IVAN MAVRIĆ D. Sc.
Faculty of Mechanical Engineering and Naval Architecture
Fakultet strojarstva i brodogradnje
Zagreb, Ivana Lučića 5

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ASSESSMENT OF OPTIMAL REPLACEMENT PERIOD OF THE SHIP EQUIPMENT BY STATISTICAL MODELLING

SAŽETAK

PRORAČUN OPTIMALNOG PERIODA ZAMJENE BRODSKE OPREME METODOM STATISTIČKOG MODELIRANJA

U radu se razmatra problem određivanja optimalnog obima i perioda zamjene brodske opreme. U uvodnom dijelu se analizira karakter i obim tehničkog održavanja i remonta brodske opreme, pojedinih sklopova i elemenata te opreme. Definiraju se mogući zadaci i varijante njihova rješenja. Poseban naglasak stavljen je na statističko modeliranje slučajnih procesa. Na kraju, dat je numerički primjer statističkog modeliranja procesa tehničkog održavanja i proračun optimalnog perioda zamjene ležaja brodske crpke.

1. INTRODUCTION

Ship equipment in general, and single assemblies and elements of this equipment as well, can be divided into two groups according to the character of their failures (breakdowns):

The first group includes the equipment whose operation parameters gradually deteriorate during exploitation, such as ship pumps for various purposes. In the usage of ship pumps, due to wear of sealing elements, the pressure decreases, the capacity gets reduced and the losses of medium through sealing elements increase.

In order to maintain the exploitation (operation) characteristics of the pumps within the allowed limits, it is necessary to perform the tasks of technical maintenance and overhaul, which is linked with certain expenses.

The second group of elements and assemblies of ship equipment includes those whose failure occurs unexpectedly and completely. The operation period (service life) of such elements is usually expressed in probability characteristics. Such elements are e.g. various electronic assemblies, condensers, some radiotechnology and navigation system elements, as well as many elements and assemblies of automated and automatic control of ship, electromechanical devices, cargo and fire prevention systems, ship facilities control system and the like.

Depending on the character of the equipment, its assemblies and elements, there are two types of tasks regarding its replacement during the repair of a ship.

The tasks of the first type include the replacement of the equipment from the first group. These tasks are used to determine the optimal replacement period of the equipment from the first group, in order to minimize the total cost of purchasing the new equipment and the expenses regarding either the deterioration of operation parameters of the equipment due to wear until replacement, or the necessity to maintain the parameters at a given level by technical maintenance and overhaul.

The extent of the repair tasks and their relatively high cost causes in many cases the assessment of its economic justification and, as a consequence the choice between the repair and the replacement of the old equipment by the new one. Moreover, today the extent of manufacturing of many devices and assemblies, which are produced either on a large or a small scale, is several times smaller than the extent of the repair of this same equipment. The reason for this is the large proportion of manual work - 50-90% in overhauling of devices and assemblies [1]. Therefore, the economic assessment of the adequacy of replacing the old ship equipment by the new one instead of its repair is of special interest.

By solving the tasks of the second type, it is possible to determine the optimal period of replacement of elements and assemblies, in order to minimize the expenses caused primarily by the price of spare parts and then by the cost of labour in replacing the part, and eventually, by the expenses due to breakdown of these elements.

For the tasks of the second type, two basic solutions for the replacement of elements can be determined:

1. replacement of elements only after their breakdown (failure), thus minimizing the costs of purchasing new elements (the operation life of the elements is maximal); however, there is a possibility of significant losses due to the breakdown during operation;

2. complete replacement of all the elements of the same type after the breakdown of any one of them; in this way the expenses of purchasing the new elements are maximal; however, the expenses that might be caused by breakdown of elements are minimized. The tasks of the second type are used to determine, especially whether the replacement of the whole group of elements is economically justifiable, and if so, which is the optimal period for the collective replacement.

The second type of replacement tasks takes into consideration those elements for which the period from the start of the exploitation until the breakdown (failure) is a random quantity, subjected to a certain law of probability. Regarding the tasks of the second type one has to bear in mind that preventive replacement of a serviceable system element already in operation for some time is justified only if the cost of the single replacement of the failed element is higher than the replacement of the whole group of the still serviceable elements, and if the new element has a lower probability to break down than the element already in operation for some time. If the probability of the breakdown is constant, the last condition is, naturally, discarded.

It is useful to assess how justified the collective replacement of elements is already in the phase of elaboration of project documentation while designing a ship. The assessment results should be taken into consideration both in the principal technology of ship's repair and in the exploitation documents. The duration of the optimal replacement period should, of course, be adjusted according to the gathered empirical data on the actual elements reliability, as well as on the expenses caused by the failure of the element.

The economic effect of applying similar assessments increases with the increase in the usage of the assessment, i.e. in its implementation on a possibly greater number of systems which are being used on ships.

2. STATISTICAL MODELLING OF TECHNICAL MAINTENANCE AND REPAIR

The volume, direct and indirect expenses of technical maintenance and repair of the ship equipment require scientific approach to this significant problem. One form of these approaches is the research based on statistical methods. They differ from other disciplines and methods not by the object of the research, but by the method of the research itself.

The statistical modelling method, known in the literature also as the "Monte Carlo" method, can be applied whenever a process or an occurrence need to be simulated. Thereby, it is necessary to know the rules obeyed by the given occurrences or to have the data on such occurrences in the past. This method represents the similar model of such a problem used to simulate the reality. It is especially characteristic that always a random sample is used as the basis for simulation. Therefore, the random numbers are of special significance [2].

In this paper, the statistical modelling method will be used in the selection of the optimal process or technical maintenance and repair of the ship equipment. Statistical modelling of technical maintenance and repair should be used in selection of the optimal versions of elements replacement in such cases where there are no probability characteristics of the reliability of elements and assemblies of ship equipment, or when the operation conditions of the equipment do not suit the situations characteristic for the replacement tasks of the first and second type.

In statistical modelling the tendency is to establish the actual operation condition of a certain equipment and, by implementing several versions of technical maintenance and repair to select the economically most suitable one. The use of random numbers compensates for the absence of data on the probability law of service life of various elements and assemblies of the equipment, as well as on laws which determine the level of influence of operation conditions of one element on the operation of the other element.

In selecting a rational system of technical maintenance and repair it is necessary to take into consideration also the possibility of replacement of the still serviceable elements and assemblies parallel to the replacement of the broken down elements. In that case, the increase in the cost of purchasing the spare parts is compensated by the fact that the equipment is already disassembled in order to replace the worn (broken down) elements. For example, if the auxiliary ship diesel-generator is disassembled for the replacement of the worn out piston rings, one should consider if it would prove justified to replace at the same time also the piston skirt. Since the engine is already disassembled, the simultaneous replacement of the skirt causes a very small prolongation of the repair time.

If the skirt is not replaced at the same time as the piston rings, there is a great possibility that the engine would have to be disassembled again.

The economic justification of one or the other replacement of elements depends on their service life classification, price of the work, price of the spare parts, and in certain cases also on the expenses (losses) caused by the downtime during the repair.

Out of the given factors we should stress the amount of expenses for repairing. Taking into consideration the tendency to reduce the number of the crew members on ships occurring today in almost all the shipping companies, the crew should have minimum tasks with the technical maintenance of the ship equipment, thus in turn enabling the reduction of the crew members.

3. NUMERICAL EXAMPLE

On some ships that are equipped with refrigerator devices, very often during navigation repair works are performed in replacing the worn out ball bearings of the horizontal centrifugal electro-pump of the refrigerating device, causing in one case the failure of the end bearing, and in the other case the bearing at the side of the flange joint which connects the pump shaft with the shaft of the electric motor needs to be replaced.

Based on the empirical (in this example assumed) data regarding the number of operation hours of these bearings, let us try and assess the two possibilities of performing the repair:

1) replacement only of the bearing which is worn out;
2) simultaneous replacement of both bearings when only one of them fails.

Table 1 shows the distribution of the random quantity - number of operation hours of the rotary pump bearing until their replacement by 150 bearings.

To carry out the economic analysis let us consider the time and value characteristics of the repair of the given pump. In order to replace one of the pump bearings one has to disconnect the pressure and delivery pipeline, to loosen the base bolts, disassemble the flange joint, dismount and disassemble the pump, and then to remove the worn out bearing, prepare the bed and fit the new

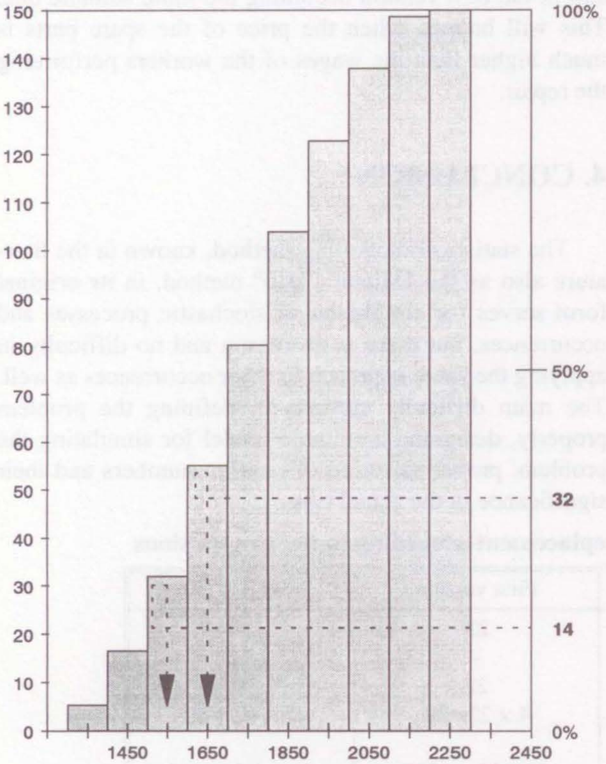

Figure 1 - **Distribution of the operation hours of pump bearings before their wear and replacement in cumulative form**

bearing. After that the pump is re-assembled and fitted into its place.

Average replacement time for one bearing performed by two medium-qualified crew members takes four (4) hours, and the replacement time for both bearings amounts to five (5) hours. The price of a new bearing is assumed 60 Kunas.

In order to assess the repair cost, the total monthly expenses for one ship mechanic of medium qualifications, who performs the pump repair during navigation (in this example - 5500 Kunas), are divided by the working hours of that mechanic during one month (approx. 150 hours). The cost of the repair is 36.6 Kunas per hour.

In order to model the different possibilities of performing the repair of the pump let us transform the distribution of the random variable from Table 1 into a cumulative form (Figure 1). The y-axis gives the cumulative frequencies and the x-axis - the appropriate number of operation hours until the bearing gets worn out and is replaced.

Cumulative frequency polygon in Figure 1 shows what proportion of the total number of studied bearings has the number of operation hours before replacement less or equal to the value which corresponds to the x-axis of the class of the polygon stepped line. The right side of the polygon, the y-axis gives the appropriate cumulative percentage. From the random numbers table or by using the computer the set of double-digit random numbers is determined, e.g. 14, 32, 61, 28 etc. If we put these random numbers on the axis of the cumulative percentage, e.g. 14, and choose on the polygon stepped line a bearing with the operation time before its wear and replacement of 1550 hours, as shown in Figure 1. Number 32 corresponds to a bearing with the operation of 1650 hours.

This method is universal and can be applied to any distribution law, theoretically and empirically. That is its great advantage. Moreover, in case of a discontinuous change of variable, as in this example due to the division into classes, it can be even simplified. Since a whole range of random numbers corresponds to one variable class, we can even without drawing the figure find out to which class a certain range of random numbers will correspond. We only have to prepare the cumulative frequencies and calculate their corresponding percentages, i.e. the range of random numbers. For example, for class 1500 - 1600, range of random numbers is $(16 : 150) \times 100 = 10.66$ up to $(32 : 150) \times 100 = 21.33$, and for the class 1600 - 1700 from 21.33 up to 36.66. Because of the double-digit random numbers the ranges are from 11 to 21, and from 22 to 36 respectively. The task could have been solved by cumulative probability, particularly in the case when the random variable is distributed according to the normal law. Moreover, in that case we can use the random numbers generator of the unit normal distribution contained in the software package EXCEL [3].

Table 1 - **Distribution of random quantity - number of operation hours of the rotary pump bearing before breakdown and replacement**

Number of bearings n_i	5	11	16	23	25	24	19	15	10	2
Operation hours before replacement, hours	1300 - 1400	1400 - 1500	1500 - 1600	1600 - 1700	1700 - 1800	1800 - 1900	1900 - 2000	2000 - 2100	2100 - 2200	2200 - 2300
Class average, x_i hours	1350	1450	1550	1650	1750	1850	1950	2050	2150	2250

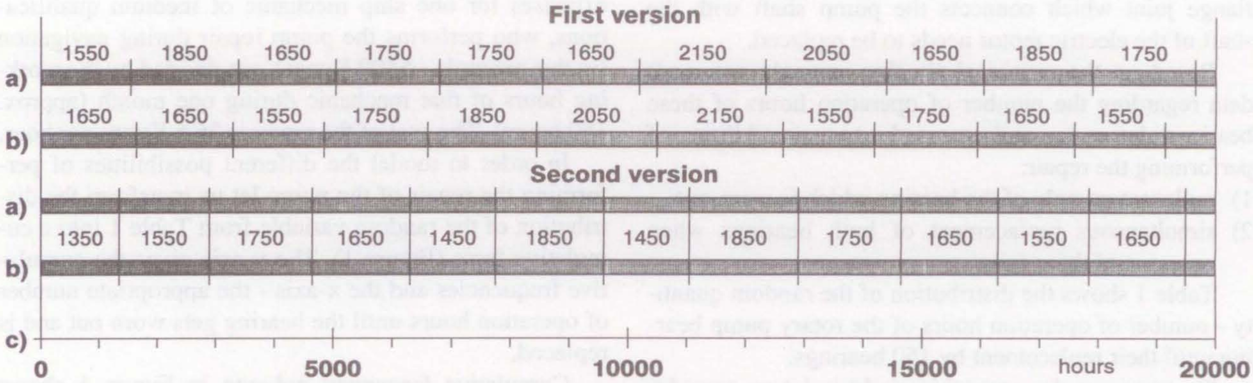

Figure 2 - **Graphic presentation of the results of the pump repair plan modelling according to two versions: a - the line of the end bearing; b - the line of the bearing at the side of the flange joint of the electric motor; c - the time axis (for 20 thousand operation hours of the pump).**

For the modelling of the first version of repair tasks (replacement only of the worn out bearing) let us choose by using the random numbers the sequence time of the operation before the replacement of the first and second pump bearing and let us put that time in the diagram (Figure 2), which is set for 20 000 operation hours of the pump.

For the modelling of the second version (replacement of both bearings when only one breaks down) the service life of both bearings is chosen also by random numbers and the polygon in Figure 1. In this case, the shorter of the two service periods of the first and the second bearing determines the time for replacement of both bearings. Thus, if the service life of the first bearing is 1650 hours, and the second 2150 hours, we put 1650 in the diagram (Figure 2) as the time for replacement of both bearings. Then the operation time before the replacement of the next bearing is calculated, and the shorter time put in the diagram as the time for replacement of both bearings etc. up to 20 thousand hours.

The summed results of modelling for both versions are given in Table 2. These data show that the second version provides lower cost. Although according to this version the number of replaced bearings is somewhat bigger, the shortening of the repairtime reduces the total expenses by 1929.6 Kunas than the expenses in the first version. The change in the structure of expenses can result in the first version becoming the more suitable one. This will happen when the price of the spare parts is much higher than the wages of the workers performing the repair.

4. CONCLUSION

The statistical modelling method, known in the literature also as the "Monte Carlo" method, in its original form serves for simulation of stochastic processes and occurrences, but there is no reason and no difficulty in applying the same approach to other occurrences as well. The main difficulty consists in defining the problem properly, designing a suitable model for simulating the problem, proper selection of random numbers and their significance in the actual case.

Table 2 - **Modelling results of the electro-pump bearing replacement according to the two versions**

Characteristics of the bearing replacement and costs	First version	Second version
Number of single replacements	22	-
Number of double replacements	-	12
Total number of replaced bearings, pcs.	22	24
Repairtime, hours	4 × 22= 88	5 × 12 = 60
Expenses, Kunas:		
– price of the bearings	60 × 22 = 1320	60 × 24 = 1440
– labour cost for bearing replacement	36.6 × 2 × 88 = 6441.6	36.6 × 2 × 60 = 4392
Total expenses, Kunas	7761.6	5832

In this work, the statistical modelling method has been used in order to choose the optimal technical maintenance and repair of ship equipment. When there are more than one version for solving a problem, all the versions can be simulated by this method. The obtained results by each of the versions are inter-comparable and serve for evaluation of how good the solution is, according to the in advance accepted criterion.

The economic effect of such an approach in choosing the optimal repair system increases with the widening of its implementation, i.e. with its application to a greater number of systems used on ships. If we analyse in this way the repair of many other ship devices, the need for which may arise during navigation, then, in principle, the application of the optimal system of technical maintenance and repair allows for the possibility of a justified reduction in the number of crew members, who are not employed only as providing "guard" of the devices in operation, but also for providing the repair of ship devices and system during navigation, should the need arise.

Similar approach for choosing the optimal system of technical maintenance and repair can be applied in production and transportation equipment of any industrial plant, commercial vehicles, construction and other machines, public transport vehicles etc., and it can be supplemented by the distribution of costs (losses) caused by the downtime of equipment or devices during repair.

SUMMARY

The article deals with the problem of assessing the optimal volume and period for the replacement of ship equipment. The introduction analyses the character and the volume of technical maintenance and the repair of the ship equipment, certain assemblies and elements of that equipment. Possible tasks and various ways in which they can be solved are defined. The statistical modelling of random processes is particularly stressed. Eventually, the numerical example of statistical modelling of technical maintenance and the assessment of the optimal replacement period of the ship pump bearing is given.

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