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# The Overall Equipment Effectiveness (OEE) Calculation to Improve Productivity: A Case Study of a SME

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The Overall Equipment Effectiveness (OEE) metric is a useful tool to determine the total equipment effectiveness of machinery. In this case study, OEE measurement was applied to a small and medium-sized enterprise (SME) located in Riobamba-Ecuador. The study is analytic, deductive, and descriptive. An individual machine analysis was developed, focused on the Cincinnati Milacron injection machine. The purpose of this paper is twofold: a) to execute a literature review about the overall equipment effectiveness (OEE) understanding, calculation, and application in SMEs and its relationship with productivity, and b) to show a calculation method to obtain the OEE performance of an individual machine and to explain a way to improve productivity. For the first goal, an exhaustive literature review about the origin, the definition, the scopes, the calculation formulae of OEE were developed, likewise, implications of productivity in small enterprises were found. For the second objective, it was performed a deductive analysis by comparing the current OEE level to the world-class obtaining: in availability, current ratio (77.78%) – world-class ratio (90%), performance efficiency, current ratio (71.94%) – world-class ratio (95%), and, in quality current ratio (90.03%) – world-class ratio (99.9%). This article might contribute to a theoretical and practical framework of OEE in small and medium manufacturing enterprises.

**Keywords:** Overall Equipment Effectiveness (OEE) – Small and Medium-Sized Enterprise (SME) – Productivity- Case Study.

## 1. Introduction

In management, SMEs must identify and control some factors such as operators, employees, raw materials, operation system, sources: time, and money. However, managers should pay special attention to the priorities in manufacturing industries. In fact, in most SME industries that depend on the accuracy of a single machine operation, factors such as the operation time of the machinery (availability), the speed applied to produce a single product (performance), and the quality of the product must be taken under control.

This is the case of Partiplast, a small enterprise located in Ecuador, its main activity comprises the production of plastic hangers through the injection process. Since the origin of the enterprise, the injection process has experienced some changes that impacted directly on its productivity.

In this case, the overall equipment effectiveness has been one of the most useful tools of production monitoring that the factory implemented. This measure helped to know the equipment performance to support the decision-making of production management. Its final goal was to establish improvement initiatives to prevent the sub-optimization of individual machines by achieving the optimum level of availability, performance efficiency, and quality (Dal et al., 2000).

The purpose of this paper is: a) to review previous evidence about the overall equipment effectiveness (OEE) to define the term, to know calculation methods for SMEs and its relationship with productivity. b) to calculate the Overall Equipment Effectiveness of the Cincinnati Milacron injection machine and evaluate results. To accomplish these goals, it was developed a literature review about OEE in small enterprises especially focused on case studies and productivity effects. And, an observational study was performed to gather data to calculate the OEE ratios of the individual machine.

## 2. Theoretical Framework

### 2.1 PRODUCTIVITY

This study refers to the analysis of productivity in manufacturing. According to Bellgran (2010), manufacturing companies need to be successful by offering innovative and high-quality products controlling lead times and designing flexible production systems to get conditions for operational excellence.

To control productivity, it is needed to identify problems and propose solutions to improve system performance (Braglia et al., 2008; De Ron & Rooda, 2005; Nachiappan & Anantharaman, 2006). Pritchard et al. (1988) state that productivity is the combination of efficiency and effectiveness. Similarly, Mouzas (2006) states that, in every organization that pursues economic revenue, efficiency, effectiveness, and productivity are measures to know the performance of the organization. However, managers need to distinguish between efficiency and effectiveness. A simple definition remarks that efficiency is “doing things right” and effectiveness is “doing the right things” (Drucker, 1999).

Trying to have a deeper insight into the two terms, it is explained that efficiency is maximizing outputs by minimizing the inputs. Therefore, it is the ability to do or produce something without wasting materials, time, or energy (Wilson et al., 2018). At the same time, effectiveness is the power to produce the desired results (Wilson et al., 2018). According to Zheng et al. (2010), effectiveness in organizations is the degree to which an organization realizes its goals.

To recap, effectiveness and efficiency are two mutually exclusive components of overall performance measure and they may influence each other. Thus, effectiveness can be affected by efficiency and, at the same time, have an impact on overall performance (Ozcan, 2008).

However, some authors agree that although productivity is broadly used, it is not well explained. Sumanth (1994) tried to be clearer and proposed a general definition of productivity by comparing outputs and inputs.

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

The formula appears to be simple, but in manufacturing industries, recognizing inputs and outputs could be a challenge because multiple inputs and outputs are needed to operate (Andersson & Bellgran, 2011). For Hill T. (1994) outputs can be goods and services produced; and inputs are labor, capital, material, and other resources.

## 2.2 OVERALL EQUIPMENT EFFECTIVENESS

Most studies focused on the so-called Six Big Losses (Badiger & Gandhinathan, 2008; Herry et al., 2018; Singh et al., 2021) to mitigate losses; others have an insight into Total Productive Maintenance (TPM) to maximize effectiveness (Espinoza Garcia, H., 2022; Gupta & Vardhan, 2016; Herry et al., 2018; Singh et al., 2021). Moreover, it was found some studies applied to individual machine equipment performance (Muchiri & Pintelon, 2008) and others use OEE in production lines (Nachiappan & Anantharaman, 2006; Tsarouhas, 2019). Also, some studies deal with productivity and OEE relationship (Gupta & Vardhan, 2016; Muchiri & Pintelon, 2008). But, to develop this study, case studies (Gupta & Vardhan, 2016; Muñoz-Villamizar et al., 2018; Tsarouhas, 2019) have been analyzed.

Regarding to OEE definition Tsarouhas (2019) states that throughout OEE, hidden costs related to the efficiency of the equipment can be discovered. According to Williamson (2006), the OEE measurement is the degree to which the equipment is doing what it is supposed to do. Singh et al (2021) note that OEE is an effective maintenance strategy, defining maintenance as the restoration or overhauling of the equipment. Its main objective is to measure performance, eliminate losses, predict errors, and process improvement activities (Andersson & Bellgran, 2015; Kumar et al., 2014).

Moreover, OEE is commonly linked to the Japanese philosophy of Total Productive Maintenance (TPM) since it is considered a key factor in determining the effectiveness of the means of production through the detection, control, and subsequent elimination of industrial losses related to stoppages, quality, and costs (Espinoza Garcia, H., 2022; Muñoz-Villamizar et al., 2018). Therefore, the OEE metric is part of TPM and measures the productivity of individual equipment in a factory, recognizing losses of manufacturing aspects: availability, performance, and quality rate (Muchiri & Pintelon, 2008; Sharmaa & Trikhab, 2011).

Because of its simple application, OEE is also commonly associated with small and medium enterprises of manufacturing and pretends to establish solution guides to improve equipment effectiveness (Muchiri & Pintelon, 2008; Muñoz-Villamizar et al., 2018; Singh et al., 2021; Tsarouhas, 2019).

### 2.2.1 The Sig Big Losses

There are multiple losses related to machinery, these losses are commonly originated because of performance, quality, and availability inefficiencies (Singh et al., 2021). Tsarouhas (2019) explains the 6 losses as follows:

Loss 1. Equipment failure losses: include failure nodes that stop the normal operation of the equipment and reduce its production rate.

Loss 2. Set up and adjustment losses: time losses that occur when production of one item ends and the equipment is adjusted to meet the requirements of another item.

Loss 3. Losses of minor stoppage and idle: occur when the production is interrupted by a temporary malfunction or when the machine is idling.

Loss 4. Losses of reducing speed: for the drop in speed from the nominal speed of the equipment.

Loss 5: Losses of defect: (rework) in process.

Loss 6. Reduce performance: losses of materials because of differences in the weight of input and output.

The same author refers to losses 1 and 2 as losses correlated to availability (A). Losses 3 and 4 are speed losses related to performance efficiency (P), and the last two losses are linked to the quality rate (Q)(Tsarouhas, 2019).

2.2.2 Calculation of OEE

It is difficult to determine a unique manner to calculate OEE because of the differences between industries (Jonsson & Lesshammar, 1999). However, according to (Nakajima, 1988), a typical manufacturing capability should have: Availability (A) > 0.9; Quality (Q) > 0.99; Performance (P) > 0.95. With these ratios, the final Overall Equipment Efficiency would be OEE > 0.85 for world-class firms (Jonsson & Lesshammar, 1999; Zuashkiani et al., 2011).

Figure 1. Overall Equipment Effectiveness Component


Source: Nakajima, 1988

According to Haddad et al. (2021), availability is based on operating time and downtime loss, which means that it is the real-time that the machine is running. Performance is the relation between what is produced and what is expected to be obtained, and quality is the relationship between the number of items in good condition and the number of items expected to be obtained Williamson R. (2006) states the formulae as follows:

Table 1. Calculation of Overall Equipment Effectiveness

| Factor | Calculation |
|---|---|
| Availability | $\frac{\text{Actual operating time}}{\text{Gross available time}} \times 100$ |
| Performance | $\frac{\text{Actual production rate}}{\text{Design production rate}} \times 100$ |
| Quality | $\frac{\text{Total units produced} - \text{Defective units produced}}{\text{Total units}} \times 100$ |
| OEE % | Availability % × Performance efficiency % × Quality rate % |

Note: Formulae to calculate OEE ratios.

Source: Williamson R, 2006.

World-class OEE

As previously mentioned, the OEE concept encompasses three components: availability, performance efficiency, and quality. Availability (A) > 0.9; Quality (Q) > 0.99; Performance (P) > 0.95 (Nakajima, 1988).

## 3. Method

This study has 3 main objectives. a) to execute a literature review about the overall equipment effectiveness (OEE) understanding, calculation, and application in SMEs. b) to show a calculation method to obtain the OEE performance of an individual machine, c) to evaluate some alternatives to improve SME's productivity. For the first aim, a revision of the literature about OEE metrics in SMEs was performed. For the second aim, data was collected by using observation worksheets and interview guides. Finally, to evaluate an improvement action that impacts on productivity rate, it was established a short analysis based on a technology changeover.

For a better understanding, each objective is going to be explained as a phase in which some actions were performed.

### 3.1 PHASE 1: TO STATE A LITERATURE REVIEW ABOUT THE OVERALL EQUIPMENT EFFECTIVENESS (OEE)

An exhaustive literature review analysis was performed to determine the main principles of Overall Equipment Effectiveness in manufacturing industries. Table 2 shows a summary.

Table 2. OEE Fundamentals by authors

| Conceptualization | Authors | Description |
|---|---|---|
| Understanding | Badiger & Gandhinathan, 2008; Herry et al., 2018; Singh et al., 2021; Tsarouhas, 2019. | Six Big Losses |
| | Espinoza Garcia, H., 2022; Gupta & Vardhan, 2016; Herry et al., 2018; Singh et al., 2021. | Total Productive Maintenance (TPM) to maximize effectiveness |
| | Muchiri & Pintelon, 2008. | Individual machine equipment performance |

| | | |
|---|---|---|
| Scope | Nachiappan & Anantharaman, 2006; Tsarouhas, 2019 | Production lines |
| Application in SMEs | Gupta & Vardhan, 2016; Muchiri & Pintelon, 2008; Muñoz-Villamizar et al., 2018. | Case studies<br>Relation OEE-productivity |
| Calculation | Jonsson & Lesshammar, 1999; Nakajima, 1988; Williamson R, 2006; Zuashkiani et al., 2011. | Calculation according to the industries.<br>Calculation for world-class firms. |

Note: Understanding, scope, application, and calculation of OEE.

Source: Above stated.

### 3.2 PHASE 2: EVALUATING THE CURRENT OEE RATIO OF THE INJECTION MOLDING MACHINE

Before calculating the OEE components, it is necessary to verify the main features of the subject of study - the Cincinnati Milacron injection molding machine described in Table 3.

Table 3. Main characteristics of the Cincinnati Milacron injection molding machine

| Machine features | Description |
|---|---|
| Plastic Processed | PP, PC, ABS, PET, PVC. |
| Screw | Screw Mixture with Nitrided Steel |
| Screw diameter | φ55 mm/26D |
| Motor | 25 HP |
| Injection capacity<br>Cylinder diameter | 600 gr/min 3 injection cycles<br>φ100~150mm |
| Controller | It consists of 6 microcontrollers, The power stage consists of transistors and contactors. |

Note: Description of the object of study.

For the OEE percentage calculation, it was used the formulas cited by Williamson R. (2006).

Table 4. Calculation of OEE - Cincinnati Milacron injection molding machine

| Factor | Formulae | Calculation |
|---|---|---|
| Availability | $\frac{\text{Actual operating time}}{\text{Gross available time}} \times 100$ | $\frac{315}{405} \times 100 = 77.78\%$<br>* in minutes |
| Performance | $\frac{\text{Actual production rate}}{\text{Design production rate}} \times 100$ | $\frac{1133}{1575} \times 100 = 71.94\%$<br>* number of hangers |
| Quality | $\frac{\text{Total units produced} - \text{Defective units produce}}{\text{Total units}}$<br>$\times 100$ | $\frac{1133-113}{1133} \times 100 = 90.03\%$<br>*number of hangers |
| OEE % | Availability % × Performance efficiency % × Quality rate % | 77.77 % × 71.9% % × 90 % = 50.37% |

Note: Ratios obtained with the calculation.

Source: Williamson R, 2006

### 3.2.1 Availability calculation

For availability calculation, it was performed an observation study for one month. Observational worksheets were used to gather data on losses of heating time, break time, and lunchtime. It is important to explain that the factory has only one operator who works 8 hours per day and due to the injection process needing the operator to enter the pellets in the cylinder and then to collect the final product (hangers), the process always requires the operator’s labor. The average of the data collected is shown in Table 5.

Table 5. Operation time of Cincinnati Milacron injection molding machine

| Equipment Losses | Gross available time | | Actual operating time | |
|---|---|---|---|---|
| | 60’ x 8 hours of workforce | 480’ | 60’ x 8 hours of workforce | 480’ |
| Heating time (to get the machinery ready) | LOSSES | ---- | LOSSES | 90’ |
| Break (operator’s resting) | | 15’ | | 15’ |
| Lunch-time (operator’s lunch) | | 60’ | | 60’ |
| TOTAL | | 405’ | | 315’ |

Note: Obtained by observation.

Table 5 shows a comparison between the operation time planned and the actual operation time, taking into consideration that the machine depends a lot on the operator’s work. Therefore, by applying the formulae stated above: actual operating time/ gross available time X 100, it is obtained 77.77% because of downtime losses especially to have the machine ready to produce (heating time: 90’)

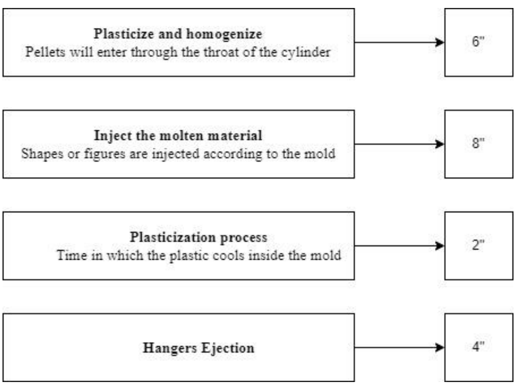
$$(A)= \frac{315}{405} \times 100$$

$$(A)= 77.78\%$$

### 3.2.2 Performance calculation

To determine the performance efficiency ratio (P), the speeding time was gathered according to each production process. In Figure 2, it could be observed the time in seconds for each production step.

Figure 2. Injection process



The injection process is explained as follows:

- Plasticize and homogenize: The plastic is placed in the hopper, normally it is granular (pellet) in the shape of a sphere or cube. In some cases, the pellets must be dried or dehumidified before using it.

- Inject the molten material: the operator adjusts the injection machine according to the specific parameters of the polypropylene and hangers. Parameters are: barrel temperature, injection pressure, injection speed, and cooling time. During this process, the polypropylene in the barrel is heated until it is in a liquid state. Then, the liquid is injected at high pressure into the mold cavity. Injection pressure and speed must be carefully controlled to get a completely shaped hanger.

- Plasticization process: the hanger piece is rapidly cooled inside the mold.

- Hangers Ejection: Finally, an inspection of the quality of hangers is conducted to guarantee high standards of the hanger.

By knowing the quantity of time employed for each process step, an observational study was performed for one day. The average data is shown in figure 2.

Thus, it is obtained 2 hangers in 20 seconds; per minute, it is obtained 6 hangers. To establish the number of pieces produced daily, speed time and availability losses (seen above) were considered. For speeding, 5 pieces were set as the ideal run rate (per minute) due to the 1/6 hanger usually being defective.

Data was entered into the OEE Spreadsheet available on the site https://www.oee.com/free-oee-tools/. Table 6. Indicates data processing OEE TOOLS (2024).

Table 6. OEE Data processing

| Production Data | | | | | | |
|---|---|---|---|---|---|---|
| Shift Length | 8 | Hours = | 480 | Minutes | | |
| Short Breaks | 1 | Breaks @ | 15 | Minutes Each = | 15 | Minutes Total |
| Meal Break | 1 | Breaks @ | 60 | Minutes Each = | 60 | Minutes Total |
| Down Time | 90 | Minutes | (calentamiento de la inyectora) | | | |
| Ideal Run Rate | 5 | PPM (Pieces Per Minute) | | | | |
| Total Pieces | 1.133 | Pieces | | | | |
| Reject Pieces | 113 | Pieces | | | | |
| **Support Variable** | **Calculation** | | | | **Result** | |
| Planned Production Time | Shift Length - Breaks | | | | 405 | Minutes |
| Operating Time | Planned Production Time - Down Time | | | | 315 | Minutes |
| Good Pieces | Total Pieces - Reject Pieces | | | | 1.020 | Pieces |

Note: Oee spreadsheet studio.

Source: OEE TOOLS, 2024

Then, it was applied the formula stated by Williamson R (2006) to calculate the performance efficiency ratio. Actual production Rate/ Design production rate X 100.

$$(P) = \frac{1133}{315 \times 5} \times 100$$

$(P) = \frac{1133}{1575} \times 100$

(P)= 71.94%

3.2.3 Quality calculation

As previously mentioned, an observational work was performed where it was concluded that for every 6 hangers 1 is defective. For this study, it is determined that around 10% of the final production items are not enough accurate. In the discussion section, it will be analyzed which are some factors that influence quality production. To sum up, to obtain the quality ratio, it was applied the formula:

$(Q) = \frac{1133-113}{1133}$

(Q) = 90.03%

3.2.4 Results of OEE calculation

Likewise, it was used the OEE Spreadsheet (OEE TOOLS, 2024) to appreciate the comparison between the two results. Table 7 contains this information.

Table 7. Results of OEE calculation. Current – Worldclass ratios

| OEE Factor | Calculation | My OEE% |
|---|---|---|
| Availability | Operating Time / Planned Production Time | 77,78% |
| Performance | (Total Pieces / Operation Time) / Ideal Run Rate | 71,94% |
| Quality | Good Pieces / Total Pieces | 90,03% |
| Overall OEE | Availability x Performance x Quality | 50,37% |

| OEE Factor | World Class | My OEE% |
|---|---|---|
| Availability | 90,00% | 77,78% |
| Performance | 95,00% | 71,94% |
| Quality | 99,90% | 90,03% |
| Overall OEE | 85,00% | 50,37% |

Note: Oee spreadsheet studio.

Source: OEE TOOLS, 2024

In the availability ratio of 77.78%, it is observed that the factory faces problems of shortages and stops. For a small enterprise, it is a challenge to manage that kind of problems mainly because of financial limitations. The ratio obtained in performance efficiency was 71. 94% this is because of small stops such as entering the pellets in the cylinder which is a manual process. The ratio obtained in quality is 90.03% which is so difficult to improve because of the low-utility raw material that the machine injects.

The Overall Equipment Effectiveness reached by the SME Partiplast is 50.37% which compared to the world-class 85% is too low. Consequently, it was established an operation changeover focused on increasing the availability of the machine, as it was one of the main objectives of OEE calculation (Muchiri & Pintelon, 2008; Muñoz-Villamizar et al., 2018; Singh et al., 2021; Tsarouhas, 2019).

Therefore, the small enterprise faces serious troubles in overall productivity. Specially ratios of availability and performance efficiency have shown a very low ratio of overall performance

A= (77.78%), P = (71.94%). In this situation, a technological changeover could be applied. Recently, some studies have been developed about the application of inductive techniques because they seem to have a faster heating rate which would improve energy rates Nian et al. (2019). However, according to Bui & Hwang (2015), there is still no literature about rapid heating or high heating efficiency technology on heating the barrel of an injection molding machine.

Fortunately, some evidence has demonstrated that the use of the barrel heating system with induction heating could be more efficient than the application of resistance heating because, within the induction system, it is possible to get a higher heating rate, energy saving, and clean working conditions (Bui & Hwang, 2015; Nian et al., 2019).

In this sense, applying an operation changeover based on the induction heating barrel could be an alternative to gain more availability in the Cincinnati Milacron injection molding machine.

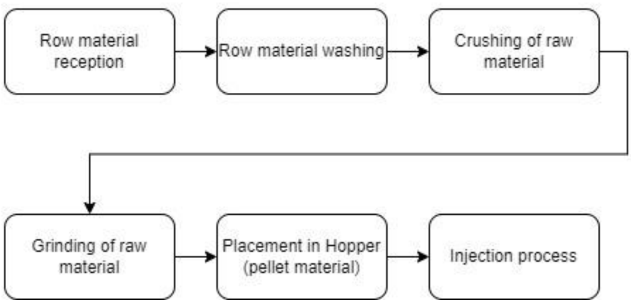
3.2.5 Approaches to increase SME productivity.

Productivity is seen as the relationship between outputs and inputs (Sumanth, 1994) . As it was previously stated, it is not so easy to identify outputs and inputs. Thus, it is needed to know a brief description of the SME Partiplast as a prior step.

3.2.5.1 Characterization of the SME

The factory is a small and medium-sized enterprise (SMEs), its main objective is to offer plastic pieces to the market. Since 2009, the factory has started the production of plastic hangers, the raw material used for this process is recycled plastic material. The production process of plastic hangers is described in Figure 3.

Figure 3. Plastic hangers production process




The whole process of obtaining plastic hangers is observed in Figure 3 and explained as follows:

- Raw material reception: plastic recycled material is received in the factory.
- Raw material washing: recycled material is enough cleaned.
- Raw material crushing: Once it is cleaned, raw material is crushed to obtain small pieces.

- Raw material grinding: with the aid of a grinding machine, the small pieces are ground to be ready for the injection process (figure 2).

Although, it is not simple to define the term productivity. One definition states that productivity is the capacity to develop tasks in a definite time and with an amount of resources Pérez Andrés (2024). In this case study, there were found problems and wastages of some resources i.e. time, workforce, energy, and machine performance. Those problems directly affect the overall performance of the factory especially availability and performance efficiency ratios.

In availability, the main losses were detected in the time needed to get the injector machine ready to operate (90'), in this sense it was proposed to apply a changeover technology by using an induction heating barrel for a plastic injection molding machine.

By using the induction heating barrel technology, it would be possible to achieve a reduction of 50% in the heating time, and automatically productivity would increase.

| Previous Availability rate | Possible Availability rate (with induction heating) |
|---|---|
| (A)= $\frac{315}{405} \times 100$ | (A)= $\frac{360}{405} \times 100$ |
| (A)= 77.78% | (A)= 88.88% |

3.2.5.2 Productivity increasing

Previous number of hangers: 1,133 units of hangers

Possible number of hangers: 45' X 5 (items)= 225

1,133+ 225 = 1,358 units of hangers

In this sense, it would be possible to increase productivity rates based on the number of produced units daily, through the induction heating changeover proposed. However, it must be analyzed the cost of it and if it is worth it.

## 4 Discussion

OEE is a useful production management tool for detecting machinery problems, but it is extremely dependent on the reliability of data collection (Saenz de Ugarte et al., 2009), for this reason, this study shows a useful and practical method to be applied to gather data and then to calculate OEE ratios.

Although the Overall Equipment effectiveness (OEE) is a metric of simple calculation and identification in small industries, it shows some limitations, especially in identifying the losses and wastages that affect the overall performance. For this reason, it is suggested that in SME organizations which generally face multi-objective environments, it is worth counting on efficient and effective decision-making tools to find solutions and problems (Nagy et al., 2020)

This case study intends to increase the availability ratio by applying the induction heating barrel technology. However, as it was previously explained, the understanding of the concept and the application of productivity is complex because it is not only based on the number of items produced but also on the total revenue amount.

Another weakness of the study is stated because it does not consider maintenance programs as a planned shutdown activity which will affect the OEE calculation.

## 5 Conclusions

In the Plastic industry, it is needed to change paradigms by switching the lineal economy to a circle economy. Therefore, the SME Partiplast must continue using recycling materials as good manufacturing practices by redesigning raw materials into hangers.

The main objective of OEE is to determine the overall state of a single machine by analyzing its availability, performance, and quality. In this sense, the OEE measure should be seen as a complementary tool for production management.

Although availability and performance ratios are not high enough, the quality ratio is acceptable (90.03%) because it uses recycled materials to produce hangers which contributes to the optimization of resources and ambiental restoration.

For SMEs, it is so difficult to have the machines operating 24/7 because of the operators' salaries. In fact, in this case study, it is impossible to have 3 operators, and because of that, shutdowns can not be avoided.

The implementation of an induction heating barrel adjusted in the Cincinnati Milacron injection molding machine could contribute to increasing SME productivity, however, it is suggested to do a previous cost study.

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