RCM: FACILITY MAINTENANCE FACING NEW CHALLENGES

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Abstract

The observed in recent times cost-oriented approach based on reliability of technical systems operations enforces engineering staff to implement modern attitude in facility maintenance oriented towards preventive inspections as well as continual supervision over the technical condition of machines and equipment. An example of such approach can be a facility management system established by American aviation and arms industry oriented on RCM (Reliability Centered Maintenance). RCM method is of particular importance in technical systems connected with public safety where even the slightest human error or an unexpected failure leads to important consequences. The concept based on RCM makes it possible to be increasingly applied in automotive and electronic industry as well as in specialized branches such as Facility Management.

Keywords: Maintenance, RCM, Facility Management, reliability

1. INTRODUCTION

Using modern technological solutions is very important in production processes optimization, as well as in ensuring continuity of production process of industrial organizations. Modern technologies enable obtaining much more end products with assumed properties, consistent with utility properties declared by manufacturer, while reducing unit costs.

It is critical that efforts are taken by businesses, as early as design phase, to ensure that the selection of production machinery and equipment is optimal not only upon purchase but also during ongoing maintenance and servicing. Selection of machinery and equipment has to account for types and properties of the production line, facility, and components of each machine, and their relations to downstream elements of the process line. The new approach to optimization of processes accounts for selection and maintenance of machine fleet that are consistent with demand and possibility of selling final products. Such an approach eliminates excessive shutdowns, need for buffers and production stock [1].

Frequency of reliability of technical system maintenance, observed in recent years, makes maintenance services provide readiness and availability of machinery, at all cost. The trend of outsourcing maintenance services leads to inclusion in Service Agreements of the requirement to ensure maximum reliability and availability of the machine fleet. In many cases contractual restrictions and competition require substituting traditional maintenance of operations, based on traditional inspection intervals, ongoing remedying of failures and defects, with modern management and engineering methods, such as RCM (Reliability Centered Maintenance) or TPM (Total Productive Maintenance).

2. TECHNICAL CONDITION OF FACILITIES, MACHINES AND COMPONENTS

Technical condition of the specific facility, appliance or machine changes during operation with time. Operation maintenance services may to a great, but limited extent, slow down physical wear by servicing operations, preventive maintenance, scheduled overhauls and conservations.

Changes in technical condition of the facility may be divided as follows [2]:

- critical - posing risk to human health and the environment;

- borderline - posing risk to the efficiency of facility operations;
- admissible - posing risk to rational utilization of the facility.

In order to present the technical condition of machinery and equipment correctly, reference to the standard PN-82/N-04001 is required, which contains the definition of use. Acc. to PN-82/N-04001 "use" is defined as: all purposeful organizational, engineering and economical actions carried out by people with mechanical object and mutual relations between them, from the moment of accepting for use to the moment of disposal.

When dealing with operation maintenance we also have to define reliability. Acc. to the standard PN 80/N-04000 reliability is defined as: all properties of the facility which describe its ability to implement specific functions, under specific circumstances and in specific time.

Extension of machine ability is however limited from the viewpoint of maintaining its technical performance, cost-effectiveness of overhaul, and state of the art, substituting existing machinery equipment with newer and better units. Technical condition of the facility is affected by such factors as loss in cohesion, material fatigue, plastic deformations, thermal impact, corrosion, aggressive working environment. The process of wear with time is shown in **Figure 1**.

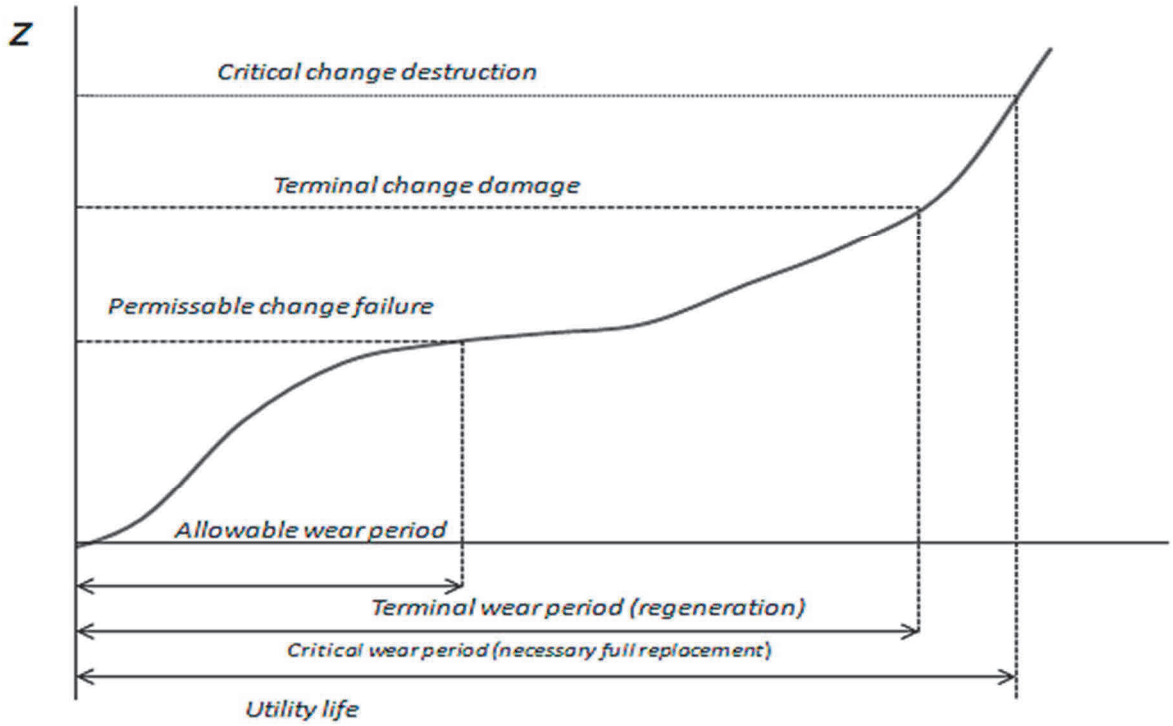

Figure 1 Changes in the wear of technical facility component in time [2]

Solving operational issues consists in seeking a general pattern of behaviour corresponding with specific group of issues. Generalization of issue enables building a model for given class of operational phenomena [3]. Using the mathematic model we may generalize and develop suitable principles and operating instructions for given appliance. Mathematic modelling of operations enables to determine, with high accuracy, the probability of failure or defect in given appliance and to respond in advance, in order to avoid serious consequences.

The fundamental value for reliability is probability of correct operation of given facility in given time [13], expressed as:

$$R(t) = P\{t \leq T\} \tag{1}$$

where: T - lifecycle.

The above equation provides the method of determining probability that the engineering facility commencing operations at the moment t=0 shall be working reliably until time $t \leq T$.

Following indicators may be included among fundamental reliability metrics:

– reliability of engineering facility (exponential quantification):

$$R(t) = e^{-\lambda t} \tag{2}$$

where: λ - intensity of damage,

– engineering reliability factor [14]:

$$K_g(t) = 1 - F(t) + \int_o^\tau [1 - F(t-x)] \cdot \mu(x) dx \tag{3}$$

where: *F(t)* - cumulative distribution function for MTBF

$\mu(t)$ - renovation density of the facility

It should be noted that presently engineering and technology are closely intertwined with economy, and they need to respond to market behaviour flexibly. Optimization of facility operation by using in its construction materials that are more resistant to preset load and to operating conditions, leads to increase in the initial price, which in the context of ever fiercer competition may lead to fluctuations in demand for given product. Adopted methods to improvement product reliability, such as RCM enable increase in facility lifecycle, and reliability throughout the lifecycle.

3. RELIABILITY CENTERED MAINTENANCE (RCM)

RCM methodology originates from 1960s and US civil aviations sector. When implementing the passenger airliner Boeing 747, the manufacturer was obligated to develop new servicing program, straying from traditional non-economic periodic inspections. The term RCM (*Reliability Centered Maintenance)* was first published in 1978, in the report on airplane reliability by engineers working for Boeing. Soon, RCM methodology was adopted by other industry sectors, such as nuclear energy, mining, oil, chemical and pharmaceutical sectors. RCM is the procedure that consists in determining necessary actions for maintenance of machinery or equipment in good working order, accounting for their working conditions [4]. RCM is considered as the method that enables selection of the best reliability management model for facilities and operation of engineering systems [5]. RCM methodology is even more important in cases where maintenance of safety critical equipment is concerned.

Due to the fact that costs of repair after failure are 1.5 to 2.0 times the costs of preventive inspections [6], adequate monitoring of facility technical conditions is critical for reliability. Each shutdown generates costs related to pause in the production process, conventional penalties for failure to keep the deadline, and possible loss of customers to competition. Therefore, manufacturers of machinery and equipment set the requirement, at the stage of design, that the risk of failure and shutdown is minimized.

Reliability Centered Maintenance (RCM) is an analytical process to determine suitable failure management program, including requirements concerning periodic inspections and other actions to ensure safe operation of machinery and equipment and their cost-effectiveness. Implementation of RCM methodology covers much broader scope than just RCM analysis.

RCM analyzes various types of failures in given system and takes steps to adequately manage current maintenance. Using the logic of RCM methodology, operations services may define the best strategy, especially for emergency operation mode.

4. IMPLEMENTING RCM METHODOLOGY

Implementation of RCM methodology covers much broader scope than RCM analysis alone. Procedure in case of implementing RCM methodology for given technical facility is shown in **Figure 2.**

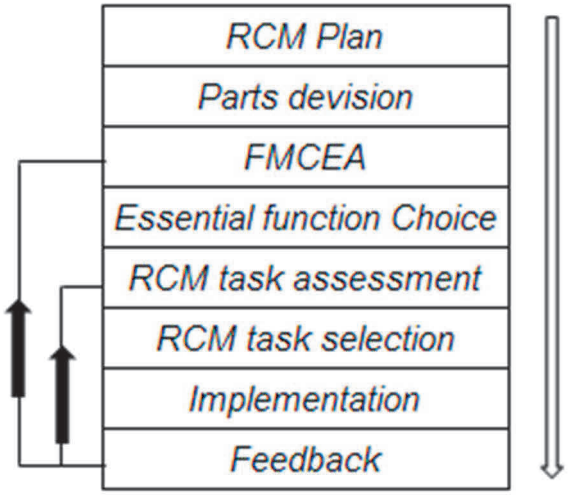

Figure 2 Implementation of RCM approach [10]

The essence of RCM procedure is establishing adequate operation maintenance schedule, where elimination of unnecessary tasks leads to effective management of reliability centered inspection works.

RCM analysis enables determination whether established preventive measures are effective, and whether other, more effective, measures may be adopted to eliminate the probability of failure. RCM methodology assumes that [8]:

- the purpose of current maintenance is maintaining the functionality of component. RCM aims at ensuring the required level of operation of the whole system or system components.
- reliability level as initially assumed during design may cannot be exceeded. RCM may ensure original reliability for the whole lifecycle of the operated facility.
- for RCM safety is the priority. When safety principles are not critical, the priority is given to economic factors.
- reliability is the base for decision-making process. Analysis of the failed facility is necessary to determine the effectiveness of preventive measures. RCM defines the probability of failure and defect, and not only failure rate, as in traditional methods.
- the concept behind RCM methodology is not only prevention of possible damages, but first and foremost extension of system functionality.

Functional diagram of RCM method, considering individual steps, is shown in **Figure 3**.

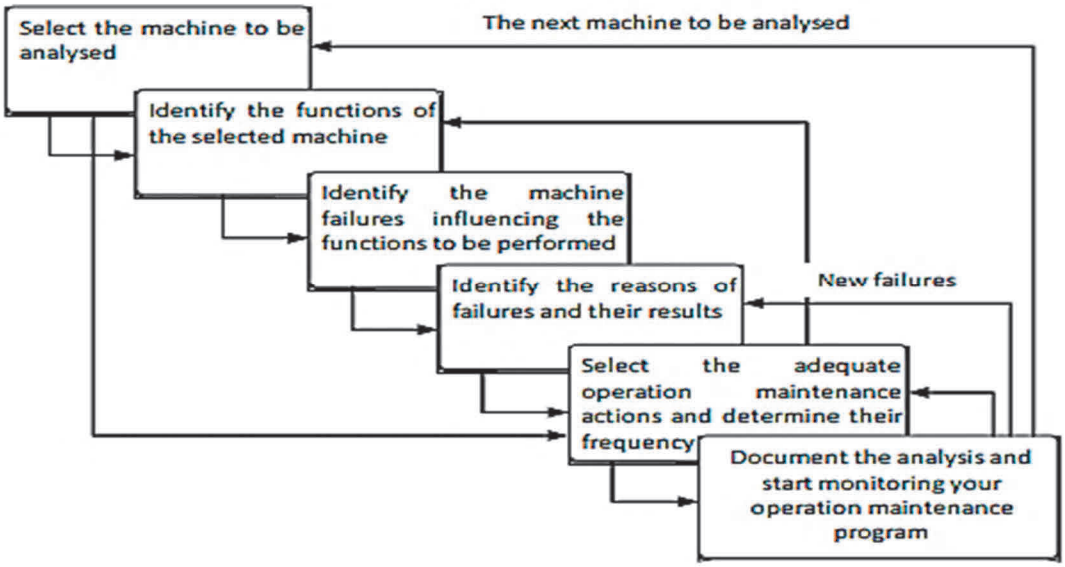

Figure 3 Procedure in RCM method [7]

5. THE ESSENCE OF RCM STANDARD

In 1998 the *Society of Automotive Engineers* presented, in the standard SAE JA-1011 *Evaluation Criteria for Reliability Centered Maintenance (RCM) Processes* presented guidelines for decision-making processes and servicing engineering facilities considering their reliability. The essence of RCM standard, included in SAE JA-1011, refers to so-called "seven questions":

1) Specification of resource functions. What are functions and related standards of utility requirements to the resource in current operating context?

Answering that question requires functional categorization of specific facility. Functional categorization is conducted by means of top-down method. Specific criteria to be met by given process are:

- defining operational context;
- defining regular and irregular functions of the facility;
- accurately defined value or function, e..g complete, full, maximum;
- implementation level should meet user requirements.

2) Functional damage. How specific facility may lose its ability to provide given function?

Answer to this question should include definition of emergency situations, deviations affecting operation of the appliance. Mortality may be partial and not causing complete shutdown of the facility. Damages include existing damages, future damages and probable damages, and damages considered in the operational process.

3) Determining the causes of damages. What causes damages?

When referring to the standard SAE JA-1011, potential causes of damages need to be detailed. The cause of damage should be determined on the level of its occurrence, and preventive measures should be presented.

4) What are the consequences of damage?

In case of not taking preventing measures, damage consequences should be detailed, their impact on the facility, surroundings, people and environment.

5) What are the consequences and the meaning of failure?

In case of key sectors, such as railways, aerospace, mining, nuclear energy, the consequences of damage to even the smallest machine or part may have catastrophic effects to the environment and public safety.

6) What preventive measures to take in order to foresee the probability of failure, neutralize or completely eliminate the risk?

- scheduled restoration tasks, consisting in carrying out periodic inspections based on equipment use factors (duration, motor-hours, kilometres, etc.);
- replacing given component before expiration of its maximum lifecycle, irrespective of wear or technical condition;
- preventive measures consisting in evaluation of technical condition by means of diagnostic surveys (laboratory analysis of engine oils, axial shift, errors in shape and position).

7) Other standard measures? What steps to take when no adequate preventive measures are selected?

- inspection aiming at checking the possibility of latent defects (Failure Finding Task);
- redesign - redesigning part of given facility in order for the part or the facility to meet safety assumptions concerning people and environment;
- permitting the damage, in the event that costs of preventive measures exceed costs and consequence of failure.

RCM methodology employs preventive maintenance (PM), control inspections and tests (PT&I), overhauls ad preservation techniques, in order to effectively increase the probability of given part or function working reliably throughout the assumed lifecycle, at minimum current maintenance costs. The main goal of RCM methodology is ensuring possible highest availability of given appliance/facility, at possible lowest costs of current maintenance. CRM methodology stresses that maintenance related decisions are based on technical requirements and economic aspects. As is the case with a number of technical processes, there are many types of procedures that enable achievement of the final outcome, which is the satisfactory reliability. RCM analysis may require specification of conditions of functional damages referring to specific damage modes, in order to improve the option of failure management.

6. RCM ANALYSIS

There are a few principles characterizing RCM methodology. First, it needs to be stressed that RCM methodology is the functionality-oriented one [11]. RCM aims to maintain functionality of the whole system, not only functionalities of individual components. In addition, RCM defines ranks of system functions and gives them precedence over component functions of the facility.

Fundamental step in development of RCM analysis is determination of major functional aspects of the system and its components. The example: determination of electric motor failure in water pump using RCM methodology sheet, is shown in **Table 1**.

Major factors in RCM methodology are [12]:

Reliability - RCM stresses mostly the initial reliability, by analyzing data from current maintenance. Improvement in reliability is achieved by ongoing monitoring and adjustment of the existing maintenance program, improving communication between technical services, production planners and designers. Improvement in communication results in providing feedback by operations maintenance services to manufacturers and designers of specific assembly of the appliance or unit, improving its reliability at the stage of design.

Table 1 Electric motor functional failure determination sheet [12]

Function: To provide sufficient power to pump 300 gpm chilled water			
Component	Functional Failure	Failure Mode	Source of Failure
Stator	Motor will not turn	Insulation Failure	Insulation contamination Excessive current Voltage spike Phase imbalance Excessive temperature
		Open winding	
Bearings	Motor will not turn	Burnt rotor	Insulation contamination Excessive current Excessive temperature Imbalance
	Wrong speed	Excessive vibration	
Bearing	Motor will not turn	Bearing sized	Fatigue Improper lubrication Imbalance Electrical pitting Contamination Excessive Thrust Excessive temperature
Motor controller	Motor will not turn	Bearing sized	Mainline contact failure Control circuit failure Loss of electric al Power Cabling Failure
	Wrong speed	VFD malfunction	
Fuse	Motor will not turn	Device Burnet out	Excessive current, Excessive torque Poor connection
Shaft / Coupling	Pomp will not turn	Shaft / coupling sheared	Fatigue Misalignment Excessive torque

Costs - in spite that original outlays on process tooling and personnel training increase costs, temporarily, with time costs are reduced, along with the number and frequency of failures. Preventive maintenance is replaced by monitoring of machinery and equipment technical conditions. Reduction in costs due to adoption of RCM methodology is shown in **Figure 4**.

Planning - implementation of control tests and inspections reduces unjustified costs of current maintenance and shutdown of machinery and equipment.

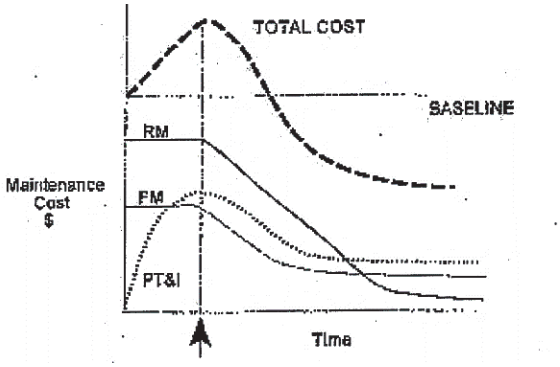

Figure 4 Reduction in current maintenance costs due to adoption of RCM methodology [12]

Effectiveness and efficiency - The first rule of RCM is orientation on safety. The second consideration important for RCM program success is cost-effectiveness. Cost-effectiveness includes functionality and purpose of given unit, and then matches cost level with operating priorities. Cost flexibility of RCM referring to

maintenance ensures taking adequate type of measure precisely when it's necessary. In the event of maintaining the above assumed costs, servicing is stopped and RCM program no longer applies. RCM promotes multi-aspect approach, with most efficient utilization of given resource. Maintenance is carried out based on utility requirements of given unit and consequences of possible damage.

Replacing parts and assemblies - The fundamental benefit of RCM is maximum utilization of machinery and equipment. Replacement of parts and assemblies is based on wear, and not time interval. Such an approach extends the lifecycle of machines and their components.

7. PRACTICAL USE OF RCM METHODOLOGY IN FACILITY MANAGEMENT SECTOR

Preventive maintenance used by engineering services in industrial facilities, factories or office buildings is one of the most commonly used methods of preventing technical failures. Engineers focusing on preventive maintenance in many cases are unable to answer to what extent preventive maintenance measures affect the reliability of engineering system. According to estimations, ca. 50% shutdowns of the facility occur within 7 days following servicing [15]. RCM methodology enables to tackle system efficiency as regards determination of failure consequences, and elimination of such consequences by their early detection or effective servicing. Many maintenance engineers consider RCM as an addition to preventive maintenance, despite the fact that RCM is the tool that enables changing current maintenance program. Results of RCM analysis may indicate the need to replace components of the device or machine, improvement of technical parameter monitoring process, adding or reducing necessary servicing measures. The majority of engineering facilities demonstrates wear process consistent with bathtub curve shown in **Figure 5**. In the first phase initial failures occur, until damage, caused by normal wear and tear of machinery and equipment.

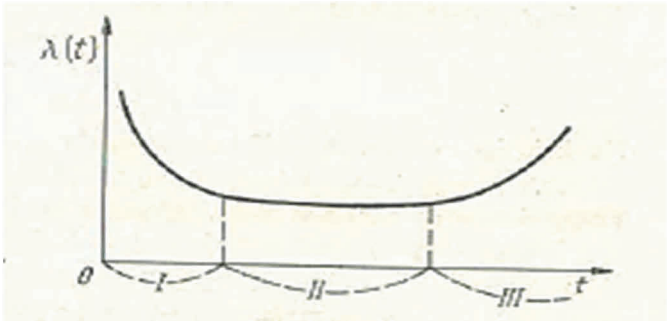

Figure 5 Degree of damage in time) [16]

The practical example of RCM methodology use is the sector of sanitary HVAC (*Heating, Ventilation, Air Conditioning).* Traditional servicing process consisting in changing filters at specific intervals, inspecting compressors and pumps, would not enable detection of issues affecting the operational effectiveness or efficiency of cooling. Adopting RCM methodology enables focusing on analysis results. Remote monitoring of initial parameters, such as outlet air temperature on evaporator, referenced to preset value, enables detecting issues related to cooling agent.

8. SUMMARY

The main issue regarding the maintenance of operations from the engineering point of view is ensuring adequate availability of machinery, equipment and engineering facilities. In the continuous production process, implemented by many companies, any unscheduled shutdown causes additional indirect costs due to failed deliveries, losing customers, damage to another process line. RCM is not a magic wand, eliminating defects and failures, but it enables significantly minimize the risk of their occurrence, and is an effective tool in the current maintenance of machinery and equipment. The major advantages of RCM methodology is that it may

be successfully applied in solving variety of technical problems and issues [9]. TCM plays an important role in complex railway, aerospace, energy projects, due to its material impact on safety of users and surroundings.

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