A Method to Optimize the Overall Equipment Effectiveness

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Abstract: Total Productive Maintenance (TPM) is a relatively new concept implemented in Romanian enterprises. This paper presents a method to optimize the most important indicator of the TPM concept: Overall Equipment Effectiveness (OEE). A real case study of implementing the proposed method is presented at the end of the paper.

1. INTRODUCTION

In a manufacturing and assembly enterprise, the production department uses the equipment to manufacture various products from raw material and parts bought from suppliers. In a usual industrial scenario there are inherent wastes of materials and time. There are also other “invisible wastes” such as operating the machines below the nominal speed, start up times, break downs of the machines and bottlenecks. The maintenance department has a key role so as to ensure the continuous production flow by up-keeping the equipment at its normal functioning state. The concept of Total Productive Maintenance (TPM) has been adopted in many industries across the world to address the above said problems (Venkatesh, 2006).

This paper is organized as it follows: first a brief presentation of the TPM concept is done. Principles and characteristics of the TPM are presented. In the next section the calculus of some important TPM parameters is given, emphasizing the role of managing their values during the manufacturing process. A method to optimise and control one of the most important indicators (Overall Equipment Efficiency – OEE) is presented in the third section. A case study and its implementation is presented in the last section. Real data is taken from ARCTIC Gaesti, a domestic appliances enterprise.

2. TOTAL PRODUCTIVE MAINTENANCE

Total Productive Maintenance (TPM) is a maintenance program, which involves a newly defined concept for maintaining plants and equipment. It can be considered as the “medical science” of industrial machines (JIPM, 2002). The goal of the TPM program is to keep emergency and unscheduled maintenance times to a minimal value, to increase production while increasing and job satisfaction.

TPM is an innovative Japanese concept. Toyota group became the first company to obtain the TPM certification. However the concept of preventive maintenance was born in USA. Preventive maintenance as concept was introduced in 1960 is when operators produced goods using machines and the maintenance group was given the task of maintaining those machines. Then automation was introduced in manufacturing process, so more qualified maintenance personnel was needed. Then the concept of Autonomous maintenance emerged. This maintenance is made by the operators on their own machines. The maintenance crew proceeds in the equipment modification for improving reliability. The modifications were incorporated in new equipment. This led to maintenance prevention. Thus preventive maintenance along with maintenance prevention and maintainability Improvement gave birth to productive maintenance. The aim of productive maintenance is to maximize plant and equipment effectiveness.

The three types of manufacturing approaches are represented in the figure 1.

Fig. 1. Manufacturing techniques (Rich, 2002)

In this paper, the TPM approach is taken into consideration. The targets of TPM are to: a) maintain an accident free
environment, b) enhance the machine efficiency towards 100%, c) reduce manufacturing wastes and costs, d) deliver the goods in time to clients, and e) develop multi-skilled workers. The five principles of TPM are (McCarthy and Rich, 2004):

1. Adopting improvement activities designed to increase the overall equipment effectiveness;
2. Improving existing planned and predictive maintenance systems;
3. Establishing a level of self-maintenance and cleaning carried out by highly trained operators;
4. Increasing the skills and motivation of operators and engineers by individual and group development;
5. Applying early management techniques to create reliable and safe equipment and processes.

These principles are supported by seven corresponding planned maintenance steps meant to guide the standardization and simplification of maintenance activities (Tajiri and Gotoh, 1999). This stepwise process has the effect of raising the capability of production, maintenance and supervision and of releasing specialist resources to focus on the next development stage. That is process optimization, a key part of the active maintainer’s role once breakdowns are brought under control. The designer of an industrial process has to take into account in his activity the prerequisites demands of the maintenance steps (Patic and Pascale, 2010).

3. OVERALL EQUIPMENT EFFECTIVENESS

Overall Equipment Efficiency (OEE) is used as an indicator of how well equipment is used in batch production. This parameter is obtained in relation to losses that can impede the equipment efficiency. Generally, the OEE of a plant before the introduction of the TPM concept was 40% or, at most, 60%. After implementing the TPM techniques, this indicator arose to 90% even to 100% in some cases. A schema of the OEE calculus is given in the figure 2 (Mainea, 2006).

OEE is a quantitative indicator. It is the product of the availability, performance, and quality of the equipment.

\[
\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}
\]

Availability indicates the performance of the Maintenance Department and its value is given by the equation (1).

\[
\text{Availability} = \frac{\text{actual run time}}{\text{planned run time}} \times 100
\]

Where

actual run time = planned run time - idle time

Performance indicates the operator’s performances and the way the equipment is used:

\[
\text{Performance} = \text{speed operating rate} \times \text{net operating rate} \times 100
\]

Where

\[
\text{speed operating rate} = \frac{\text{standard cycle time}}{\text{real cycle time}} \times 100
\]

\[
\text{net operating rate} = \frac{\text{number of products} \times \text{standard cycle time}}{\text{actual run time}} \times 100
\]

Quality indicates the capability of the process:

\[
\text{Quality} = \frac{\text{quantity produced right}}{\text{quantity produced}} \times 100
\]

4. A METHOD TO OPTIMIZE THE OEE

In the next section the following notations are used:

\[
\begin{align*}
& m \quad \text{number of workstations} \\
& n \quad \text{number of tasks} \\
& i \quad \text{index of an operation/task} \\
& j \quad \text{index of a workstation} \\
& t_{ij} \quad \text{cycle time} \\
& t_j \quad \text{operational disassembly time of the task } j \\
& X \quad \text{tasks possible assignment matrix} \\
& Y \quad \text{tasks effective assignment matrix} \\
& F \quad \text{objective function} \\
& T[n] \quad \text{operational times array} \\
& W_j \quad \text{workstation } j 
\end{align*}
\]

Where

\[
X(i, j) = \begin{cases} 
1 & \text{if task } i \text{ can be allocated to station } j \\
0 & \text{elsewhere} 
\end{cases}
\]

\[
1 \leq i \leq n \\
1 \leq j \leq m
\]

In the equation (3) given above, if the real cycle time is minimized, then the speed operating rate increases so the value of the OEE goes towards a maximal value.

Hence, the objective function of our optimization problem is

\[
F(t) = \min (\text{real cycle time})
\]
In (Duta, 2006a; Duta et al, 2008), the cycle time is the maximal sum of the operational times:

\[ t_{cy} = \max_{j \in \text{tasks on } W_j} \sum_{i} t_i \]  

(7)

Merging equations (6) and (7), the objective function is:

\[ F(t) = \min_{j \in \text{tasks on } W_j} \sum_{i} t_i \]  

(8)

The minimum value of this function is obtained when the manufacturing line is balanced (Duta et al, 2006b)

5. CASE STUDY

The present study is made on a line of five workstations performing ten different operations, whose operational times are given. The line is supposed to work in continuous flow, the times are deterministic and the production is flow shop.

The optimisation problem consists in calculating the minimal cycle time from the objective function F (equation (8)) taking into account the four linear constraints below. The input size of the problem is the length of a binary representation of the problem data.

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>7 Major Lost</th>
<th>Calculating the overall equipment effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading Time</td>
<td>1. The equipment failure</td>
<td>Availability = [(Loading Time – Idle time) \times 100] / Loading Time</td>
</tr>
<tr>
<td>Operating Time</td>
<td>2. Settings and adjustment</td>
<td>Availability = \frac{400}{470} \approx 85%</td>
</tr>
<tr>
<td>Net Operating Time</td>
<td>3. Changing tools</td>
<td>Performance Rate = Speed</td>
</tr>
<tr>
<td>Quality operation Time</td>
<td>4. Starting transitory regime</td>
<td>Operating Rate \times Net operating rate</td>
</tr>
<tr>
<td>Performance availability</td>
<td>5. Minor interruptions and idly functioning</td>
<td>Performance Rate = 85 % \times 90 % = 76.5 %</td>
</tr>
<tr>
<td>Performance</td>
<td>6. Speed</td>
<td>Products Quality Rate = [(Number of units of processed product-Number of product units with deficiencies) \times 100] / Number of units of processed product</td>
</tr>
<tr>
<td>Defects and rehabilitation</td>
<td>7. Defects and rehabilitation</td>
<td>Products Quality Rate = \frac{432}{450} \approx 96%</td>
</tr>
</tbody>
</table>

Overall Equipment Effectiveness (OEE) = Availability \times Performance Rate \times Product quality Rate

Overall Equipment Effectiveness (OEE) = 85 \% \times 76.5 \% \times 96 \% = 62.4 \%

Fig. 2. OEE calculus example

### a. The non divisibility constraint

Every task is performed on a single workstation. A task cannot be divided between workstations.

\[ \sum_{i=1}^{n} Y(i,j) = 1 \quad \forall i = 1..n \]  

(9)

### b. The precedence constraint

\[ Y(i,j) \leq X(i,j) \quad \forall i = 1..n, \forall j = 1..m \]  

(10)

### c. Time constraint

The cycle time is an upper bound on the workload assigned to each workstation.

\[ \sum_{j=1}^{m} T(j) \times X(i,j) \leq t_{cy} \quad \forall i = 1..n \]  

(11)

### d. Real assignment constraint

\[ Y(i,j) \in \{0,1\} \quad \forall i = 1..n, \forall j = 1..m \]  

(12)
Let us consider the following numeric values:

\[ m=5, n=10 \]

The possible assignment matrix is

\[
X = \begin{pmatrix}
1 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\
0 & 1 & 1 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\
1 & 0 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\
0 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 0 & 1 \\
0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 & 1 & 1
\end{pmatrix}
\]

The array of the operational times (minutes) is given below:

<table>
<thead>
<tr>
<th>Wi</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>T[n]</td>
<td>38</td>
<td>10</td>
<td>8</td>
<td>26</td>
<td>13</td>
<td>18</td>
<td>25</td>
<td>9</td>
<td>15</td>
<td>30</td>
</tr>
</tbody>
</table>

The simulation was performed on an Intel Core 2Duo T7500 2.2 GHz Processor with a RAM of 2 GB.

6. IMPLEMENTATION

The proposed method was implemented in the Romanian enterprise ARCTIC Gaesti, a domestic appliances manufacturer.

Here, the TPM concept was implemented with success since 2004. This was created by the Japan Institute Plant Maintenance and implemented with the help of a Japanese consultant. The system’s concept is “zero losses” and it correlates the augmentation of the production capacity with the costing diminution.

The values of the necessary parameters to calculate the OEE are registered on line in Excel files like the one presented in the figure 3. These parameters are considered input data for our optimization method.

Fig. 3. Registration of parameters of the line

Doruk Automation Enterprise from Turkey has implemented a monitoring system to supervise all steps of the production line.

A computerized system monitors the work on line and displays the values of OEE for each workstation in real time. Integrating our method in the informational system gives the possibility to control the assignment of the tasks on the workstation and to increase the values of the OEE to 100% which is the maximal performance of the equipment.

Figures 4 and 5 are photos of the real time parameters displayed by the Doruk system. Values of different OEEs are shown in figure 4. They are displayed in the same time on the computer and on the monitoring panels from the section walls.
7. CONCLUSIONS

An optimization method for the Overall Equipment Effectiveness maximization, the most important indicator of the Total Productive Maintenance (TPM), was presented in this paper. The proposed method is applied in the case of refrigerators assembly when the operational times are known and deterministic. When perturbations appear in the system one has to deal with stochastic operational times and other optimization methods have to be applied as heuristics or stochastic algorithms (Duta and Addouche, 2007).

TPM is a new manufacturing approach implemented in Romania and the results in increasing the productivity are over the expectations.

One of the first Romanian enterprises that implemented this concept is ARCTIC Gaesti which is now at the third stage of the TPM implementation concept.

Our work aims to find new methods to apply the TPM concepts on a balanced assembly line. In this way, the productivity of the line as well as its maintenance is maximized.

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