PERFORMANCE IMPROVEMENT USING ANALYTICAL HIERARCHY PROCESS AND OVERALL EQUIPMENT EFFECTIVENESS (OEE): CASE STUDY

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Abstract

Improving productivity using an efficient measurement approach is essential for any manufacturer. One of the most used approaches that significantly value the current situation is overall equipment effectiveness (OEE) by intending to reduce breakdowns to increase the performance. Underutilized machinery, over-utilized machinery, and poor maintenance are leading to waste of the company's resources. In this case study, a comprehensive analysis has been conducted that never been done in the company to ensure a high utilization rate. It has been observed that some of the machines in the production line are idle and unused. The main objective of this research is to improve the productivity of one of the manufacturers of a concrete pole by determining the current Overall Equipment Effectiveness (OEE) value of the most critical machines in the production line, analyse the causes of losses. To achieve the objective, the following three steps were conducted: (i) data collection and analysis, (ii) collection of in-depth information about the raw material and the production line using visual investigation, history, and (iii) in-depth interview with the key stakeholders in the company. A nine-metre concrete pole production line was selected to conduct the study. The research is focused on to identify the most critical machines on the production line. Those machines were selected by using multi-criteria decision-making method Analytical Hierarchy Process (AHP). Three consecutive steps were conducted: computing the vector of criteria weights, computing the option scores’ matrix, and ranking the options. Six alternatives were considered. In AHP calculations, four machines were selected to perform this study: top cage machine, wire cage machine, wire straightening machine, and concrete pump injection machine. Rank number one is the highest percentage of 32.9%, which is a frequent breakdown. The second highest rate is 29.4%, which is machine that are producing primary parts of the final product. The third-highest percentage is 22.4%, which are the machines that have historical production data. The OEE for the selected machines was conducted by calculating the quality level, performance, and availability. The result shows that the wire straightening machine's performance score was satisfactory with OEE of 85.17%. In contrast, the wire caging machine, top caging machine, and the concrete pump injection machine were found to have unsatisfactory OEE scores of 54.3%, 15.37%, and 68.84%, respectively. As a result, OEE can drive the company improvement by providing a better understanding of the losses that give a real metric to improve productivity and better utilization for the company resources.

Keywords: AHP, Manufacturing sector, OEE. Productivity.
1. Introduction

Productivity is considered one of the most effective technical efficiency measures in any production line [1]. It is a measure of efficiency considers the value of output in relation to the cost of inputs used. Increasing productivity means an increase of output by less input utilization. Based on cost-effective, productivity can be defined as the ratio of outputs to the inputs as Eq. (1) [2]. This cost-effective system for adding values to the inputs to create outputs can be presented in Fig. 1 [2]. However, Eq. (2) is normally used for measuring productivity in automated production lines [2].

\[
\text{Productivity} = \frac{\text{Goods produced}}{\text{Input used}} \tag{1}
\]

\[
\text{Productivity (Q)} = \frac{\text{Number of parts produced}}{\text{time for production}} \tag{2}
\]

![Fig. 1. Cost effective system [2].](image)

Many researchers used different techniques to improve productivity [2-7]. Hussain [2] has developed a new novel productivity model using an integrated approach of DAMIC and PACE techniques. His result shows high accuracy with only 3.3% errors in productivity estimating as compared to real productivity level. Hussain [3] optimized the productivity using 5S and Kaizen approach by trying to eliminate the rejection frequency. Hussain [4] showed a different approach to
improving the production rate. He used statistical data analyses to establish an appropriate model.

Singh et al. [5] investigated the effect of lean manufacturing approach in improving the productivity using a questionnaire survey in collecting data to evaluate the performance of different lean manufacturing tools on productivity improvement. Yemane et al. [6] used an integrated approach by combining manual line balancing techniques with computer simulation to find the optimal solution in productivity. Khan et al. [7] preferred to use DMAIC as a continuous improvement tool in productivity improvement. However, one of the most essential and efficient technique is named: Total Preventive Maintenance (TPM).

Nakajima, in the 1980s, has introduced TPM concept that provided a quantitative metric Overall Equipment Effectiveness (OEE) for measuring the productivity of individual equipment in a factory [8, 9]. Ishigame [10] defined the OEE for any process is a result of breaking the process down into three constituent components: availability, performance, and quality.

TPM is a maintenance program with the concept for maintaining plant and working the equipment effectively [11]. TPM aims to maximize the OEE by establishing a comprehensive preventive maintenance system for the whole life span of the equipment, involve activities like make plans, use and maintaining equipment by involving all departments, participation of all employees from the top to the bottom is vital in TPM, and promotes preventive maintenance through supportive management such as through small group activities [12, 13]. TPM seeks to minimize all the potential losses in the production and to operate the equipment with full design capability. Those losses as mentioned by many researchers as the big six losses [14-19]. Of the 6 main losses grouped into 3 namely downtime losses, speed losses, quality losses [20]. However, the six big losses of TPM are classified into six major categories namely: breakdown losses, setup and adjustment losses, defect and rework losses, start-up losses, speed losses, and idling and minor stoppage losses [21]. Figure 2 presents the six losses and it is related to the OEE with examples of causes.

Fig. 2. Hierarchical problem based on the six losses.
In OEE, the individual machine or equipment as part of a system should be operating as designed. However, downtime must be at a very minimum level [22]. OEE is an active production and maintenance tool that increases profits by bringing together the social and technical aspects [23]. OEE is an excellent way of measuring machinery utilization and evaluating machine performance.

Ishigame [10] defined the OEE for any process is a result of breaking the process down into three constituent components: availability, performance, and quality. He considered the OEE as a framework for measuring the efficiency and effectiveness of OEE. It is a useful tool for helping the management see and measure the problems to be fixed. OEE has been used widely in the manufacturing sector to determine productivity at the machinery level [24].

Raguram [25] claims that one of the best practices in manufacturing is by measuring OEE because companies could identify losses and improving the productivity of manufacturing equipment. OEE is a hierarchy of metrics to measure machine performance in any manufacturing industry. The measurement of OEE is inspired by the Total Productive Maintenance (TPM), which has been used as a critical machine performance technique that measures availability, performance, and quality rate [26]. OEE is a practical and straightforward, powerful calculation tool. OEE focused on the most common sources of manufacturing productivity losses and categorized them into three understandable categories, which are availability, performance, and quality [27]. By doing so, it simplifies the complexity of the problem into more straightforward and more understandable measures.

Some researchers found that integrating Value stream mapping (VSM) and OEE can give a good improvement in the production line. Shakil and Parvez [28] used the Value stream mapping (VSM) to improve the OEE in a sewing line industry. The results show an improvement of OEE from 45 to 53.75%. Dadashnejad and Valmohammadi [29] attempted to discover the relation between VSM and OEE using a structured questionnaire. The results show that the OEE metric is positively significantly influenced through identified improvements of VSM.

Tsarouhas [30] studied a croissant production line, and to measure the OEE characteristics. He claims that OEE is a useful guide to aspects of the production process, which identifies the critical points of the production line that needs more improvement using an effective maintenance strategy. Tsarouhas [31] analysed an ice cream production line and improved the overall equipment efficiency (OEE) by identifying significant stoppage losses using a TPM approach. Musa et al. [32] investigated the effect of Autonomous Maintenance (AM) implementation in the CNC machine at the automotive components manufacturing line on OEE. The result shows a significant improvement from 65.8% to 80.4%.

Tomar and Soni [33] measured the (OEE) for a plastic moulding machine in the automobile industry in terms of availability, performance, and quality and identified significant productivity losses. Their study was measured and identify downtime, speed loss, and quality loss. Responsible main factors that affect those losses were measured and identified. The OEE was 59.88% of production. This value is below the standards (85%) due to the considerable change over time.

Singh and Narwal [34, 35] examined the OEE concepts in different lines and took up the availability, performance, and quality. They found that minimizing the breakdowns, changeovers losses, defects, and setup scraps losses will lead to
increased OE. Shah et al. [36] tried to investigate OEE's improvement for a bending machine and labour productivity of the header machine shop. The researchers used the cellular layout technique at a boiler manufacturing organization. Nallusamy et al. [37] conducted TPM to improve OEE to meet the global standard. They found that not only the downtime losses are the influencing parameter, but the idle time of a machine is also another factor. The examined results showed that the percentage of OEE could be improved from 55.45% to 68.04% by implementing this technique.

TPM is manufacturing excellence based on eight pillars with the foundation of 5S [38]. They tried to prioritize the eight TPM pillars, terms of four significant parameters productivity, cost, quality, and delivery in time. The eight pillars are continuous improvement, do the necessary calibration, plan periodical maintenance, upgrade the skills and knowledge, work with suppliers to improve the design, use 5M to aim for zero defect, proper administration system, and improve work environment aiming for zero accident [39].

However, to select the most critical machine that need to be evaluated is a difficult and complex procedure. Therefore, selecting the best method become one of the main success factors to manufacturers. Thus, a multicriteria decision making methods (MCDM) will be useful and effective. MCDM included both factors of quantitative and qualitative which considered as a complex decision-making tool, making it the most widely used and favourable decision methodologies in many fields Mardani et al. [40] in their valued review, they covered the period from 2000 to 2014 by discussing the different methods in decision making and their application. They identified various methods in multi-criteria decision making that have been used and applied by different researchers in different sectors that need to decide such as machine selection. Those methods are Multi-Attribute Utility Theory, Analytic Hierarchy Process (AHP), Fuzzy Set Theory, Case-Based Reasoning, Data Envelopment Analysis, Simple Multi-Attribute Rating Technique, Goal Programming, ELECTRE method, Simple Additive Weighing, and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). However, in this research the AHP method was used to reduce the number of machines under investigation.

OEE enhancement is a continuous improvement cycle that need to be a part of the production activities. This cycle can use different approaches in the analysis or in the decision making. However, the suggested steps that the organizations need to follow is shown in Fig. 3.

![Fig. 3. Proposed steps for OEE enhancement procedure.](image)

Finally, in the above discussion, it can be recognized that many researchers have applied OEE as a part of the TPM approach to improve productivity in different types of industries and sectors. Few of them tried to use the OEE to recognize the unused capacity and highlighted the advantages of using this approach by identifying the weakness of the capacity used. In this research, OEE approach is
used to analyse and optimise the whole manufacturing processes for concrete electric pole. The novelty of this research is in terms of applications.

2. Methodology

The research was conducted based on structured steps, as shown in Fig. 4. The data collected give in-depth information about the raw material used, machines, how they are processed, and the quantity needed to produce the 9.0 m concrete pole. The research is focused on the critical machines on the production line: wire machines, concrete injection pump machine, spinning machine, rivet head machine, pole pushing machine, and pole pulling machine. And then, using (AHP) method as one of the multi-criteria decision makings, the most critical ones were selected. The OEE for the selected machines was measured by three evaluating measures: quality, performance, and availability.

![Fig. 4. Main steps for the research.](image)

The information gathered was in two directions: machinery and human resources. Visual investigation and cycle time measurement had been made to identify the current OEE value and identify the source of losses from the OEE that has been calculated. It is essential to measure the machinery and human resources' current utilization rate. OEE is a framework for measuring the efficiency and effectiveness of a machine by breaking it down into three constituent components. OEE is consisted of 6 metrics which often referred to as the hierarchy of metrics which are [25]:

i. **OEE**: the method of determining and measuring how well a unit performs when it is operational, in comparison to how it ought to perform.

ii. **Total Effective Equipment Performance (TEEP)**: the second metric which measures the OEE set against time.

iii. **Loading**: part of TEEP representing the amount of time that machines are in operation.

iv. **Availability**: uptime or the time when the equipment is available to operate. The availability is calculated by Eq. (3) [12].

$$ Availability = \frac{Required\ availability - Downtime}{Required\ availability} \times 100\% \quad (3) $$

v. **Performance**: the speed at which the production machine operates in a % form of the machine's capacity. Eq. (4) is the performance Formula [9].

$$ Performance = \frac{design\ cycle\ time \times \ Output}{operating\ time} \times 100\% \quad (4) $$
Quality: number of good parts or products with no defects. Equation below is the equation of quality Eq. (5) [12].

\[
\text{Quality} = \frac{\text{Output} - \text{Rejected}}{\text{Output}} \cdot 100\% \tag{5}
\]

OEE takes a manufacturing machine and break down into three components which are availability, performance and quality. Each of the components involved in OEE will highlight any aspect of the manufacturing process where improvements can be made and where output produced is not in a good quality. OEE can be calculated using the formula Eq. (6) [12]:

\[
\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \tag{6}
\]

Another important measure that was needed is the Cycle time. Cycle time refers to time taken to produce one part or product. To get a more accurate data, the average of three measurement have been conducted.

OEE have benchmark so that any manufacturing company can easily set a benchmark of OEE to be followed. Below are the lists of commonly used OEE benchmarks [41]:

i. OEE percentage of 100% is a perfect production in which only good products are produced with no stop time.

ii. OEE percentage of 85% can be considered as a world class for discrete manufacturers. For most of the companies, it is a suitable for achieving long-term goal.

iii. OEE percentage of 60% is typical for discrete manufacturers but indicates there is substantial room for improvement.

OEE percentage of 40% is common for most of manufacturing companies that are just starting to improve their manufacturing performance. It is a low score but, in most cases, can be improved through straightforward measures for example by tracking stop time and addressing the largest sources of down time, one at a time.

3. Data Collection

The main product of this company is the pre-stressed concrete pole for electrical use. The company has three main products: a 10-meter pole of 5.0 kN, a 9-meter pole of 2 kN, and a 7.5-meter pole of 2 kN. In this research, the 9-meter pole of 2 kN was selected to conduct the study due to the high demanded than other products.

The basic dimensions for selected concrete pole are 9000 mm of length, top diameter of 140 mm, bottom diameter of 260 mm with wall thickness of 33mm. The total weight of the pole is about 410 kg. Figure 5 shows the product shape and dimensions. All the machinery used is semi-automated and human intervention is needed at each workstation. The production line use cranes, forklift, and conveyor as material handling equipment.

![Fig. 5. Schematic diagram of a concrete electric pole (dimensions are in mm).](image-url)
Data collection is a systematic process that gathers and measures information on the area of the research. A step by step of data collection for this research has been identified as follows:

1. Identification of process involved and components of the 9.0 m concrete pole by plotting the flow diagram,
2. Record the names of the machines used to produce 9.0 m concrete pole, and
3. Selection of the most suitable machine to perform the study based on AHP method to give priority for the study.
4. Analysing the availability, performance and quality level for each machine
5. Determine the OEE level of each machine.
6. Propose suitable solutions.

The flow of the process is crucial to determine the operations and machines used to produce the product. The researcher needs to identify all the processes involved in the production line. The process involved in the production line of industrial company divided into seven main sections: Moulding section, concrete section, spinning division, steam curing section, demolding-1, demoulding-2 with inspection section and stacking section

However, there are sub-sections in each of the main sections, and one section might have several tasks and machines. The concrete pole goes through several operations of concrete injection, spinning, boiling, and assembling different parts. All the machines involved in the production line of the company were identified with all the processes required to produce the 9.0 m concrete pole, thus develop a production process flowchart, as shown in Fig. 6. All the processes involved were recorded by using the camera to understand the process and machines required carefully. The final product is as shown in Fig. 7.
After analysing the production process, all the machines and material handling equipment used in all the sections were identified. Figure 8 shows the list of all machines used in each section.

Fig. 8. Machines and material handling equipment used in each section.

However, not all the machines used in the production line are problematic. The focuses are on the machines that face problems like frequent breakdown, underutilized, need to be handled by skilled operators and more. However, after visual analysis and deep discussion six machines were involved in the study wire machine, concrete injection pump machine, spinning machine, rivet head machine, pole pushing machine and pole pulling machine. Table 1 shows the machines taken as part of this research.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Name of the machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mc1</td>
<td>Wire Machine</td>
</tr>
<tr>
<td>Mc2</td>
<td>Concrete injection pump machine</td>
</tr>
<tr>
<td>Mc3</td>
<td>Spinning machine</td>
</tr>
<tr>
<td>Mc4</td>
<td>Rivet head machine</td>
</tr>
<tr>
<td>Mc5</td>
<td>Pole pushing machine</td>
</tr>
<tr>
<td>Mc6</td>
<td>Pole pulling machine</td>
</tr>
</tbody>
</table>

4. Machine Selection

In this research, the Analytical hierarchy process (AHP) technique used to define the most critical machine to perform the study. AHP, was developed in 1971 by Saaty [42] that matches the product characteristics with the supplier’s characteristics, considering multi criteria in one decision, especially when both quantitative and qualitative factors are involved. It helps to assign weights for the selected criteria, and to structure the problem in a hierarchical way, dividing it to
many levels (at least three levels: the goal, the criteria, and the possible suppliers), then to make the integration between these levels. AHP is one of the practical tools that can help in the complex decision-making process. It can improve the decision-makers set priorities and make the best decisions [33]. The AHP considers a set of evaluation criteria and alternative options among which the best choice is to be made. The AHP generates a weight for each evaluation criterion according to the decision-maker’s pairwise comparisons of the criteria. The higher the weight means, the more critical the corresponding criterion and priorities must be on the criteria with high weight. Next, for a fixed criterion, the AHP assigns a score to each option according to the decision-maker’s pairwise comparisons of the options based on that criterion. The higher the score means, the better the option's performance concerning the considered criterion. Finally, the AHP combines the criteria weights and the options scores, thus determining a global score for each option, and a consequent ranking.

Three key persons from the company were selected and interviewed to obtain accurate information from the respondents regarding machinery used in the production line. Five criteria were defined to choose the critical machine to conduct this study which are historical data, producing original parts, frequent breakdown, skilled operator, and high rejected parts. The first step is to establish the hierarchy, which is similar to the decision tree with three levels: the goal, the criteria, and the alternatives, the available (alternatives) machines are located at the last level of the hierarchy. Figure 9 illustrates the three basic levels of each AHP hierarchy.

The pairwise comparisons between each two elements in the same level, considering the parent element which is from the upper level. In such a way, these comparisons will cover all the possible combinations that can be done between the elements. A set of matrices depending on each group comparison, this matrix will lead to the final selection of the machine. The last step is to compute the numerical comparison between all the decision alternatives. By comparing the numerical values coming from the matrices' calculations, considering the criteria importance values (weights). The machine which will get the highest ranking among all is the one that have to be selected.

Three AHP interviews using structured questionnaire were filled based on comments from three respondents chosen randomly to avoid the bias from the key members in the staff. The interview questionnaire were six sections that cover their opinion on following topics: problems often faced by machines, prioritizing the
problematic machines, criteria need to be considered to conduct the study, machines that need skill workers and complex maintenance requirements. The comparison between two elements using AHP can be done in different ways. However, the most used way is to compare the relative importance between two alternatives is Saaty scale as shown in Table 2 [42].

<table>
<thead>
<tr>
<th>Numerical:</th>
<th>9</th>
<th>8</th>
<th>7</th>
<th>6</th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale:</td>
<td>Extremely preferred</td>
<td>Very strong to extremely preferred</td>
<td>Very strong to strongly preferred</td>
<td>Strongly preferred</td>
<td>Moderately to strongly preferred</td>
<td>Moderately preferred</td>
<td>Equally to moderately preferred</td>
<td>Equally preferred</td>
<td></td>
</tr>
</tbody>
</table>

The odd numbers are mostly used, even numbers are used only when there is a need (even number is the middle point as negotiated solution when the consensus cannot be reached). The following steps were applied as an AHP methodology among a set of criteria:

Step 1. Lies in the determination of the criteria to be compared.

Step 2. Determining the Comparison Matrix, the Priority Vector, and the Inconsistency, following the Table 3.

Step 3. The comparison matrix must be normalized, by dividing each number by the sum of its column.

Step 4. The weight of each criterion is calculated by using the priority vector (Eigen vector). By calculating the average of each criterion (each raw).

Step 5. Calculation of the consistency index.

<table>
<thead>
<tr>
<th>Criterion 1</th>
<th>Criterion 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion 1</td>
<td>1</td>
</tr>
<tr>
<td>Criterion 2</td>
<td>1/ Numerical rating</td>
</tr>
</tbody>
</table>

The consistency calculation is to determine how consistent the decision is. It is totally related to transitive property. To make this idea clearer, assume that you have three statements, (A, B, and C), and an evaluation must be conducted among them. If the evaluator stated that he prefers A over B (A>B). And stated that he prefers B over C (B>C): So, when the evaluator is asked to compare between A and C: (Logically he must answer that he prefers A over C). If the answer received (A>C), then the decision can be confirmed as consistent, If the opposite, then the decision is inconsistent. A similar concept applied to the AHP criteria that are being compared.

In this case study a comparison matrix between the five criteria have been developed and the normalized by the comparison matrix has been normalized, by dividing each number by the sum of its column. Then The weight calculated by using the priority vector (Eigen vector). Figure 10 shows the AHP chart developed from the interview. The AHP is conducted in three simple consecutive steps: computing the vector of criteria weights, computing the matrix of option scores, and ranking the options. Figure 11. also shows the weight developed based on the AHP matrix for each criterion and each machine.
Fig. 10. Machine indicator for AHP.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequent breakdown</td>
<td>32.9%</td>
<td>1</td>
</tr>
<tr>
<td>Producing primary parts</td>
<td>29.4%</td>
<td>2</td>
</tr>
<tr>
<td>Historical data</td>
<td>22.4%</td>
<td>3</td>
</tr>
<tr>
<td>High rejected parts</td>
<td>9.8%</td>
<td>4</td>
</tr>
<tr>
<td>Skilled operator</td>
<td>5.5%</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 11. Weight and rank for each selection criteria.

The AHP chart shows that frequent breakdown is the highest percentage factor that needs to be considered to select the most critical machine and suitable machine to perform this study. The focuses are on the machine that has a frequent breakdown in comparison to another machine. Figure 11 shows the percentage of weight for each criterion tested and the rank of the machines according to the weight.

Rank number one is the highest percentage of 32.9%, which is a frequent breakdown. Frequent breakdown means that the machines are facing frequent failure in comparison to other machines. The second highest percentage is 29.4%, which is a machine that are producing primary parts fundamental elements of the final product. The third-highest percentage is 22.4% which are the machines that have historical production data. Next, the selection of machines is based on the most critical factor chosen earlier, based on the highest percentage of weight. From the calculations, Mc2 under the criteria of frequent breakdown has the highest percentage of 42.1%, followed by Mc1 23.9% and Mc3 16.1%.

5. OEE Calculation

The weight percentage for each machine was calculated as shown in Fig 10. The calculations show that the most critical machines based on frequent breakdown are Mc2, a concrete injection pump, and Mc1 Wire machines. There are three machines under the wire section: top cage machine, wire caging machine, and wire straightening machine. In conclusion, four machines were selected to perform this study: top cage machine, wire cage machine, wire straightening machine, and concrete pump injection machine. The OEE for the selected machines is listed in Table 4.
Table 4. Overall equipment efficiency calculations for four machines.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Concrete Pump Injection Machine</th>
<th>Top Cage Machines</th>
<th>Wire Caging Machines</th>
<th>Wire Straightening Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shift Time</td>
<td>540 min</td>
<td>540 min</td>
<td>540 min</td>
<td>540 min</td>
</tr>
<tr>
<td>2</td>
<td>Planned Downtime</td>
<td>130 min</td>
<td>130 min</td>
<td>130 min</td>
<td>130 min</td>
</tr>
<tr>
<td>3</td>
<td>Running Time</td>
<td>410 min</td>
<td>410 min</td>
<td>410 min</td>
<td>410 min</td>
</tr>
<tr>
<td>4</td>
<td>Unplanned downtime</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Machine breakdown</td>
<td>18 min</td>
<td>1.5 min</td>
<td>9.75 min</td>
<td>3 min</td>
</tr>
<tr>
<td></td>
<td>adjustments and Set-ups</td>
<td>102.5 min</td>
<td>41.67 min</td>
<td>27.5 min</td>
<td>10 min</td>
</tr>
<tr>
<td>5</td>
<td>Operating Time</td>
<td>307.5 min</td>
<td>366.83 min</td>
<td>372.75 min</td>
<td>397 min</td>
</tr>
<tr>
<td>6</td>
<td>Availability</td>
<td>75%</td>
<td>89.47%</td>
<td>90.91%</td>
<td>96.83%</td>
</tr>
<tr>
<td>7</td>
<td>Output</td>
<td>150 pole</td>
<td>250 cage</td>
<td>150</td>
<td>900 wire</td>
</tr>
<tr>
<td>8</td>
<td>Cycle time (min/ pole)</td>
<td>1.94 min</td>
<td>0.26 min</td>
<td>1.68 min</td>
<td>0.45 min</td>
</tr>
<tr>
<td>9</td>
<td>Performance</td>
<td>94.63%</td>
<td>17.71%</td>
<td>61.58 %</td>
<td>90.68%</td>
</tr>
<tr>
<td>10</td>
<td>Reject</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>Quality</td>
<td>97%</td>
<td>97%</td>
<td>97%</td>
<td>97%</td>
</tr>
<tr>
<td>12</td>
<td>OEE = A<em>P</em>Q</td>
<td>68.84%</td>
<td>15.37%</td>
<td>54.30%</td>
<td>85.17%</td>
</tr>
</tbody>
</table>

*A: Availability, P: Performance, Q: Quality

The calculated OEE values for four machines are being compared with the standard class value of OEE. An OEE value of 85% is considered as a world-class value [31, 43]. As discussed earlier, an OEE value of 100% is regarded as the perfect production. The production line is only producing the right parts with no reject, as fast as possible, and with no machine downtime. Meanwhile, an OEE value of 60% is the most common value for a manufacturing company, and there is substantial room for improvement for the machines.

Figure 12 shows the OEE value for four machines and comparison with an OEE value of 60% as it is a typical value for most manufacturing company. It is clear from Fig. 12 that two machines are not satisfying the common OEE value: top cage machines and wire caging machine. It is clear from Fig. 12 and Table 4 that two machines are not satisfying the common OEE value which are top cage machine and wire caging machine. The top caging and wire-gaging machines have a low OEE of 15.37% and 54.30%, respectively. The low value is due to the low-performance levels of 17% and 61.58, as shown in Table 4. Visual observations, root cause analysis, and cycle time analysis have been made to investigate the low-performance reasons. It was found that both machines are idle sometimes due to low in the daily demand, especially for the top cage machine. The causes of low OEE for top caging machine and wire caging machine were analysed and identified.

Fig. 12. OEE value for all the machines studied.
There are many rooms for improvement in the production line. However, the starting point should be from focusing on the top cage machine and wire caging machine due to the low performance of (15.37%) and (54.3%). Other measures for quality and availability considered acceptable except for the concrete pump injection machine with 75%. Based on this research findings the following suggestions are made to enhance the performance level of the top cage machine and wire caging:

- Implementation of total productive maintenance (TPM): TPM can be used to minimize the potential losses and to operate the equipment with full design capability using autonomous maintenance and preventive maintenance:
- Planned downtime is not part of the OEE calculations, but it can have a significant impact on the overall productivity. All activities that halt the production, such as equipment wash down, maintenance programs, and line changeovers, are an example of planned downtime. Another essential contributor to planned downtime is product changeovers. The company should not change parameters too often between product batches for the concrete pole are 7.5 kN, 9.0 kN, and 10.0 kN load capacity. Therefore, well planning for production is vital.
- Create performance evaluation daily or weekly to OEE provides a comprehensive and clear view of performance of machineries. OEE forces an organization to look at individual equipment and ensure that the maximum benefits obtained. OEE makes the manufacturing unit or piece of equipment visible, and it allows real in-depth analysis of how the group performs. For poor production output (<85%), the objective of evaluating machine performance is to calculate the actual versus planned production quantity of the day.

6. Conclusions
At the beginning of this research, information was extracted from journal, books and articles related to the topic. It was found that one of the main factors that greatly affected productivity in production line is the effective use of machinery and manpower. The efficiency of the most critical machines selected by using AHP technique at the production line Dalia Industries Sdn. Bhd. has been studied. This research showed that:

- For wire caging machine, the availability and the quality of the machines are found to be 90.91% and 97% respectively which is good and well performed. However, the only factor that affected the OEE score is performance which is only 61.58% and considered as weak in comparison with both availability and quality.
- For top caging machine, the availability and the quality of the machines are 89.47% and 97% respectively. In this case also, the performance score of 17.71% is extremely low in comparison with both availability and quality and remains as a critical concern.
- With the implementation of the suggested improvements, performance scores are expected to be increased and eventually increase the level of OEE to improve the productivity and eventually enhance company’s competitiveness in the market.
- In this research, the data collection and improvement activities have been compared for one month only due to some constraint from company. However,
it is recommended to evaluate the improvement for a period of at least three months. As a conclusion the objective of this case study has successfully completed for machine by collecting all the data for machine within this project.

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<table>
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<tr>
<th>Abbreviations</th>
<th>Description</th>
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<tbody>
<tr>
<td>5S</td>
<td>sort, set in order, shine, standardize, and sustain</td>
</tr>
<tr>
<td>AHP</td>
<td>Analytical Hierarchy Process</td>
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<tr>
<td>AM</td>
<td>Autonomous Maintenance</td>
</tr>
<tr>
<td>CNC</td>
<td>Computerized Numerical Control</td>
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<tr>
<td>DMAIC</td>
<td>Define, Measure, Analyze, Improve and Control</td>
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<tr>
<td>ELECTRE</td>
<td>Elimination Et Choix Traduisant la REalité (family of multi-criteria decision analysis methods)</td>
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<tr>
<td>MCDM</td>
<td>Multi criteria decision making</td>
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<tr>
<td>OEE</td>
<td>Overall Equipment Effectiveness</td>
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<tr>
<td>PACE</td>
<td>Primary, Alternate, Contingency, and Emergency</td>
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<tr>
<td>TPM</td>
<td>Total Productive Maintenance</td>
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<td>TEEP</td>
<td>Total Effective Equipment Performance</td>
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<tr>
<td>TOPSIS</td>
<td>Technique for Order of Preference by Similarity to Ideal Solution</td>
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<td>VSM</td>
<td>Value stream mapping</td>
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References


