Designing engine rooms of new generation ships realized within the framework of European research projects EUREKA - chosen questions

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ABSTRACT

Importance of reliability and safety in the operation phase of engine rooms has been proven. A concept of designing engine rooms taking into consideration their reliability, safety of functioning as well as ecological features has been proposed. The need for as well as the main principles of carrying out empirical research in particular ship design stages have been introduced. Possibilities of the use of the semi-Markov theory in designing engine rooms have been justified. Possibilities of formulation and importance of hypothesis in scientific research related to engine rooms of sea going and inland ships depending on their particular specific features have been introduced. Examples of such hypothesis and their verification methods have been given. Possibilities of the use of semi-Markov processes in optimization of the ship operation have been signalled.

Keywords : ship power plant, sea-going ship, reliability and safety, design, semi-Markovian process

INTRODUCTION

Ship engine rooms should be designed so that, assuming that the ship carries her tasks, she could be operated with in the highest in these conditions (if possible – optimum) rentability but keeping proper reliability, required safety of motion as well as meeting ecological measures. This is especially important for transport ships operating in relatively restricted sea areas such as the Baltic Sea. Thus problems of economic functioning of engine rooms of ships taking into consideration their reliability should be judged as the most important.

Design solutions used in engine rooms can be different but the general way of forming their reliability (understood as the choice of types of their activities as well as the choice of possible resources ensuring reaching needed level of reliability) can in principle be the same. Building the reliability of each ship engine room in the design phase is based on consecutive solution of problems resulting from the need to obtain answers to the following questions :

- What criteria of creation of reliability should be adopted ?
- What is the risk of excessive increase of the cost of designing in case of starting an original design of engine room ?
- What could be the cost of obtaining the required level of reliability of an engine room similar to an already designed and operated engine room ?
- How to divide the machines and equipment of the engine room in order to shorten the design phase and in the same time to obtain the required reliability ?
- Against which requirements should the reliability be considered ?

This is why scientific research is indispensable in the design stage of ship engine rooms. Such research is also indispensable in further stages of existing of an engine room, namely during its building period as well as operation. Such scientific research enables to create scientific knowledge, i.e. such a knowledge which is justified using scientific methods of its creation. In result of such research information of cognitive as well as useful value can be obtained. In the first case new knowledge is created in process of verification of hypothesis and/or proving thesis explaining relations between new facts, ascertained during research carried out during operation of engine rooms of particular ships, used by different shipwoners, with the existing scientific knowledge. The second case refers to the sphere of scientific knowledge which is used in practice as to designing engine rooms as well as other structural nods e.g. ship hulls. This way the number of true information creating useful knowledge but checked using scientific methods is increased and in the same time the number of so called "common sense knowledge" information is decreased. This way useful knowledge becomes a more precise tool which can be used in the design processes and later on in the phases of building and operation of engine room [4,8,9,17,18 and 19].

The importance of scientific research in designing engine rooms is based on the fact that their introduction enables to explain facts ascertained during designing, building and operation of already existing engine rooms and using desirable solutions in the phase of consecutive designing. The importance of such research is also based on the fact that during repair of engine rooms they should be modernized using knowledge of designers who followed up the construction as well as the operation of the engine rooms.

To show this importance one should first signal the contemporary design concept of ships and navy vessels.

OUTLINE OF THE DESIGN CONCEPT OF MODERN SHIPS VERSUS SCIENTIFIC RESEARCH

Deterministic design methods are used in contemporary design of engine rooms (as well as of ships treated as a whole) [1,8,15]. Although the use of these methods enables to prepare designs leading towards building engine rooms with a level of reliability judged intuitively as high (in principle the measure of such assessment is subjective or psychological probability) but does not allow to present such reliability in form of reliability factors. Such indicators even in form of probabilities (logical or statistic) are indispensable for rational planning and later on control of the process of operation of engine room. This is why there is a need to develop probabilistic methods shaping the reliability of engine rooms and to use them in the engine room design phase [6,7,17,18 and 19].

Probabilistic methods enabling shaping reliability and functional safety including proper ecological safety can be developed using the contemporary theory of reliability and safety of complex technical systems (engine rooms obviously can be treated as such systems), probability calculation methods, mathematical statistics, the theory of machines (mainly thermal machines) installed in engine rooms as well as using the theory of semi-Markov processes. In turn in order to prepare a set of reliability conditions of engine rooms one should use technical diagnostics as well as the results of damages of machines and equipment used in similar engine rooms. The knowledge of reliability and safety indicators of particular engine rooms enables to take rational decisions related to operation.

During operation of sea going ships decisions are taken always in stochastic decision situation i.e. in conditions of uncertainty (statistic risk conditions). This means that the probability and induction (mathematic) statistic rules are to be used when making decision. Decisions concerning operation are taken before commencement of the operation as well as during operation of the mentioned ships. This means that at least once such decisions are taken basing on initial information (obtained for example from research of reliability of engine rooms as well as of their particular machinery and equipment or basing on databanks of similar engine rooms). Such decisions can be named "a priori" decisions. Following decisions are based on information obtained during operation of the technical systems (e.g. in result of diagnostics, not only of technical diagnostics) and can be described as "a posteriori" information.

Decisions taken at the beginning of the operation are indispensable to plan the process of operation and maintenance of the said ship engine rooms. When taking decisions one should consider the statistic risk estimated as probability of taking wrong decision resulting from [2,7,9,19] :

- ⊙ impossibility of precise assessment of unknown parameters of the distribution of random variables, especially of such variables, which represent conditions of the operation process of the engine room and of particular machinery and equipment
- ⊙ lack of possibility to prepare full and/or reliable enough information indispensable to take the right decision.

The first case generates stochastic type of errors being subject of the so called **statistic precision of conclusions** while the second – both random mistakes as well as such which cannot be described as random (systematic). Determining the latter errors is a subject, which I suggest to name as **problems of precision or scrupulous way of concluding**. In total determining such errors is a question described as **accuracy of statistical conclusions. Accuracy of conclusions** results from the present level of scientific and applied knowledge, while **scrupulous way of concluding** results from insufficient appreciation or neglecting some information by the decision maker, who first could have checked that the information was really not so important. On the other hand decisions made during ship engine room operation are erroneous or irrational due to difficulties in preparation of full diagnosis and lack of proper credibility of information related to the technical conditions of these engine rooms, their machinery and equipment as well as to the foreseen external conditions (atmospheric and sea conditions), which could be expected during the ship's voyage [3,5,10,12].

In the presented decision situation taking rational decisions is possible in case of use of statistic theory of decision [4,5,18,19]. However determining the set of decisions, which can possibly be taken in accordance with the assumed criterions of optimization, requires identification of problems of assessment of reliability of the engine room, at least of its main energetic systems.

Different reliability and safety indicators of engine rooms, its machinery and equipment can be considered in designing engine rooms.

The most useful reliability indicators are [6,19] :

- ★ probability of correct work until the first damage
- ★ probability of correct work between two consecutive damages
- ★ single-dimensional distribution of process (instantaneous distribution) the elements of which are $P_k(t)$functions describing the probability that in moment *t* the process would attain condition *k*
- ★ limit distribution of the process $P_j = \lim_{t\to\infty} P\{Y(t) = j\}$
- ★ conditional probability described as probability of transition of the process from *i* to *j* condition, $P_{ij}(t) = P\{Y(t) = j / Y(0) = i\}$ (probability of transition)
- ★ distribution of the time of the first transition from *i* to subset of A [$\Phi_{iA}(t)$] conditions, if such subset is a one element set – to condition *j* , i.e. condition $\Phi_{ij}(t)$
- ★ distribution $\Phi_{jj}(t)$ of the time of return of the process back to condition *j*
- ★ asymptotic distribution of the renewal process $\{V_{ij}(t) : t \geq 0\}$ generated by the distance in time of the return of the stochastic process (to condition *j* obtained from condition *i* , which in the moment *t* takes the value equal to the number of "entries" of the process into condition *j*
- ★ approximate distribution of the total time of the presence of the process Y(t) in condition *j* provided that condition *i* is the initial condition
- ★ expected value $E(T_i)$ of the time T_i of i-duration of the process condition independently to which condition the transition is being effectuated in moment τ_{n+1}
- ★ variance $D^2(T_i)$ of the time T_i of the duration of i-condition
- ★ expected value $E(T_{ij})$ of the time T_{ij} of i-duration of the process condition provided that condition *j* will be next condition
- ★ expected value $E(\Theta_{jj})$ of the random variable Θ_{jj} describing the time of return of the process to condition *j*
- ★ expected value $E\{V_{ij}(t)\}$ of random variable $V_{ij}(t)$ describing the number of "entries" of the process into condition *j* in the range [0, t]
- ★ variance $D^2\{V_{ij}(t)\}$ of the random variable $V_{ij}(t)$
- ★ average number of "entries" $\lambda_{ij}(t)$ of the process into condition *j* occurring per time unit provided that the initial condition of the process is condition *i* (i.e. intensity of "entries" of the process into condition *j* provided that Y(0) = i)
- ★ limit intensity of "entries" of the process into condition *j* i.e. intensity $\lambda_{ij} = \lim_{t\to\infty} \lambda_{ij}(t)$.

Reaching numerical values mentioned in characteristics is possible only in case when the following conditions are met :

- ❈ Appropriate statistics have been gathered. The set includes values of assessed probabilities of transition p_{ij}, of the expected value $E(T_i)$ etc.
- ❈ Construction of a stochastic model of the process of operation of technical objects having small number of conditions

and not much complicated number (in mathematical sense) of transitions (changes) from one condition into other condition.

All the above mentioned types of reliability indicators are important for the operator but the most useful and in the same time the most easy to determine are the first two indicators.

Among the most useful safety indicators one can mention :

- expected value of random variable $N_s(t)$, i.e. the number of damages of the machinery and equipment of the engine room within the time range [0, t], causing a complicated situation describer with symbol $E\{N_s(t)\}$
- expected value of random variable $N_n(t)$, i.e. the number of damages of machinery and equipment of engine room in range [0, t], causing a dangerous situation described with symbol $E\{N_n(t)\}$
- expected value of random variable $N_a(t)$, i.e. the number of damages of machinery and equipment of engine room within the time range [0, t], causing a emergency situation described with symbol $E\{N_a(t)\}$
- expected value of random variable $N_k(t)$, i.e. the number of damages of machinery and equipment of engine room within the time range [0, t], causing a catastrophic situation, described with symbol $E\{N_k(t)\}$
- expected value of sail outs of the ship per one sea accident, described with symbol $E\{N_w(t)\}$
- expected value of sail outs of the ship per one sea catastrophe, described with symbol $E\{N_t(t)\}$
- expected value of death casualties per one sea catastrophe, described with symbol $E\{N_d(t)\}$
- expected value of death casualties per one sea mile, described with symbol $E\{N_m(t)\}$
- probability of safe ship (engine room) movement at sea $P_b(t)$, within the time range [0, t]
- probability of non-occurrence of a complicated situation of the engine room at sea $P_s(t)$, within the time range [0, t]
- probability of non-occurrence of a dangerous situation of the engine room at sea $P_n(t)$, within the time range [0, t]
- probability of non-occurrence of an emergency situation of the engine room at sea $P_a(t)$, within the time range [0, t]
- probability of non-occurrence of a catastrophic situation of the engine room at sea $P_k(t)$, within the time range [0, t].

It is obvious that in order to estimate the mentioned expected values of particular random variables $N_i(i = s, n, a, k)$ one should apply interval and not point estimation because only then the error of estimation can be determined. Determining the mentioned expected values is relatively simple. During investigations within the time period [0, t] one can determine the average (arithmetic) value $\overline{n}_i$ being the observed statistics $\overline{N}_i$, which as it is well known has a normal asymptotic distribution

$$N\left(m_i;\frac{\sigma_i}{\sqrt{n_i}}\right)$$

where :

m_i - expected value (average)
σ_i - average (standard) deviation of the random variable
N_i , n_i - number of registered events [1,4,16,18].

Reliability and safety requirements concerning functioning of the given engine room are as important as the technical and economic requirements formulated by the shipowner ordering a new ship in order to obtain the highest possible rentability of the ship as well as efficiency of its propulsion. Considering reliability and safety factors of a ship's engine room at the stage of design enables to influence its readiness to start up in any moment of operation, which should be maintained using possibly lowest operation cost. Thus economic calculations should be considered in the design stage in such a way as to control the process of engine room operation when in the same time maximizing the income. However this economic goal cannot be met without considering in the design process all the conditions of construction as well as operation and service of the engine room. This means that there are two staged which should be differentiated in the design of engine rooms [1,8,14] :

★ The first stage encompassing activities enabling designing of the process of fulfilling the need for production of energy indispensable to ensure the movement of the vessel as well as social needs of the crew and passengers, proper organization and control of work process proper for the design of engine rooms.

★ The proper design stage i.e. the stage of creation of new values in result of which is created a more or less original design of the engine room is created. Said design stage is needed to realize the above mentioned process of meeting the need for energy production.

The second design stage is finished with constructing, which is leading to creation of the final form of the designed engine room, namely to the creation of the final ship structure.

In both mentioned design stages one should consider such properties of the engine room as: functionality (functional correctness), safety, efficiency, reliability, durability, easiness to make diagnosis, renewability, ability to be controlled, life expectancy, ergonomics, ecological aspects, low level of noise and vibrations and toxicity of exhaust gases.

In the so understood design process one should assume that the basic information for design of engine room is the information which is related to the performed targets and conditions in which it can be realized. This means that one should first design the process of the engine room operation. The process will be a discreet process in conditions and continuous in time. It results from the hitherto considerations that a semi--Markov process, especially of controlled semi-Markov can be a model for of such a process [3,4,5,6,7,17,19]. Therefore the theory of semi-Markov processes, can be used in the process of designing ship engine rooms.

SEMI-MARKOV PROCESSES AS MODELS FOR REAL PROCESSES CONSIDERED IN THE PHASE OF ENGINE ROOM DESIGN

The use of the theory of semi-Markov processes to create semi-Markov models of real processes as semi-Markov processes can take place only when [4,6,19] :

✷ the Markov condition is met, what means that the evolution of conditions of the investigated objects (e.g.engine rooms) in the future, for which the semi-Markov models have been built, should depend only on the present condition of the given object (from the condition in the present moment) and not from the functioning of the object in the ”future”, what means that the future of the object should not depend on its ”past” and only on its ”present condition”.

✷ random variables describing the time intervals when the subjects of investigations remain in particular conditions reveal different distributions than exponential.

Thus when modelling, which has to lead to preparation of a semi-Markov model of the engine room operation of any ship, one should consider the change of real conditions of the process of the given subject of investigations.

In case of engine room of each vessel its operation process can be interpreted as a process of simultaneous changes of technical and service conditions [4,6,7,19]. Designing such process of engine room of any ship requires to solve using scientific methods the problem of forecast of particular conditions of the process. This requires to assume the following hypothesis (H1) : **prognosis of the condition of the process of operation of any ship or marine vessel in moment $\tau_n + \tau$, when it is known in the moment τ_n is known because its condition considered in any moment τ_n (n=0,1,…,m; $\tau_0 < \tau_1 < \ldots < \tau_m$) depends in an important way directly from the previous condition and not from the conditions which occurred earlier and time intervals when the condition occurred.**

It has to be noticed that the formulated hypothesis does not include any contradictions, which would classify it from the logical point of view even before its checking.

The consequences of this hypothesis are as follows [4,6,19] :

- probabilities (p_{ij}; $i \neq j$; $i,j \in N$) of the transition of the process of operation of engine room or any of its machinery or equipment from any conditions *i*, in which the process is at the moment, to any other condition *j* do not depend from the fact in which conditions the process used to be in the past
- intervals of the unconditional time of durations of particular conditions of ship engine room operation process *i* are stochastically independent random variables (T_i; $i \in N$)
- intervals of the duration of each possible occurrence of conditions i of the engine room process are random stochastically independent variables (T_{ij}; $i \neq j$; $i,j \in N$), provided that the next condition is one of the remaining processes *j* of the process.

The mentioned consequences show the probabilistic law of changes of conditions of the mentioned operation process. They are not internally contradictory and their logic truth does not allow for any doubts. Thus the condition of no contradiction of consequences is met. Therefore there is no reason not to understand the named consequences as one joint consequence K1 and to use it to check empirically the introduced basic hypothesis H1. This means to verify it in order to accept it or classify. The verification of the introduced hypothesis is based on experimental checking of the truth of the joint consequence K1. The verification of the introduced hypothesis H1 through experimental checking of the truth of the mentioned consequence K1 requires to assume the truth of the following syntactic implication :

$$H1 \Rightarrow K1 \quad (1)$$

In such a case one can apply noninduction (induction) conclusion carried out according to the following scheme:

$$(K1,\ H1 \Rightarrow K1) \vdash H1 \quad (2)$$

The logical interpretation of the scheme (2) is as follows : **if the experimental checking of the consequence K1 proved its rightness and if implication (1) is right, then hypothesis H1 is also right and can be accepted**. Concluding made in accordance with scheme (2) is a means concluding of reduction type, which is one of the types of induction concluding and thus does not lead to sure conclusions and is only probable.

In case when for any structural solution of ship's engine room, its machinery or equipment operated in any operation system it would result that empirical checking of the said consequence (K1) may contradict the formulated hypothesis (H1), then the conclusion about the truth of hypothesis (H1) can take place in accordance with the "modus tollens" scheme :

$$(\sim K1,\ H1 \Rightarrow K1) \vdash \sim H1 \quad (3)$$

The scheme of concluding defined by the relationship (3) has the following interpretation :

if experiment does not confirm the correctness of the sequence K1, then in case of correctness of implication H1 ⇒ K1, the hypothesis H1 is not correct and therefore cannot be accepted.

Both ways of concluding (2) and (3) have to be supported with statistical conclusions [6,7,19].

In service practice it is important to plan the preventive maintenance of particular engine rooms as well as of particular machinery and equipment with regards to the undertaken tasks and the need for gathering appropriate resources to carry out indispensable operations.

The application of semi-Markov processes as models of real operation processes of ship's engine rooms enables, already in its design stage, optimization of the time interval after elapsing of which one should carry out particular preventive operations. In this case one can consider two variants resulting from the necessity and possibility of considering two functions [4] :

- function $k_g : T_p \to G$, which describes the dependence between the readiness factor of the investigated object (engine room or any of its machinery or equipment) and time T_p elapsing from the moment of the start of the use of the object, being in condition of ability to the moment of the start of the preventive operation
- function $k_d : T_p \to D$, which describes the dependence between the average income (or cost) per unit of time and time T_p .

The first case results from the need for maximization of the readiness factor of the object (ship's engine room, its main engine or any other machinery or equipment), while the second – – from maximization of income and minimalization of cost. In these variants G and D mean in turn : readiness of the object to start carrying tasks and average income per unit of time.

The correctness of hypothesis H1 can be confirmed in case of verification and acceptance of a more detailed hypothesis. Among such hypothesis is the hypothesis H2 explaining the fact observed in practice that wearing of the trybologic sliding systems of marine machinery (e.g. diesel engines) is weakly correlated with time [2,9,16]. This observation allowed to forecast the technical condition of machinery basing only on its current condition with omission of earlier conditions. Explanation of this fact can be presented in form of the following hypothesis (H2): **the condition of any trybologic sliding system as well as the time of its duration considerably depend on the earlier condition and not on earlier conditions and time intervals of their duration because its load and both implied speed and increase of wear are processes having asymptotically independent values**.

The statement given in this hypothesis that **load and both implied speed and increase of wear are processes having asymptotically independent values** results from two obvious facts :

- there exists an exact dependence between load of the sliding trybologic systems and their wear [2,9]
- there is a lack of monotonous changes of the load of the sliding trybologic systems of machinery in longer periods of operation. Thus it can be assumed that the load of such systems is stationary [10,12,13].

Verification of the introduced thesis H2 requires to determine (foresee) the consequences, the occurrence of which can confirm the correctness of the formulated hypothesis. The consequences K2, which can be drawn from the hypothesis H2 are as follows [2,9,16] :

- irregular wear of particular sliding trybologic systems
- interlacing of realized wearing processes of the sliding trybologic systems
- the course of correlation function for a given sliding trybologic system such that with the increase of distance the function first quickly decreases and then oscillates around zero with a relatively small but gradually smaller amplitude in function of distance
- nearly normal distribution of increase of wear of the sliding trybologic systems in appropriately long time period of proper operation
- linear dependence between the variance of the process of wear of sliding trybologic systems and the time of operation.

The mentioned consequences show the probabilistic law governing the wear of sliding trybologic systems. The verification of hypothesis H2 can be done in a similar way as in case of verification of hypothesis H1. However in this case one should accept the correctness of the following syntactic implication :

$$H2 \Rightarrow K2 \tag{4}$$

and then to apply noninductive (inductive) concluding in accordance with the following scheme :

$$(K2,\ H2 \Rightarrow K2) \vdash H2 \tag{5}$$

what is known as reduction conclusion.

FINAL REMARKS AND CONCLUSIONS

Carrying scientific research in order to prepare semi-Markov models of engine rooms adequate for operation processes already in the design phase of these objects gives the possibility to present to shipowners the concept of control of the above mentioned processes in accordance with optimization criterions, which are important for them. Among these criterions one can mention: maximum income, minimum operation investments, required (also maximum) technical readiness factor etc. To prepare this concept one can apply decision (controlled) semi-Markov processes i.e. such semi-Markov processes in which realization depends on the decisions taken in particular moments of changes of process conditions. The processes are subject of considerations of semi-Markov decision (controlled) process theory.

The control of the processes of engine room operation in the phase of operation enables maintaining proper durability, reliability and safety of functioning of the objects and of their ecologic features.

Preparation of the above mentioned models of operation processes is equal to determination of a set of information, which should be at the disposal of designer, builder and operator so that they could ensure rational control of real processes of such engineer rooms. Without doubt it will influence the progress in operation of engine rooms and thus the progress in shipbuilding technology.

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Acronyms

SPE KBM PAN	-	Section on Exploitation Foundations, Machine Building Committee, Polish Academy of Sciences.
MCNEM	-	TInterministerial Scientific Centre on Exploitation of Fixed Assets
ITE	-	Operation Technology Institute
PWN	-	State Scientific Publishing House
WN-T	-	Scientific-Technical Publishing House
WM	-	Maritime Publishing House
WOiO PG	-	Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology
WSM	-	Maritime University of Szczecin