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ROTARY EQUIPMENT MAINTENANCE COST MANAGEMENT USING RELIABILITY-CENTERED MAINTENANCE (CASE STUDY: IMAM KHOMEINI SHAZAND REFINERY)

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Abstract

The purpose of this study was to manage maintenance costs of rotary equipment using the maintenance and repair technique based on reliability at Imam Khomeini Shazand Oil Refining Company. So far, this type of maintenance has not been carried out at the oil Company. In this study, the two libraries and field methods were used to collect information. The statistical population was all engineers of the maintenance unit of the Imam Khomeini Shazand Oil Refining Company. Considering that the number of these people was 10, the study utilized all respondents' answers and guidance. The results of this study showed that minimization of preparation and repair times and ultimately the total time of the system will be significant. This can be achieved by reducing the time of preparation and maintenance, and ultimately helping to reduce the cost of the production system.
Keywords: Rotating Equipment, RCM technique, Maintenance Unit Engineers, Minimizing Preparation Time, Maintenance Cost Management

I. INTRODUCTION

All manufactured objects and devices have limited lifetimes and a device or an entire system may fail any moment. We know that every device has an optimum level of reliability and function. In order to exceed these limits, it is necessary to pay expensive prices, which in this case, the production of these products will not be cost-effective. There are also better solutions for making the best of the existing facilities through precise and continuous planning and ensuring maximum efficiency and availability of devices [1]. Accordingly, the selection of an optimum maintenance policy can solve the problems of industrial units and can increase production and efficiency by reducing the sudden failure of equipment. It also reduces other limitations such as the costs and working hours of human resources. Various maintenance strategies have been introduced so far and each of these strategies has its own advantages and disadvantages depending on the industry [2]. Today, the main challenge faced by maintenance engineers involves not only learning the related techniques but also selecting one or several maintenance methods and implementing them. Reliability-centered maintenance (RCM) is one of the most efficient and most effective methods of maintenance and it is currently employed in many countries and industries around the world. This process firstly shows the actions that must be taken to extend the lifetime of any physical capital and secondly guarantees fulfilment of user expectations regarding the equipment [3]. The most difficult and critical phase of a reliability-centered maintenance project is its implementation, which is referred to by some practitioners as the "cemetery of the reliability-centered maintenance process". This is because the output of the analysis process can be turned into a document that is archived indefinitely but is never implemented. Simply analyzing this technique is insufficient. Thus, it is necessary to also implement the technique because it is the only way of calculating Return On Investment in the reliability-centered maintenance analysis. The successful application of this technique requires leadership throughout its implementation. Therefore, in such projects, a person must be in charge of directing the implementation of the technique. This person can be referred to as the director of implementation of reliability-centered maintenance. This person supports the team in the course of the analysis, helps the team develop an output plan, and assigns people and schedules to each part of the plan. They also update the reliability-centered maintenance worksheets on a weekly basis and submit them to the appropriate teams and managers [4].

Reliability-centered maintenance starts with a comprehensive and fundamental review of the maintenance requirements of each physical asset in operation, and it is among the most effective growth and development policies because of managing equipment failure risks [5]. In oil and petrochemical complexes, rotary machinery is among the most important process equipment and their operability plays a substantial role in reducing the commissioning costs of projects, increasing the reliability of units, reducing operational costs, reducing risks, and increasing safety. The different phases of petroleum projects are the installation, pre-operation, and machinery operation phases. Moreover, under optimum conditions, maintenance strategies are introduced shortly after the units start to operate. Reliability-centered maintenance, as a highly successful strategy for the maintenance of rotary equipment, is based on the predictive maintenance (PM) and Root Cause Analysis (RCA) approaches. The present research investigated the management of maintenance costs at Imam Khomeini Shazand Oil Refining Company using the RCM technique.

II. RESEARCH BACKGROUND

Reliability-centered maintenance is a process for identifying the maintenance activities and actions required for keeping equipment operable. It was initially developed for the aviation industry; it was introduced to the nuclear industry in the mid-1980s and was finally adopted in all industries. According to the results from a survey of different organizations in the world (749 responses to the survey), more than seventy percent of the organizations have practiced reliability-centered maintenance or are planning to adopt this approach. Hence, only less than one-third of the existing organizations lack specific plans to implement the reliability-centered maintenance approach [6]. Numerous studies including the studies introduced in the following have been carried out on the reliability-centered maintenance technique.

[7] used the Analytic Hierarchy Process (AHP) technique to prioritize the equipment required for reliability-centered maintenance. This technique was applied to a sample network (i.e. Neka

Electric Power Distribution Network in Mazandaran Province).
[8] conducted an extensive review of the reliability-centered maintenance approach and its implementation, which had been discussed by other researchers. Some of the studies carried out on this approach are as follows:
[9] proposed an electric maintenance system to increase system efficiency. [10] used AHP to simulate the maintenance process in a process factory in India. [11] developed a multi-objective model to mathematically solve the problem of optimization of the reliability-centered maintenance planning for an electric power distribution system with the aim of minimizing predictive maintenance costs and maximizing the overall reliability of the system. [12] used fuzzy vector, failure mode and effects analysis, and risk analysis methods to develop a framework for identifying the maintenance of important items. [13] carried out a systematic review using the fuzzy AHP method based on Goal Programming (GP) to select transformer maintenance policies. [14] developed a model based on AHP, which enables managers to prioritize related choices with proper means. This model has been tested on two industrial units. [15] attempted to select an optimum maintenance and rehabilitation strategy for multilane highways. They selected a strategy by comparing various maintenance and rehabilitation alternatives using highway management and development tools in multilane highways in the north of India. [16] adopted the sustainability approach to select a maintenance strategy for a production unit. They first used the factor analysis concept to identify the primary factors in each sustainability dimension and then used the fuzzy VIKOR technique to select the most suitable maintenance strategy. [17] introduced a new approach for selection of the optimum maintenance strategy using qualitative and quantitative data and through interaction with maintenance experts. [18] combined the AHP and goal programming to select a maintenance policy for the gasoline unit of a chemical company. [19] proposed an approach based on the Analytic Network Process (ANP) for the selection of an optimum maintenance strategy for transportation trains.

Theoretical Framework and Conceptual Model

Reliability-centered maintenance is a process that determines the actions required for the continued life of a physical capital and fulfillment of user expectations regarding the equipment. It is a logic-based engineering method for the establishment of a connection between maintenance activities and failure mechanisms. The goal of reliability-centered maintenance is to achieve the desired level of reliability (in proportion to costs) by taking the necessary actions. The reference for these types of maintenance actions is a maintenance approach that is based on condition-based monitoring because this technique is not an invasive technique and does not hinder the production process [3].

Reliability-Centered Maintenance Process [20]

- Identifying the system and listing its critical and secondary equipment
- Error rate and the effect of error analysis on each component
- Identifying the error rate and prioritizing the errors
- Grouping the error effects (using a proper flowchart)
- Allocating proper maintenance states
- Plan assessment (including cost analysis)

In order to implement the reliability-centered maintenance approach, it is necessary to use an organized format to respond to the following questions about existing equipment and their operating conditions [21].

1) Functions: What are the operational standards and functions of the equipment?
2) Functional failures: Which functional dimension of a machine fails?
3) Failure modes: What types of functional failure occur?
4) Failure effects: What happens after the occurrence of a failure?
5) The above four questions can be referred to as the components of the analysis of the failure modes and their effects.
6) Consequences: Why are the failures important?
7) Preventive tasks: What tasks should be accomplished to prevent failures?
8) Default tasks: What actions should be taken to prevent and eliminate failures if no preventive task is taken?

Implementation of the Reliability-Centered Maintenance Procedure

The following three steps must be taken to implement and develop the reliability-centered maintenance approach in a factory. The successful completion of each phase ensures the success of the subsequent phases. These phases are as follows [22].

1. **Starting the operation, training, and early successes**
   The first year of implementation of the reliability-centered maintenance method is normally dedicated to conceptual assessment. This process generally starts in factories that only have relatively successful plans for proactive maintenance (PaM) and predictive maintenance (PdM). The first step in the successful implementation of reliability-centered maintenance is the formation of two workgroups for maintenance planning and reliability improvement. The "maintenance planning" group can be the same as the predictive maintenance group, but it must be focused on inclusive planning rather than absolute agendas. The "reliability improvement" group first focuses on the implementation of the predictive maintenance plan and then gradually switches to proactive maintenance as the group members gain more experience.

2. **Predictive and proactive implementation and development**
   The condition monitoring (CM) and predictive maintenance methods are introduced in the second and third years of implementation of a plan. In this phase, information about the operating conditions of the machinery is merged with the predictive and proactive maintenance methods (including precise aligning, balancing, and analyzing the root causes of failure). In the more advanced phases of implementation of the reliability-centered maintenance procedure, the factory tends to eliminate unplanned production interruptions, permanently solve the machinery problems, increase production quality, and maximize efficiency.

3. **Assessment of the implementation of reliability-centered maintenance**
   In order to gain management support for this plan, it is necessary to assess and evaluate the results of the reliability-centered maintenance plan and record the results in writing. The

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important criteria for the assessment of the reliability-maintenance approach include monthly maintenance sector costs; maintenance costs per unit of distance or produced energy; distance travelled freely per month; the number of failures and downtimes per month; percentage of failures and downtimes per travelled distance or produced energy; maintenance sector overtime work; the number of emergency maintenance operations as compared to the total maintenance hours; the percentage of downtimes caused by the maintenance process as compared to the total operability hours; the percentage of the operating hours of the equipment (out of the total operability hours); the number of faults detected by the reliability-center maintenance plan per month; the number of corrections proposed by the reliability-centered maintenance plan per month; the total profit produced by implementation of predictive maintenance methods, and the percentage of factory machinery covered by the predictive maintenance plan.

III. RESEARCH METHODOLOGY

The desk research method was used in this research to collect information and study the records and theoretical literature of the research. Subsequently, the theoretical model of the research was developed and the field research method was used to seek the opinion of the research population about the research variables. A questionnaire was used to collect the research data because it is more scientific and practical than the interview and observation methods and offers equal conditions to all respondents. In this research, the rotary equipment of Imam Khomeini Shazand Oil Refining Company was examined. Following monthly visits by maintenance engineers and based on our six-month findings, three pumps in the critical conditions, which were labeled the P-1541B, P-157A, and P-642B pumps, were randomly selected from unit 15 (gasoline production unit), unit 01 (distillation unit), and unit 06 (Isomax unit) of the refinery, respectively. Data was collected from the questionnaires completed by the maintenance engineers of Imam Khomeini Shazand Refinery and was used in solving the model. Since ten respondents were included in this research, the total count method was used and then the problem parameters and sets were identified. In this research, we proposed a decision-making model with proper constraints and implemented the model at Imam Khomeini Shazand Oil Refining Company using the gathered data.

Information Analysis

In many production systems, the setup time required for switching activities is an integral part of the system and delayed maintenance imposes heavy expenses on the organization. Sometimes, the setup time of the parts of a machine depends on the previously processed part and these problems are known as sequence-dependent setup time problems. The scheduling theory is associated with mathematical models and establishes a link between scheduling and developing of the scheduling models. It continuously assesses these models against theoretical and scientific problems. The theoretical viewpoint offers a quantitative approach aimed at obtaining a compressed mathematical problem structure. This quantitative approach starts with the interpretation of decision-making goals as an explicit objective function and the statement of the barriers to decision making in the form of explicit limitations. The research model and its relevant parameters are discussed in the following.

Table (1): Research parameters

Parameter	Definition
N	The number of existing activities assigned to a multipurpose machine
P_j	Production time of the j-th activity
d_j	Due date of the j-th activity
C	Completion time of the j-th activity
C_{mj}	Completion time considering the maintenance time of the P-642B, P-1541B, and P-157A pumps
$S_{j,k}$	Setup time for switching from activity j to k
M_{pj}	The cost of the product lost because of maintenance of the P-1541B, P-157A, and P-642B pumps
T_{tj}	Total delay costs
k_j	Unit delay costs
q_{tj}	Total products lost due to the maintenance of the P-1541B, P-157A, and P-642B pumps
q_j	The number of the products lost per unit time of the maintenance time of the 1541B, P-157A, and P-642B pumps
$B_{k,j}$	The maintenance times of the 1541B, P-157A, and P-642B pumps when activity k comes before activity j in the sequence.

In this model, M is an infinite positive number, L_{kj} is a binary variable, and if k comes before j in the activity sequence, L_{kj} is equal to 1; otherwise, it is zero.

Determining the Objective Function and Limitations

$$Min\ z = \sum_j \sum_k S_{(j,k)} \cdot Y_{(j,k)} \tag{1}$$

Subject to:

$$\sum_j M_{pj} \leq Totalcost \tag{2}$$

$$c_k - c_j + m(1 - Y_{j,k}) \geq s_{(j,k)} + p_k \tag{3}$$

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$$\sum_j Y_{j,k}(c_j + s_{j,k}) + p_k = c_k \quad (4)$$

$$c_j + \sum_k L_{k,j} \cdot B_{k,j} = c_{mj} \quad (5)$$

$$c_j \le d_j \quad (6)$$

$$\sum_j \sum_k Y_{j,k} = n - 1 \quad (7)$$

$$\sum_j Y_{j,k} \le 1 \quad (8)$$

$$\sum_j L_{k,j} \le 1 \quad (9)$$

$$Y_{i,j} = 0 \quad (10)$$

$$T_{tj} = (c_{mj} - c_j) * k_j \quad (11)$$

$$q_{tj} = (c_{mj} - c_j) * q_j \quad (12)$$

$$M_{pj} = q_{tj} * T_{tj} \quad (13)$$

In this model, the first limitation is associated with the cost of products lost in the product system and it has the upper bound of the costs set.
The second and third limitations ensure the sequence of the activities. The third limitation states that all activities of a workshop's production process are scheduled and planned sequentially, and it assumes the completion time for the activities without the maintenance times.
The fourth limitation adds the maintenance times of the P-1541B, P-642B, and P-157A pumps to the time of the previous activities and yields Cm.
The fifth limitation ensures that all activities can be completed before the due time.
The tenth limitation shows the delay costs set. The eleventh limitation shows the number of the products lost during the maintenance period. The twelfth limitation shows the total costs of the lost product.
Finally, the objective function yields the optimum sequence by optimizing the total setup times and optimizes the costs of the lost product.

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Identifying the Problem Variables for the Case Study

Table (2): Problem variables

Parameter	Problem variable value		Parameter	Problem variable value
N	3		**M_{11}**	1800
P_j	P_1	13	**M_{12}**	1800
	P_2	60	**M_{13}**	1800
	P_3	48	**T_{11}**	60
d_j	d_1	230	**T_{12}**	60
	d_2	240	**T_{13}**	20
	d_3	265	**K_1**	1000
C	C_1	60	**K_2**	1000
	C_2	225	**K_3**	100
	C_3	163	**q_{11}**	18
C_{mj}	C_{11}	63	**q_{12}**	10
	C_{12}	228	**q_{13}**	0
	C_{13}	164	**q_1**	30
$S_{j,k}$	S_{11}	24	**q_2**	30
	S_{12}	20	**q_3**	10
	S_{13}	20	**b_{11}**	60

Forming the Objective Function for Reducing the Costs of Maintenance Delays in Lingo

$$\min = s_{jk} * y_{jk};\tag{14}$$

$$M_{pj} \le totalcost;\tag{15}$$

$$c_k - c_j + m(1 - y_{jk}) \ge s_{jk} + p_k;\tag{16}$$

$$Y_{jk} * c_j * s_{jk} + p_k = c_k;\tag{17}$$

$$c_j + B_{kj} * l_{kj} = c_{mj};\tag{18}$$

$$c_j \le d_j;\tag{19}$$

$$y_{jk} = n - 1;\tag{20}$$

$$y_{jk} \le 1;\tag{21}$$

$$l_{kj} \le 1;\tag{22}$$

$$Y_{jj} = 0;\tag{23}$$

$$T_{tj} = c_{mj} - c_j * k_j;\tag{24}$$

$$q_{tj} = e * q_j;\tag{25}$$

$$m_{pj} = q_{tj} * T_{tj};\tag{26}$$

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Solving the Objective Function for Reducing the Delivery Time Costs

Table (3): Results from solving the model

Feasibilities	2.000000
Total solver iterations	3
Elapsed runtime seconds	1.06
Model Class	QP
Total variables	16
Nonlinear variables	9
Integer variables	0
Total constraints	44
Nonlinear nonzeros	5
Total nonzeros	29
Nonlinear nonzeros	5

Table (3): Model variables values

Variable	Value
SJK	4.000000
YJK	3.000000
MPJ	2670.000000
TOTALCOST	2670.000000

IV. CONCLUSION

Today, one of the costs taken into account in the maintenance planning process is the cost of delayed delivery. In many production systems, the setup time for the replacement of activities is an integral part of the system, and untimely maintenance imposes heavy costs on the organization. Hence, a study was conducted to examine the costs incurred by delayed delivery and to reduce these costs. Scheduling is a decision-making activity performed to optimize one or several objectives. Sequencing problems are generally stated as static and dynamic problems with the aim of optimizing the overall time, minimizing the number of activities accomplished following the due time, and optimizing the current system time. Considering previous research and the importance of time optimization, this research was conducted around optimization of sequential setup times based on maintenance times. Attempts were made to propose and solve a nonlinear planning mode. Since maintenance is carried out in many industries, maintenance time was also taken into account in developing the aforementioned model. Moreover, by introducing the limitations covering the scheduled activities, attempts were made to optimize the setup times. Our ultimate goal was to find the optimum sequence of the activities by minimizing the total setup time. It is possible to reduce the production system costs by reducing the setup and maintenance times.

In the course of solving the model in Lingo, the optimum value of s_{jk} was found to be four and the optimum value of s_{jk} was three. The total optimum cost was also 2670. In other words, by reducing the operation time by four units a minute, the costs were reduced by three units and the total cost was 2670. Given the resulting values and the maintenance costs and times of the pumps, a drastic decrease is observed in this unit.

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