THE EXPERIENCE OF APPLYING THE METHODOLOGY OF RELIABILITY CENTERED MAINTENANCE AS AN EFFECTIVE TOOL IN ASSET MANAGEMENT FOR MAINTENANCE

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KEYWORDS
Equipment reliability, failure prevention, functional failure, failure modes, reliability centered maintenance, RCM.

ABSTRACT
The importance of maintaining high reliability and operational availability of equipment is becoming of great importance for the oil industry. This occurs due to the constant need for resource optimization and business survival regarding the aspects of competitiveness in the current economic and social context.

Thus, this work presents a case study using the methodology for Maintenance management called Reliability Centered Maintenance - RCM. This aims to ensure the provision of information necessary to define a better strategy to develop plans for preventive and predictive maintenance for equipment belonging to the Storage Terrestrial Terminals and Oil and Byproduct Transport Pipelines.

The RCM, although arising from and duly widespread in the aviation industry, has been adapted by other industries and this work suggests its adaptation for the oil industry. In order to assist the analysis of this context, a wide reference review was set as a basis, in order to allow a better understanding of its application in the Industrial Maintenance.

INTRODUCTION
The main purpose of this report is to present the work developed by the Industrial Maintenance team of Campos Elíseos Terrestrial Terminal (TECAM) on the upgrade of Maintenance Plans according to the methodology of Reliability Centered Maintenance (RCM) for the components of the Oil pumping system ORBEL II of TECAM, in Duque de Caxias – RJ.

This work was developed by a Working Group (WG), consisting of seven employees, covering the Maintenance, Operation and HSE departments, as shown in Table 1.

Table 1. Table of WG participants.

<table>
<thead>
<tr>
<th>Title</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Leader</td>
<td>JR Engineer</td>
</tr>
<tr>
<td>Operation Representative</td>
<td>SR Operation Technician</td>
</tr>
<tr>
<td>HSE Representative</td>
<td>Security Technician</td>
</tr>
<tr>
<td>Maintenance Representative</td>
<td>Maintenance Technician</td>
</tr>
<tr>
<td>Electrical Representative</td>
<td>JR Maintenance Technician</td>
</tr>
<tr>
<td>Mechanic Representative</td>
<td>JR Maintenance Technician</td>
</tr>
<tr>
<td>Instrumentation Representative</td>
<td>JR Maintenance Technician</td>
</tr>
</tbody>
</table>

The use of RCM methodology provided the equipment failure modes, which could lead to system unavailability, to be evaluated together with their respective causes. Since then, effective and cost-efficient maintenance actions were proposed in order to avoid failures and preserve the system functions. RCM seeks to minimize the frequency of corrective interventions, as well as to reduce the maintenance plan cost, also during Scheduled Shutdowns, through the execution of more labor-saving and objective maintenance tasks for the failures diagnosed as major and relevant.

The MCCNet® software (Image 1) was used in all stages of the RCM study, owned by Petróleo Brasileiro SA, which offers manual interaction (import/export) with SAP/PM, providing the optimized update of the maintenance plans.
The software enables the creation of FMECA for functional failures, in which there are measured failure modes, causes/mechanisms of failure and the severity of its effects.

After measuring the effects severity the use of Decision Diagram is evaluated, where the types of potential tasks are identified. In the tasks selection it is possible to create tasks based on time (BT), condition (BC) or failures detection test (TDF) and in case of, even be asked to redesign the equipment. In this stage, it is performed the cost-efficiency analysis for each task, in which professionals, materials and required equipment are included.

The work was performed for three months, with weekly WG meetings.

**RCM IMPLEMENTATION STAGES**

In order to provide the development of a Maintenance Plan, based on the methodology of Reliability Centered Maintenance (RCM), the stages described below were followed.

**System Definition**
- Criteria that guided the system choice.

**Information Collection and Parameters Settings:**
- Get engineering flowcharts, descriptions, equipment manuals, etc;
- Get Maintenance Plans in force;
- Establish parameters for failure severity and failure probability and frequency.

**Failure History and System Performance Indicators Survey**
- Survey data of the event/existing failure;
- Establish system performance indicators.

**System Functional Modularization**
- Subdivide the system into modules/functional subsystems for better understanding of its operation;
- Identify the interface input and output for each functional module;
- Identify the items and borders of each subsystem.

**Functional Failure Analysis and Definition of Components Matrix and Functional Failures by Subsystem**
- Describe the Module/Subsystem;
- Identify the functions performed by the subsystem;
- Identify the functional failures related to each function of the subsystem;
- Identify and include components of each subsystem;
- Create a Component matrix / Functional Failure.
Failure Mode, Effects and Criticality Analysis (FMECA)
- Create FMECA for each functional failure of each component,
- Select the dominant Failure Modes for each Functional Failure;
- Identify the respective Causes and Effects for the selected Failure Modes;
- Classify the severity of each effect, Classify each failure as for the severity of failure effect and impact on other systems and/or subsystems.

RCM Decision Diagram
- Classify the failure modes according to the severity;
- Identify and measure potential applicable tasks;
- Select cost-efficient tasks;
- Determine the frequency of tasks.

Correctives Validation Test
- Reanalyze the list of studied tasks in order to validate them, or not, as more cost-efficient.

Creation of the Maintenance Plan based on RCM
- Structure the selected tasks by the RCM decision diagram in the form of a Maintenance plan, according to Transpetro.

ANALYZED SYSTEM

For the pilot study of RCM technical application, the pumping system of the pipeline Rio-Belo Horizonte II (ORBEL II) in Campos Elíseos Terminal was chosen, taken into account its great importance for the supply of the State of Minas Gerais.

The ORBEL II system comprises a 24” and 358km long duct, a starting terminal (TECAM), two intermediate pump stations (ESTAP and ESMAN) and the REGAP input scraper.
- Tapinhoã Station (ESTAP) in Rio das Flores - RJ;
- Mantiqueira Station (ESMAN), in Santos Dumont - MG,
- Gabriel Passos Refinery (REGAP), in Betim - MG.

Its pumping starts-up in Campos Elíseos Terminal (TECAM) through two auxiliary pumps (300CV) and four main pumps (2,800 CV), generating an operating capacity of 25.200 m³/day. Its function is to transfer oil from Campos Elíseos Terminal (TECAM), in Duque de Caxias - RJ, to Gabriel Passos Refinery (REGAP), in Betim, MG.

SYSTEM MODULARIZATION

Modularization was created to improve the organization during the meetings. Thus, the pumping system ORBEL II - TECAM was subdivided into three subsystems:
- Auxiliary Pumping Subsystem (auxiliary motor-pump set and peripherals);
- Main Pumping Subsystem (main motor-pump set and peripherals);
- Scraper Subsystem (output scraper components and components related to auxiliary and main pumps).
Image 2. Schematic representation of TECAM-ORBEL II system.

Image 3. Schematic representation of the section of the three subsystems components

The components of each subsystem were selected after the definition of borders, described as follows:

**Auxiliary Pumping Subsystem (SSBAE):**

Start:
- Mechanical: Booster Pump Suction Valve;
- Electrical: Booster Pump Feed Breaker;
- Instrumentation: Instruments related to the auxiliary Motor-pump set.

Conclusion:
- Mechanical: Booster Pump Discharge Valve;
- Electrical: Booster Pump Engine;
- Instrumentation: Instruments related to the auxiliary Motor-pump.

**Main Pumping Subsystem (SSBP):**

Start:
- Mechanical: Main Pump Suction Valve;
- Electrical: Main Pump Feed Breaker;
- Instrumentation: Instruments related to the Main Motor-Pump set

Conclusion:
- Mechanical: Main Pump Discharge Valve;
- Electrical: Main Pump Engine;
- Instrumentation: Instruments related to the set of the Main Motor-Pump.

**Scraper Subsystem (SSSC):**

Start:
- Mechanical: Cannon Block Valve
- Electrical: Feed ram of the Scraper Motor Valves;
- Instrumentation: Instruments related to the Launch Cannon.

Conclusion:
- Mechanical: Scraper End Safety Valve;
- Electrical: Scraper Moto Valves Actuator;
- Instrumentation: Instruments related to the Launch Cannon.
ANALYSIS OF FUNCTIONAL FAILURE AND DEFINITION OF COMPONENT MATRIX /FUNCTIONAL FAILURE

In this stage, there were defined the functions developed by each subsystem, as presented in the previous stage and, therewith, all the functional failures were identified, as related to each of these functions. Since the main objective of RCM is to secure the system operation, this stage is essential in order to duly regard all the operating factors.

Furthermore, it was studied the relation between the components of each subsystem and the identified functional failures. Thus, only the components whose failure modes may result in the related functional failure were studied in FMECA (following stage of RCM).

FAILURE MODE, EFFECTS AND CRITICALITY ANALYSIS

The Failure Mode, Effects and Criticality Analysis – FMECA is a methodology that aims to investigate the components of a system in order to survey all the elements that may interrupt or degrade its operation.

In order to perform the FMECA it is required to identify the failure modes of all system components, so as to detect the causes and effects of failure modes.

At this stage, a compilation of failures already known by failure history was performed, made by the maintenance control database (SAP-R3/PM) and by anomaly reports (defects fixed in preventive/predictive maintenance).

After the evaluation of FMECA results for each component it was then decided whether to use the corrective maintenance for the failure mode of the said component or if there will be the need to perform the next stage of analysis, called Task Selection.

TASK SELECTION

Maintenance tasks were defined the in order to solve each of the failure modes that have not defined their maintenance in the previous stage (FMECA).

To perform this step it was used the Decision Diagram shown in Image 6. Thus, it was determined the types of maintenance tasks used for the related failure modes.

Image 6. Decision Diagram - Task Selection
For each selected task, the costs of consumables, execution and HSE were calculated. The consumables costs were identified through the supply history. The implementation costs were calculated by estimating the run time, based on a similar Maintenance Orders (MO) history and Hour-man (HM) tax. The HM rate was calculated for Abraman professionals, and was driven off base salary of the Industry Workers Union of Duque de Caxias.

The HSE cost was included in the tasks to comprise the times in which performers carry out activities related to requirements of Health, Safety and Environment of the Company, as the issuance of Work Permits (WP), HSE Daily Debate, (HSEDD), etc. Therefore, 25% was added to the tasks execution times.

The commuting times were not considered in this study due to the proximity between the workshop and the pump yard.

**CONSOLIDATION OF MAINTENANCE PLAN**

Tables were created for each subsystem, including the description of the components, their criticality (a cross between failure probability and severity of effects), selected maintenance tasks, frequency of the labor and materials plans and costs.

Table 2 summarizes the total number of components that were classified for corrective maintenance, the number of components that had preventive maintenance tasks, and the number of preventive tasks set for the TECAM ORBEL II System.

**CONCLUSION**

The RCM implementation in pilot system TECAM ORBEL-II, using the software update MCCnet provided the maintenance plans in a more labor-saving way, including failure probability and the severity of the effects on safety, environment, production, financial and system availability.

Comparisons were made between the status BEFORE and AFTER the technique of the RCM in system TECAM ORBEL-II and the results obtained after the final analysis are shown in Tables 3, 4, 5 and 6, which present respectively the reduction in the amount of maintenance plans, the amount of Maintenance Orders created, the cost and amount of the used hour-man.

Table 2. Summary of the Number of Preventive Maintenance Tasks

<table>
<thead>
<tr>
<th>SUBSYSTEMS</th>
<th>Number of Components with Corrective Maintenance</th>
<th>Number of Components with Preventive/Predictive Maintenance</th>
<th>Number of Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Pumping</td>
<td>88</td>
<td>92</td>
<td>612</td>
</tr>
<tr>
<td>Auxiliary Pumping</td>
<td>10</td>
<td>24</td>
<td>260</td>
</tr>
<tr>
<td>Scraper</td>
<td>10</td>
<td>17</td>
<td>100</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>108</strong></td>
<td><strong>123</strong></td>
<td><strong>972</strong></td>
</tr>
</tbody>
</table>

Table 3. Reduction in the maintenance plans amount.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>BEFORE</th>
<th>PREDICTIVE</th>
<th>AFTER RCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRICAL</td>
<td>59</td>
<td>0</td>
<td>57</td>
</tr>
<tr>
<td>MECHANICAL</td>
<td>15</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>INSTRUMENTATION</td>
<td>3</td>
<td>78</td>
<td>30</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>103</td>
<td>110</td>
<td></td>
</tr>
</tbody>
</table>

-64.1%

Table 4. Reduction in the maintenance orders amount created.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>BEFORE</th>
<th>PREDICTIVE</th>
<th>AFTER RCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRICAL</td>
<td>49</td>
<td>0</td>
<td>47</td>
</tr>
<tr>
<td>MECHANICAL</td>
<td>15</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>INSTRUMENTATION</td>
<td>33</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>97</td>
<td>37</td>
<td></td>
</tr>
</tbody>
</table>

-23.4%

Table 5. Reduction in the maintenance plans cost.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>BEFORE</th>
<th>PREDICTIVE</th>
<th>AFTER RCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELECTRICAL</td>
<td>R$ 21,162.2</td>
<td>R$ 0.0</td>
<td>R$ 20,204.1</td>
</tr>
<tr>
<td>MECHANICAL</td>
<td>R$ 1,471.3</td>
<td>R$ 0.0</td>
<td>R$ 1,471.3</td>
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<tr>
<td>INSTRUMENTATION</td>
<td>R$ 366.0</td>
<td>R$ 0.0</td>
<td>R$ 366.0</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>R$ 23,000.0</td>
<td>R$ 0.0</td>
<td>R$ 23,000.0</td>
</tr>
</tbody>
</table>

-9.6%

Table 6. Reduction of the amount of hour-man used
Moreover, the planning of multidisciplinary maintenance plans in a more organized, streamlined and labour-saving way led to reduction of the times of intervention in the system, to the availability increase and hence to prevent the loss of profit economy.

Finally, we conclude that the reduction of maintenance costs at 9.6%, the benefits from preventing loss of profit and increasing the reliability of the single supply system of a refinery of great relevance within the domestic market, associated with the low cost of implementation, by using its own maintenance engineering staff, have turned the RCM technical application more feasible and effective.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>PLAN ANNUAL HR</th>
<th>BEFORE</th>
<th>AFTER RCM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PREVENTIVE</td>
<td>PREDICTIVE</td>
<td>PREVENTIVE</td>
</tr>
<tr>
<td>ELECTRICAL</td>
<td>688.0</td>
<td>0.1</td>
<td>222.0</td>
</tr>
<tr>
<td>MECHANICAL</td>
<td>625.5</td>
<td>0.1</td>
<td>210.0</td>
</tr>
<tr>
<td>INSTRUMENTATION</td>
<td>445.1</td>
<td>0.1</td>
<td>978.0</td>
</tr>
<tr>
<td></td>
<td>1,455.0</td>
<td>0.1</td>
<td>1,252.0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1,313.7</td>
</tr>
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NOMENCLATURE

RCM - Reliability Centered Maintenance;
WG - Working Group;
TECAM - Campos Elíseos Terrestrial Terminal;
FMECA - Failure Mode, Effects and Criticality Analysis;
ORBEL II - Pipeline Rio-Belo Horizonte II;

ACKNOWLEDGMENTS

The author would like to acknowledge the contributions of Maintenance Engineering Team of Transpetro and Prof. Eduardo Seixas.

REFERENCES