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DETERMINATION OF A TASK'S VALIDITY IN THE MARINE ENGINE ROOM OPERATING PROCESS WITH AHP METHOD – PART 2 – SIMULATION RESULTS

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Abstract

The frequent causes of ships' detentions by port authorities are abnormalities of marine power plant functioning. Each extended ship lay time in port results in a waste of ship operating time thus costs rise to ship owners. This is connected with improper marine power plant management. In order to avoid it, a ship engineer should have disposal computer aided at his system supporting him in the managing of the marine power plant. Such a system can be worked out on the condition that a mathematical model, which represents the decision – making process of an engineer has been built. One element of the decision making process in managing the marine engine room is to determine how important is each of the tasks which the operators have to do. This estimation is the base to choose the most important tasks and make optimal schedule with them. The present work shows the approach to the rating method of operating tasks using AHP method. Based on practice, a hierarchic structure of factors influencing tasks validity in the engine room operating process was made. Next, a preliminary questionnaire was conducted, which put questions to the experts as chief engineers next. This enabled to define numerical values of suitable coefficients influencing on the validity of operating tasks. The equation contains this all coefficients permit to determinate numerical values of an operating task's validity in given engine room operating processes.

Keywords: *engine room, task scheduling, hierarchy, AHP*

1. Introduction

In situation where the strict time limitations are present such as e.g.: during a ship staying in a port where the ship's strict departure time is known and the number of the tasks to be realized is usually much greater than that possible for the staff of the power plant. In such a situation the chief engineer must make a decision regarding which of the operational tasks should be made during the time being at his disposal and which could be postponed to another time, as well as who should be assigned to execute particular tasks. In such a moment, making incorrect decisions can cause non-fulfilment of the tasks, that consequently may result e.g.: in stopping the ship by port control (*PSC, FSC*) or subsequently in breaking the normal process of marine power plant operation (e.g. *black-out*). The decision problem in such situation can be formulated as the choice of the crucial tasks from the point of view of the marine power plant operation, and planning them in such a way as to make use of the available time most effectively.

Another situation is that in which both the strict time limitations are present and one aims at the best making use of the available resources, where the features of the first above described situation and the other one are combined in a sense. Such formulation of the decision problem may concern the situation when a ship undergoes repair in a shipyard.

In ship operation many other situations (ship service states) can also happen such as e.g.: lying at anchor, manoeuvres, canal passing etc., in which the chief engineer may be forced to take decisions dealing with planning the operational tasks. However, such states constitute a very small part of the overall operational time of a ship as they appear very rarely during its service process, or a situation requires to promptly make a decision regarding a way of action to be undertaken (e.g. manoeuvres in port) where possible making use of a computer system is not rational. In this connection for further considerations only two – out of the presented service states – namely sea voyage and staying in port, are taken into account. In the general theory of decision making the decision problem is such a situation in which the decision maker faces necessity of choosing one – out at least two possible – variants of acting. In the marine power plant, the chief engineer must take a decision on which of the acting variants (sets of sequenced operations) would be the best from the point of view of ship service. According to the definition of the problem faced by the ship engineer, he must, out of all operations to be executed, select and sequence as well as assign (to respective members of machinery crew) the most important ones in a given operational situation taking into account all relevant conditions and limitations. A very important phase of this process is to determine the importance (validity) of all operating tasks, which is the background to make an optimal schedule of it.

2. The AHP methodology

The Analytic Hierarchy Process (AHP) is a method of measurement for dealing with quantifiable and indefinable criteria that has been applied to numerous areas, developed by Thomas Saaty in the 1970's. Many uses of this method to support decision-making processes, in fields such as government, business, industry, healthcare and education, convince us of its usefulness, especially in situations when the experience of the judge is the main source of opinions or the estimations have a strongly subjective quality.

AHP provides a comprehensive and rational framework for structuring a decision problem for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions [1]. It is based on the following three principles: decomposition, comparative judgments and the synthesis of priorities. AHP starts by decomposing a complex, multi-criteria problem into a hierarchy where each level consists of a few manageable elements that are then decomposed into another set of elements [3]. The second step is to use a measurement methodology to establish priorities among the elements within each level of the hierarchy. The third step in using AHP is to synthesize the priorities of the elements to establish the overall priorities for the decision alternatives.

For computing the priorities of the elements, a judgmental matrix is assumed as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}, \quad (1)$$

where a_{ij} represents the in pairs comparison rating between the element i and element j of a level with respect to the upper level. The entries a_{ij} are governed by the following rules: a_{ij} >0;

$$a_{ij} > 0; \;\; a_{ij} = 1/a_{ji}; \; a_{jj} = 1 \quad \forall i . \quad (2)$$

Following Saaty, the priorities of the elements can be estimated by finding the principal eigenvector w of the matrix A, that is:

$$AW = \lambda_{\max} W . \quad (3)$$

When the vector W is normalized, it becomes the vector of priorities of elements of one level with respect to the upper level. The λ_{max} is the largest eigenvalue of the matrix A.

In cases where the in pairs comparison matrix satisfies, transitivity for all in pair's comparisons it is said to be consistent and it verify the following relation:

$$a_{ij} = a_{ik} a_{kj} . \quad (4)$$

Saaty has shown that to maintain reasonable consistency when deriving priorities from paired comparisons, the number of factors being considered must be less or equal to nine. *AHP* allows inconsistency, but provides a measure of the inconsistency in each set of judgments. The consistency of the judgmental matrix can be determined by a measure called the consistency ratio (*CR*), defined as:

$$CR = \frac{CI}{RI}, \tag{5}$$

where:
CI – the Consistency Index,
RI – the Random Index.

Furthermore, average consistencies (*RI* values) of randomly generated matrices (Tab. 2) were provided. *CI* for a matrix of order *n* is defined as:

$$CI = \frac{\lambda_{\max} - n}{n-1}. \tag{6}$$

In general, a consistency ratio of 0.1 or less is considered acceptable; this threshold is 0.08 for matrices of size four and 0.05 for matrices of size three. If the value is higher, the judgments may not be reliable and should be elicited again.

Tab. 1. The average consistencies of random matrices (RI values)

n Size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.2	1.35	1.40	1.45	1.49

3. Decompositions of evaluation criteria

To apply the *AHP* method to rating the factor's impact on validity of operating tasks in the engine room, it requires the executions of this factor's hierarchy (priority). The decomposing of the validity factors in the hierarchic structure permits us to estimate each factor individually, which makes the problem easier, than the assessment of all factors simultaneously. The proper hierarchy process of factors was realized by the defining of main and detailed factors division. According to this, the factors receive a hierarchic structure compatible with Saaty's theory (Fig. 1).

- high-level goal of the analysis – the "global" validity indicator of operating tasks (*VI*),
- second-level, multi criteria – presented by the six general factors C_i,
- third-level, sub-criteria – presented by the detailed factors c_i,
- low-level – individual operating tasks, t_i, which are estimated by general and detailed factors.

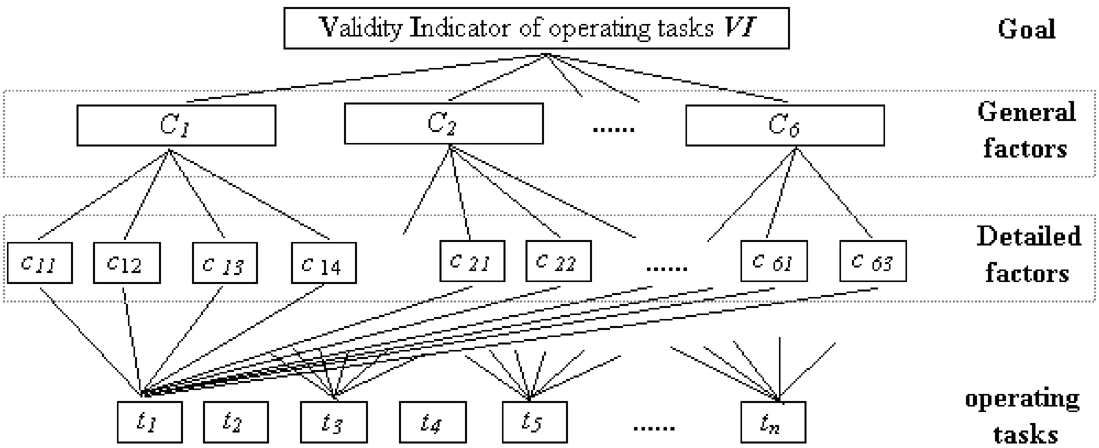

Fig. 1. Hierarchic structure of factors influencing on validity of operating tasks

In this method, the value of a factor's rating is obtained from the opinions of users and experts who know the character of the estimated objects. This opinion is a result of in pair's comparison of the objects. It makes possible and easy comparative estimation of the individual elements based on the decision-maker's preference in this problem. To compare and estimate objects, the punctual relative mark in 1-9 scale following T. Saaty's theory is used, presented in Tab. 2.

The last phase of the *AHP* method processing was aggregation all coefficients of individual general and detailed factors in one global validity indicator of operating task permissive to the comparison of their validity.

4. Aggregation of the weight factor coefficients

The aggregation of preferences in the AHP method is generally executed by additive utility function, synthesizing the weight parts of individual factors (criterions) as well as value of fulfilment extent of the fractional objective function by all factors (criterions) [3]. According to this principle, the aggregation of all factor coefficients was applied additive method with few exceptions.

For example, the factor related with the possibility of shift task execution identifies the option of changing the operating task execution time in schedule to the near future. This factor was defined by two detailed factors, which described the combination of many different operating stage of ship and engine room, but they are not alternative mutually. Only part of these operating stages combinations permitted the execution of a single operating task then both factors must be right in each considered situation. For that reason, these two detailed factor coefficients (c_{51}, c_{52}) were aggregated by multiplicative method. Moreover, if the there is a possibility of moving the time of operating task execution it means then the validity of it should be lower, therefore the weight factor coefficient WC_5 takes a minus sign.

Similarly, with the detailed factors (repetition frequency and task-executed time) of factor related with time. These two are clearly dependent then the aggregation of their coefficients (c_{22} c_{23}) has to be realized also by multiplicative method [2].

Moreover, the detailed factors of factor related with possibility to omission of engine room device in operating process (number of devices, avoidance of devices in operating process) could be active only one of them in the same time (if $c_{41}=1$ then $c_{42}=0$).

Tab. 2. The AHP in pairs comparison scale

Numerical values	Verbal scale	Explanation
1	Equal importance of both elements	Two elements contribute equally
3	Moderate importance of one element over another	Experience and judgment favour one element over another
5	Strong importance of one element over another	An element is strongly favoured
7	Very strong importance of one element over another	An element is very strongly dominant
9	Extreme importance of one element over another	An element is favoured by at least an order of magnitude
2, 4, 6, 8	Intermediate values	Used to compromise between two judgments

Based on this the final form of utility function (the validity index of operating task *VI*) was accepted as:

$$
\begin{aligned}
VI = WC_1 \cdot \sum \left(c_{1h} \cdot wc_{1h}\right) + WC_2 \cdot \left(c_{21} \cdot wc_{21} + c_{22} \cdot wc_{22} \cdot c_{23} \cdot wc_{23}\right) + \\
+ WC_3 \cdot \sum \left(c_{3h} \cdot wc_{3h}\right) + WC_4 \cdot \sum \left(c_{4h} \cdot wc_{4h}\right) \\
- WC_5 \cdot \prod \left(c_{5h} \cdot wc_{5h}\right) + WC_6 \cdot \sum \left(c_{6h} \cdot wc_{6h}\right).
\end{aligned} \tag{7}
$$

This way of factors aggregation unifies the estimations of operating tasks validity and allows us to compare each one with remaining and make their hierarchic list, which is essential to optimal scheduling.

5. Results of preliminary simulation

Based on the presented model of validity rank of operating tasks in the engine room a comparative inquiry form was prepared. It was intended for experts of decision-making in the engine room like chief engineers. In this questionnaire, the experts made the comparison between each of factor, the first general factors and next to the detailed factors separately in every general factor area. They estimated his preference which factor in compared pair is more important to operating tasks validity. There was inquiry for more than twenty of chief engineers and they used the scale from Tab. 1 for the estimation. As a result of the data processing from inquiry, form was series of numeric values of weight factor coefficients.

One more question was how to aggregate many different numeric values of each validity factor coefficients received from different experts. In general, there are two most popular ways to do this: by average value in arithmetic mean or geometric mean. The problem with the second option was that then the sum of the average value in general factors series and in each detailed factors series does not equal 1. Moreover, there was a sensible inequality between values received in these two ways and these differences were from 0.00% to 20.5%. The normalized process of these values in 0-1 range decreased this inequality to a small level, where the maximum of that value was 13.63% (two last columns in Tab. 3).

$$WC_{i(norm.)} = \frac{WC_i}{\sum WC} \; ; \; wc_{ij(norm.)} = \frac{wc_{ij}}{\sum wc_i} \, . \tag{11}$$

In order to control the results of the AHP method, the consistency ratio for each of the metrics and overall consistency for the hierarchy were calculated during data processing and verified currently. For the part of experts' judgments, the *CR* was larger than 10%. Those judgments were not taken into account to average values of weight factors coefficients. The *CR* for the expert's judgments, which include all coefficients, was from the field 0-10% and amount from 1.59% to 9.76%. All values of weight factor coefficients are presented in Tab. 3.

Basis on these two collections (arithmetic mean, geometric mean) of weight factor coefficients (WC_i, wc_{ij}) and factor indexes (C_i, c_{ij}) were accomplished a few scheduling operating tasks simulations. The simulations of scheduling were performed for the set of 12 various operating tasks (the features of the tasks were difference and chance). During these simulations were a varied number of tasks, number of operators, deadline time for a schedule, etc. For the first part of simulation, a collection of arithmetic mean coefficients values was used. Next, a collection of geometric mean coefficients values was used. Those two collections of result simulations were compared. The schedules received in the same conditions for both collections of weight factor coefficients were the same sequence of assigning. One difference that was observed, was the value of result quality (value of objective function for the best result – schedule). This kind of difference was expected because of the various values of weight factor coefficients. There was no sense to compare these values.

6. Conclusions

In this paper is presented an approach to solving the decision problem link to the operating tasks scheduling problem in a marine power plant. Very often in practical situations, the chief engineer in the engine room has to make a hierarchy of operating tasks. This approach proposes to use the AHP method to do it. This methodology could help assess relevant criteria critically and logically and assist in sensible decision-making.

Tab. 3. Exemplary set of the operating tasks validity values obtained by the AHP methods

		Arithmetic mean (Avg.)		Geometric mean (Avg.)				Difference between arithmetic mean & geometric mean	
		weights vector	sum	weights vector	sum	normalized weights vector	sum	before normal	after normal
General factors	WC_1	0.3752		0.3501		0.3841		6.70%	2.35%
	WC_2	0.1130		0.0951		0.1043		15.80%	7.64%
	WC_3	0.2576		0.2283		0.2505		11.36%	2.76%
	WC_4	0.0425		0.0412		0.0452		2.89%	-6.53%
	WC_5	0.0468		0.0461		0.0506		1.38%	-8.18%
	WC_6	0.1650	1	0.1507	0.91	0.1653	1	8.67%	-0.19%

		Arithmetic mean (Avg.)		Geometric mean (Avg.)				Difference between arithmetic mean & geometric mean	
		weights vector	sum	weights vector	sum	normalized weights vector	sum	before normal	after normal
Detailed factors	wc_{11}	0.2885		0.2723		0.2808		5.60%	2.68%
	wc_{12}	0.6463		0.6344		0.6540		1.85%	-1.19%
	wc_{13}	0.0652	1	0.0633	0.97	0.0652	1	2.92%	-0.09%
	wc_{21}	0.4310		0.3594		0.4116		16.60%	4.49%
	wc_{22}	0.1472		0.1439		0.1648		2.28%	-11.91%
	wc_{23}	0.4218	1	0.3699	0.87	0.4236	1	12.30%	-0.43%
	wc_{31}	0.4822		0.4657		0.4851		3.43%	-0.60%
	wc_{32}	0.2698		0.2690		0.2802		0.30%	-3.86%
	wc_{33}	0.1665		0.1499		0.1562		9.96%	6.20%
	wc_{34}	0.0815	1	0.0754	0.96	0.0785	1	7.53%	3.67%
	wc_{41}	0.6875		0.6777		0.6951		1.43%	-1.10%
	wc_{42}	0.3125	1	0.2973	0.98	0.3049	1	4.86%	2.42%
	wc_{51}	0.5000		0.5000		0.5000		0.00%	0.00%
	wc_{52}	0.5000	1	0.5000	1.00	0.5000	1	0.00%	0.00%
	wc_{61}	0.4094		0.3806		0.4414		7.02%	-7.83%
	wc_{62}	0.2129		0.1712		0.1986		19.57%	6.73%
	wc_{63}	0.3231		0.2569		0.2979		20.50%	7.80%
	wc_{64}	0.0546	1	0.0535	0.86	0.0621	1	2.02%	-13.63%

Processing of the data of expert preferences permits us to obtain a collection of weight factor coefficients, which define the importance of a few factors in operating processes in the engine room. What is important is that, and then it is necessary to collect a large number of expert's preferences to receive reliable values of all coefficients.

Two tribulations are observed, the first was the consistency ratio *CR* for a large number of experts answers was larger than 10%, which made these answers incapacitated. The reason for this could be not enough clear explanations of the comparisons way, sense of factors, etc. The second was values divergence of weight factors coefficients received from different experts. The most probable reason for this was that then the experts have their experience on many different types of ships. The priorities of engine room operating process there could be dissimilar and the factors forced on this process could take different weight values.

This paper does not attempt to set out an infallible priority processes or a set of some checklist for performance measurement of operating tasks in the marine power plant. The idea presented here needs to be integrated with general engine room management strategy and in this way; the application of *AHP* should be still enhanced. This study is unique in the sense that a different methodology of operating tasks importance measurement was used. The presented model might be enlarged due to the specific of type of ships or engine rooms in which they are implemented. It is possible to build a complex decision support system connecting many models (scheduling, diagnostic, etc.) – especially focused on strategy managing in difficult situations. The most important element for successful implementation of the *AHP* method is explaining to decision makers the general idea of the method.

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