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INCREASING OF EQUIPMENT RELIABILITY BY RCM APPLICATION

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Over the past twenty years, maintenance has changed, perhaps more than any other management discipline. Managers seek new methods that can be implemented in their current maintenance systems or they strive for radical change of the maintenance system. In recent years, TPM (Total Productive Maintenance) and RCM (Reliability Centred Maintenance) have been recommended as appropriate methods to improve maintenance. While the TPM method has already been described in the literature and some examples of its practical applications can be found, the second method (RCM) has not been sufficiently clarified even in theory and so far it has not been fully implemented in any of the Czech companies. It therefore seems helpful to state benefits of RCM by way of the example of the selected maintenance system and to outline the basic principles that should be observed in its application.

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Introduction

In the highly competitive environment, to be successful and to achieve world-class-manufacturing, organizations must possess both effective manufacturing strategies and efficient maintenance [1]. To support production, maintenance must ensure equipment availability in order to produce products at the required quantity and quality levels. This support must also be performed in a safe and cost-effective manner [2].

Over the past twenty years, maintenance has changed, perhaps more than any other management discipline. The changes are due to a huge increase in the number and variety of physical assets (plant, equipment and buildings) which must be maintained the world over, much more complex designs, new maintenance techniques and changing views on maintenance organization and responsibilities. Rapidly grows awareness of the extent to which equipment failure affects safety and the environment and awareness of the connection between maintenance and product quality, too.

Maintenance people are having to adopt completely new ways of thinking and acting, as engineers and as managers. Managers everywhere are looking for a new approach to maintenance [3]. They seek new methods that can be implemented in their current maintenance systems or they strive for radical change of the maintenance system. The main goal of these changes is the improvement of the maintenance performance in an enterprise. In recent years, TPM (Total Productive Maintenance) and RCM (Reliability Centred Maintenance) have been recommended as appropriate methods to improve maintenance; they can be used separately or simultaneously. While the TPM method has already been described in the literature and some examples of its practical applications can be found, the second method (RCM) has not been sufficiently clarified even in theory and so far it has not been fully implemented in any of the Czech companies. It therefore seems appropriate to state benefits of RCM for improving maintenance by way of the example of the current maintenance system in a selected company and to outline the basic principles that should be obeyed in its application.

The main objective of this article is to define the possibilities of improvement of company maintenance system by application of principles of RCM. To achieve this primary objective, the following partial goals were defined:

- describe different approaches to the maintenance of production equipment with a focus on new methods used in maintenance, in particular TPM and RCM,
- cover the maintenance system currently used in selected manufacturing facilities in the company of chemical industry and evaluate the current application of the approaches to its improvement,
- propose a modification of current maintenance system, applying the principles of RCM.

The targets thus identified will be achieved partly on the basis of literature research (analysis of literary data sources and the subsequent synthesis of established facts) and partly using results from primary researches undertaken in spring 2010. This qualitative survey was conducted in a company of the chemical industry.

The main objective of the primary researches undertaken was:

- describe the product produced on a selected manufacturing equipment and its customers,
- identify the major problems arising from unplanned downtime of production equipment,
- map simultaneously carried out activities of planned maintenance on a selected manufacturing equipment including their strategic and tactical operational management method,
- analyze repairs after a failure in terms of type, frequency and causes and
- identify the most serious failures, including possibilities of their elimination.

Primary data were collected using an interview method according to a prepared interview script. The respondents were managers of sales, production and maintenance departments and other workers with responsibility for planning and realization of maintenance of the selected production equipment.

Theory

Approaches to the maintenance and development of maintenance systems can be divided into several developmental stages. Firstly unplanned (Reactive) Maintenance or breakdown repair is the practice of caring for equipment when and only when it is not functioning properly, and there is no particular person or department responsible for it. Workers take action only if machine is broken and cannot continue production. In such case production system capacity is reduced, workers are idle which causes direct labor costs to rise. Because of urgency in repairing equipment overall costs will increase [4-6]. This system is called Corrective Maintenance.

The first scientific approaches to maintenance management date from the 1950s and 1960s. At that time preventive maintenance was advocated as a means to reduce failures and unplanned downtime. In many companies large time-based preventive maintenance programs were set-up [7]. Planned Maintenance system is always organized and always a person/department is responsible for keeping records and taking action in case of breakdown. The necessary spare parts have already been purchased and kept in inventory. Maintenance procedures and manuals are always available. In this case machine downtime and the overall maintenance costs are less than unplanned maintenance because it tends to reduce

worker and machine idle time [5,6,8]. Preventive Maintenance (PM) is the practice of tending to equipment so it will not break down and will operate according to requirements. It entails understanding and maintaining all physical elements of manufacturing so they consistently perform at the level required by design. Preventive maintenance is the work activity that has been programmed on a regular basis to inspect a system, uncover potential problems and make whatever repairs are necessary to ensure that the system does not fail during normal operation. The costs include personnel, inventory of parts and the lost time when equipment is down for repairs [4-6,8]. In the 1970s condition monitoring came forward, focusing on techniques which predict failures using information on the actual state of equipment (e.g., luboil debris analysis, vibration monitoring) [7] (Dekker 1996). This approach is called Predictive Maintenance. This proved to be more effective than the large time-based preventive maintenance programs. In the 1980s the computer was brought to the maintenance function. Initially most attention was paid to facilitating administrative processes, later on by making management information readily available (e.g., the registration of the causes for overtime); yet their influence on decision making was limited. An important approach worth mentioning is Reliability Centred Maintenance (RCM) [7]. RCM is defined by SAE Standard "Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes" as "… a specific process used to identify the policies which must be implemented to manage the failure modes which could cause the functional failure of any physical asset in a given operating context." In the RCM approach, maintenance is carried out at the component level and the maintenance effort for a component is a function of the reliability of the component and consequence of its failure under normal operation. The approach uses failure mode effects analysis (FMEA) and to a large extent is qualitative [9,10]. Any RCM process shall ensure that all the following seven questions are answered satisfactorily and are answered in the sequence shown as follows:

1. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
2. In what ways can it fail to fulfill its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when each failure occurs (failure effects)?
5. In what way does each failure matter (failure consequences)?
6. What should be done to predict or prevent each failure (proactive tasks and task intervals)
7. What should be done if a suitable proactive task cannot be found (default actions)? ([3]).

After these questions are answered, maintenance activities are optimized, i.e. maintenance strategy is determined for each fragment of production facilities, and activities are defined to ensure maximum reliability of the various parts of the

production equipment (and in consequence of it, the equipment as a whole). According to Moubray, RCM thus serves to find the economically optimal way of maintenance of each manufacturing equipment in the long term [3].
At the same time, the Japanese evolved the concept of Total Productive Maintenance (TPM) in context of manufacturing [10,11]. Total Productive Maintenance (TPM) is a well defined and organized maintenance program, which places a high value on team work and continues improvement. Specific actions required for restoring equipment to a like-new condition, having operators involved in maintenance, training the labor force and, using the overall preventive maintenance effectively [5,6]. A goal of TPM is to upgrade equipment so it performs better than new ones. In TPM the maintenance responsibility is spread over many departments such as production, engineering, and maintenance, and to a range of people, especially operators and shop workers. In TPM, operators perform basic equipment repairs and team of maintenance staff redesign and reconfigure equipment to make it more reliable and easier to maintain [4,6,8]. Both RCM and TPM view maintenance in the broader business context and take into account the link between component failure and their impact on the business performance [10].

Experimental

The primary research has studied the recently used maintenance system in selected manufacturing equipment in the chemical industry. Manufacturing equipment processes the output of the previous production process of the enterprise and produces a product for sale to its customers (manufacturers of products for construction industry). The product is made by mass, process production. The main part of the manufacturing equipment is the reactor and accessories (pumps, ventilators, gas piping, inlet and outlet pipes for the material, compressors and coolers).

Maintenance of the given production equipment is relatively important for the enterprise because its failure means emergence of some serious problems, especially:

- The need to shift production to other production equipment, originally designed to produce special products. However, it will cover only 25% capacity of the monitored manufacturing device. Consequently, meeting customer requirements is at risk.
- The need to deliver products to customers in the required time and amount using pre-sale from a competing manufacturer. This has a direct economic impact on corporate profits, while the enterprise simultaneously puts at risk its share of expenditures with individual customers.
- Establishment of stock at the entry to the production equipment and the need to shutdown the previous process when reaching the storage capacity.

The enterprise assesses the importance of individual production facilities, by the criteria of irreplaceability, importance of the product in the product line and the frequency of failures. Based on this evaluation, the given manufacturing equipment is assigned with a maintenance strategy. The monitored production equipment is rated as indispensable and, consequently, the decision is taken on the application of preventive maintenance. Within the maintenance, activities are performed such as:

- cleaning (after shutdown),
- replacement of oils and lubrication (by the operators on the manufacturing equipment),
- technical inspections
  - (partly by production equipment operators in which monitor noise and leakage is monitored and vibration is assessed subjectively and
  - partly by external maintenance workers, under which also minor maintenance tasks are carried out, such as replenishment and replacement of oils and tightening of valves and pumps seals).
- Then, overhauls are carried out and
- preventive repairs within the shut-down, based on findings during the removal of production equipment and the results of predictive maintenance conducted by company diagnostician.

In the maintenance, the company utilizes both its own staff (operators on the manufacturing equipment and maintenance staff), and maintenance outsourcing. External service workers provide approximately 80 % of the maintenance.

Preventive maintenance is planned; the planning is carried out in the horizon of strategic, tactical and operational. In planning, it is necessary to respect financial constraints though, and therefore the business makes use of deferred repairs risk assessment methodology. If it is necessary to reduce the cost of planned maintenance, repairs are excluded which pose only a negligible risk. Subsequently, a plan of repairs is made, from which tasks are then directly derived for both internal and external maintenance staff. If on the basis of applied predictive maintenance a need arises of an originally unplanned repair, the plan is corrected. The planned preventive maintenance activities then accumulate until the shutdown of production equipment. Its activities are planned and regulated with a shutdown schedule that is processed for each manufacturing equipment and for individual departments. Maintenance tasks performed within the planned preventive repairs are allocated in the form that also serve for the operational maintenance records. Repairs check has several forms. Quality control is performed of the work done as well as repair time process inspection. Also, a report is compiled on the operation stop process, maintenance budget check and the overall assessment of corporate maintenance using performance indicators for maintenance.

Corrective maintenance is performed after it is reported, either immediately or it is planned into activities of the nearest shut-down for repair. The most significant failures on the manufacturing equipment (in terms of absolute frequency) were identified by the company to be pump filter basket clogging and steam pipe defects. The company strives to reduce the number of repairs after a failure through the elimination of the aforementioned defects. A reserve pump was acquired, so in the case of failure a repairing method can be applied of "interchangeable manner". Defects in the sealing could be solved by replacing the sealing with the best commercially available seals. This seal, however, presents risks in terms of health and safety at work. Therefore, the enterprise in the case of the pipe rather applies the predictive maintenance, but the problem is that the defect may occur at a place different from that where the diagnostics of the pipe performed.

Results and Discussion

If we evaluate the maintenance system of the given production equipment, we can state that it is based on a combination of theoretical approaches outlined. It is based on the preventive maintenance, which also includes elements of predictive maintenance. At he same time, principles are also applied of the Total Productive Maintenance approach, especially the autonomous maintenance (consisting of the involvement of operators in simpler maintenance activities). Despite the sophistication of the entire maintenance system of the selected manufacturing equipment, however, the company does not avoid unplanned repairs, i.e. it is also necessary to simultaneously apply the corrective maintenance.

The company strives to eliminate unplanned shutdowns, but only through the elimination of most frequent failures. However, evaluation of the importance of individual failures should be comprehensive. It should be aimed at assessing the overall impact of each failure on the company (in a similar way as it is done in the context of enterprise-wide strategy in setting maintenance for each production equipment). Overall, it can be concluded that the system of maintenance of production equipment includes all the principles of theoretically cited approaches to maintenance. Differentiation of the maintenance work is carried out only in the enterprise-wide context, i.e. it concerns individual manufacturing facilities as a whole. Application of RCM method could contribute to improving the maintenance system of both the selected manufacturing equipment and the company.

Applying the RCM principles for maintenance of the selected production equipment would appear very desirable because of its indispensability. This would mean to convert the current maintenance system based on the standards of repairs (which determine the frequency, scope and time of the repair) to the repair system

favouring a response to the current status of the production equipment (measured by the predictive maintenance).

In modifying the current method of maintenance (of the selected manufacturing equipment), the production equipment should be first identified as a set (in terms of maintenance) of individual parts. Subsequently, failure rate is assessed of these components and importance is examined of each failure. This importance is not given by the frequency of failures, but by their overall impact on the business. The objective of this evaluation is to estimate the risk posed by each of the failures. In the evaluation, it is possible to use the Risk Assessment Matrix. For each defect is determined:

- the overall impact on the firm (in terms of safety, damage to property, environment and the company goodwill) and
- the probability that a failure occurs.

Table I An example of Risk Assessment Matrix

Consequence				Probability				
				1	2	3	4	5
				A	B	C	D	E
People	Assets	Environment	Reputation					
No health effect / Injury	No damage	No effect	No impact					
Slight	Slight	Slight effect	Slight					
Health effect / injury	Damage		Impact					
Minor health effect / injury	Minor damage	Minor effect	Local impact					
Major health effect / injury	Localised damage	Localized effect	Regional impact					
Permanent total disability	Major damage	Major effect	National Impact					
1 or more fatalities	Extensive damage	Massive effect	World wide					

1 – Never heard of in industry; 2 – Heard of in industry; 3 – Incident had occured in our company; 4 – Happens several times per year in our company; 5 – Happens several times per year in location

In the impact of the failure on the goodwill of the company, the impact should be considered on the most important key stakeholders, especially suppliers and customers as well as the public in the neighbourhood of the business. The example of Risk Assessment Matrix is shown in Table I.

If the size of risk is identified for each defect, appropriate activities are

defined to eliminate the most serious failures (or to lessen their consequences). Simultaneously, an optimal maintenance strategy is determined for each part of the production equipment. For parts of the production equipment where there is a low risk it is possible to use Corrective Maintenance System. In case of parts with the most serious risk, it is appropriate to apply a maintenance system leading to maximum reliability.

If it is desirable to provide maximum reliability for specific parts of the production equipment, the repair must be performed before the limit wear is reached. To determine the actual date of correction, it is necessary to use:

- past data on the prevalence of individual failures (and to process it through mathematical and statistical methods) and
- information about the current state, which can be identified using predictive maintenance.

The enterprise has already experienced predictive maintenance and could therefore relatively easily define the technical parameters for monitoring the rate of wear and also a place in which to perform this measurement. By the way of example of the predictive maintenance application in the piping it is clearly evident that the suitability of the parameter and the number of points at which the measurement is made must be continuously reassessed.

A fixed term of the repair should ensure high reliability of the production equipment by exercising only the necessary amount of money for repairs. The repair is carried out only when it is strictly necessary, but before the failure of the manufacturing equipment.

Providing a different maintenance strategy for each part of the production equipment that leads to different schedules of repairs would, however, involve extending the total repair time (and reduce the time available for production). It is therefore necessary to synchronize the performance of maintenance on the components. This synchronization is provided in merging terms of repairs to one term, or to a certain maintenance cycle. Generally, it is possible to adapt to the shortest time, or to the maintenance cycle, and to plan a repair before the first limit wear is reached. But it is also possible to apply the Theory of Constrain approach and fix the date of repairs under the main part and to synchronize other recommended deadlines with it. In this case, however, it is necessary to consider the consequences of postponing the repairs, as postponing the recommended term may lead to repair costs increase as a result of the damage that would have been prevented by an earlier repair. It is therefore necessary to carry out a thorough analysis of the results of synchronization of terms to repair individual parts with the main part and then to apply measures in which it is possible. These measures are to allow extending or shortening the time for repair. In an effort to extend, the basic question is: What should be done to prevent the production equipment or its part from exceeding the limit wear? For example, the material from which the

manufacturing equipment is made may be replaced with higher-quality one, or doubling of the device may be performed. Conversely, if it is desirable to make a repair before it is recommended for the part, one may ruminate contrariwise and make use a low quality material form which the spare part is manufactured.

An extremely important part of the maintenance management is providing the spare parts and materials for the maintenance. For the growth of maintenance performance it is possible to apply a new system of inventory management of spare parts which are not used by the enterprise yet. Especially for strategic spare parts, Quick Response and Collaborative Planning, Forecasting and Replenishment may be used as methods aimed at JIT-based stock replenishment. The basis of these stock replenishment systems is the supplier's response to the current level of inventories. The supplier and buyer share the information on planned maintenance, allowing suppliers to prepare the future need for spare parts. They also share information on the current level of stocks and its approximation to the ordering limit. At the instant it is reached, the customer makes an order or the inventory is replenished directly by the supplier. Spare parts that are not designated as strategic may be replenished based on demand forecasting. Implementation of this method of inventory management of spare parts allows readiness not only for the planned maintenance, but also for corrective maintenance, whilst reducing maintenance costs.

Conclusion

Based on the results of the primary research, it can be stated that the company uses a maintenance system that is primarily aimed at preventing and combines several theoretically described systems (Preventive Maintenance, Predictive Maintenance and Total Productive Maintenance). By the example of selected production equipment it is clear that despite the elaborateness of the current maintenance system it is not possible to ensure full reliability of the production equipment. Therefore, the enterprise must also apply corrective maintenance and then address the problems resulting from the failure of the production equipment. Implementation of the RCM method should significantly improve the reliability of the production equipment.

If it is successfully implemented, it is possible to expect not only greater reliability of the production equipment, but consequently also greater continuity of production processes and less loss of production, improvement of the supplier-customer relations, reduction of the impact on the environment and increase of safety at work. Another benefit for the enterprise will be a greater awareness of the manufacturing equipment and involvement of more company workers into the care of the production equipment.

On the contrary, one can not say unequivocally that the implementation of

RCM will bring significant cost savings in maintenance and if that happens, then only in the long term. When considering the economic impact of the introduction of the method, one should also take account of costs related to the actual implementation of the new system. Generally, it is therefore recommended where downtimes of the manufacturing equipment bring about extreme or significant impact on the business, such as in companies seeking corporate and inter-company interconnection of material flows, for example on the basis of Quick Response, or Collaborative Planning, Forecasting and Replenishment or in companies with a large number of environmental accidents. On the contrary, it is not suitable for businesses with high share of the production equipment that is subject to revision, since their maintenance is determined by legislative action.

Nevertheless, an appropriate implementation of RCM, especially in combination with TPM, contributes to improved corporate maintenance performance and the company as a whole. It can therefore be expected that in the coming years it will see expansion also in Czech, not just chemical, companies.

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