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*Original Article*

# Operational Efficiency in Industrial Systems through OEE Analysis

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***Abstract*** *- Overall Equipment Effectiveness (OEE) is a commonly applied metric for assessing productivity in industrial operations. This study analyzes its practical application through a stepwise implementation based on production data obtained from an active manufacturing line. In situations where complete operational records were not available, supplementary data were constructed using realistic assumptions consistent with observed operating conditions. The analysis emphasizes losses associated with equipment availability, operating performance, and product quality, which are frequently underestimated in conventional production monitoring. Recorded operational data were used to characterize these losses and to evaluate their distribution throughout the production process. Based on the observed results, improvement actions related to downtime registration, basic preventive maintenance practices, and rapid changeover techniques, such as SMED, were examined within the evaluated context. The findings indicate that variations in unproductive time have a measurable impact on OEE values, demonstrating that performance improvements can be achieved without immediate investment in additional equipment. The results are representative of manufacturing environments operating under technical and resource-related limitations.*

***Keywords*** *- OEE, Operational Efficiency, Availability, Performance, Quality, Total Productive Maintenance.*

## 1. Introduction

Modern manufacturing and service organizations operate in increasingly competitive environments, where maintaining operational efficiency demands continuous and systematic process improvement. Traditionally, capacity constraints have been addressed through reactive actions, including extended work shifts, increased overtime, or investment in additional capital equipment. While common, these measures often involve high operational costs and do not consistently deliver proportional gains in performance. A more sustainable approach focuses on the structured evaluation of existing infrastructure, emphasizing the improvement of asset performance through the effective use of Key Performance Indicators (KPIs) and the optimized management of available resources.

Peruvian industries face significant challenges in maintenance management, largely influenced by the high degree of economic informality. Previous studies report that approximately 60% of the productive sector operates under informal conditions, which hinders the systematic adoption of preventive and predictive maintenance programs [1] and limits the capacity of small and medium-sized plants to reduce downtime and productivity losses effectively. Although maintenance practices within the formal sector also present limitations, the overall outlook in this segment remains comparatively more favorable. In recent years, a growing number of organizations have implemented Total Productive Maintenance (TPM) and Lean Manufacturing approaches—such as 5S and Single Minute Exchange of Dies (SMED)—together with performance indicators including Overall Equipment Effectiveness (OEE), with the aim of improving operational efficiency. Despite this progress, the adoption of Computerized Maintenance Management Systems (CMMS) remains uneven, particularly in sectors such as food processing and textiles. This situation is mainly associated with limited access to specialized technical training and insufficient institutional support for manufacturing companies [2]. As a result, a noticeable gap persists between internationally established maintenance standards and the predominantly empirical practices observed within the Peruvian industrial context.

Despite the extensive presence of OEE in international industrial research, its application within the Peruvian context remains limited, mainly due to the lack of clearly defined and operational implementation guidelines. Most local studies focus on conceptual aspects and provide little empirical evidence derived from real production environments, particularly those involving small-scale manufacturers. In practice, these manufacturers operate under conditions characterized by equipment aging and restricted technical staffing. The application of OEE in industrial environments characterized by operational constraints is examined using observations obtained from production data.

## 2. Fundamentals of OEE

Through the Japan Institute of Plant Maintenance (JIPM), OEE was defined as an indicator used to evaluate equipment performance under real operating conditions.

In practice, OEE is calculated from production records and is based on three components: Availability, Performance, and Quality. These components are used to identify losses that are not always visible in conventional production reports. The classification includes short-cycle events such as micro-stoppages, failed starts, and defective units, which reflect actual operating behavior on the shop floor. In the Peruvian industrial context, a significant portion of production equipment is acquired through the second-hand market. As a result, many production lines operate with machinery that has undergone partial reconditioning, such as selective component replacement and limited repairs, to remain in service. Within this type of operating environment, OEE is commonly applied to monitor equipment behavior and to examine performance variations using available production information, even when advanced technological monitoring systems are not present.

A central element of the OEE framework is the Six Large Losses, which represent the most common sources of inefficiency: breakdowns, long setups, short stops, speed reduction, defects of process, and startup waste. Instead of addressing one by one, the methodology groups into three main dimensions: availability, performance, and quality. Each one reflects a specific aspect of team behavior and helps to determine where the time is.

**Table 1. Classification of the six big losses**

| OEE | Recommended Approach | Traditional Approach |
|---|---|---|
| Availability Losses | Unscheduled Downtime | Equipment Failures |
| | Unscheduled Downtime for Adjustments | Setup and Adjustments |
| Performance Losses | Minor Stops | Idling and Minor Stoppages |
| | Slow Cycles | Reduced Speed |
| Quality Losses | Rejected Products | Process Defects |
| | Startup Losses | Reduced Yield |
| Overall Equipment Effectiveness | Fully Productive Time | Operating Time |

*Source: Adapted from Vorne Industries, Inc. (n.d.). Six Big Losses.*

Over time, different classifications of production losses have been proposed. Early models provided a general overview but showed limitations when applied to detailed operational analysis. Overlapping categories made it difficult to assign losses consistently, particularly in maintenance-related cases. Later formulations, promoted by TPM-oriented organizations such as the Japan Institute of Plant Maintenance (JIPM), introduced clearer definitions to reduce overlap and improve consistency. Table 1 summarizes the Six Big Losses based on Nakajima's OEE formulation, as used by organizations involved in continuous improvement activities, including Vorne Industries [3-4].

### *2.1. Availability Losses*

Availability losses are related to situations in which equipment is scheduled to operate but, for different reasons, does not actually produce. In practice, this usually happens either because the machine stops unexpectedly or because certain planned activities take longer than anticipated. Unexpected interruptions are commonly linked to mechanical failures or external conditions that are beyond the immediate control of the production team, such as power outages or temporary shortages of raw materials. Unexpected events stop the production process without warning and immediately shorten the time in which the equipment can actually be used. Situations of this type usually leave little room for planning and have a direct effect on daily output. Planned activities are different in nature. Tasks such as setup, adjustments, or changeovers are part of routine operation and are normally scheduled in advance.

### *2.2. Performance Losses*

During normal production activities, equipment may remain in operation while producing lower output than expected.

The line remains active throughout the shift, although final production figures are lower than expected. Production continues during the shift, but final figures are lower than planned. This situation is usually identified after reviewing shift records, not during direct observation of the process.

### *2.3. Quality Losses*

Quality losses include rejected products, rework, and material waste generated during both routine production and periods of instability. These events are considered quality-related losses within the OEE analysis and were evaluated using normal production records.

#### *2.3.1. Process Defects, Rework, and Startup Losses*

Production and commissioning activities generate quality losses associated with defects, rework, initial waste, and speed reductions. Therefore, these losses are included in OEE calculations to assess their effect on equipment efficiency.

## 3. Methodology

### *3.1. Research Design and Analytical Approach*

The analysis used production records generated during normal plant operation. Manual logs and operator sheets were reviewed for a defined production period. OEE indicators (Availability, Performance, Quality) were calculated using conventional TPM equations. Productive time was distributed to identify operational losses. Economic impact was estimated by loss category. Results were contrasted with reference OEE values reported in the literature [3].

### *3.2. Data Collection Procedure and Variable Definition*

Data collection was restricted to OEE-related variables available in manual production records. Incomplete data were complemented with reference values from comparable industrial processes. Scheduled time, downtime, output, defective units, and ideal cycle time were used for loss classification under the Six Big Losses model and for consistency checks of the calculated indicators.

#### *3.2.1. Operational Data*

Data were collected on the production line during a standard work shift. Manual observation and supervision were used. The recorded variables included:

- Scheduled Operating Time (TPO)
- Unplanned Downtime (PNP)
- Actual Operating Time (TO)
- Total production output
- Number of defective units
- Ideal cycle time

These variables directly support the calculation of the three OEE components: Availability, Performance, and Quality using standard formulations.

$$Availability = \frac{TO}{TPO}$$

$$Performance = \frac{Total\ Pieces\ x\ Ideal\ Cycle\ Time}{TO}$$

$$Quality = \frac{Good\ pieces}{Total\ Pieces}$$

$$OEE = Availability\ x\ Performance\ x\ Quality$$

The analysis used only essential operational variables available in manual production records. These variables supported OEE calculation and loss classification under the Six Big Losses framework.

#### *3.2.2. Classification of Losses*

After data collection, inefficiencies were classified using the Six Big Losses model to relate specific operational events to their impact on Availability, Performance, and Quality within the OEE framework.

In this study, losses were grouped into the following categories:

- Unplanned stops, including unexpected mechanical, electrical, or hydraulic failures that immediately interrupt production and directly affect equipment availability.
- Planned stops, consisting of scheduled interruptions such as setups, adjustments, cleaning activities, minor changeovers, and preventive maintenance, reduce the effective time available for production.
- Micro-stoppages, defined as brief interruptions that do not require formal maintenance intervention but accumulate over time, significantly reduce effective operating time.
- Reduced operating speed when the actual cycle time is longer than the nominal value.
- Production defects, corresponding to units that fail to meet quality specifications during normal operation, therefore represent direct quality losses.
- Rework or Reprocessing refers to products that require additional processing to meet specifications, consuming extra time and resources despite eventual recovery.

Operational events were classified by OEE component and used consistently in both operational and economic analyses.

#### *3.2.3. Economic Analysis*

Economic analysis was incorporated into this study to give greater meaning to the results by translating the different types of production losses into monetary terms. While the OEE percentage provides an overall view of efficiency, managers and entrepreneurs also require information that reflects the financial consequences of downtime, defects, and reduced operating speed. For this reason, each loss category identified within the Six Big Losses model was evaluated using cost parameters representative of the real conditions of a medium-sized manufacturing plant.

To carry out the analysis, three cost factors were defined:

- Labor cost: S/ 25.00 per hour. This rate reflects the combined cost of operator labor, including wages, benefits, and overhead expenses associated with personnel assigned to the production line. It represents the expense incurred even when the line is not producing due to stoppages.
- Opportunity cost of lost production: S/ 40.00 per hour. This value reflects the profit margin or contribution that the company fails to obtain when the equipment does not operate at the expected rate. Opportunity cost is particularly relevant in industries with continuous or near-continuous flow, where each minute of downtime affects total monthly production, especially in the mining sector, where loading and hauling equipment is mostly rented.

- Cost per defective unit: S/ 1.50. This amount includes material waste associated with nonconforming (defective) units and the resources invested in rework or replacement. Although the exact value depends on the product and production sector, the figure used here is representative of medium-volume packaging operations with regular, though not massive, production.

The economic impact was estimated by assigning a specific cost factor to each loss category. Time losses caused by micro-stoppages and reduced operating speed were treated as opportunity costs. Downtime associated with equipment failures was evaluated using direct labor costs and lost production capacity.

### 3.3. Formulas for Calculating OEE and Its Components

Overall Equipment Effectiveness (OEE) was calculated from three indicators obtained from production time and output records. Each indicator was computed separately. The global value was determined by their multiplication.

$$OEE = A \, x \, P \, x \, Q$$

The definition and calculation of each indicator are presented in Table 2.

**Table 2. OEE indicators and calculation formulas**

| Indicator | Definition | Formula |
|---|---|---|
| Availability | Proportion of scheduled time in which the equipment was running | $Availability = \frac{Actual\ operating\ time}{Planned\ Time}$ |
| Performance | The degree to which operating time was used at the expected production rate | $Performance = \frac{Actual\ Production\ \ x\ Ideal\ cycle\ time}{Actual\ operating\ time}$ |
| Quality | Share of produced units that met acceptance criteria | $Quality = \frac{Good\ units}{Total\ units\ produced}$ |

Availability is reduced by unplanned stoppages occurring during scheduled production time. These stoppages include failures and adjustment-related interruptions.

Performance is reduced when the actual operating speed is lower than the reference cycle rate while the equipment remains in operation.

Quality losses correspond to nonconforming output generated during production, including defective units and reprocessed material.

By treating each indicator independently, losses are allocated to their corresponding category. This allocation allows comparison of loss magnitude across availability, performance, and quality.

### 3.4. Hierarchical Representation of Time in OEE Calculation

Production time was divided into successive levels. Scheduled Operating Time (TPO) was reduced to Operating Time (TO), Net Operating Time (TON), and Net Production Time (TPN) by subtracting corresponding losses.

The terms TPO, TO, TON, and TPN were used throughout the analysis.

Classical OEE models are based on three indicators: Availability, Performance, and Quality. Intermediate time variables are used to relate production time directly to these indicators. The mathematical relationships are:

$$Availability = \frac{TO}{TPO}$$

$$Performance = \frac{TON}{TO}$$

$$Quality = \frac{TPN}{TON}$$

These ratios express the distribution of productive time within the OEE structure and link time reductions to specific loss categories.

### 3.5. Definition of Terms in the Hierarchical Breakdown of Productive Time

OEE calculation uses a hierarchical division of production time. Each level represents a reduction from the previous one due to operational losses.

#### *3.5.1. TC – Chronological Time*

Total time available in the analyzed period, including operating time and all planned and unplanned stoppages.

Example: A full 8-hour shift equals 480 minutes.

#### *3.5.2. TPO – Scheduled Operating Time*

The time during which the equipment is planned to operate according to the production schedule. It is calculated by subtracting Planned Stops (PP) from the chronological time.

Example: If there are 30 minutes of scheduled maintenance, then

TPO = 480 – 30 = 450 min.

*3.5.3. TO – Operating Time*

The time during which the equipment was running, discounting both Planned and Unplanned Stops (PNP). It reflects the real availability of the equipment.

*3.5.4. TON – Net Operating Time*

Represents the time during which the equipment operated at its nominal or ideal speed, free from speed losses. It is obtained by subtracting Speed Losses (TPV) from TO. It measures operational performance.

*3.5.5. TPN – Net Production Time*

Time devoted to producing units in good condition, meaning products not rejected due to quality losses (TPC). It is the purest and most representative time in terms of value-added activities.

$$TPN = TON - TPC$$

*3.5.6. PP – Planned Stops*

Refer to scheduled interruptions such as maintenance activities, product changeovers, meetings, regular cleaning tasks, and similar operations. They are not considered losses, since they are part of the planned production schedule. Although planned maintenance programs usually consider 48 hours of advance notice to schedule a shutdown, from an OEE perspective, lead times greater than 4 hours are usually sufficient, as this allows production to adjust plans and not expect productive activities during that period.

*3.5.7. PNP – Unplanned Stops*

Are unexpected interruptions caused by equipment failures, material shortages, operational problems, safety-related events, and any other unplanned stopping event. These stoppages have a direct impact on availability and usually require corrective interventions before production can be resumed.

*3.5.8. TPV – Speed Losses*

Time lost due to equipment operation below ideal speed, including micro-stoppages, slow cycles, intentional speed reductions, and delays caused by manual adjustments. These losses affect the Performance component of OEE.

*3.5.9. TPC – Quality Losses*

Time associated with the production of defective units, rework activities, or failed startups that do not yield conforming products. These losses directly affect the Quality component of the OEE indicator. These loss categories are integrated into the hierarchical productive time model and define how speed- and quality-related losses contribute to the overall OEE calculation.

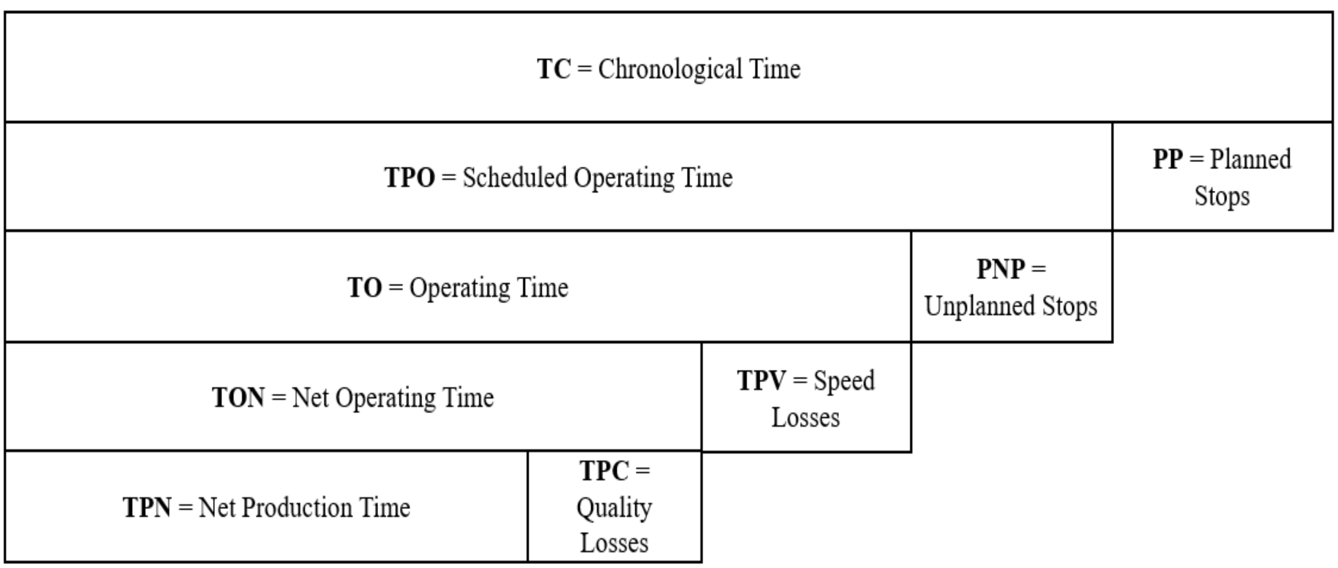


**Fig. 1 Hierarchical breakdown of productive time in the OEE calculation. Source: author's own elaboration.**

***3.6. Practical Analysis Case***

This practical case is based on operating conditions and loss patterns commonly reported in industrial technical literature. The company name, PackBox Solutions S.A.C., is fictitious, while the production data and operating conditions reflect typical industrial scenarios. The case is used to apply OEE calculation and to identify and quantify losses using the hierarchical productive time structure.

*3.6.1. Performance Evaluation in a Packaging Box Factory:*

PackBox Solutions S.A.C. operates a semi-automated packaging box production line in three continuous daily shifts. Operational data were collected over a 30-day period for OEE calculation.

- Thirty minor stoppages of 2 minutes each, related to polypropylene roll changes.
- One scheduled preventive maintenance stoppage of 1 hour with a full line shutdown.
- Three unplanned mechanical failures.

**Fig. 2 Three unexpected mechanical failures**

In addition, each shift includes a 30-minute meal break, which is deducted from the total shift time.

The production line has a nominal capacity of 60 units per minute. The monthly production report registered a total output of 1,927,100 units. From this total, 423 units were identified as defective.

The evaluation addresses the following items:

a) Quantification of availability, Performance, and quality losses.
b) Calculation of the Availability Index, Performance Index, and Quality Index.
c) Calculation of the overall OEE for the evaluated period.

*Solution*

The calculations were performed using the defined productive time structure. Time variables and loss data were processed directly from the recorded production information.

The formula is:

$$TPO = TC - PP$$

Where Chronological Time (TC) represents the total available operating time in one month:

$$TC = 30\ days\ x\ \frac{3shift}{day}\ x\ \frac{8h}{shift}\ x\ \frac{60min}{h} = 43{,}200\ min$$

Planned maintenance and changeovers are included in scheduled production time.

Meal breaks throughout the month for 3 daily shifts:

$$PP1 = \frac{30min}{shift} x \frac{3shift}{day}\ x\ 30days = 2{,}700\ min$$

30 minor stops of 2 minutes each (polypropylene roll changes, considered normal process activity):

$$PP2 = 30\ stops\ x\ \frac{2min}{stop} = 60\ min$$

Scheduled preventive maintenance stop lasting 1 hour:

$$PP3 = 1h = 60\ min$$

Total Planned Stops:

$$PP = 2{,}700 + 60 + 60 = 2{,}820\ min$$

Calculating TPO

$$TPO = TC - PP = 43{,}200 - 2{,}820 = 40{,}380\ min$$

*Unplanned Stops (PNP)*

In this study, unplanned stoppages refer to interruptions that were not part of the regular operating schedule. Unplanned stoppages reduce effective production time and are recorded for equipment stability assessment.

$$\boldsymbol{PNP = 15 + 25 + 20 = 60\ min}$$

*Operating Time (TO)*

Actual equipment operating time after planned and unplanned stoppages is deducted.

$$TO = TPO - PNP = 40{,}380 - 60 = 40{,}320\ min$$

*Availability Index (ID)*

Ratio between actual operating time and scheduled operating time.

$$ID = \frac{TO}{TPO} = \frac{40{,}320}{40{,}380} = 0.99851 \equiv 99.85\%$$

Even though the primary goal is to calculate OEE, a low availability index may indicate:

- Frequent failures,
- Prolonged corrective maintenance, or
- Poor planning of stoppages.

Since this analysis uses a modern, non-traditional approach, not all stoppages are considered losses, such as preventive maintenance. The interpretation of the Availability

Index (ID) is usually grouped into ranges that indicate different performance levels, from low to excellent.

These ranges, shown in Table 3, are supported by references from JIPM (Japan Institute of Plant Maintenance), Vorne Industries, and industrial studies such as The OEE Primer.

**Table 3. ID interpretation range**

| ID Range (%) | Interpretation |
|---|---|
| > 90% | Excellent (World-class level) |
| 80% – 90% | Good – Competitive |
| 70% – 80% | Fair – Opportunity for improvement |
| < 70% | Low – Requires analysis and urgent actions |

*Source: Own elaboration based on data from JIPM (Japan Institute of Plant Maintenance), The OEE Primer (D. Smith & D. Hawkins, 2003), and technical documentation from Vorne Industries*

An availability value of 99.85% was obtained. The relevance of this value depends on the production context and operational characteristics of the process.

Continuous processes usually require higher availability levels, while more flexible or low-volume manufacturing systems may operate with lower values.

To evaluate performance, the following formulas are used:

$$IR = \frac{Total\ production}{TO\ x\ VIP} = \frac{Total\ production\ x\ TCI}{TO}$$

This index shows how the equipment behaved when operating below its theoretical maximum capacity.

$$IR = \frac{Total\ production}{Expected\ production}$$

$$IR = \frac{Actual\ production\ speed\ (VRP)}{Ideal\ production\ speed\ (VIP)}$$

According to Smith & Hawkins (2003), the Ideal Cycle Time (TCI) corresponds to the most efficient production rate possible in the absence of losses, while the Ideal Production Speed (VIP) is its reciprocal:

$$TCI = \frac{1}{VIP}$$

Based on the available data, the formula that includes the ideal production speed (VIP) is used:

$$IR = \frac{Total\ production}{TO\ x\ VIP}$$

The maximum theoretical line capacity or ideal production speed (VIP) is 60 units per minute:

$$VIP = \frac{60\ units}{min}$$

Therefore, the Performance Index (IR) is:

$$IR = \frac{1{,}927{,}100\ units}{40{,}320\ \text{min}\ x\ \frac{60\ units}{min}}$$

$$IR = \frac{1{,}927{,}100\ units}{2{,}149{,}200\ units} = 0.8966 \equiv 89.66\%$$

Compared to Availability, a lower Performance Index was obtained. Operating time remained high, while operating speed was reduced. Micro-stoppages and short adjustment delays were present. Smith and Hawkins (2003) report that performance losses are not always captured in non-monitored systems. These losses are related to micro-stoppages and reduced cycle speed and accumulate during operation. In the Six Big Losses model, they are classified as small stops and speed reduction. Product quality was evaluated using the Quality Index (IC), defined as the ratio of conforming units to total production:

$$IC = \frac{Good\ units}{Total\ production}$$

At the end of the month, a total of 423 defective units were recorded out of 1,927,100 total units produced, meaning:

$$IC = \frac{1{,}927{,}100\ units - 423\ units}{1{,}927{,}100\ units}$$

$$\rightarrow IC = \frac{1{,}926{,}677\ units}{1{,}927{,}100\ units} = 0.9998 \equiv 99.98\%$$

Defective units represented a small fraction of total production. Rework activities were limited during the evaluated period. Smith and Hawkins (2003) report that high-quality index values reduce the relative contribution of quality losses in OEE calculations. In regulated production environments, defect occurrence is monitored regardless of magnitude [3].

### *3.7. Final OEE Calculation*

$$OEE = 0.99851\ x\ 0.8966\ x\ 0.9998 = 0.89506 \equiv 89.51\%$$

An OEE value above 85% is commonly reported as a benchmark for high-performing processes [5].

**Table 4. World-class targets for OEE components**

| Component | World-class target (%) |
|---|---|
| Availability | 90 |
| Performance | 95 |
| Quality | 99 |
| OEE Total | 85 |

*Fuente: Elaboración propia con base en datos de OEE.com (s.f.).*

**Table 5. Sensitivity Analysis of OEE Components**

| OEE Component | Observed value (%) | Typical Loss Sources | Sensitivity to Variation | Impact on Global OEE | Improvement Priority |
|---|---|---|---|---|---|
| Availability | ≈ 99.85 | Unplanned downtime, minor failures, setup overruns | Low | Limited impact due to the low frequency of stoppages | Low |
| Performance | ≈ 89.66 | Reduced speed, micro-stoppages, and operating variability | High | Strong impact; small variations produce significant OEE changes | High |
| Quality | ≈ 99.90 | Scrap, rework, startup defects | Very low | Minimal impact under stable operating conditions | Low |

The Performance Index registered a value of 89.66%. Performance losses were associated with micro-stoppages and speed reductions. Comparable observations are reported by Smith and Hawkins (2003). The analysis considered existing equipment only. Operational actions were identified.

## 4. Sensitivity Analysis of OEE Components

The sensitivity analysis evaluated the variation of OEE with respect to changes in its components. During the analyzed period, Availability and Quality remained close to their upper values. Variations in performance produced the largest numerical change in the OEE result. Reductions in operating speed and the occurrence of micro-stoppages were reflected in the Performance component under these conditions.

## 5. Results and Discussion

The analysis followed the previously defined time hierarchy. Availability losses include unplanned downtime and unscheduled stoppages, such as equipment failures (PNP).

$$PNP = 60\,min$$

The Performance Index (IR), according to the same criteria, is calculated as follows:

$$IR = \frac{TON}{TO}$$

Although the Operating Time (TO) has been calculated and has a value of 40,320 minutes, the Net Operating Time (TON) is unknown, even though the Performance Index (IR) has already been estimated as 0.8966.

$$IR = 0.8966 = \frac{TON}{TO} = \frac{TON}{40{,}320\,min}$$

Therefore, the Net Operating Time is:

$$\rightarrow TON = 36{,}151\,min$$

Based on the time breakdown for OEE, it is established that:

$$TPV = TO - TON$$

Thus, the time lost due to operating at a speed lower than the ideal is:

$$TPV = 40{,}320 - 36{,}151 = 4{,}169\,min$$

The Quality Losses (TPC), expressed on time, are also calculated based on the OEE time breakdown, like the steps performed previously:

$$IC = 0.997 = \frac{TPN}{TON} = \frac{TPN}{36151} =\rightarrow TPN = 36{,}043\,min$$

The time associated with defective products that generate nonconforming units is then:

$$TPC = TON - TPN$$

Finally, the time lost due to defective pieces is:

$$TPC = 36{,}151 - 36{,}043 = 108\,min$$

Summary of Results

- Time lost due to availability: 60 min
- Time lost due to production speed: 4,169 min
- Time lost due to defective pieces: 108 min

As shown in Figure 3, the main source of loss comes from low process performance, which reaches 4,169 accumulated minutes — more than 95% of all unproductive time. This result makes it clear that improvement efforts should concentrate on minimizing micro stoppages and general slowdowns in the production flow. The analysis of operational losses shows that the low Performance Index (IR) remains the main opportunity for improvement. Unlike availability or quality losses, in this type of loss, since the equipment does not stop or stops only for brief periods, a sense of normality is often perceived; small companies are not prepared to record micro-stoppages, losses of pace, or stoppages lasting only seconds, and for this reason, they rarely appear in regular production records. The Overall Equipment Effectiveness (OEE) indicator has been used since its early development in a broad range of industrial sectors worldwide.

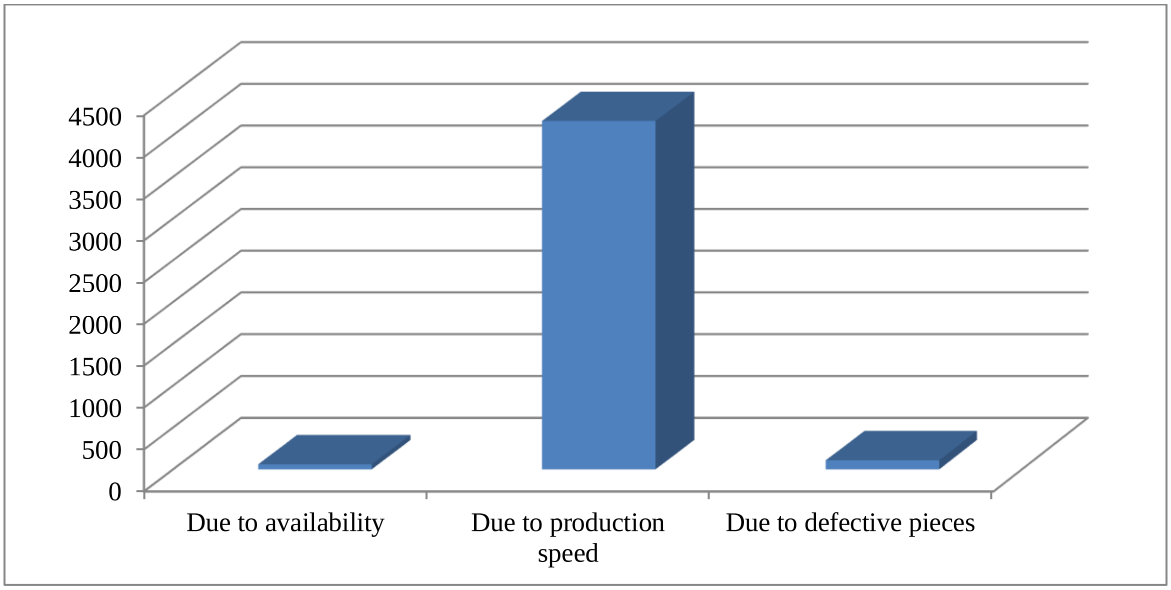


**Fig. 3 Analysis of losses by OEE component (in minutes).**

*Source: Own elaboration.*

Beyond functioning as a performance metric, it has served as a practical reference tool for organizations engaged in continuous improvement initiatives. Although the volume of available data is limited, several documented case studies provide relevant points of comparison for production environments similar to those found in the Peruvian industrial context. These studies highlight not only common operational difficulties but also recurring sources of loss that may be used as benchmarks and as practical references derived from real industrial applications. Once the technical causes of inefficiency have been identified, evaluating their economic impact becomes a necessary step.

Accordingly, the losses determined through the OEE analysis were translated into estimated costs for each loss category. This estimation was based on average values for direct labor, energy consumption, and material waste, which are summarized in Table 6.

The following assumptions were adopted:

- Labor cost per hour: S/ 25.00
- Opportunity cost of lost production: S/ 40.00 per hour
- Equivalent cost associated with quality losses: S/ 1.50 per minute

In the case of quality-related losses, the value of S/ 1.50 does not represent the cost of a single defective unit. It is an equivalent time-based value that reflects the combined effect of wasted materials, energy, and brief operator interventions that normally occur when defective pieces are produced. Using this value keeps the economic calculation aligned with the time structure applied in the OEE methodology.

Lost time according to OEE analysis:

- Availability: 60 min
- Performance: 4,169 min
- Quality: 108 min

The values used for the economic loss calculation were not taken from a generic table. They were selected considering local conditions and what is usually seen in medium-scale manufacturing plants. The labor cost per hour (S/. 25.00) reflects the average compensation for skilled operators in the Peruvian industrial sector, based on information from the Ponte en Carrera [6] portal and previous experience in production environments where similar tasks are performed. The opportunity cost of lost production (S/. 40.00 per hour) was estimated from the typical production value generated per hour in comparable processes. This amount gives a practical idea of what the plant stops earning when equipment is not producing at its expected rate. A reference value of S/. 1.50 was assigned to defective products. This value accounts for material waste and minor adjustments during production. It was used to keep the cost estimation consistent with the time-based OEE calculation.

**Table 6. Summary of losses and estimated costs**

| Type of loss | Lost time (min) | Estimated cost (in S/.) |
|---|---|---|
| Due to availability | 60 | $60\, min\, x\, \frac{1h}{60\, min}\, x\, (25+40)\frac{S/.}{h} = S/.\ 65.00$ |
| Due to production speed | 4,169 | $4{,}169\, min\, x\, \frac{1h}{60\, min}\, x\, (25+40)\frac{S/.}{h} = S/.\ 4{,}516.42$ |
| Due to defective pieces | 108 | $108\, min\, x\, \frac{S/.\ 1.5}{min} = S/.\ 162.00$ |
| Total estimated | 4,337 | S/. 4,743.42 |

***Source:*** *Own elaboration, based on the economic loss analysis methodology for OEE according to Smith & Hawkins (2003) and OEE.com (n.d.).*
***Note.*** *Monetary values expressed in* ***S/.*** *correspond to Peruvian soles (PEN), the official currency of Peru.*

## 6. Comparative Cases

OEE has been reported in case studies from different industrial sectors. Although the number of published studies is limited, some describe applications in production environments similar to those in Peru.

The reported cases focus on operational losses identified during implementation.

### *6.1. PT. Riken Indonesia – PVC Production Line*

In the study by Wahyudi and Syafrudin (2019), Line 5 of PT. Riken Indonesia, a manufacturer of PVC compounds for electrical applications, was evaluated during a standard 480-minute work shift [7].

Its relevance lies in the fact that it is a continuous flow system with efficiency limitations like those of many Latin American plants.

Recorded data:

- Planned Production Time (TPO): 480 minutes
- Downtime (PNP): 112 minutes
- Actual Operating Time (TO): 368 minutes
- Total Production: 1,200 units
- Defective Units: 13 units
- Ideal Cycle Time per Unit (TCI): 0.25 minutes/unit

OEE Calculation:

Availability

$$ID = \frac{TO}{TPO} = \frac{368\, min}{480\, min} = 0.767 \equiv 76.7\ \%$$

Performance

$$IR = \frac{PT\ x\ TCI}{TO} = \frac{1{,}200\, unit\ x\ 0.25\, min/unit}{368\, min}$$

$$IR = \frac{300\, min}{368\, min} = 0.8152 \equiv 81.52\%$$

Quality

$$IC = \frac{Good\ units}{Total\ production} = \frac{1{,}200\, units - 13\, units}{1200\, units}$$

$$IC = \frac{1{,}187\, pz}{1{,}200\, pz} = 0.9892 \equiv 98.92\%$$

$$OEE = 0.767\ x\ 0.8152\ x\ 0.9892 = 0.6185 \equiv 61.85\%$$

The obtained OEE value of 61.85% is significantly below the reference level of 85%, which is commonly associated with world-class manufacturing performance. Although the result may seem unfavorable at first glance, it does not necessarily indicate deficient operational effectiveness. Rather, it reveals specific areas with potential for improvement, particularly in availability and performance. Previous studies indicate that stabilizing production cycles and reducing downtime can generate significant efficiency gains without requiring major capital investment.

### *6.2. Manufacturing Industry – CNC Machine (India)*

Ahuja and Kumar (2019) applied the OEE methodology to a CNC milling and drilling machine in an industrial plant in India [8]. Their results indicated that availability losses were the main operational constraint, leading to the implementation of targeted technical and organizational actions.

Data were collected over five consecutive 8-hour shifts. During this period, changes were made to maintenance routines and operating practices, together with minor organizational adjustments. After implementation, higher availability was reported, along with improvements in performance and quality.

The observed results show that changes in operating practices influenced overall equipment effectiveness. No new equipment was introduced during the study. Under these conditions, OEE served as a reference tool to analyze performance and support decision-making in a resource-constrained manufacturing setting.

- Availability: 82.23% → 88.41%
- Performance: 76.92% → 85.71%
- Quality: 97.50% → 98.59%
- OEE Total: 62.00% → 75.00%

In addition to the previously mentioned improvements, a specific training program was scheduled for operators, as otherwise the improvements would be only temporary and could not be sustained in the medium term. The case demonstrates how well-conducted diagnosis and well-targeted interventions can substantially improve efficiency in manufacturing processes.

### *6.3. Mining Industry – Open Pit Electric Equipment (Turkey)*

In the study by Yıldız and Keleş (2022), the OEE of haul trucks and electric shovels was evaluated in open-pit mining operations in Turkey, mining modalities that are also common in countries of the region, such as Peru and Chile [9]. The analysis focused on loading and hauling activities under different operating and load conditions, with data recorded between 2021 and 2022. The main losses were associated with adverse weather conditions, mechanical failures, and delays caused by route-related issues. Unlike manufacturing processes, in this sector, "quality" refers to transport accuracy and the effective payload transported per trip. It should be noted that although weather conditions cannot be modified, this does not imply that no action can be taken; under such circumstances, both responsive and preventive actions are possible (shift planning, route stabilization, etc.).

The authors proposed improvements such as:

- Strengthening preventive maintenance
- Updating digital routes
- Reinforcing operator training
- Incorporating data analytics to anticipate failures

This case shows that OEE is also useful in mining, particularly for evaluating fleet performance and guiding long-term investment decisions.

The three cases show similar operational issues, despite differences between industries. OEE was applied under different conditions, with better results when local constraints were taken into account. The reported changes occurred progressively during operation.

### *6.4. OEE in Peru*

In Peru, the use of Overall Equipment Effectiveness (OEE) has been reported mainly in large industrial companies [10]. In many production plants, equipment monitoring is limited to basic records, such as downtime logs or defect registers. The use of an integrated indicator is uncommon.

Some applications have been documented in large food-processing companies. Mondelez has reported the use of OEE together with Total Productive Maintenance, including implementations in Peru aimed mainly at reducing downtime and improving process stability [11–12]. In contrast, evidence from other industrial sectors is scarce. Available case studies are few, access to operational data is often limited, and many facilities rely on older equipment with incomplete production records [13].

### *6.5. Comparative Analysis of OEE Methodologies in Different Sectors*

The table shows how OEE is applied in different industrial settings, where operating conditions and data availability vary. These differences lead to distinct emphases on availability, performance, or quality, indicating that OEE is typically adapted to the specific context of each sector.

**Table 7. Comparative analysis of OEE methodologies across industrial sectors**

| Sector | Operational Characteristics | OEE Component with Highest Priority | Typical Data Source | Main Objective of OEE Use |
|---|---|---|---|---|
| Discrete Manufacturing (Metalworking, CNC) | Batch production, frequent adjustments, and manual intervention | Performance | Manual logs, cycle time records | Identify speed losses and micro-stoppages |
| Continuous Process Industry (Petrochemical, Energy) | Continuous operation, high cost of stoppages | Availability | Automated monitoring systems | Minimize unplanned downtime |
| Food Industry | Frequent changeovers, sanitation requirements | Availability / Quality | Mixed (manual + automated) | Control startup losses and variability |
| Highly Regulated Industry (Pharmaceutical, Aerospace) | Strict quality standards, traceability | Quality | Automated quality records | Ensure compliance and reduce defects |

| | | | | |
|---|---|---|---|---|
| Low-Automation Manufacturing (SMEs, Emerging Economies) | Aging equipment, limited monitoring | Performance | Manual records | Diagnostic analysis and loss identification |

## 7. Conclusion

Overall Equipment Effectiveness (OEE) makes it possible to identify losses linked to availability, performance, and quality. In many production plants, especially small and medium-sized ones, these losses are not formally documented. Maintenance activities are usually carried out only after failures occur, and operational records are incomplete or fragmented. In this context, OEE can still be applied using basic shop-floor information. The case analyzed shows that the indicator can be used as long as losses are classified in a consistent way and some form of data recording is maintained. The records do not need to be complex. Simple logs, if kept over time, allow the identification of repeated failures and deviations in machine behavior. In micro and small enterprises, the absence of historical data remains common. This problem is mainly organizational and can be reduced through basic documentation practices and the participation of technical personnel. The overall OEE value obtained is within the ranges reported in previous studies. Differences between components were observed. Performance losses were higher than those related to availability and quality. This result suggests that speed losses and minor stoppages deserve more attention. When production is evaluated only through total output, these issues are not clearly visible.

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