Journal of Machine Construction and Maintenance
PROBLEMY EKSPLOATACJI
QUARTERLY ISSN 1232-9312 4/2017 (107)
p. 99–105

Marcin KOŁODZIEJSKI
Prosafe Offshore,
Greenwell Road,
East Tullos Industrial Estate Aberdeen AB12 3AX, United Kingdom

Zbigniew MATUSZAK
Faculty of Marine Engineering,
Maritime University of Szczecin, Szczecin, Poland
z.matuszak@am.szczecin.pl

RELIABILITY CENTRED MAINTENANCE (*RCM*) – BASICS OF IMPLEMENTATION AND GENERAL CHARACTERISTICS

Key words: operating, maintenance, maintenance process, reliability.

Abstract: In the article, the literature notions of maintenance and exploitation have been characterized. The process of incorporating *RCM* into the industry from the seventies has been presented. The major features of reliability centred maintenance (*RCM*) as well as maintenance activities complying with *RCM* assigned to different categories have been characterized. In the final part of the paper, it has been highlighted that *RCM* is the only maintenance method which includes all the maintenance variants: planned servicing caused with the diagnosed technical condition, planned components' replacement, searching for hidden faults, and one-off modifications, such as redesigning of some components, changes of operating procedures, and additional trainings or other activities going beyond the scope of service works.

Reliability Centred Maintenance (*RCM*) – podstawy wprowadzania i ogólna charakterystyka

Słowa kluczowe: obsługiwanie, utrzymanie ruchu, proces obsługiwania, niezawodność.

Streszczenie: Scharakteryzowano literaturowe pojęcia obsługiwania i eksploatacji. Przedstawiono historię powstania obsługiwania zarządzanego niezawodnością (*RCM*). Przedstawiono proces wprowadzania *RCM* w przemyśle od lat siedemdziesiątych. Scharakteryzowano podstawowe cechy obsługiwania zarządzanego niezawodnością (*RCM*) oraz zgodne z metodologią *RCM* czynności obsługowe przypisane do różnych kategorii. W końcowej części podkreślono, że *RCM* jako jedyna z metod utrzymania ruchu uwzględnia wszystkie warianty obsługi: wywołane diagnozowanym stanem technicznym urządzenia, planowe konserwacje, planowe wymiany komponentów, poszukiwanie uszkodzeń ukrytych oraz jednorazowe modyfikacje takie jak przeprojektowanie komponentów, zmiany procedur operacyjnych, dodatkowe szkolenia lub inne działania wybiegające poza zakres prac serwisowych.

Introduction

Faultless operation of technical devices realized in every community, regardless of how technically (technologically) advanced and civilised it is, is the basics of the economic activity involving technical facilities.

Maintaining vehicles and machines is a technical discipline of theoretical and practical knowledge, including methods, means, and systems of functional and task-oriented suitability condition control in order to use them rationally and effectively according to their destination in certain conditions and time, at certain restrictions and interference [11]. According to [9], exploitation is a broad range of all the events, phenomena and processes taking place in a given vehicle or machine from the completion of its production process until its disposal.

Another definition of exploitation is provided by [5] who describes it as utilizing and operating the devices. In the works [12–14], the notion "operating" has been defined as the operating process. According to [6–8], operating is a collection of proactive-preventative actions, whose main role is to maintain functional properties as well as a collection of corrective actions, whose main goal is to recreate the functional properties of the technical objects. [9, 10] define operating as a range of processes performed in order to keep technical objects in a good functional and task-oriented state. Functional properties can be maintained and recreated, so they can be controlled by means of rationally organized and realized operating processes [11].

During utilizing the object, its condition changes, so the dates of operating the object should be variable, adjusted to the actual, changing technical condition of the object. The operating process is performed according to the needs, meaning according to the current object condition and the intensity of changes of this condition [11].

Managing maintenance has been a subject of evolutionary transformations that stemmed from still increasing number of systems underlying maintenance activities, the growing complexity of these systems, new techniques supporting maintenance, and organizational changes. Exploitation strategies underlined changes also due to the changing expectations towards maintenance engineers. It was related to the growing awareness of connections between the breakdowns of the devices and safety of work, environment protection, and the relationships between maintenance and the quality of the final product. The increasing emphasis on the high accessibility of the devices and the minimising of the costs has had higher and higher influence on maintenance. These changes showed the restrictions of the exploitation systems used and the need to search for brand new systems of maintenance management.

The need for improving new systems of maintenance management as well as developing the present systems in a way that their usage in different branches of industry is possible has led to the appearance of the logical discipline of maintenance, meaning *Reliability Centred Maintenance (RCM).*

1. Appearance of Reliability Centred Maintenance (*RCM*)

RCM stems from the American aviation industry in the 60s of the last century with the fluent transformation from the planning-prevention operating system (according to the resource/exploitation potential) to the modern, proactive maintenance systems. Traditional operating programmes, according to the resource, were based on the principle that, for every element of the complex technical system, one can tell a right moment at which the renovating and ensuring the proper work to the device should be performed [15, 21].

However, during the next years of research and practical observations, it has been observed that, regardless of the frequency of operating, many types of breakdowns cannot be avoided throughout the operation compliant with the planning-preventive method. As a result, in the aviation industry, a new trend of designing devices in a way to limit the effects of prospective breakdowns has developed. Critical elements have multiplied, multiengine aircraft have been used, etc. These improvements have decreased the relation between the safety of the aircraft and the reliability of its particular elements, but total elimination of this relation has not been possible. The influence of the maintenance model on the reliability of the aircraft systems was still discussed.

In the 50s, the number of passenger planes in the US reached the level allowing for collecting statistical data that were used for analysing the relation mentioned above. The costs of maintenance run according to the resource have reached such a level that it justifies investing into the research on the effectiveness of this operation model. *The Federal Aviation Agency* carried out a study of operation effectiveness according to the exploitation potential. In the study, it was pointed out that decreasing the intensity of breakdowns of the aircraft engines via changing the type or the frequency of operating activities according to the resource is impossible. In order to continue the research in the 60s, a working party including the representatives of *FAA* and the aviation industry was created. The task of the group was to analyse the opportunities and restrictions of the planning-preventative method used in the maintenance. The first conclusion coming from the works of the group was that, in many cases, there is no connection whatsoever between the frequency of operation according to the resource and the reliability of the devices. This statement undermined the basic assumption of the traditional maintenance systems that shortening the time between the operating activities for the device was supposed to be the key condition decreasing the intensity of the damages. The working group introduced a brand new system of operating driving units of the aircraft. The results of observations showed that the operation according to the resource has a minor impact on the reliability of the complex technical systems and that there are devices for which an effective operation according to the resource cannot be specified [21].

The next stage in the development of maintenance systems was collecting the findings resulting from the observation of aviation systems ensuring the high reliability of the devices and, on this basis, creating a new approach to maintenance. The first works in this field were started in 1965, and they resulted in the document published in June, 1967: *Instruction of maintenance programme estimation and development.* Moreover, then the special group was brought together and their task was to create maintenance system for the new *Boeing 747* [1, 18, 30]. Since the plane was more complex than its older model 707, it was thought that also the programme must be more sophisticated. Group members were aware of the fact that the traditional plane exploitation based on the operation according to the exploitation potential will be non-economic. American companies *Boeing* and *United Airlines* decided to work together to create brand new maintenance programme for the B-747. The group was led by Tom Matteson, who was the technical director and vice president of *United Airlines.* The works of this group resulted in publishing the document named *MSG-1* (*Maintenance Steering Group*) [4, 18, 21, 25, 28]. *MSG-1* became the pillar for further work on new maintenance systems in the aviation industry and it was a foundation for *RCM*.

Creating maintenance programme for *Boeing 747* turned out to be successful. It was later improved, and two years later, the *MSG-2* system was announced to be introduced. *MSG-2* was used in developing maintenance systems for the next implemented aircraft: *Lockhead 1011* and *Douglas DC10*. Then *MSG-2* was introduced in military aircrafts, starting from the *Lockhead S-3*, then the P-3, and the *MacDonnell F4J*. Within the next years, *RCM* was utilized by the European companies of the aviation industry (*Airbus A-300* and *Concorde,* among others) [28].

The purpose of both *MSG-1* and *MSG-2* was to establish a maintenance system that would ensure safety and reliability on the maximum level for a given device/ system and achieving this at the minimum possible costs. Traditional maintenance systems for the aircraft *Douglas DC8* required maintenance according to the resource for 339 different components of the plane. After introducing *MSG-2* for more technically advanced DC10, the number of maintenance activities according to the resource equalled only 8 [25]. Another example of *MSG* effectiveness is the comparison of man-hours for *Boeing 747* underlying overhauls and repairs according to the *MSG* assumptions: During first 20 000 hours of exploitation, the number of man-hours equalled 60 000. For the smaller and less complex plane, *Douglas DC8,* underlying traditional maintenance activities, the man-hours for the similar exploitation time equalled 4 million [18, 25, 28]. The reduction of maintenance costs as a result of introducing *MSG* was tremendous, and it did not entail decreasing the plane's reliability. Better understanding of the damage occurrence process in the complex technical systems led to decreasing the number of damages and increasing the plane's reliability. It has been achieved thanks to directing proactive actions into preventing certain damages (as opposed to the periodical renewals of the whole systems).

MSG-1 and *MSG-2* have dominated maintenance programmes in the aviation industry; however, implementing them in other branches of industry was limited, because the *MSG* perspective itself (covering only aviation industry) was limited. Some subjects needed improvement, e.g., the decision making process, instead of focusing on the analysis of damage consequences and its impact on the safety and reliability of the system, concentrated on estimation of the proposed maintenance activities. The topics of the estimation of time for necessary repair activities and the role of the hidden damages have not been sufficiently worked out. The issue of collecting and editing information during maintenance activities and then utilizing this information to the continuous improvement of the maintenance system was neglected.

The need for improving MSG and simultaneously developing the system in a way that it is possible to use it in other branches of industry resulted in the new logical discipline of maintenance coming to life – *Reliability Centred Maintenance*. In the year 1978, *Nowlan* and *Heap* published the report entitled *Reliability Centred Maintenance*, which became the basis for the *RCM* programme in other branches of industry [1, 18, 21, 23, 28].

2. Introduction of *RCM*

In the year 1978, *RCM* was first introduced on a vessel of the US Navy – *USS Roark*. In the next years, *RCM* became the dominant maintenance system on the next vessels of the US Navy. In the 1980s, *ATA* (*Air Transport Association of America)* introduced a new developed maintenance system – *MSG-3* [17]. *MSG-3* was based on the report of *Nowlan* and *Heap*, taking the assumptions of *MSG-1* and *MSG-2* into account. The document became the foundation for creating maintenance programmes for the vast majority of the contemporary passenger planes. *MSG-3* underlined further improvements, and its four consecutive versions were published in the years 1983, 1993, 2001, and 2002. The system has been incorporated by the majority of airlines around the world and became the base for establishing maintenance systems for the modern planes, such as the Boeing 777 and Airbus 330/340. The civil aviation industry introduced revolutionary changes in the approach to the maintenance issues that significantly decreased the costs and increased the reliability of aircraft. In their next years, the report of *Nowlan* and *Heap* became the centre of attention of the Ministry of Defence of the United States. Since the middle of the 1980s, the maintenance programmes worked out on the basis of the *RCM* method were developed, first in the United States Army, then in the Air Force and Navy. *RCM* standards used by the US Department of Defence were published in the year 1984 in the document *Military Standards and Military Specifications* [20].

RCM was found in the centre of interests of services responsible for maintenance in the nuclear power stations. *US Electric Power Research Institute* decided to introduce a pilot *RCM* in two nuclear power stations [28]. The pilot programme turned out to be successful, and since 1987, *RCM* became an official maintenance system in the US nuclear power stations. In the next years, until 1994, the *RCM* method became a basis to establish exploitation programmes for 50 power units with nuclear reactors. At the same time, the *RCM* process was used at the works on maintenance programmes in the conventional power plants, power distribution systems, and in the industry of crude oil exploration.

In the same period, *RCM* was introduced in the coal and diamond mines in the RSA, and then in different branches of industry, first in the UK, and then in other western European countries. The works were performed by the group led by *Johna Moubray* with the cooperation with *Stanley Nowlan* [18]. In the 1990s, the programme was used in French nuclear power plants in order to prolong their lifetime.

In the second half of the 1980s, natural environment protection and safety started to play a more significant role in production systems (the influence of production processes on the environment). In the first years of *RCM* development, it focused on preventing functional damages of the devices. Then environment protection and safety were considered secondary. At the beginning of the 1990s, *RCM* evolved in the direction of ensuring environment protection and work safety as two main tasks of the maintenance strategy. It resulted in the next version of the programme known under *RCM 2* [18]. This programme was published in September, 1990. In 1996, NASA introduced *RCM 2* as an official maintenance system in their dependent facilities [24]. *RCM* gained popularity in different branches of industry, and it was also introduced in maintenance systems of the land transport, e.g., in the railway industry [22, 29]. In the 1990s, more and more organizations started to employ the name *RCM* for defining the maintenance systems they use. Some of them, for instance, *The British Royal Navy* with their system *NES45* [3], or *US Naval Command* (standard *MIL-STD-2173* [20]), based their systems on the assumptions presented in the report [21]. At the same time, a large number of maintenance programmes came to life. They used the name *RCM*; however, they did not have much in common with *RCM*, *MSG*, or the report [21]. This caused the devaluation of the notion *RCM*. At that time, there was a need for unifying the standards for maintenance systems referring to the assumptions of *RCM* and *MSG*. In the year 1996, *SAE* (*Society of Automotive Engineers*) began works on describing a *RCM* standard. One year later, the works were completed, and *SAE* published a standard [1, 26]. In the year 2002, *SAE* published an improved version of the standard *RCM SAE JA-1012* [27]. The *RCM* system was also used for vessels and marine extractive installations. In the year 2004, *RCM* was approved by *Lloyds Register of Shipping* [16].

3. The general characteristics of *RCM*

Maintenance, or sustaining machine operation, is, according to [6, 7], a collection of proactive-preventative activities, whose purpose is to recreate usage properties of technical objects. In compliance with [6, 7] maintenance is oriented on the technical object. On the other hand, *RCM* is a collection of activities which are taken up in order to ensure the reliability of performing a particular function by the object [15, 18, 19, 23]. The abovementioned definition presents the basic characteristic distinguishing *RCM* from other maintenance systems – focusing on the function performed by the technical object and not on the object itself. Highlighting the role of function, which is what the object produces or provides, became the basics of the new definition of maintenance. So what follows is that a functional damage becomes one of the basic notions of *RCM,* and it is defined as a condition of the object's damage in which the object does not perform its function.

One of the conclusions stemming from the works that resulted in establishing *MSG 1* standard, which was a precursor of *RCM,* was the following statement [21]: *The necessity of performing maintenance activities stems from degradation of equipment reliability which proceeds along with time of their usage. The main task of maintenance is to keep the reliability during exploitation or restoring their original reliability. Maintenance needs to be economically justified.*

There are three *RCM* hypotheses discussed in [30] coming from the aforementioned statement:

– The necessity of running the maintenance activities results from the degradation of the equipment condition with time of its usage. It is illegitimate to use the resources of maintenance for the maintenance of objects whose reliability does not undergo degradation during exploitation. Deterioration of the equipment condition with time of its usage is defined as decreasing of its resistance to failure (probability of functioning) caused with decreasing the ability of the object to keep its reliability.

– The task of *RCM* is to keep or restore the maximum level of object's inherent design reliability. *RCM* eliminates all the operating procedures which do not have an impact on the level of resistance to failure of the devices.
– Maintenance has to be economically justified. There is a trend to resign from the maintenance activities preventing the damage if their costs are higher than the economic consequences of the damage occurring. It does not refer to the damages which have consequences either to safety or to the natural environment.

These hypotheses refer to all types of maintenance activities stemming from the *RCM* strategy. Each technical object undergoes degradation with the time of its usage, but this degradation does not always cause the deterioration of the object's resistance to failure. From the *RCM* perspective, the key factor is the speed of object's degradation in exploitation time. Some objects undergo degradation so slowly that it does not influence their resistance to failure. Maintenance activities are justified only when their result is restoring the original reliability (resistance to failure) of the object. Every technical object possess a maximum inherent design reliability which arises from its construction, the way it is made, exploitative conditions, etc. Maintenance activities may restore the reliability of the object only to this maximum level. If the reliability level, characteristic for the object, is too low (for instance, due to the faulty construction or production of the object), the maintenance will not improve this level, then the modification of the object is necessary, for example, a construction change.

According to *RCM* methodology, maintenance activities may be assigned to four categories [1, 18, 25, 28, 30]:
– **Corrective maintenance**: It is maintenance done having recognized the unreliability, aimed at restoring such condition of the object so that it can perform its required functions. Corrective maintenance cannot be planned, since the time of damage occurrence is impossible to predict. *RCM* specifies only how fast the reliability has to be restored to the object. Unplanned renewal or exchange, adjustment, and others belong to this category of maintenance activities.
– **Preventive maintenance**: It is maintenance done in certain intervals or according to the agreed criteria which aims at decreasing the probability of the functional damage of the object. Diagnostic tests and inspections (for the evident and hidden functions), planned adjustments and renewals or exchanges, as well as all routine maintenance activities fall under this category. For the elements revealing the symptoms of usage due to getting old, a preventive maintenance is performed according to the strategy with respect to the resource as well as according to their condition.
– **Modifications of the object**: This is maintenance done in order to eliminate the reasons for the functional damage through redesigning and alternatively reconstruction of the object. Modifications are also done when increasing maximum inherent design reliability is necessary. The maintenance is planned (once).
– **No maintenance activities**.

It is not possible to fully eliminate breakdowns, because they are mistakes in the process of the realization of a certain function by the object. In order to limit the number of these mistakes to the accepted level or to minimize their results, *RCM* strategy is oriented on two types of actions: the limitation of the number of breakdowns and risk management.

Defining the functions of the objects and connecting them to the criteria of effectiveness enables the formulation of tasks of maintenance activities with respect to the functions performed by a given object. Stating the functional damages allows for direct defining of the damages according to *RCM* method assumptions. Pointing out failure modes gives us the possibility to learn the conditions that cause functional damages. The first of four stages of the RCM process are carried out through the analysis of types and results of failure modes (*Failure Modes and Effect Analysis*) [1, 18, 24, 25, 28, 30] and the other two are carried out through the decision algorithm of *RCM*.

Summary

RCM has become one of the most often used exploitation strategies in the industry of Western Europe and the USA. As it was created, *RCM* became a methodology that integrated a number of techniques and allowed meeting the expectations of the modern maintenance systems. *RCM* ensures required reliability of the process (or device) by forcing the use of the most technically and economically effective techniques [23]. *RCM*, as the only one out of all maintenance methods, includes all variants of maintenance, i.e. those caused with the diagnosed technical condition of the device, planned maintenances, planned exchanges of the components, seeking for the hidden damages, as well as one-off modifications, such as redesigning of components, changes of operational procedures, additional trainings, or other activities excluded from the scope of service works. One of the original findings coming from the *RCM* method is a deliberate negligence of performing the maintenance and thus allowing for the occurrence of the damage [25]. According to [2, 25] *RCM* comes down to identification, planning, preventive realizations, and corrective maintenance activities for ensuring a proper level of a device's reliability, on the condition that the usage of the maintenance resources is minimal and safety of devices and personnel, as well as the requirements for the environment protection, are observed. *RCM* combines proactive preventive maintenance activities referring to the critical devices as well as corrective maintenance done for non-critical devices that are exploited until the failure occurs. The proactive measures do not fully eliminate the occurrence of breakdowns, so another category of dealing with the current repairs is corrective maintenance performed in the case of occurring damages of the critical devices. Proactive maintenance actions are there to protect the system as a whole from the consequences of the breakdown at the level of components, so they prevent functional damage. Proactive maintenance actions are supposed to secure the device from the possible damage, while corrective actions are employed after the damage has occurred.

Having analysed *RCM,* the implementation of the analyses results takes place. It assumes the introduction of maintenance activities stated in the *RCM* analysis to the computer system – *CMMS – Computerised Maintenance Management System*. It also states carrying out the comparative analysis of the mentioned maintenance activities stated by the previous exploitation strategy. Currently, one may notice the trend to integrate RCM systems as a part of general exploitation planning system *CMMS*, which leads to more effective management of the company's resources and allows for the direct implementation of the findings and RCM suggestions as well as monitoring their effects with the use of the system [23]. *RCM* technology should be introduced as a computer system, including a well-developed data base. This system may be autonomous, yet compatible and cooperating with the integrated management IT system, and especially its module of maintenance [2].

From its definition *RCM* is a dynamic exploitation strategy, *RCM* process undergoes continuous changes and improvements. In order to monitor the effectiveness of the analyses and described maintenance activities, it is necessary to register all failure modes, in other words – the reasons for breakdowns, which took place regardless of having introduced proactive actions. It is aimed at verifying whether each failure mode that has been reported was identified during *RCM* analysis. If it turns out that it was omitted, the correction of *RCM* analysis is necessary: New failure modes have to be added to it and, in some cases, maintenance activities preventing it from happening again have to be stated.

Acknowledgements

This research outcome has been achieved under the research project *Badanie efektywności energetycznej siłowni okrętowej w aspekcie niezawodnej i bezpiecznej eksploatacji* **No.** 5/S/IESO/14 **financed from a subsidy of the Ministry of Science and Higher Education for statutory activities.**

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