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PREVENTIVE MAINTENANCE REVISION OF NAVAL SYSTEMS

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ABSTRACT
Navy has made a huge applying of preventive maintenance that has been recognized as the greatest source of costs. Scheduled overhaul is the most expensive. Revising preventive maintenance and selecting maintenance concepts according to a new algorithm should result into lowering those costs and at the same time maintaining function safety and system readiness. A reversible FMEA analysis coupled with the RCM maintenance concept selection has been modeled. The methodology used is qualitative and starts with the hypothesis that statistic data are not only insufficient but they are inadequate too.
Keywords: reverse FMEA, RCM, Navy

1. INTRODUCTION
Classical Reliability Centered Maintenance - RCM analysis is intended as a "zero based" maintenance determination analysis, and so the effects of existing maintenance policies are discounted. Under the conditions of the scarcity of resources necessary for the analysis, starting from the very beginning is not the best solution, because the experience of applying the existing maintenance program would be useless. There are a few similar methodologies in the world. Working on this paper we made allowances for some positive achievements that came out as a result of some optimization methodologies [1,2,3,4]. A general opinion that former maintenance covers all critical failures was enough for a starting decision on modeling the reverse analysis. The reverse FMEA analysis that enables detailed quality and systematic modeling of failures based on the previous maintenance is used. The main goal was creating the conditions for applying the algorithm of maintenance concept selection that would be used for systematic selection of predictive and detective maintenance parallel with the previous preventive and corrective maintenance.

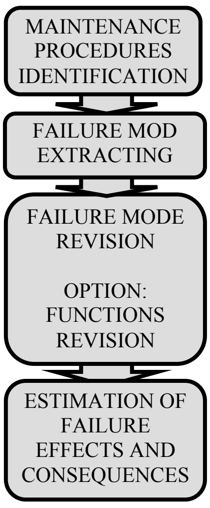

Figure 1. Reverse FMEA steps

However, it has been decided that in every single case the analysis has to be made concerning the current maintenance conditions to check if some preventive maintenance steps are lacking because it might cause some unexpected failures with eventual safety and system consequences. That is the main reason those reverse methods, that suggest using only preventive maintenance, have been criticized [5]. For this reason, in this paper we suggest a corrective maintenance analysis too, either formally documented or not. A step modeling failure modes, that have not been treated in previous neither preventive nor corrective maintenance systems, has been introduced too. That is option - a revision of system functions.

2. REVERSE FMEA STEPS

The steps of the reverse FMEA analysis are shown in Figure1. It starts with identification of maintenance procedures from the previous maintenance program. That means that each maintenance task is named, its performance interval and the branch that performs the task are written down. The second step is extracting the failure modes from previous maintenance tasks. A single preventive or predictive task can be applied to several failure modes. The failure mode revision step starts with grouping all the maintenance tasks and joint failure modes to prepare and facilitate their revision. It identifies if there are any failure modes that have not been taken into account in previous maintenance tasks. This is a crucial part of this step. A functions revision can be an option to this step. That would make it easier to identify the possible lacking of reasonably likely failure modes. Since functions identification would make this step difficult, we point out that it is meant to be only an option. Revision is also about identifying different procedures that apply to the same failure modes, and that could be defined in terms of their being necessary or not. The next step is about estimation of effects and consequences of failures with current and additional failure modes. Effects are defined the same way as in the classical *FMEA* analysis. Consequences are categorized the same way as in the classical *RCM* analysis: hidden - for hidden failures, safety - for failures that could be of hazardous to ship safety, safety of people and environment, system - for failures that could have unfortunate consequences to system functioning and nonoperational - failures with no consequences to system functioning.

3. MAINTENANCE-CONCEPTS SELECTION

The original algorithm of maintenance-concepts selection is applied. This algorithm is developed according to the classical RCM methodology (Figure 2). The first fact to define is to check if there are some legally set maintenance procedures in terms of previously analyzed failure modes. This step is included because maritime business is under strict legislative regulations. The second step is grouping failure modes into four possible analysis directions based on failure consequences. Special attention has to be paid to failures that could have unfortunate consequences to the safety of ship, people and environment, as well as failures with hidden consequences. Failures with hidden consequences are mostly connected to protection systems that are the first step of defense from multiple failures and damages with severe final consequences. Failures with the possible consequences to system functioning need preventive maintenance if there are real conditions for its application. The failures without consequences to system functioning need corrective maintenance without special analysis. Those are only the main principles that specify the next step.

The next step is about considering technical characteristics of failures. This serves the purpose of analysing the possibility of applying preventive or corrective policy. According to literature [6], if RCM is taken as a model, then an optimal combination of maintenance concepts is requested. Prevention consists of: technical diagnostics, as a way of condition based or predictive maintenance; preventive repair and replacement, as a way of preventive maintenance. Specially defined technical feasibility and effectivness are tested for each concept. Cost analysis of the concept is a result of choosing a variant or a concept that is cheaper than corrective maintenance. If there is no possibility of applying preventive, corrective policy is applied: corrective repair, detective maintenance for hidden failures or redesign.

When we consider the application of preventive policy in the process of maintenance-concepts selection, first comes testing the possibilities of applying condition based maintenance. Research in Federal Aviation Agency, Navy, and in Swedish Navy [7,8] have shown that complex systems do not fail only according to a well-known bathtub curve, but according to six dominant failure patterns. The research is difficult to apply and costly, and as a consequence not every firm or organization is able to apply it on their own. Its results are used as a model that shows that random failures are leading in complex ship systems. If the intensity of failure is constant, the classical reliability literature says that by applying preventive maintenance nothing is gained [9]. Only testing the possibility of defining the point of potential failure and interval of predictive inspection is used. Naturally, this is applicable if the condition based maintenance procedure is technically feasible and effective, in other words, if there are situation for its setting up. If it is not technically feasible and effective, we continue testing possibilities of applying other concepts. Another reason for using diagnostic techniques, i.e. condition

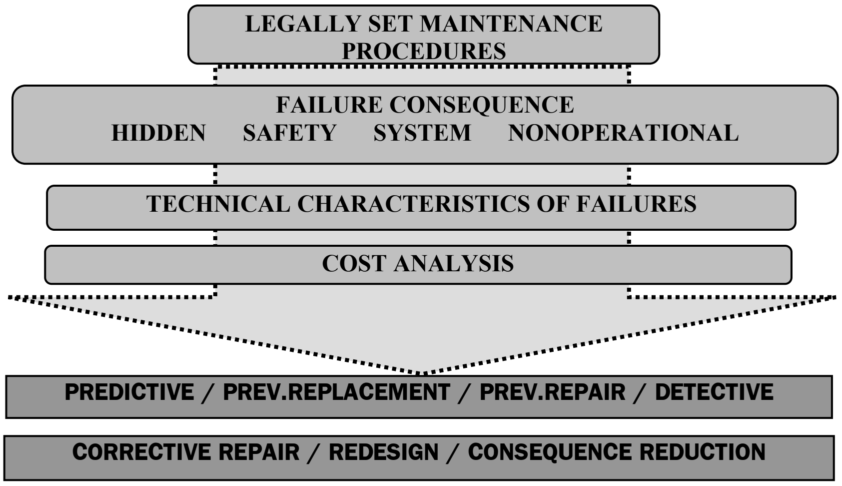

Figure 2. Maintenance revision results

based maintenance, is the techniques' being indestructible and non invasive. The operation of a system does not usually have to be stopped in order to monitor the condition. Finally, it has been proved that it is the best economical and technical choice [10]. Predictive maintenance opens the possibility of acquiring the maximum remaining useful life of equipment using preventive policy. So it can be concluded that, at current technological level, if there are conditions for its setting up, condition based maintenance is the best choice that satisfies the safety and economy criteria.

The possibility of prevention policy lies in the preventive replacement or preventive repair if the observed part of the system entered the period of frequent failures. Same as with predictive maintenance, precise criteria of technical feasibility and effectiveness are defined.

In terms of equipment that has no direct or important effect on safety or operation accomplishment, it can be repair when it fails. The possibility of accepting the risk of equipment failure is a crucial precondition for suggesting corrective maintenance. In case of hidden failure detective maintenance is applied. Detective maintenance is mostly applied to protection devices that fail without giving any signals of their impending failure.

Redesign or modification is the last alternative. When there are no reliable data on failures and when possible dangerous consequences cannot be tolerated, the change of design or process functioning is recommended. It is quite logical that this maintenance procedure is the last one on the list for it is rarely applied because of its big price.

In the case of corrective maintenance, i.e. accepting a failure risk, failure- consequences reduction procedures have to be worked out. That means repair in due time according to developed technology and stock of spare parts.

4. EXPECTED SAVINGS

At the level of maintenance concepts, costs can be lowered as follows:

1. By selecting maintenance concepts it should be defined for which failure modes current maintenance is useless. Preventive maintenance should be applied only to the systems that started to wear out, age, degrade, etc. E.g. according to literature [11] in industrial sector, 40-60% of preventive procedures are useless.
2. If some of the maintenance procedures overlap, the redundant ones should be eliminated.
3. Some procedures can be applied too often. The cycle of applying those procedures should be prolonged, if there is a reason for doing that. By applying condition based maintenance, where possible, the maximum degree of utilization the useful remaining life of the equipment is accomplished.
4. It is possible to determine lack of maintenance. It particularly affects protection systems and elements, and for that reason a special concept, detective maintenance, has been introduced. Detective maintenance should be applied to redundancy systems and protection system.
5. It is possible to determine if there are some failures that could have been prevented.

If we analyze the suggested procedure of revising the current maintenance program, we can notice that it is only a systematic analysis for the purpose of making certain presumptions on it's optimizing by applying a maintenance-concepts selection algorithm.

5. A SAMPLE OF PREVIOUS MAINTENANCE REVISION

As a sample of a previous maintenance revision, there will be presented another pilot project for a naval fire-control system - FCS, on a missile gunboat - 401 type. It is a very complex system for which 16 basic system functions can be defined at the high level of a system. It has a high level of maintainability. It consists of 85 typically electronic cabinets which are maintained by replacing the plates and modules, and consequently repairing the module at the Naval Repair Facility.Localizing defects is easier with the installed system for monitoring operation efficiency (*BITE*) and the program for testing functional competence (*FC* program).

According to producer's documentation, maintenance concepts are divided into corrective and preventive maintenance. Analysing the documentation, consulting some maintenance experts and system operators, 241 corrective maintenance procedures have been identified. In terms of preventive maintenance, according to the documentation, preventive repairs, replacements or inspections have been identified for a period of a six-year-overhaul. So doing a special analysis 70 maintenance procedures have been defined. After that a reverse FMEA analysis and maintenance-concepts selection were done. The results are shown in Figure 3.

Concept	Old program	New program
Corrective	241	218
Preventive	143	40
Predictive	0	35
Detective	0	3
Redesign	-	2

Figure 3. Maintenance revision results

It is suggested that the general repairs should not be obligatory, since it has been confirmed that a servo system of antenna and steering gear is sensitive to unnecessary dismantling. A technical diagnostics of system has been suggested as a replacement: vibration analysis, oil leakage inspection, oil analysis, parametric-performance analysis according to a special program and thermography. Servo system of steering gear and antenna will be dismantled when technical diagnostics results show it as necessary.

It is concluded that technically the new maintenance program has been improved with respect to the old one. If it is applied properly, higher reliability and system readiness can be expected. Comparison of the previous and the new program maintenance expenses is done according to the standards of the NRF. When compared to the previous program the new one is confirmed to be 22% cheaper.

It is very interesting to compare the pattern of the costs during the overhaul cycle. In six-year-period the costs per inspection are somewhat increased, but those relatively small costs are arranged continuously. The previous program has cheaper inspections, but at the time of the overhaul a big price is paid. Consequently the new program is more convenient than the previous one.

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