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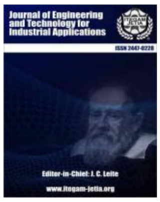

RESEARCH ARTICLE OPEN ACCESS

FRAMEWORK FOR TOTAL PRODUCTIVE MAINTENANCE FOR AN SME

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ABSTRACT

Total Productive Maintenance (TPM) is a worldwide maintenance program for plant equipment and machinery. It is a proactive maintenance that optimizes Overall Equipment Effectiveness (OEE) to get rid of the six (6) big losses. The research was inspired by observations made over a six (6) months period at Company X, a Small and Medium Enterprise (SME). Observations made were that the SME produced a lot of defective items, some requiring reworks, the SME had poor maintenance plans, poor relationship between departments, resulting in low morale of workers, frequent breakdowns of machines, as well as low production rate. The main objective of the research was to design a framework that would identify and address the aforementioned problems, resulting in an optimized OEE rate. The research data was obtained through various methodologies, including observation, questionnaire as well as interviews among the company employees - technicians, operators, and maintenance engineers. The data was analysed using Microsoft excel performance dashboards as well as TPM templates. Based on the findings, a framework was designed and developed that sought to address the aforementioned problems at the company. The study improved the OEE of machines and processes through the implementation of TPM approach at Company X.

I. INTRODUCTION

Many SMEs and other established companies experience a lot of scrap due to machine failure or equipment breakdowns and frequent production stops which affects productivity. Frequent breakdown or slow running of equipment and machines could be reduced by the use of Total Productive Maintenance (TPM) philosophy. Case study Company X, a Small and Medium Enterprise (SME) in the manufacturing sector has been faced with producing a lot of defective items, poor maintenance plans, poor relationship between departments, frequent breakdown of machines, as well as low production rate.

The research intends to develop a framework for TPM implementation in the SME manufacturing sector, focusing on Company X. Other interventions involve creating a working environment that is clean and well-organized using the 7S approach, as well as evaluating OEE factors on the TPM tool recommended for the company. The research achieves its purpose by focusing on improving maintenance methods and reducing setup times, job changeovers, downtimes, scraps as well as waste. These operations are sectioned by the quality and maintenance departments of the company.

The TPM approach operates according to the thinking that anybody in a facility has to take part in maintenance alternatively, than just the maintenance team. TPM is defined as a methodology created with the aim of increasing production efficiency by implementing efficient equipment maintenance, having a methodical nature of implementation (TPM pillars), which promotes the involvement of all employees as a way to increase their sustainability and effectiveness [1], [2]. TPM implementation is a change management process and its goal is to improve core business processes. Among things emphasised by TPM are proactive and preventative protection in order to maximize the operational affectivity of equipment. TPM puts emphasis on empowering operators to assist preserve their equipment.

Proper and regular maintenance of production equipment and machines results in high operational efficiency of equipment (fewer breakdowns, few production stoppages, few defects, and zero accidents), hence increased production [3]. Productivity in manufacturing is very important as it measures how efficiently production inputs such as labour and capital are being used in an organisation to produce a certain level of output. Productivity increase is a target for many manufacturing firms because as it increases it allows the firm to make more products without increasing the costs. This helps manufacturing firms to benefit from economies of scale. Almost all industrial manufacturing processes are carried out with the useful resource of machines, as a result of which each production-oriented company is mostly structured on its machinery.

Maintenance downtime is included in manufacturing scheduling, and in many cases, turns into a critical part of the manufacturing process [4]. TPM assigns the responsibility for preventive and routine maintenance to the same humans who operate that character equipment. The result is that the human beings most familiar with the specific machines are put in charge of the machine's care. TPM is constructed on the 5S foundation, which creates high-quality administrative centre company and standardized methods to enhance safety, quality, productivity and employee attitudes.

II. LITERATURE REVIEW

II.1 TOTAL PRODUCTIVE MAINTENANCE (TPM)

TPM is a broad maintenance program which includes an idea for keeping up plant and equipment. A typical TPM program in an organisation expands employee morale and employment fulfilment, thus bringing maintenance at the center as a vital and indispensably critical part of the business. TPM implementation methodology follows a prescriptive process in which the steps that companies must follow to implement the process and achieve intended benefits are detailed [5]. Organisations ultimately achieve sustainable and profitable growth in the long term by monitoring three – Availability, Performance, and Quality. These three key parameters are a direct contribution from each machine of the overall production system and the efficiency of the operators responsible for the machines [6]. Keeping a health check on the three parameters lead to optimal levels for productive plant efficiency.

TPM strategy help improve the competitiveness and economic benefits of a manufacturing or service organization [7]. According to [8], a program to turn the staff into TPM workers under the slogan "My machine my responsibility, I receive well, I deliver well" increased the production standards on average of 5%. There is shared accountability for tools that encourage higher involvement by plant floor workers when TPM is implemented.

TPM philosophy closely resembles another popular Japanese philosophy, Total Quality Management (TQM). The two programs share many common tools such as employee empowerment, benchmarking, documentation, etc, for implement and optimization [9]. Some similarities between the two programs are stated below:

1. Upper level management should show total commitment to the program in both TPM and TQM
2. Employees must be empowered to initiate corrective action, and
3. TPM and TQM require a long range outlook as the programs may take a year or more to implement and are an on-going process. Change management is required as well.

Notable differences between TQM and TPM are summarized in Table 1 below.

Table 1: Differences between TQM and TPM.

Category	TQM	TPM
Goal	Quality (Output and effects)	Equipment (Input and cause)
Means of attainment	Systematize the management. It is software oriented	Employees participation and it is hardware oriented
Target	Quality for PPM	Elimination of losses and wastes.

Source: Authors, (2021).

Overall TPM objectives include:

- Maintain an accident free environment,
- Increasing the operator involvement,
- Maximizing the Reliability of machine,
- Improving the Quality and Reduce cost,
- Focus on Maintainability engineering,
- Improving trouble solving via team,
- Upgrading every operator,
- Motivating the operator,
- Increasing the OEE.

The term PQCDSM is used to denote TPM performance indicators. These are known as productivity (P), quality (Q), cost (C), delivery (D), safety (S) and morale (M) [10]. Specific targets for the key performance indicators (KPIs) [11] are provided in Table 2.

Table 2: TPM key performance indicator targets.

KPI	Target(s)
P – Productivity	80% minimum OPE (Overall Performance Efficiency). 90% OEE (Overall Equipment Effectiveness)
Q – Quality	90% reduction in process defect rate. 75% reduction in customer returns/claims.
C – Cost	30% production costs reduction.
D – Delivery	50% reduction in finished goods and Work in Progress (WIP).
S – Safety	Zero shutdown accidents. Zero pollution incidents. Zero accident environment
M – Morale	5 to 10 times up employee improvement suggestions. Develop Multi-skilled and flexible workers.

Source: Authors, (2021).

II.I1 ORGANIZATION STRUCTURE FOR TPM IMPLEMENTATION

The procedure for introducing TPM in an organization undergoes through four major stages – Stage A: Preparatory Stage, Stage B: Introduction Stage, Stage C: Implementation, and Stage D: Institutionalisation [12]. OEE implementation starts with management awareness of total productive manufacturing and their commitment to focus the factory work force on training in teamwork and cross-functional equipment problem solving. Details of each stage are given below [12].

STEP A - PREPARATORY STAGE:

STEP 1 - Announcement by Management to all about TPM introduction in the organization:

Proper understanding, commitment and active involvement of the top management is needed for this step. Senior management should have awareness programmes, after which announcement is made to all. The awareness is done through in-house publications, announcements, and display on notice boards.

STEP 2 - Initial education and propaganda for TPM:

Training is to be done based on the need. Some individuals need intensive training and some just an awareness. Take TPM mainline personnel to places where TPM is already successfully implemented.

STEP 3 - Setting up TPM and departmental committees:

Committees should cater for TPM pillars and related needs.

STEP 4 - Establishing the TPM working system and target:

Each area is benchmarked and targets for achievement set up.

STEP 5 - A master plan for institutionalizing:

Next step is implementation leading to institutionalizing wherein TPM becomes an organizational culture. Achieving PM award is the proof of reaching a satisfactory level.

STEP B - INTRODUCTION STAGE

This is a ceremony and all should be invited. Suppliers should be made aware of the demand for quality from them. Related companies and affiliated companies who are potential customers are also invited. Some may learn from the new TPM certified company and some can help achieve more. Customers receive the communication that their supplier cares for quality output.

STAGE C - IMPLEMENTATION

In this stage eight activities are carried which are called eight pillars in the development of TPM activity. Of these four activities are for establishing the system for production efficiency, one for initial control system of new products and equipment, one for improving the efficiency of administration and are for control of safety, sanitation as working environment.

STAGE D - INSTITUTIONALISING STAGE

By all the activities one would has reached maturity stage. Now is the time for applying for PM award. The company should also think of challenging levels to which TPM movement can be taken. Figure 1 shows the plant-wide TPM structure.

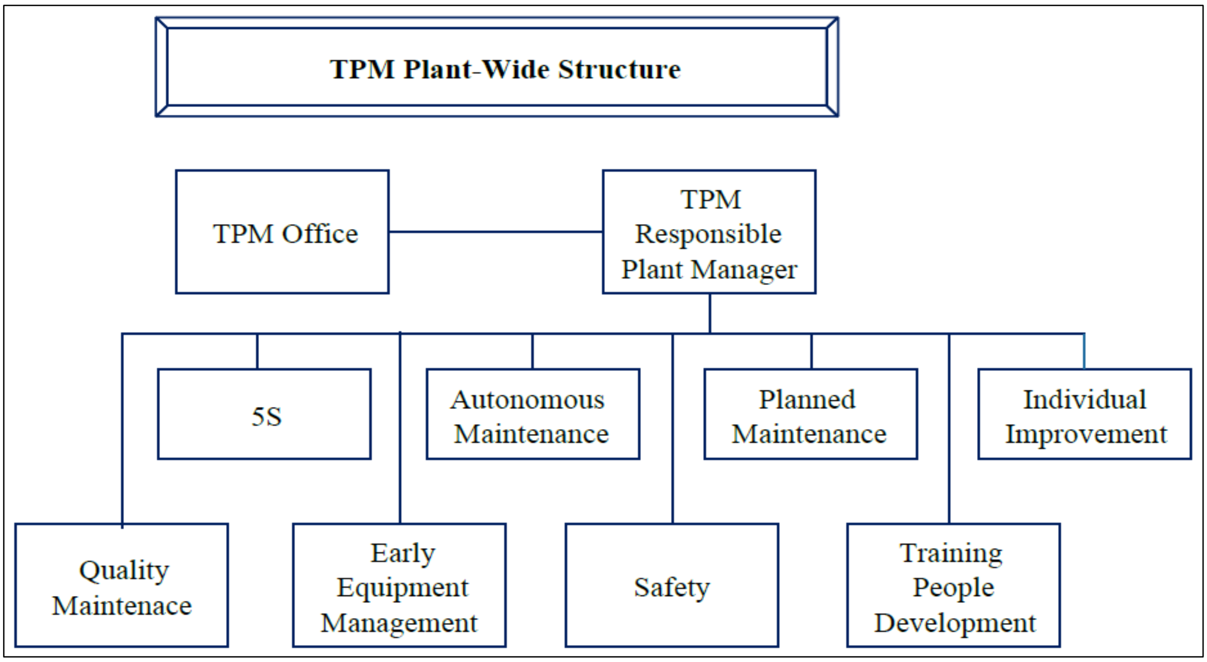

Figure 1: TPM company-wide structure.
Source: Author redrawn from [13].

II.1I 8 PILLARS OF TPM

TPM includes eight supporting activities that are centred on proactive and preventative techniques for enhancing plant and equipment reliability. These supporting activities are listed below [14]:

- Autonomous Maintenance
- Process and Machine Improvement.
- Preventative Maintenance
- Early Management of New Equipment
- Process Quality Management
- Administrative Work
- Education and Training
- Safety and Sustained Success

Figure 2 illustrates the TPM house built on the 5S foundation and supported by 8 pillars.

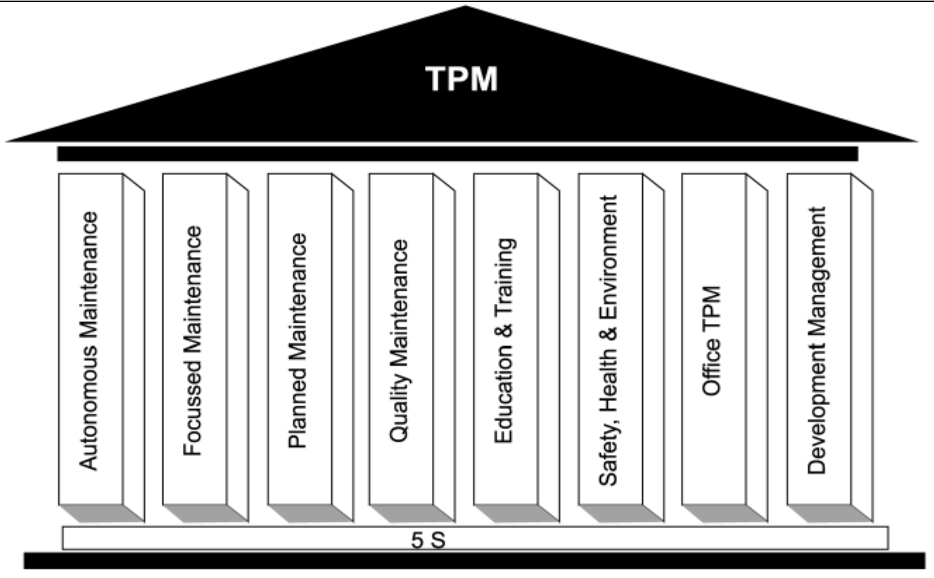

Figure 2: Eight pillars of TPM implementation (suggested by JIPM).
Source: [13].

II.1II 7 S

5S is the foundation of TPM. An organisation establishing a TPM program will center its attention on establishing the 5S basis and creating an autonomous maintenance plan [15]. The 5s system derives its name from the five Japanese words which define the process: seiri, seiton, seiso, seiketsu and shitsuke. The English translation is: sort, set in order, shine, standardize and sustain. Organization, cleanliness and standardization are the guiding principles behind the 5S system. This results in overall workplace cleanliness, created by removing waste from the work area, promoting internal organization and enhancement of visual communication. Later the 5S methodology was then developed to include the "Safety" aspect and it was called 6S. Recently another S (Spirit/Support) was added to the 6S framework and this formed the latest 7S methodology. The 7th S, Spirit/Support, seeks to enhance team consistent cohesion, motivation, and cooperation from top down and up top in the Organizational hierarchy [16], [17]. Table 3 below shows the 7S methodology words and meaning.

Table 3: 7S Word and Definitions.

7S Word	Meaning
SORT	Dispose all useless and waste materials from the workplace
SET IN ORDER	Put everything in the appropriate places for quick access.
SHINE	Make sure that the workplace is clean and tidy at all times.
STANDARDISATION	Make a habit out of keeping order in the workplace at all times.
SUSTAIN	Practice 6S daily without ceasing.
SAFETY	Use all appropriate safety equipment and adhere to all safety requirements.
SPIRIT/SUPPORT	Willingness to cooperate as part of a team. An additional piece to make explicit the reliance on the people factor and the need to continually keep it in mind as other steps are undertaken.

Source: Authors, (2021).

The main objective of the 7S system is to grow the value added to each worker. To grow the added value, manufacturers must create ordered and well adjusted production lines based on the principles of the 7S's: organization and order. A way to improve precision for the entire production and maintenance work in the factory is to give people an extremely organized work environment where a big part of their work is controlled visually. The visual workplace is an ideal one with no defects and no anomalies. The first step in creating a visual workplace is the 7S organization.

II.1V OVERALL EQUIPMENT EFFECTIVENESS (OEE) AND SIX BIG LOSSES

OEE (Overall Equipment Effectiveness) is a metric that is at the core for measuring manufacturing productivity in TPM [18], [19]. It identifies the percentage of planned manufacturing time that is used for actual production. OEE was developed to help TPM programs accurately track productive and strive to attain "perfect production". An achievement of 100% OEE rating means an organisation is achieving 100% Quality (produces good parts only), 100% Performance (Quickest rate), and 100% Availability (Plants runs non-stop). This means it's almost unrealistic to achieve 100% OEE. TPM has the standards of 90% Availability, 95% Performance efficiency, and 99% Quality rate [20]. The overall goal of TPM is to raise the OEE measure, with 85% being the world class measure.

There are six equipment losses identified within TPM that are used to calculate your OEE [21], [22]:

Availability

- Unplanned stops.
- Setup and Adjustments.

Performance

- Small stops.
- Slow running.

Quality

- Defects.
- Reduced yield.

These losses must be routinely observed, studied, computed, and analysed graphically so that the organisation can understand and monitor OEE. Employees must be trained so that they acquire ability to identify and prioritize losses, through practical sessions involving seven steps [23]. In order to effect continuous improvement, an organisation must compare the expected and current OEE measures. This picture will give the organisation the drive to improve its maintenance policy. OEE consists of three underlying components, each of which maps to one of the TPM dreams set out at the start of this topic, and every of which takes into account a distinctive kind of productivity loss [12].

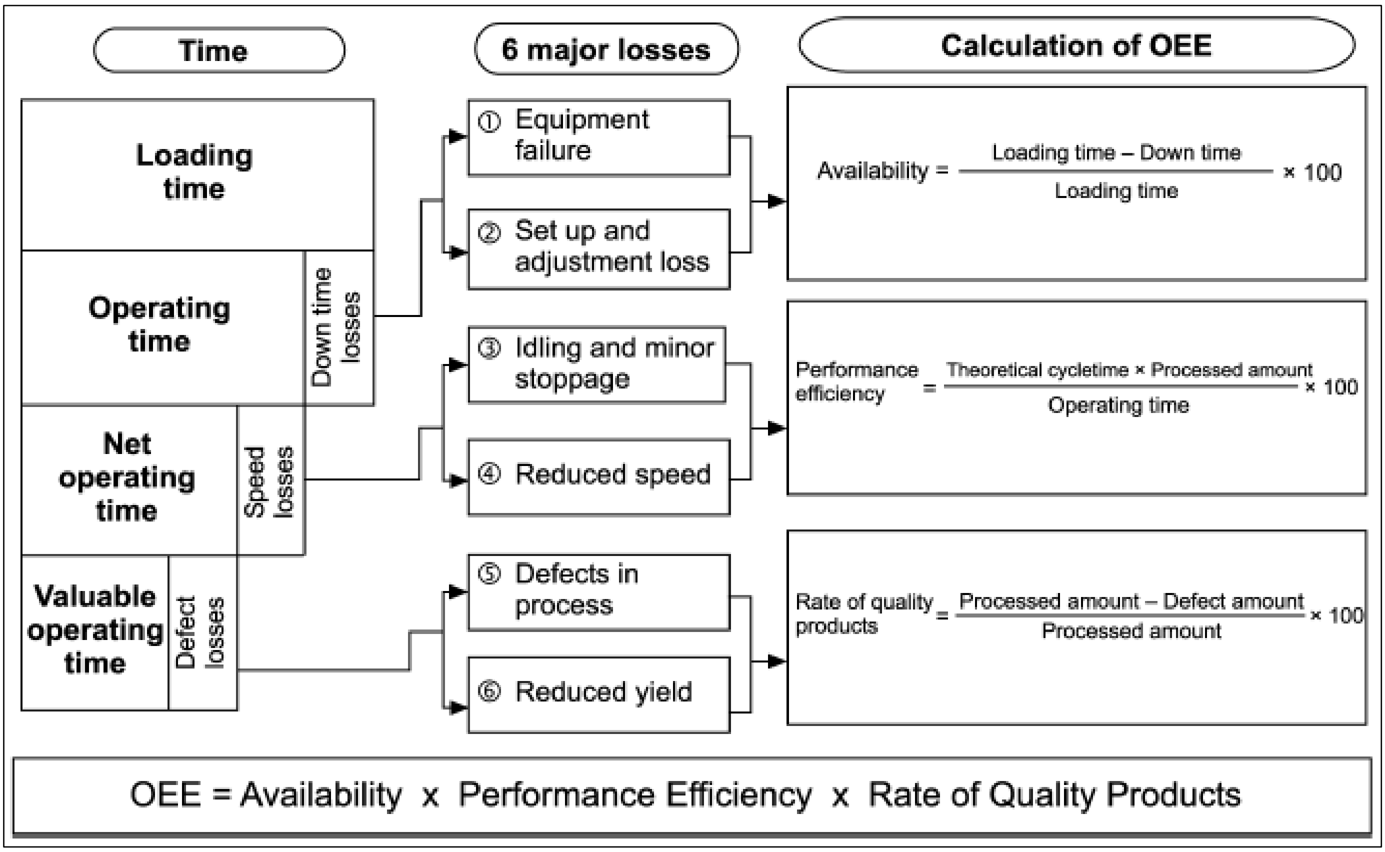

Figure 4: Calculation of OEE based on six major production. losses.
Source: [13] and [24].

OEE is calculated by obtaining the product of availability of the equipment, performance efficiency of the process and rate of quality products [25-27], [29]. The OEE calculation process is depicted in Figure 4 and also summarised below:

OEE=Availability (A)×Performance efficiency(P)×Rate of quality (Q); (1)

Availability refers to the ratio of loading time minus downtime and loading time. Performance refers to the ratio of processed amount times theoretical cycle time and operating time.

Quality refers to the ratio of processed amount minus defect amount and processed amount. The calculations of Availability, Performance and Quality are as follows:

Availability (A) = [(Loading time-Downtime) ÷ Loading time] × 100, (2)

Loading time refers to the running time after the removal of planned activities that affect production [30].

Performance efficiency (P) = [Processed amount ÷ (Operating time ÷ Theoretical cycle time)] × 100, (3)

Theoretical cycle time refers to the shortest cycle time that can be achieved under optimal conditions [30].

Rate of quality (Q) = [(Processed amount-Defect amount) ÷ Processed amount] ×100 (4)

III. MATERIALS AND METHODS

II.1 METHODOLOGY

The study uses field research through data collection over a horizon of 6 months in which the information is condensed in data tables. An SME in automotive manufacturing is used as a case study for the quantitative research approach as an initiative to innovate their processes and research new technologies that help increase their productivity.

An open-ended questionnaire was used for data acquisition inside the firm along with a series of interviews, observations on the production process, and monitoring the machines or equipment. The interview process was done by asking directly to the related stakeholders at the company. The questions used in the questionnaire and interviews were based on knowledge of lean manufacturing principles, production time per unit, bottleneck activity, steps to distribute load at bottleneck, automation level, quality control measure in the firm, industry layout, machine downtime, repair time, maintenance policy, etc.

Follow up questions were asked further which were strictly based upon the responses of the participants. Based on these responses conclusions were drawn through current OEE performance of the SME. By analyzing the current OEE performance and maintenance practices, the state of the firm was determined and then studies were conducted for the implementation of the TPM concept through an appropriate model for SMEs. Secondary data were obtained through a company audit so as extract historical data for the firm, such as downtime, the amount of production, the number of defects, non-productive time, the amount of damage to the machine, the standard repair time, product prices, component costs, and labor costs.

Calculations begin by finding OEE values comprising of three factors - availability, performance, and quality values. The three values are compared with world-class standard values to see the most significant factor. The next step is calculations for the six big losses to find out the big mistakes that impact on availability, performance, and quality.

Evaluation of TMP strategies and general maintenance policy for the SME was carried out in order to overcome the problem of low OEE values that did match with world-class standards. The overall research methodology used in the study is shown in Figure 5.

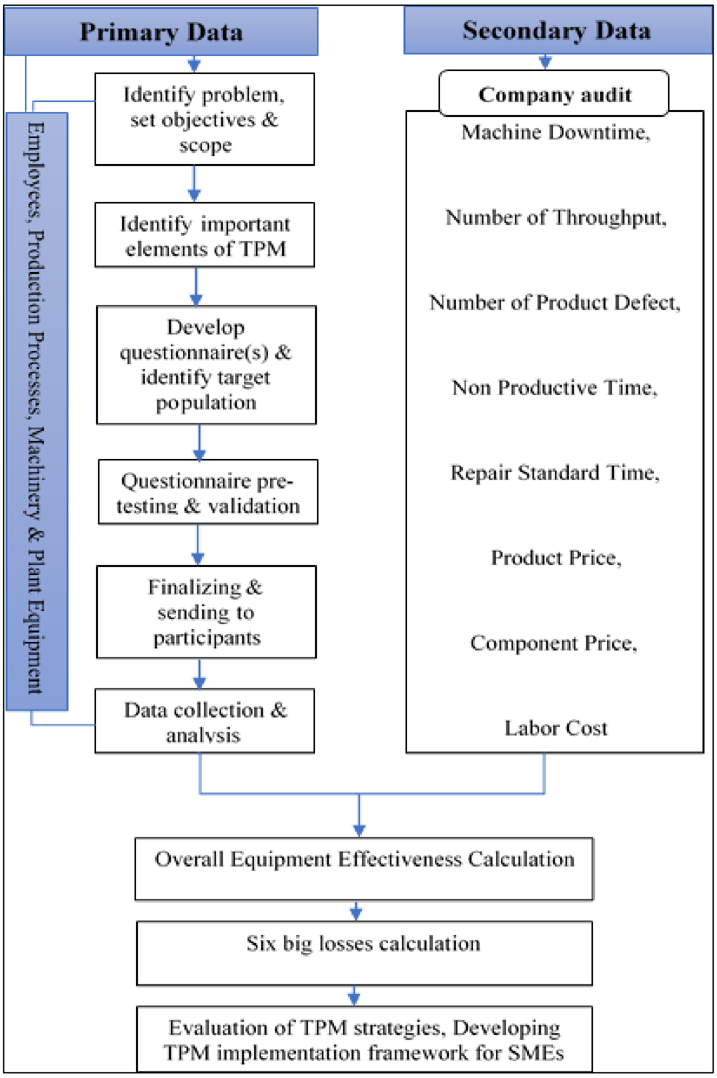

Figure 5: Research methodology.
Source: Authors, (2021).

III.I1 COMPANY PROFILE

The case study company is an SME automotive parts manufacturing company. The company has a fixed production irrespective of market demand. The data collected is tabulated in Table 4 below.

Table 4: Production line profile.

Psudo Company Name	Company X
Age of the company	16 years
Number of employees	36
Number of processes	11
Planned production time	570 minutes per day (inclusive of breaks)
Run time (Available production time)	500 minutes per day (excludes breaks)
Lead time	10 days
Ideal cycle time	1.5
5S foundation	Implemented
Scheduled maintenance	60 minutes duration

Source: Authors, (2021).

II.1II PROBLEMS IDENTIFIED

Based on the methodology used, the problems which led to various types of wastes in the company were identified and listed below:

1. Excess inventory - raw materials, work-in-process, finished goods,
2. Improper management of inventory and tools,
3. Industry works on push system,
4. Delay in the shipment of the orders,
5. Low level of automation,
6. Outdated machinery increases the level of pollution in the firm's environment,
7. Machinery is outfitted for product (consumes too much energy, huge and bulky),
8. Frequent breakdowns of machines,
9. Unbalanced production line,
10. Low production rate,
11. No proper movement of the workers and goods,
12. Improper utilization of floor space,
13. Loading and unloading of raw material and finished goods is a slow process due to space constraint,
14. Lack of commitment from top management,
15. Work attitude from middle management, which is supervisors etc.
16. Lack of dedication by shopfloor workers,
17. Poor relationship between departments, resulting in low morale of workers,
18. Safety measures are inadequate.

IV. ANALYSIS OF DATA AND IDENTIFIED SOLUTIONS

IV.1 OEE CALCULATION

Table 5 represents a seven days sample data set used to calculate Availability, Performance Efficiency and Rate of Quality values for the company. the average availability value of 82.56% with values ranging from 65.22%-87.35%. The average performance value is 90.83%, ranging from 65.22%-87.35%, and the average quality value is 95.04%, ranging between 91.15%-97.67%. Table 6 shows availability, performance, quality, and OEE values over the six months period between March – August 2019.

Table 5: TPM Dataset over seven days.

Item	D1	D2	D3	D4	D5	D6	D7
Shift (min)	570	570	570	570	570	570	570
Breaks	T(20) L(50)	T(20) L(50)	T(20) L(50)	T(20) L(50)	T(20) L(50)	T(20) L(50)	T(20) L(50)
Planned production time	500	500	500	500	500	500	500
Downtime	35	30	40	36	40	35	45
Run time	465	470	460	464	460	465	455
Ideal cycle time	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Total count	450	490	450	400	420	400	400
Rejects count	16	20	13	10	9	10	7
Good count	434	470	437	390	411	390	393

Source: Authors, (2021).

Table 6: Availability, Performance Efficiency, Quality Rate and OEE values over six moths.

Month	Availability (A)	Performance Efficiency (P)	Quality Rate (Q)	OEE
March	81.32	75.33	96.56	59.15
April	77.54	70.56	90.23	49.37
May	63.33	68.89	86.65	37.80
June	87.43	80.12	83.78	58.69
July	74.61	69.87	91.32	47.61
August	70.73	73.43	84.77	44.03
Average	**75.83**	**73.03**	**88.89**	**49.44**
World class	**>=90**	**>=95**	**>=99**	**>=85**

Source: Authors, (2021).

The company performance shows relatively low values against the world class standards. This is caused by equipment failures, idling, minor stoppages, and reduced yield. It can be seen that the OEE value is far below the world-class standard. Figure 6 shows the graph comparing actual compny performance against the world class performance metrics. Corresponding six big losses will help to expose the ultimate causes of low company performance.

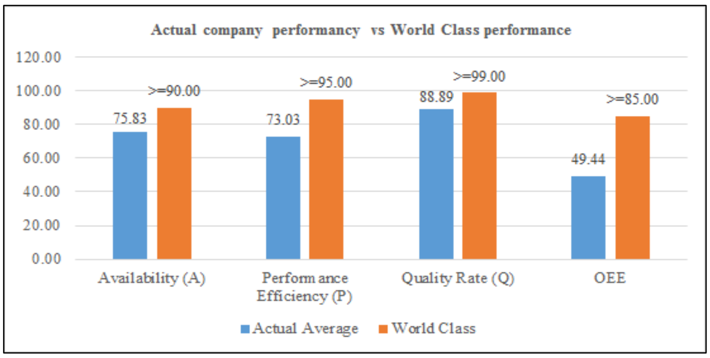

Figure 6: Actual company performance vs World Class performance.
Source: Authors, (2021).

IV.1 6 BIG LOSSES CALCULATION

The next effort after calculating OEE is to identify six big losses factors. The factors are grouped into Avilability (A), Performance Efficiency (P), and Quality (Q). The data obtained from the company is shown on a graph in Figure 7. The graph shows that unplanned stops contribute the largest loss factor of 19.61%. This heavily impacts on plant and equipment availability. This indicates that the company needs a sound maintenance strategy in order to boost availability.

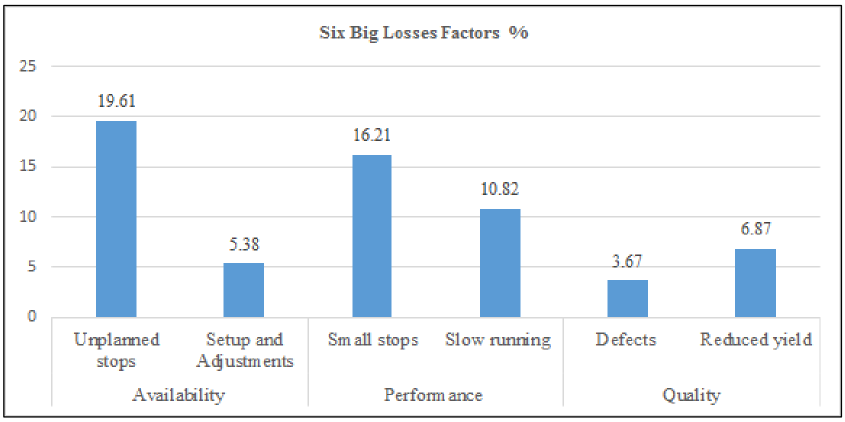

Figure 7: Six big losses.
Source: Authors, (2021).

IV.1 TPM IMPLEMENTATION FRAMEWORK

Based on various claims from literature, TPM has strong stern effects in manufacturing performance. Some case studies have proved that successfully implementing TPM brings out invaluable impacts to the overall performance of the organization or a company. TPM has shown significant improvements of the ranges 30-40% improvement in Overall Equipment Effectiveness, a 45% improvement in manufacturing output, 55-75% reduction in accidents as well as 70-80% reduction in defects & rework, 15% reduction in power costs as well as 75% reduction in breakdowns, downtimes [31-33].

Considering the above benefits, TPM was proposed as a tool for improving OEE and associated metrics for the case study company. A ladder model approach is proposed as a suitable framework for the company as illustrated in Figure 8.

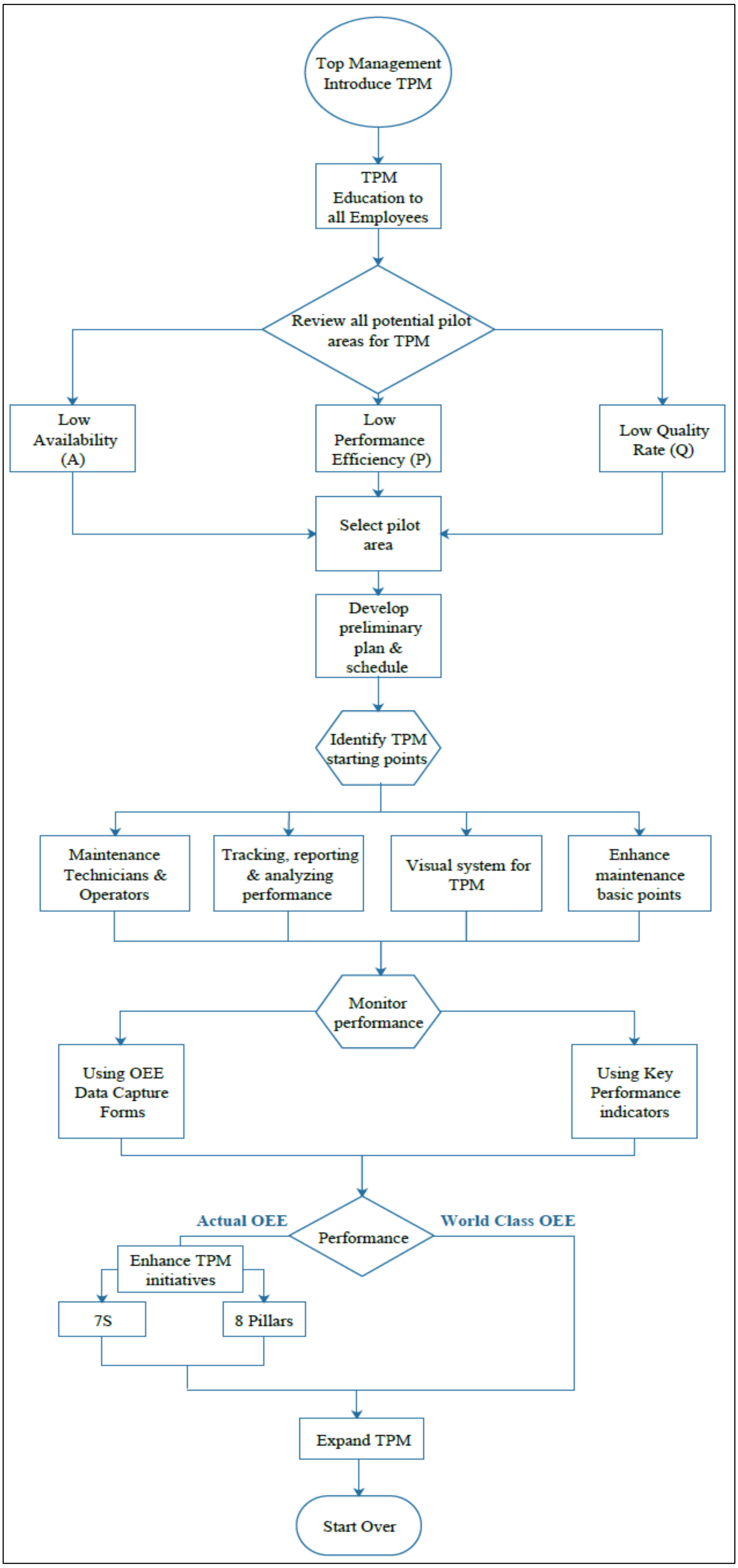

Figure 8: TPM framework.
Source: Authors, (2021).

V. CONCLUSIONS

Overall Equipment Effectiveness (OEE) value for the case study firm was 49.44% over the six months period of observation. Values for availability, performance, and quality over the same period are 75.83%, 73.03%, and 88.89% respectively. All the metrics rank well below the world class standards. The company did not have TPM in place at the time of performance measurement. Further analysis of the six big losses revealed that unplanned stops constituted the highest loss factor of 19.61%, followed by small stops (16.21%), slow running (10.82%), reduced yield (6.87%), setup & adjustments (5.38%), and defects (3.67%). Since the biggest loss contributor affected plant availability, an efficient maintenance strategy is being recommended. We propose a ladder model TPM framework suitable for the manufacturing based case study company. The framework emphasize top management approach, company-wide education of TPM philosophy, prioritization of specific plant equipment,and starting points. Performance is monitored using TPM data capturing forms and computing contributing performance metrics. Comparison against world class performance is emphasised so as to gain drive for improvement. 7S and 8 pillars are recommended bases for company-wide TPM enhancement. The whole framework views TPM strategy as a tool for continuous improvement, hence the last stage is prescribed as a ‘start over’ phase. The framework helps the company to expand the TPM program across all the processes, as well as stive for world class performance.

VI. AUTHOR’S CONTRIBUTION

Conceptualization: Norman Gwangwava.
Methodology: Norman Gwangwava.
Investigation: Goabaone A. Baile, Pageal Dikgale, and Ketsile Kefhilwe.
Discussion of results: Norman Gwangwava, Goabaone A. Baile, Pageal Dikgale, and Ketsile Kefhilwe.
Writing – Original Draft: Norman Gwangwava.
Writing – Review and Editing: Norman Gwangwava.
Resources: Norman Gwangwava, Goabaone A. Baile, Pageal Dikgale, and Ketsile Kefhilwe.
Supervision: Norman Gwangwava.
Approval of the final text: Norman Gwangwava, Goabaone A. Baile, Pageal Dikgale, and Ketsile Kefhilwe.

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