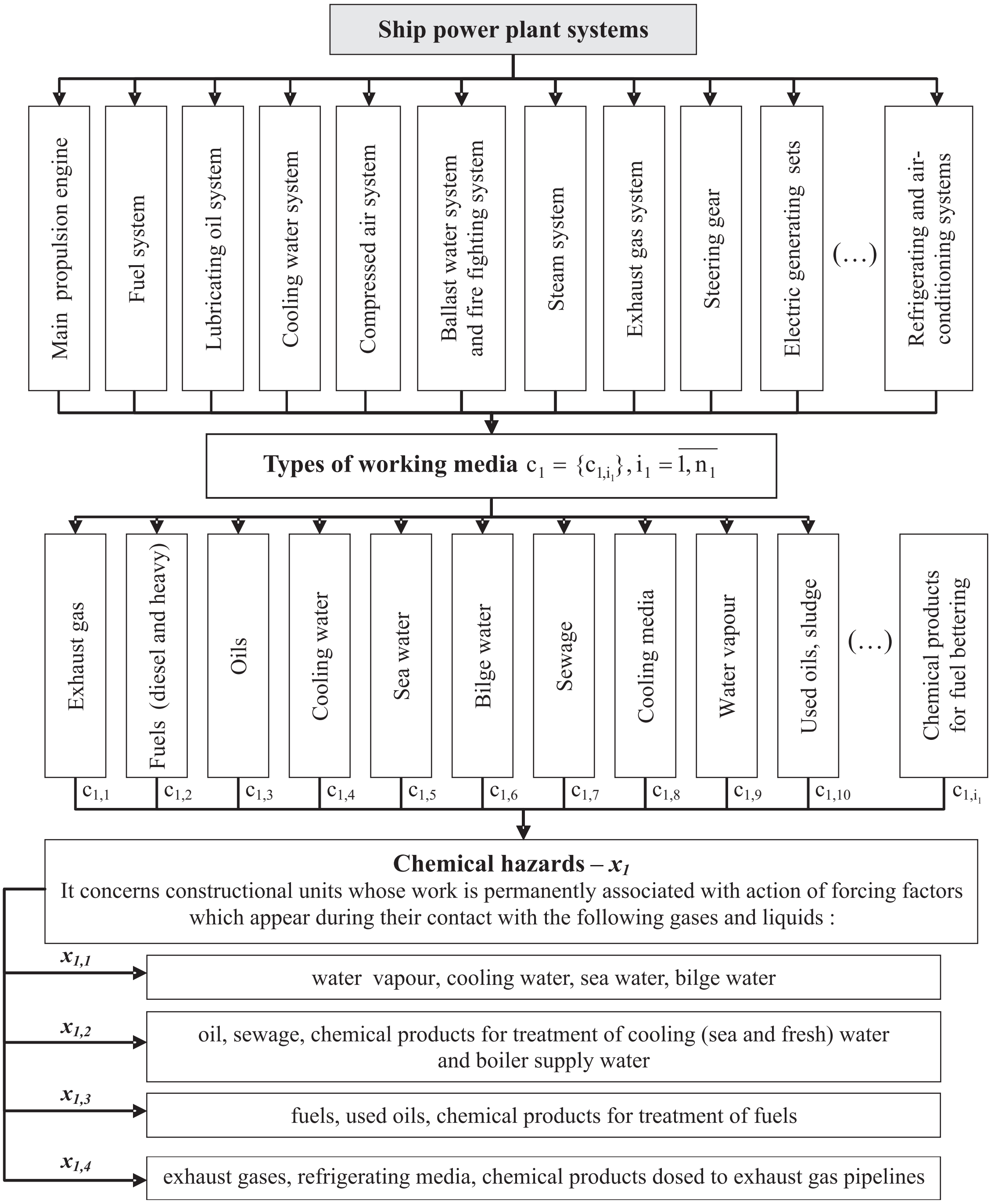

Fig. 2. *Classification of chemical hazards*

Among the internal forcing factors are numbered the following: load-generated forces, vibrations, actions of working media, etc.

Simultaneous consideration of the sets of external and internal factors occurring in various states of power plant operation, differing to each other by a number and type of realised operational processes, is specially important for assessment of potential hazards to the operator.

To distinguish the set of elementary functional factors C_f, the decomposition of power plant was performed by increasing the detail consideration minuteness of its functional structure [2]. At the first level of the minuteness its systems were distinguished (Fig.2) and the set was formed of the working media used in them, c_1, whose chemical composition may expose operator's health to a danger.

In each of the systems, such sub-systems were distinguished, whose analysis made it possible to elaborate the set of values of working media temperatures, c_2, and pressures, c_3 (Fig.3). And, the set of states of power plant thermal energy loading, c_4, was distinguished, depending on a switching-on sequence of the successive main processes, beginning from the power plant stand-by state and ending with its operational states during manoeuvres and sea voyage (Fig.4).

The components (subsystems) distinguished at two first detail minuteness levels are to a large extent common for majority of ship power plants fitted with main combustion engines. Also, a great similarity can be observed at the third level into which the units were distinguished. The units are integral structural parts such as a fuel filter at the inlet of fuel delivery pump, overflow pipeline fitted with check valve, centrifugal separator's delivery pump, boiler fuel daily tank.

For the units the following set of kinds of the operational movements, c_5, and their components, as well as the set of modes of electric energy supply, c_6, were distinguished (Fig.5).

Each of the distinguished factors may differently affect occurrence of hazard to operator. Hence it is desirable to assess their significance for hazard generating and to compose

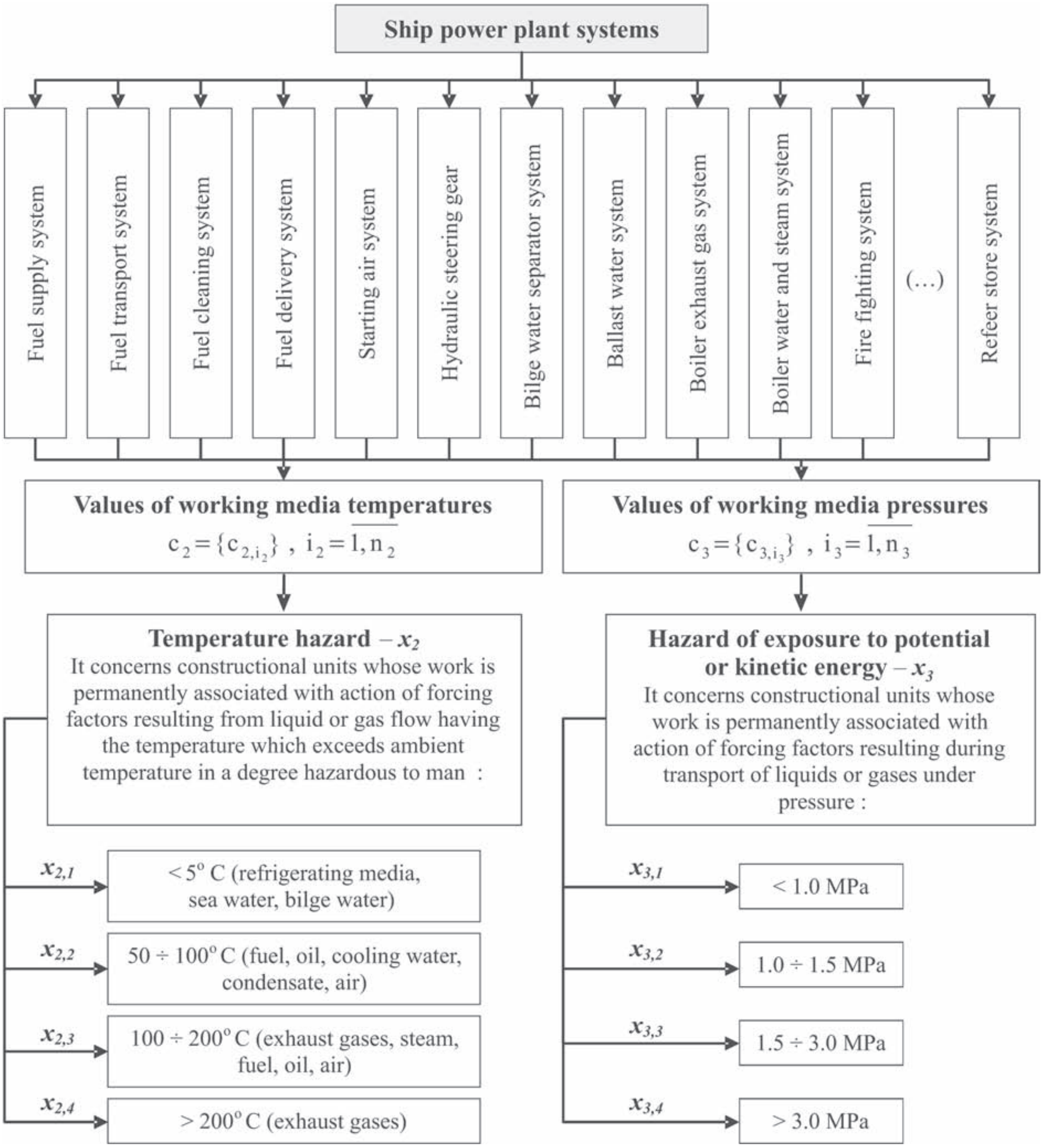

Fig. 3. *Classification of hazards associated with working media temperature and pressure .*

them into the „entities" containing a subset of similar factors, regarding both their character and effects to operator's health. The so aggregated factors represent the states of the input functional variables X_f of the identification system in question. On the basis of opinions expressed by experts – marine engineers, four states successively characterizing higher and higher hazard levels, were assigned to each of the distinguished variables. Names of particular variables and description of their states are presented in Fig. 2 ÷ 5.

SUBSET OF OPERATIONAL INPUT VARIABLES

In order to determine the subset of elementary factors C_e associated with kind of operational tasks realized in given internal and external conditions it was assumed that ship power plant should be considered as an anthropo-technical system (Fig. 6) i.e. that consisted of operators, machines and their environment (in the sense of space and organization).

In ship power plant a set of operators (machinery crew either itself or in cooperation with shipyard personnel, producer servicemen etc, or under supervision of various surveyors) realizes given service operations. Safety of the personnel taking part in realization of the operations is exposed to hazards connected with :

- ship operational process (sea voyage, manoeuvres, port stay etc in given external conditions, i.e. climatic zone, weather state)
- power plant running process (number and kinds of operational processes associated with its energy state)
- process of realization of operational tasks by operators (number and kinds of realized tasks depending on a given state of service demands and technical state of power plant).

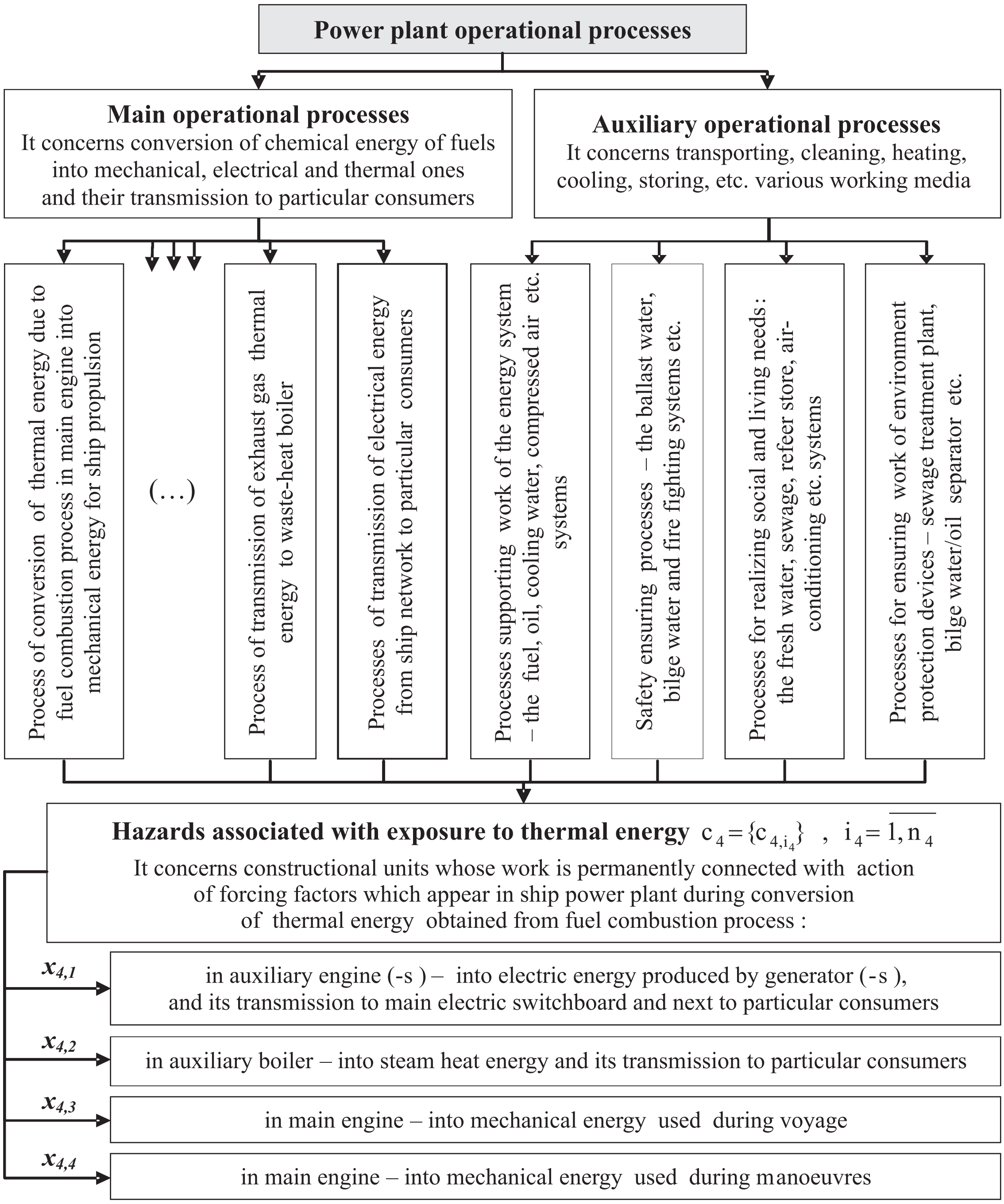

Fig. 4. *Classification of hazards resulting from exposure to thermal energy .*

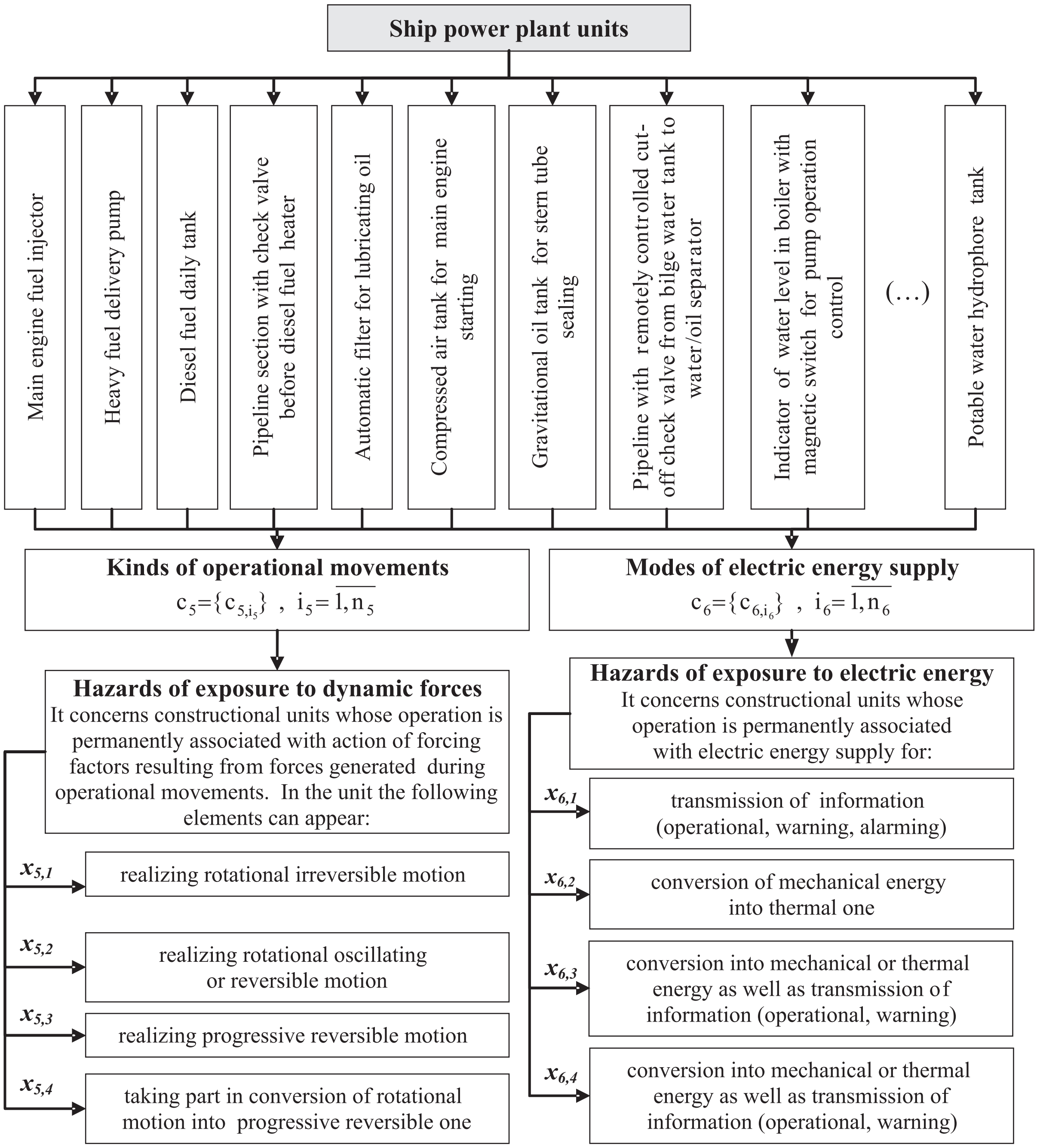

Fig. 5. *Classification of hazards resulting from action of dynamic forces and electric energy supply .*

In accordance with the classification system used in shipping the four groups of operational tasks are distinguished [5] :

- tasks associated with power plant running (use of power plant machines and devices, e.g. main engine preparation to starting-up, fuel transporting to settling tank, starting-up sewage treatment plant, shaft generator switching-off)
- tasks associated with power plant maintenance (preventive and repair maintenance, e.g. overhaul of main engine cylinder head, oil sampling, cleaning the water side of air cooler, replacement of fuel filter cartridge)
- tasks associated with power plant material procurement (e.g. delivery of fuel and oil, ordering and delivery of spare parts, transport of technical gases, handing - over used parts to regeneration)
- tasks associated with control of power plant safety state (e.g. control of insulation state of electric motors, control of emergency lighting, control of signalisation of high level of bilge water).

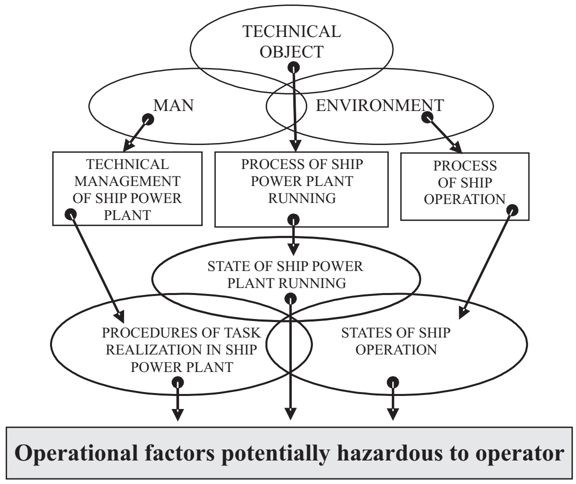

Fig. 6. *Kinds of operational factors influencing hazards to ship power plant operator .*

The ship power plant management amounts to a decision –making on which of the procedures determining the appropriate ways of realization of operational tasks, are applicable. The procedures contain a.o. sequential list of operations of different detail minuteness levels (number of required persons, duration time, technical parameters). They are based on :

- technical – operational documentation of ship power plant machines and systems
- requirements associated with safety at sea and marine environment protection (conventions, codes, rules of classification societies, regulations of maritime administrations, ship owner's regulations etc.)
- knowledge and professional experience of ship owner's technical department.

To distinguish the set of service operations performed by operator, for each of the ship power plant systems the set of operational procedures, divided into four subsets depending on the kind of relevant task (power plant running, maintenance, material procurement and control of its safety state), was elaborated [1].

The service operation represents a set of operator's elementary actions aimed at realization of a given elementary operational task, e.g. shutting a valve, disassembling a cover, measuring liquid level in a tank, pressure control, switching-off a pump. The operational procedure represents a set of service operations aiming at realization of a given complex operational task, e.g. fuel bunkering, overhaul of a centrifugal purifier, oil replacement in main engine, replacement of a fuel filter cartridge.

The procedures associated with ship power plant running deal with the operational tasks connected with start-up preparation, starting-up, load change, control of running, run supervision, stopping and switching-off its machines, devices and systems, including also tasks associated with coping with emergency situations which may occur in service.

The procedures associated with ship power plant maintenance deal with the operational tasks aimed at maintaining its machines, devices and systems in a physical state deemed to be correct for fulfilling their operational functions or recovering such state.

The procedures associated with ship power plant material procurement deal with the tasks connected with running reasonable economy of materials used for the power plant's operation, such as : fuels, oils, chemical products, spare parts, tools etc.

The procedures associated with ship power plant safety deal with the operational tasks aimed at fulfilling requirements covering its operational safety and marine environment prevention. The requirements for fulfilling the tasks are imposed by the international conventions and rules of classification societies.

The set of the procedures was elaborated by experts- marine engineers on the basis of the functional schematic diagrams and technical data on major machines and devices, available in the preliminary design phase of ship power plant. The kinds of the information used in the designing process of procedures for task realization by operators, are given in Fig.7. The model of the process of task realization by ship power plant operators was presented in [5] as a function mapping the set

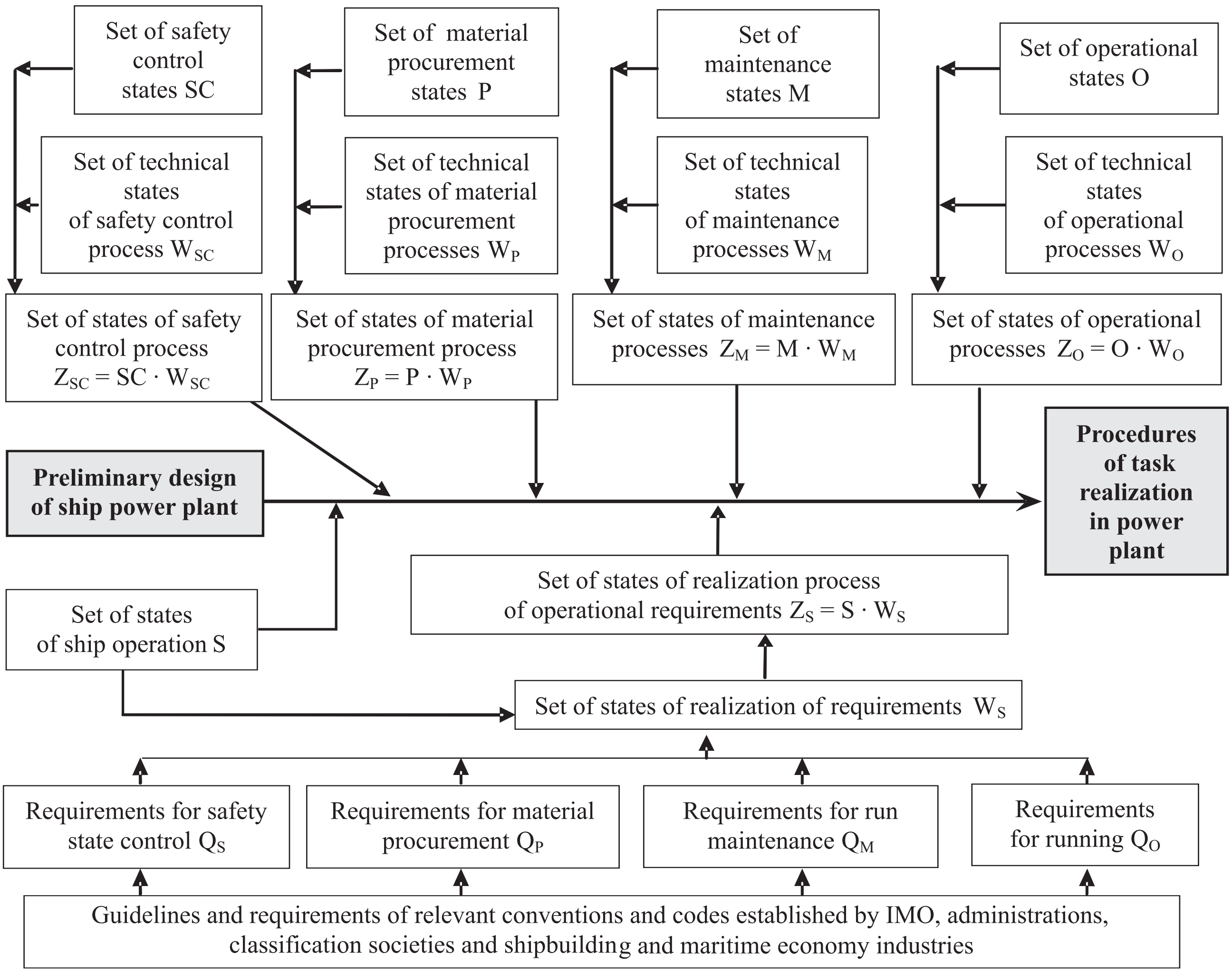

Fig. 7. Kinds of information used in designing process of task realization procedures in ship power plant .

of ship operational states into the set of relations covering possible combinations of the procedures, resulting from the necessity of fulfilment of the requirements dealing with ship power plant running, maintenance, material procurement and control of its safety state.

In elaborating such set of procedures the following remarks should be accounted for :

- the set of procedures realized in a given ship operation state is strictly connected with the state of realization of operational requirements as well as ship power plant technical state.
- The states of realization of operational requirements for ship power plant in a given ship operation state have to be described by values of the features contained in the set of the requirements dealing with :
  - ship running, Q_O (e.g. ship speed, fuel consumption, electric power loading, serviceability time required for various systems, air parameters for living accommodations)
  - maintenance, Q_M (e.g. status of schedule of planned overhauls, status of classification society surveys)
  - material procurement, Q_P (e.g. state of amount of fuel, oil, water, spare parts)
  - safety, Q_{SC} (e.g. status of schedule of control of : fire fighting systems, marine environment protection systems, ship's security level according to International Ship & Port Facility Security Code – ISPS).
- In particular ship operation states, various operational processes and associated running procedures are realized by operators in ship power plant. It means that in a given ship operation state occurs a varying number of running states of ship power plant, associated with periodical realization of some operational processes, e.g. transport of fuel, transport and cleaning of bilge water, ventilation and air-conditioning of accommodations. The set of running states covers combinations of the procedures associated

Tab. 1. *Input operational variables resulting from kinds of operational procedures*

Name of variable	Description of variable	States of variable
Hazard due to realization of operational procedures x_7	The variable deals with operational tasks associated with preparation of starting-up, load change, run control, run supervising, stopping, switching-off ship power plant machines and devices	$x_{7,1}$ – procedure is performed only during stand-by (e.g. set of procedures for power plant preparation to manoeuvres or a longer ship stay in a port)
		$x_{7,2}$ – procedure may be performed both during voyage and manoeuvres, as well as stand-by (e.g. fuel transport, servicing ballast and bilge tanks)
		$x_{7,3}$ – procedure is performed only during manoeuvres and/or voyages (e.g. those relating to operation of thruster, shaft generator, procedures for main engine starting-up and stopping)
		$x_{7,4}$ – procedure is associated with run in a failure state (e.g. operation of main engine with one cylinder out of work, various control procedures of local machines and devices in case of break-down of automatic control systems)
Hazard due to realization of maintenance procedures x_8	The variable deals with operational tasks associated with realization of scheduled preventive and repair maintenance operations of ship power plant machines and devices	$x_{8,1}$ – procedure may be performed both during voyages and port stays, if not disturbing main engine running (e.g. cleaning the purifiers, oil replacement in air compressor, replacement of bilge pump packing)
		$x_{8,2}$ – procedure may be or is performed during realization of operational process (e.g. oil make-up, filtering cartridge replacement in a double filter, indication of engine cylinders, water washing the turbo-compressor)
		$x_{8,3}$ – during realization of the procedure the main propulsion system cannot operate (e.g. replacement of main engine injector, oil replacement in main transmission gear, cleaning the main engine air cooler)
		$x_{8,4}$ – procedure is aimed at transition to a failure state operation hence the main propulsion system cannot then operate (e.g. disassembling a failed turbo-compressor's rotor, suspension of injection pump's drive, blocking a clutch in working position)
Hazard due to realization of material procurement procedures x_9	The variable deals with operational tasks associated with realization of material procurement for power plant machines and devices	$x_{9,1}$ – with transport or storage of spare parts, transport of to-be-repaired objects to and from land-based workshops
		$x_{9,2}$ – with transport and storage of technical gases, chemical products, material stores and tools
		$x_{9,3}$ – with receiving or storing oils, giving-up sludge or oily water
		$x_{9,4}$ – with receiving or storing, and giving-up fuel oils
Hazard due to realization of safety state control procedures x_{10}	The variable deals with operational tasks associated with realization of safety state control procedures for ship power plant	$x_{10,1}$ – deals with operation control of devices and systems for marine environment prevention against pollution
		$x_{10,2}$ – deals with operation control of devices and systems aimed at emergency stopping, running or signalisation of extreme states
		$x_{10,3}$ – deals with operation control of devices and systems for fire or water fighting in ship power plant
		$x_{10,4}$ – deals with operation control of emergency supply sources for devices and systems, including emergency electric generating set, objects supplied by it as well as systems cooperating with it

with realization of the operational processes in various ship operation states. Similar situation occurs in considering the maintenance, material procurement and safety state control processes that leads to distinguishing the relevant sets of states of the processes.

- In practice, in various ship operation states, often the states of partial serviceability or unserviceability of technical objects which take part in realization of particular processes of task realization (constructional units of systems, accommodations, transport devices and ways, tools, measuring instruments, stores, etc) periodically occur. For each of the process, to distinguish elements (units) taking part in its realization as well as their technical states (full serviceability, limited serviceability and unserviceability [9]) is necessary in the course of designing the set of kinds of procedures for a given ship operation state, including the procedures of coping with possible emergency situations.

The process of changing the technical states and that of changing the realization states of the procedures are dependent on each other and hence they must be considered together as the components of a resulting process which can be called the process of task realization by ship power plant operators [5].

In order to determine the subset of input operational variables, X_e, of the ship power plant hazardous zone identification system, it was assumed that each variable should concern the entire procedure (e.g. the preparation of main engine to work, oil replacement in auxiliary engine, heavy oil bunkering, etc) but not particular service operations (e.g. valve opening, pump switching-on, level checking etc). As a result the impact of the variable concerning the entire procedure will be assigned to the operations contained in it. It means that the level of hazard to the operator performing a given operation depends on the kind of the service task which the procedure deals with. Therefore, four input operational variables, namely the hazards arising from realization of : the running procedures x_1, maintenance procedures x_2, material procurement procedures x_3, safety state control procedures x_4, were distinguished.

Each of the procedures contained in one of the distinguished variables may differently affect generating the situation hazardous to operator. The hazardous situation occurs only in a determined place of ship power plant in a given operational state, and if the operator performing a given operation within a given procedure, is present there. Ship power plant's operational states are strictly associated with ship's operational states and the fact should be accounted for in determining importance of the procedures for hazard generating.

On the basis of opinions of experts – marine engineers four states successively characterizing higher and higher hazard levels, were assigned. to each of the distinguished operational variables, like in the case of functional variables.

Names of particular variables and description of their states are presented in Tab.1.

CONCLUSIONS

Basing on the results obtained in the course of the performed considerations dealing with the determination of input variables of the system for identification of hazardous zones within ship power plant, one can offer the following conclusions:

- The determination of functional and operational factors influencing hazards to operator can be performed on the basis of information contained in the preliminary design of ship power plant and dealing with its functional structure, as well as of the knowledge of operational procedures performed by operator.
- The conversion of the determined factors into the set of input variables of the system can be performed by using to this end the knowledge derived from experts in the field of designing and running the ship power plants.
- Having determined values of the decision variables the system's user can determine zones potentially hazardous for the operator performing service operations in ship power plant.

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