

Assessment of critical success factors, barriers and initiatives of total productive maintenance (TPM) in selected Ethiopian manufacturing industries

TPM in
Ethiopian
manufacturing
industries

51

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Abstract

Purpose – This research aims to investigate critical success factors, barriers and initiatives of total productive maintenance (TPM) implementation in selected manufacturing industries in Addis Ababa, Ethiopia.

Design/methodology/approach – This study built and looked into a conceptual research framework. The potential barriers and success factors to TPM implementation have been highlighted. The primary study techniques used to collect relevant data were a closed-ended questionnaire and semi-structured interview questions. With the use of SPSS version 23 and SmartPLS 3.0 software, the data were examined using descriptive statistics and the inferential Partial Least Square Structural Equation Modeling (PLS-SEM) techniques.

Findings – According to the results of descriptive statistics and multivariate analysis using PLS-SEM, the case manufacturing industries' TPM implementation initiative is in its infancy; break down maintenance is the most widely used maintenance policy; top managers are not dedicated to the implementation of TPM; and there are TPM pillars that have been weakly and strongly addressed by the case manufacturing companies.

Research limitations/implications – The small sample size is a limitation to this study. It is therefore challenging to extrapolate the research findings to other industries. The only manufacturing KPI utilized in this study is overall equipment effectiveness (OEE). It is possible to add more parameters to the manufacturing performance measurement KPI. The relationships between TPM and other lean production methods may differ from those observed in this cross-sectional study. Longitudinal experimental studies and in-depth analyses of TPM implementations may shed further light on this.

Practical implications – Defining crucial success factors and barriers to TPM adoption, as well as identifying the weak and strong TPM pillars, will help companies in allocating their scarce resources exclusively to the most important areas. TPM is not a quick solution. It necessitates a change in both the company's and employees' attitude and their values, which takes time to bring about. Hence, it entails a long-term planning. The commitment of top managers is very important in the initiatives of TPM implementation.

Originality/value – This study is unique in that, it uses a new conceptual research model and the PLS-SEM technique to analyze relationships between TPM pillars and OEE in depth.

Keywords Maintenance, Total productive maintenance, TPM, Overall equipment effectiveness, OEE, PLS-SEM, Structural equation modeling, Manufacturing industries

Paper type Research paper

1. Introduction

1.1 Background and justification

As a result of the intense worldwide competition and ever-changing customer demands, many businesses have been driven to improve their performance through effective management programs, such as total productive maintenance (TPM) (Ahuja, 2009). Companies need to deploy high-performance manufacturing to stay competitive in the global economy, and maintenance management is a key function that supports effective production operations because increased maintenance function effectiveness leads to the development of key manufacturing competencies. The cost of operations and maintenance



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affects a company's ability to succeed (Chaurey *et al.*, 2023). In general, the impact of insufficient and inefficient maintenance can determine the profitability and survival of a corporation. Furthermore, when this maintenance function is actively led, operational effectiveness improves (Al-refaie *et al.*, 2022; Al-najjar, 2009). The importance of TPM in gaining and retaining a competitive edge has grown as worldwide competition has increased. To improve their competitive position, more and more companies are turning to proactive solutions like TPM. TPM plays a vital role in enhancing the global competitiveness (Toke and Kalpande, 2023).

TPM is a source of potential improvement for a company. It encompasses the whole organization, and when properly applied, it improves all areas of the business by increasing efficiency and improving overall performance. The relationship between people and machines is more productive when TPM is practiced (Kalpande and Toke, 2023). Being competitive in a market requires a high level of productivity and quality, and TPM is crucial to accomplishing these goals (Chaurey *et al.*, 2023). TPM is becoming a critical strategic tool for businesses, and its significance is no longer limited to the manufacturing industry.

This study constructs a structural model to evaluate the interactions between the eight TPM pillars and overall equipment effectiveness (OEE) to assess the success of TPM pillar implementation, examine the linkages between them and study their implications on OEE. The findings give decision-makers a clear picture of the links between TPM pillars, highlight the most (and least) impactful pillars on OEE and point them in the right direction for improving Ethiopian manufacturing sector performance.

As far as the knowledge of the researchers, previous studies (Brown *et al.*, 2002; Gupta *et al.*, 2016; Sharma *et al.*, 2012; Sharma *et al.*, 2006; Singh *et al.*, 2013; Tsang and Chan, 2000) mainly focused on TPM implementation without studying the existing status of TPM initiatives in manufacturing industries, little effort has been done to assess the overall initiatives of TPM implementation in manufacturing industries, identify the interrelationship between pillars of TPM and OEE, identify TPM pillars that have been best exercised and TPM pillars that needs more attention. Moreover, there are no recent studies done on Ethiopian manufacturing industries to identify barriers and critical success factors to TPM implementation. Therefore, this research is done to fill the gap stated.

1.2 Problem statement

Global competitiveness is one of the issues confronting the industrial sector today. OEE is one of the pillars of industrial competitiveness in the face of today's fierce global competition as it is one of the indicators of manufacturing performance. In the manufacturing industry, machine availability, performance and quality are crucial for increasing production and meeting or exceeding customer expectations. Maintenance activities must be well-managed to offer a high-quality product at a reasonable cost, allowing manufacturing companies to compete in the global market.

Ethiopian industrial enterprises have low production performance and high maintenance cost due to frequent machine malfunction (Lemma *et al.*, 2013). As per the preliminary study and interview with employees of the organization in Ethiopian manufacturing industries:

- (1) Sudden breakdown of machines and production interruption is a common problem. The top managers follow the firefighting approach; the effort to prevent sudden breakdown is less.
- (2) There is no synergy between production managers and maintenance managers, the top management gives priority to production activities rather than maintenance related initiatives.

- (3) Most of the machines in the manufacturing industries are old where failure is a frequent problem.
- (4) As machines are too old the companies that manufactured forgot the machines and are not supplying spare parts to the market.
- (5) Experienced maintenance technicians are leaving the companies due to retirement age.
- (6) The effort to train and educate operators and maintenance technicians to operate and maintain the old and new machines is little.
- (7) There is a huge problem of spare parts related to the current currency starvation

All the aforementioned problems result in unnecessary production shutdowns, excessive maintenance costs, customer dissatisfaction due to delayed deliveries and poor product quality in the manufacturing industries.

Hence, following an appropriate maintenance policy/philosophy will alleviate these problems. As TPM is a maintenance philosophy targeting zero breakdowns, zero defect and zero accident through the involvement of all employees, it will help the manufacturing companies to solve the stated maintenance related problems. In addition to this; enlisting critical success factors and barriers of TPM implementation, identification of the weak and strong pillars of TPM will help companies to allot their limited resource to vital areas only.

1.3 Research questions

- (1) Is there any initiative for TPM implementation in Ethiopian manufacturing industries?
- (2) What is the relationship between TPM pillars and OEE in the case companies?
- (3) What type of maintenance policy is commonly practiced in the case companies?
- (4) Which TPM pillars are best practiced in the case companies and which pillars of TPM are less addressed and need more attention?
- (5) What are the barriers and critical success factors toward TPM implementation in the case companies?

1.4 Objectives of the study

1.4.1 General objective. The general objective of this research is to investigate the critical success factors, barriers and initiatives of TPM implementation in selected manufacturing industries in Addis Ababa, Ethiopia.

1.4.2 Specific objectives. In line with the general objective and research questions, the specific objectives of this research are:

- (1) To investigate the current initiatives of TPM implementation in Ethiopian manufacturing industries.
- (2) To investigate the relationship between TPM pillars and OEE in the case companies.
- (3) To identify the type of maintenance policy commonly followed in the case companies.
- (4) To identify TPM pillars best practiced in the case companies.
- (5) To identify TPM pillars less addressed so far and needs more attention in the case companies.

- (6) To identify barriers and critical success factors to TPM practice in the case companies.

2. Related literature review and conceptual framework

In this section, definitions of Equipment maintenance, types of maintenance, the eight pillars of TPM and OEE have been discussed. The research hypotheses have been developed as well.

2.1 Definitions of equipment maintenance

The practice of preserving a condition or situation or the state of being well-kept, is defined as maintenance. Almost every industry has a physical asset maintenance program. The goal of maintenance activities is to ensure equipment operational capability, detect problems and/or prevent functional failures (Joshua and Mathew, 2016). In industrial, commercial and residential settings, maintenance entails functioning checks, servicing, repairing or replacing necessary devices, equipment, machinery, building infrastructure and supporting utilities (Agency, 2016; Aigboje *et al.*, 2019). This has evolved over time to include a variety of terms that indicate various cost-effective procedures for keeping equipment operating; these operations might occur before or after a breakdown (Peltier, 2011; Rastegari, 2015).

2.2 Types of maintenance

2.2.1 Preventive maintenance (PvM). PvM is a method of equipment maintenance that entails replacing or repairing an asset regularly, regardless of its condition. Scheduled restoration and replacement are examples of PvM tasks. PvM is a sort of maintenance that is performed on equipment at regular intervals while it is still operational to prevent or minimize the chance of failure. PvM can be scheduled on a weekly, monthly or three-monthly basis (Trojan and Marçal, 2017).

Other types of maintenance that fall under the heading of PvM, in addition to the regular interval approach, include: time-based maintenance (TBM), failure-finding maintenance (FFM), risk-based maintenance (RBM), condition-based maintenance (CBM), reliability-centered maintenance (RCM), predictive maintenance (PdM) and prescriptive maintenance (PrsM).

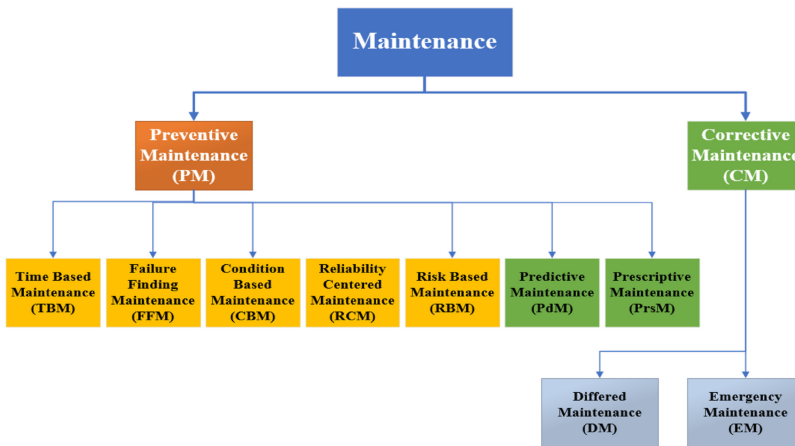
2.2.2 Corrective maintenance (CM). CM is the process taken to restore an item to its original working state after failure or inadequacies were discovered during PvM or otherwise. After allowing an item to fail, a run-to-failure or CM plan restores its function. It is based on the notion that the failure is tolerable and that avoiding failure is either too expensive or impossible (Rastegari, 2015).

In addition to being the outcome of a planned run-to-failure technique, CM is the result of unforeseen breakdowns that were not prevented by PvM. When the implications of failure are low and repair is not required immediately, a run-to-failure technique can be used effectively.

In the chart of maintenance types, CM has been broken into two sub-types: deferred maintenance (DM) and emergency maintenance (EM) (See Figure 1).

2.3 Total productive maintenance (TPM)

TPM is a maintenance commitment that extends beyond preventive and predictive maintenance. TPM and total quality management (TQM) are comparable in certain aspects. The customer is the individual at the next level of the process, and all workers are involved in meeting customer demands. TPM interprets this as delivering the highest level of support and service to all equipment users. TPM considers a machine breakdown to be a fault, and it



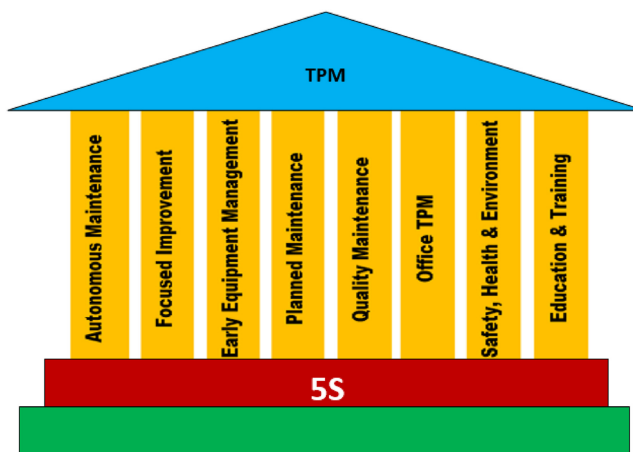
Source(s): Figure created by author

Figure 1.
Types of maintenance

is dedicated to preventing breakdowns and malfunctions in the first place (Madani, 1996; Abhishek Jain, 2014; Prabowo *et al.*, 2018).

2.3.1 *Pillars of TPM*. As per the Japan Institute of Plant Maintenance (JIPM), TPM has eight pillars including autonomous maintenance (AM), focused improvement (FI), planned maintenance (PM), quality maintenance (QM), early equipment maintenance (EEM), education and training (EduT), office TPM (OTPM) and safety, health and environment (SHE) (see Figure 2).

2.3.1.1 Autonomous maintenance (AM) pillar. The AM pillar is crucial. The term “total” in TPM refers to including everyone in the maintenance process (Chaurey *et al.*, 2023). In a nutshell, the idea is that the machine’s operators take on part of the maintenance responsibilities. This is a really smart and practical solution. Nobody knows the machine better than the individual who spends eight hours a day with it. To minimize failures and



Source(s): Figure created by author

Figure 2.
Jipm's pillars of TPM

respond more rapidly when a specific defect is identified, AM allows operators to undertake minor maintenance operations on their own. This pillar covers the training of operators to handle initial maintenance needs as well as the responsibilities that are required on a regular basis to keep operations running smoothly (Trutkowski, 2016; Firdos Jahan and Quazi, 2014; Labiyi, 2019; Ngaich and Malviya, 2015).

H1. Implementation of AM pillar positively and significantly affects OEE of Ethiopian manufacturing industries.

2.3.1.2 Focused improvement (FI) pillar. FI is one of the framework's pillars, where TPM truly shines and brings significant value to the industry. It is centered on a team's collective effort to enhance the entire system. Their objective is to increase the equipment's capacity and efficiency while reducing the company's losses and waste. This pillar enhances efficiency by eliminating defects in products, processes and systems; it also improves safety performance by lowering risk factors in processes by assessing risk levels and taking appropriate steps; and it helps cross-functional teams identify and address recurrent issues (Labiya, 2019; McKone *et al.*, 2001; Prabowo *et al.*, 2018).

H2. Implementation of the FI pillar positively and significantly affects the OEE of Ethiopian manufacturing industries.

2.3.1.3 Early equipment management (EEM) pillar. EEM is a well-organized procedure that directs the machine's design and manufacture. It focuses on eliminating the challenges associated with machine operation and maintenance. Early equipment management attempts to provide new goods and processes with the shortest possible development time and the ability to mass-produce them. This pillar aids in the reduction of product and process setup time, the improvement of OEE and the delivery of large quantities of high-quality products (Ahuja and Khamba, 2008).

H3. Implementation of the EEM pillar positively and significantly affects the OEE of Ethiopian manufacturing industries.

2.3.1.4 Planned maintenance (PM) pillar. This pillar's goal is to increase equipment effectiveness and generate zero faulty items. Focusing on the preventive, breakdown and CM can help achieve this. Planned maintenance alters daily operations transforming maintenance operations from reactive to proactive (Chaurey *et al.*, 2023). This action also improves dependability, maintainability and performance. With the use of recorded failure rates, we can design our maintenance program. The goals of this pillar are to have zero breakdowns, reduce mean time to repair (MTTR) and increase mean time between failures (MTBF). Planned maintenance aids in the reduction of breakdowns, the reduction of product defects, the improvement of machine efficiency, the improvement of machine dependability and maintainability, the reduction of unplanned downtime and the growth of production uptime (Adesta *et al.*, 2018; Firdos Jahan and Quazi, 2014; Ngaich and Malviya, 2015).

H4. Implementation of planned maintenance pillar positively and significantly affects OEE of Ethiopian manufacturing industries.

2.3.1.5 Quality maintenance (QM) pillar. The basic idea behind QM is to provide a framework for detecting and preventing errors in manufacturing processes. Zero breakdowns lead to defect-free output, often known as zero quality faults. Observing the changes in functioning machines can assist us in preventing machine failure defects. Everyone is in charge of maintaining ideal circumstances and achieving zero faults. By enhancing the product's quality, QM lowers the cost of quality, minimizes poor quality wastes and reworks and

lowers customer complaints (Adesta *et al.*, 2018; Firdos Jahan and Quazi, 2014; Ngaich and Malviya, 2015).

H5. Implementation of planned maintenance pillar positively and significantly affects OEE of Ethiopian manufacturing industries.

2.3.1.6 Office TPM (OTPM) pillar. The application of TPM techniques to administrative operations is the focus of this pillar. This pillar's goals include achieving zero function losses, establishing efficient offices and implementing service support functions for industrial processes. This pillar has several advantages, including better utilization of workspace, reduction of repetitive tasks and increased inventory levels across the whole supply chain. Administrative and overhead costs have been reduced. Due to logistics, there has been a decrease in the number of office machine breakdowns and customer complaints, as well as a decrease in the cost of emergency dispatches and purchases (Adesta *et al.*, 2018; Prabowo *et al.*, 2018).

H6. Implementation of OTPM pillar positively and significantly affects the OEE of Ethiopian manufacturing industries.

2.3.1.7 Safety, health and environment (SHE). Maintaining a safe and healthy working environment is the focus of this pillar. This pillar's goal is to have no accidents, no health problems and no fires. As a result, workers must be able to carry out their duties in a safe workplace free of health hazards. This pillar's implementation avoids possible health and safety issues. This pillar guarantees that all employees operate in a safe and accident-free workplace. It enhances the motivation of employees. Employee attitudes about work alter substantially in a safe atmosphere, resulting in increased productivity, quality and delivery performance (Agung and Siahaan, 2020; McKone *et al.*, 2001).

H7. Implementation of SHE pillar positively and significantly affects OEE of Ethiopian manufacturing industries.

2.3.1.8 Education and training (EduT). The most crucial aspect of accomplishing the TPM goal is training. All operators, supervisors and managers are affected. Operators learn how to maintain the machine and spot any faults. The operator learns proactive and preventive machine maintenance practices. Training and education guarantee that employees are properly trained to do their jobs; managers identify the skill, which aids in the effective implementation of TPM by the organization's goals and objectives. The appropriate kind of practice and training raises skill levels and constant repetition produces flawless performance (Chaurey *et al.*, 2023).

All personnel's abilities and performance improve as a result of education and training. Human potential wastes a lot of money in a company if it is not developed. We may have multi-skilled employees through training and education, allowing the operator and supervisor to perform more efficiently, effectively and autonomously (Firdos Jahan and Quazi, 2014; Kelly *et al.*, 2002; Prabowo *et al.*, 2018).

H8a. Implementation of EduT pillar positively and significantly affects AM pillar of Ethiopian manufacturing industries.

H8b. Implementation of EduT pillar positively and significantly affects FI pillar of Ethiopian manufacturing industries.

H8c. Implementation of EduT pillar positively and significantly affects EEM pillar of Ethiopian manufacturing industries.

H8d. Implementation of EduT pillar positively and significantly affects OEE of Ethiopian manufacturing industries.

- H8e. Implementation of EduT pillar positively and significantly affects PM pillar of Ethiopian manufacturing industries.
- H8f. Implementation of EduT pillar positively and significantly affects QM pillar of Ethiopian manufacturing industries.
- H8g. Implementation of the EduT pillar positively and significantly affects the OTPM pillar of Ethiopian manufacturing industries.
- H8h. Implementation of EduT pillar positively and significantly affects SHE pillar of Ethiopian manufacturing industries.

2.3.2 Overall equipment effectiveness (OEE). Manufacturing productivity is measured by OEE. It expresses how much of the equipment’s full capability is being utilized (in %). The measure is largely determined by assessing three OEE factors: availability, performance and quality. OEE is not just an element of the TPM concept, but it may also be utilized independently as a machine or process performance evaluation. The goal of OEE is to continuously enhance and maintain the equipment in terms of effectiveness and efficiency (Dreher *et al.*, 2019; Al-refaie *et al.*, 2022; Ngaich and Malviya, 2015). OEE is a component of the industrial efficiency improvement process (Vairagkar and Shyam, 2015; Bamber *et al.*, 2003; Yimam Ali and Ali, 2019).

2.4 Conceptual model

In this study, a conceptual research model shown in Figure 3 was developed. The model hypothesizes that the implementation of TPM pillars leads to OEE improvement and if TPM pillars are implemented, it shows the presence of good TPM implementation initiative in the organization. Moreover, this model based on the information from previous literature hypothesized that EduT have direct and indirect effect on OEE.

In studying the relationship between EduT pillar, other TPM pillars and OEE, the dependent and independent variables should be identified. In the conceptual model, EduT pillar is defined as an independent variable, while OEE is classified as a dependent variable. The AM, FI, EEM, Planned Maintenance (PM), QM, OTPM, and SHE constructs are endogenous and have dual relationships as both independent and dependent. They are

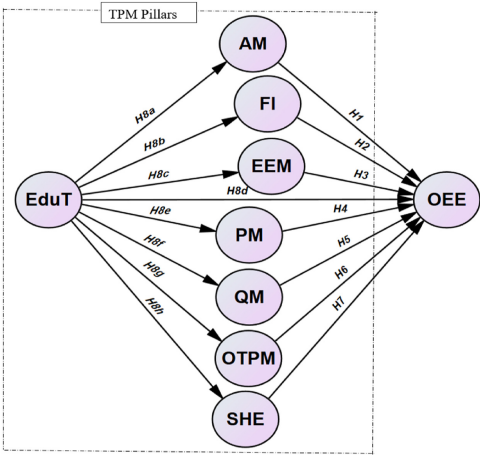


Figure 3.
Research
conceptual model

Source(s): The authors

dependent constructs because they are predicted by EduT, but they are also independent constructs because they predict OEE. The path relations of the variables are shown in the conceptual model (See [Figure 3](#)).

3. Research methodology

This section discusses the conceptual research model, sample size, sampling technique, research instrument, study area, time frame, data analysis method, data collection and processing procedures.

3.1 Study area

The area of this study is Addis Ababa, Ethiopia. This area is selected as it is the one with many manufacturing industries in the country.

3.2 Sample size and sampling procedures

The sampling technique applied for this research is purposive sampling. The key informants for this study were selected based on maintaining the appropriate mix of individuals related to the research title from 18 manufacturing industries. The selection of the 18 manufacturing industries was based on factors including the machine-intensive operations that make the implementation of TPM more relevant in these industries, the company's willingness to share information with the researchers about TPM, the company's representativeness in its sector and the ease of accessing the firm's operations and data. Metal industries, food processing industries, printing industries, bottling and packaging industries, chemical industries and tire manufacturing industries were all included in the list of selected industries. To determine the sample size required for analysis using PLS-SEM, the minimum R-squared table produced by ([Kock and Hadaya, 2018](#); [Priyanath et al., 2020](#)), has been employed. Three elements are required to determine the minimum sample size using this method. The first element is the maximum number of arrows pointing at latent variable. The used significance level is the second element and the third element is the minimum R^2 in the model. In this research model, there are seven arrows pointing to a construct (see [Figure 3](#)). Using a 5% significance level and assuming the minimum R^2 value to be 0.25 and referring [Table 1](#) this research required 80 samples to reach 80% prediction power for identifying R^2 values of at least 0.25 with a 5% chance of error. The researchers feel that the 102 data that have been gathered go well beyond the necessary minimum.

Maximum number of arrows pointing at a construct	Minimum R^2 in the model			
	0.1	0.25	0.50	0.75
2	110	52	33	26
3	124	59	38	30
4	137	65	42	33
5	147	70	45	36
6	157	75	48	39
7	166	80	51	41
8	174	84	54	44
9	181	88	67	46
10	189	91	59	48

Source(s): Table created by author, Adapted from [Priyanath et al. \(2020\)](#)

Table 1.
Reduced version of the
table presented by [Hair
et al. \(2014\)](#) for
estimating minimum
sample size on
"minimum R-squared
method"

3.3 Research instrument

The primary research instrument that was used to collect relevant data concerning the practice of TPM and OEE from manufacturing industries in Addis Ababa, Ethiopia, was a close ended questionnaire and semi-structured interview questions. The questionnaire was adapted from previously used well tested questionnaires ([Al-refaie et al., 2022](#); [Ahuja, 2009](#)) in the literature concerning TPM pillars and OEE. The researchers conducted semi structured interviews with industry managers, operators and maintenance technicians to triangulate the finding of the questionnaires.

The questionnaire was filled by technical managers, general managers, maintenance technicians and operators of the company, who have experiences of more than two years and above. During the data collection, the purpose of the study was made clear and the consent of the respondents was assured with official letters written from the School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology, Addis Ababa University, Ethiopia. Before the data collection, the questionnaire was peer reviewed and pilot tested in five industries. Based on the feedback obtained, the questionnaire was modified and improved, such as eliminating redundant questions or improving the clarity of the questions. At last, the reliability of the measurement model was tested using SPSS version 23 software the result shows that Cronbach's alpha value greater than 0.70 and above, which is above the acceptable cut-off point ([Cronbach, 1951](#)). In the end, the final questionnaire (see [Appendix 1, Table A1](#)) was distributed to the target sample of 130 respondents. Among distributed questionnaires 102 collected showing the response rate to be 78.46%.

3.4 The study area and timeframe

The study was conducted in Addis Ababa, Ethiopia. It has considered the selected 18 manufacturing industries in Addis Ababa, Ethiopia. The data collection was conducted in a time frame of February 2022–April 2022.

3.5 Data collection and processing

After the construction of the research's conceptual model ([Figure 3](#)), the questionnaire for data collection was then created. The questionnaire consists of three sections. [Section 1](#) involves general data, such as personal information, type of maintenance policy and company size information. [Section 2](#) deals with questions related to TPM pillars and OEE. [Section 3](#) contains questions related to opinions of respondents, regarding implementation of TPM in their company and critical barriers and success factors of TPM implementation. The questionnaires in [section 2](#) used a five-point Likert scale from Strongly Disagree to Strongly Agree. A self-administered questionnaire was distributed to 18 manufacturing companies in Addis Ababa, Ethiopia. A total of 102 valid responses were recorded. The data were then processed using partial least squares structural equation modeling (PLS-SEM) method. PLS-SEM is one of the most popular multivariate data analysis techniques and has a remarkable capacity for working with small samples ([Hair et al., 2021](#)), which is the justification for choosing it for data analysis. Moreover, PLS-SEM is the preferred method even when the study object does not have a well-developed theoretical base, particularly when there is little prior knowledge of causal relationships. Unlike covariance-based structural equation modeling (CB-SEM) and multilinear regression analysis, PLS-SEM does not require a large sample size, a specific assumption about the distribution of the data, or even the missing data ([Hair et al., 2014](#)). Users with small sample sizes and less theoretical support for their research can apply PLS-SEM to test the causal relationship. The algorithm of PLS-SEM is different from the common structural equation modeling (SEM), which is based on maximum likelihood. When the sample size and data distribution of research can be hardly used by a common SEM, PLS-SEM has a more functional advantage ([Fan et al., 2016](#)) ([Hair et al., 2014](#)).

Descriptive statistics were initially used to analyze the data. Additionally, given that there were numerous independent factors and a dependent variable in this study, path analysis using Partial Least Square Structural Equation Modeling (PLS-SEM) was used to test the main effect and mediation hypotheses. To this effect, the data were analyzed using SPSS Version 23 and SmartPLS 3.0 software.

4. Results and discussion

4.1 Descriptive statistics

4.1.1 Profile of respondents and the case companies. The descriptive data which includes gender, age, educational level, work experience, position of the respondents, company type and the company size are shown in Table 2.

As shown in Table 2, the majority of respondents (96.08%) were males, while only (3.92%) were females, indicating that the proportion of females in this study is too low. The bulk of respondents (65.69%) had first-level degrees, while (34.31%) had master's degrees. The majority of respondents (32.35%) have worked in the case companies for more than 15 years, followed by 26.47% who have worked there for 6–10 years, 26.47% who have worked there for 11–15 years and 14.71% who have worked there for 2–5 years. It was done on purpose to include technical managers, maintenance technicians, general managers, production managers and operators among the positions of the respondents as these respondents may have more reliable information about TPM. The sizes of all the selected manufacturing organizations were large.

4.1.2 Response given to the question “what type of maintenance policy best describes your company’s maintenance practice?” As shown in Figure 4, a large number of respondents (85) indicated that breakdown maintenance is the most commonly employed maintenance strategy in their company, followed by TBM (56), CBM (28), PdM (10), TPM (7) and PrsM (1). According to the responses, the majority of the case companies use breakdown maintenance as their primary maintenance strategy.

Profile		Number of respondents	% respondents
1. Gender	- Male	98	96.08
	- Female	4	3.92
2. Age	41–45	29	28.43
	36–40	25	24.51
	31–35	24	23.53
	>45	14	13.73
	26–30	10	9.80
3. Educational level	First Degree	67	65.69
	Masters	35	34.31
4. Work experience	>15 years	33	32.35
	6–10	27	26.47
	11–15	27	26.47
	2–5	15	14.71
5. Position	Technical Manager	18	17.65
	Maintenance technician	23	17.65
	G. Manager	18	17.65
	Production Manager	18	17.65
	Operators	25	29.41
6. Company size	Large	102	100
7. Company type	Manufacturing	102	100

Source(s): Table created by author

Table 2.
Profile of respondents
and the case companies

4.1.3 Responses given to the question “have you implemented total productive maintenance in your company?”. According to Figure 5, the majority of respondents (61.8%) believed that TPM was not adopted in their company, 27% believed that it was only partially implemented, and only 11.2% said that TPM had actually been implemented in their organization. Based on the responses, TPM is not implemented in most of the case companies.

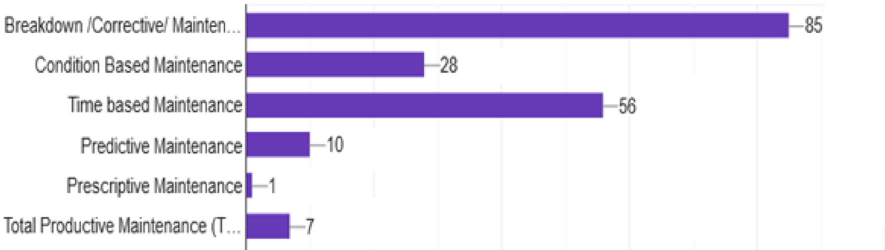
4.1.4 Responses to the question “if TPM (total productive maintenance) is not implemented in your organization yet, what were the barriers of TPM implementation in your company?”. As shown in Table 3, the main implementation challenges for TPM are broken down into the following categories: behavioral, strategic, technical, human and cultural, operational and financial, supporting the findings of (Chaurey et al., 2023; Ahuja and Khamba, 2008; Panneerselvam, 2012; Tyagi et al., 2013). In addition to this, critical barriers are ranked under these categories based on the opinions of the respondents.

4.1.5 Comments in response to the query “if TPM is implemented in your organization, what were the critical success factors that helped you?”. Table 4 shows the ranked critical success factors of TPM implementation as the per the response rate of the key informants. The result supports the finding of (Ahuja and Khamba, 2008; Panneerselvam, 2012; Tyagi et al., 2013).

4.1.6 The findings of the mean, standard deviation and correlation analysis. As indicated in Table 5 the mean value for the constructs (TPM pillars) is considered low, since the corresponding mean value is lower than the mid-point of the response scale (i.e., three for a five-point Likert scale). The low mean values for all TPM pillars indicate that there is low initiative toward implementation of TPM in the case companies.

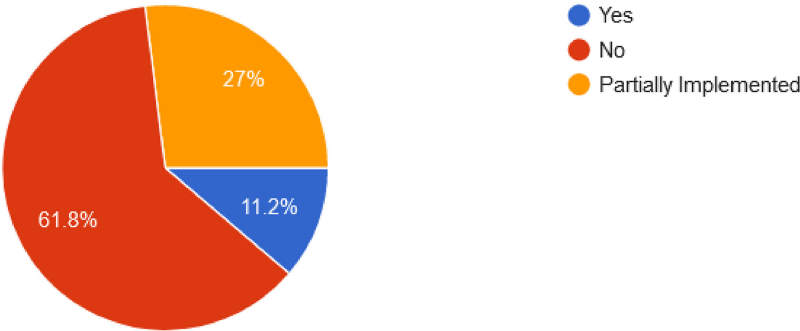
The association between the TPM pillars and OEE is significant at the 0.01 level for each correlation value (see Table 6). This suggests that OEE will increase as TPM pillar

Figure 4.
The type of
maintenance best
practiced in the
selected
manufacturing
industries



Source(s): Figure created by author

Figure 5.
Answers to the
question, “do you
believe total productive
maintenance is used in
your company?”



Source(s): Figure created by author

Category	Critical barriers of TPM implementation	Responses		Rank
		Frequency	%	
1. Behavioral	Lack of top management commitment	54	41.86	1
	Employee resistance	30	23.26	2
	Lack of clear vision	19	14.73	3
	Poor coordination between maintenance and production	18	13.95	4
	Lack of focus to maintenance activities	8	6.20	5
	<i>Total</i>	<i>129</i>	<i>100.00</i>	
2. Strategic	Poor structure to support TPM initiatives	43	27.56	1
	Ineffective long-term planning	34	21.79	2
	Non-clarity of organizational objectives	34	21.79	3
	Failure to allow sufficient time for evolution	25	16.03	4
	Non-clarity of organization policy on TPM	20	12.82	5
	<i>Total</i>	<i>156</i>	<i>100.00</i>	
3. Technical	Lack of training and development	57	24.68	1
	Lack of understanding of TPM concepts and principles	51	22.08	2
	Lack of technical knowledge	49	21.21	3
	Lack of educated workforce	44	19.05	4
	Absence of computerized maintenance management system (CMMS)	30	12.99	
	<i>Total</i>	<i>231</i>	<i>100.00</i>	
4. Human and cultural	Lack of coordination	45	0.23	1
	Lack of motivation	44	0.23	2
	Inability to change organizational culture	44	0.23	2
	Unwillingness of human resources to adopt TPM	36	0.19	3
	Less empowerment	25	0.13	4
	<i>Total</i>	<i>194</i>	<i>100.00</i>	
5. Operational	Lack of follow up of progress of TPM initiatives	52	30.23	1
	Lack of standard operating procedure	41	23.84	2
	Poor workplace environment	31	18.02	3
	Inadequate use of tools, techniques and methodologies	28	16.28	4
	Absence of preventive maintenance schedule	20	11.63	5
	<i>Total</i>	<i>172</i>	<i>100.00</i>	
6. Financial	Lack of sufficient budget for TPM	50	53.19	1
	Return on investment from TPM is not immediate	27	28.72	2
	TPM is too expensive to implement	17	18.09	3
	<i>Total</i>	<i>94</i>	<i>100.00</i>	

Source(s): Table created by author

Table 3.
Critical barriers of
TPM implementation

deployment increases and vice versa. Additionally, there is a strong and positive association between the TPM pillars.

4.2 Evaluation of measurement model

The first step in PLS-SEM analysis is to evaluate the measurement model. The purpose is to determine how well the items load on the hypothetical-defined construct. The assessment of outer model involves: the examining of reliabilities of the individual items, reliability of each latent variables, internal consistency, convergent validity and discriminant validity (Hair *et al.*, 2017).

Composite reliability (CR), individual indicator reliability and average variance extracted (AVE) are all used to evaluate the measurement model's internal consistency and convergent

Table 4.
Critical success factors
of TPM
implementation

S/ N	Critical success factors	Responses		Rank
		Frequency	%	
1	Long-term commitment and support to TPM by senior managers	25	16.56	1
2	Overall employee involvements in TPM implementation activities	17	11.26	2
3	The Launched 6S(5S + Safety) movement and carried out complete implementation	16	10.60	3
4	Established thoughtful preventive maintenance policies	15	9.93	4
5	The properly promoted and established team culture	14	9.27	5
6	High involvement willingness of the operators to the maintenance works	13	8.61	6
7	Continuous educational trainings and cooperate with the carrying out of TPM	10	6.62	7
8	Good maintenance data record or maintenance status	9	5.96	8
9	Full empowerment to the employees	8	5.30	9
10	Acquired consensus of all employees within the company about TPM	8	5.30	10
11	The obtained full understanding on the basic conditions that equipment should possess	8	5.30	11
12	Upgraded maintenance management technologies	8	5.30	12
	<i>Total</i>	<i>151</i>	<i>100</i>	

Source(s): Table created by author

Table 5.
Mean and standard
deviation of the
responses given to the
questions related to
TPM pillars

TPM pillar	N	Mean	Std. deviation
AM	102	2.94	0.88
EduT	102	2.63	0.72
SHE	102	3.01	0.81
OEE	102	2.73	0.88
PM	102	2.93	0.78
EEM	102	2.81	0.87
QM	102	2.83	0.85
OTPM	102	3.03	0.79
FI	102	2.88	0.78
Valid N (listwise)	102		

Source(s): Table created by author

Table 6.
Correlations between
pillars of TPM
and OEE

	AM	EduT	SHE	OEE	PM	EEM	QM	OTPM	FI
AM									
EduT	0.698**								
SHE	0.652**	0.609**							
OEE	0.549**	0.583**	0.692**						
PM	0.440**	0.598**	0.664**	0.606**					
EEM	0.507**	0.618**	0.457**	0.572**	0.594**				
QM	0.569**	0.606**	0.748**	0.741**	0.696**	0.686**			
OTPM	0.363**	0.561**	0.603**	0.564**	0.576**	0.553**	0.661**		
FI	0.575**	0.670**	0.594**	0.715**	0.670**	0.825**	0.731**	0.620**	

Note(s): **. Correlation is significant at the 0.01 level (2-tailed)

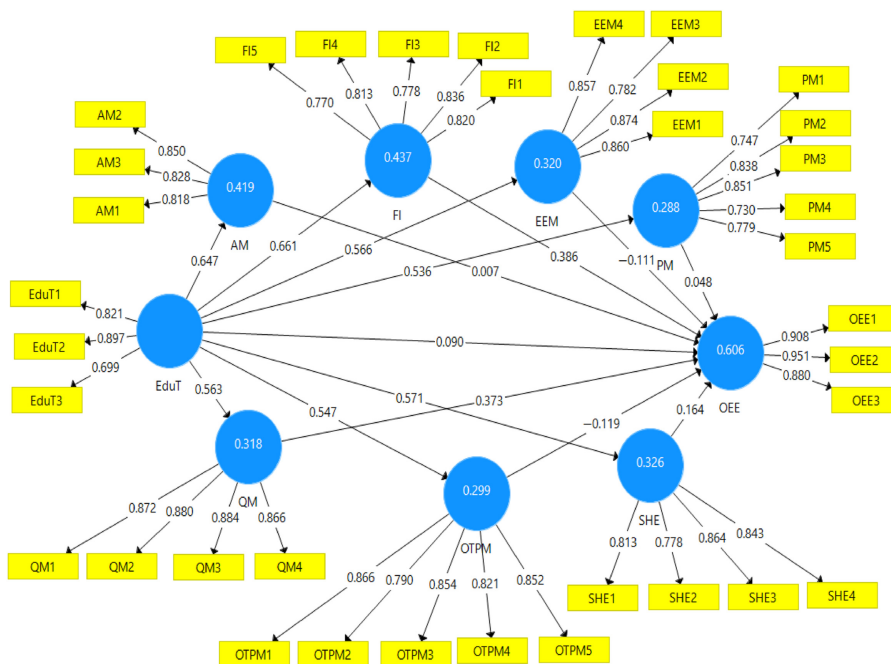
Source(s): Table created by author

validity. Additionally, the Fornell–Larcker criterion and cross-loadings are used to assess discriminant validity.

4.2.1 Indicator reliability. According to a common rule of thumb for indicator reliability, a latent variable should explain a significant part, usually at least 50%, of each indicator's variance (Hair *et al.*, 2013). Therefore, the outer loading of an indicator should be more than 0.708, because that value squared (0.708^2) equals 0.50. Except for EduT3 (0.699), all the indicators for the constructs in this work were well above the minimum acceptable level for outer loadings (see Figure 6 and Table 7).

4.2.2 Internal consistency. The most common measurement used for internal consistency is Cronbach's alpha and CR, in which it measures the reliability based on the interrelationship of the observed items. In PLS-SEM, the values are organized according to their indicator's individual reliability (Hair *et al.*, 2017). The values range from 0 to 1, where a higher value indicates higher reliability level. Cronbach's alpha and composite reliability value > 0.70 is acceptable (Cronbach, 1951; Hair *et al.*, 2017). As shown in Table 7, Cronbach's alpha values for all constructs are > 0.70 and the composite reliability (CR) of all variables are > 0.70, showing the internal consistency of the measurement items.

4.2.3 Convergent validity. Convergent validity is the assessment to measure the level of correlation of multiple indicators of the same construct that are in agreement. To establish convergent validity, the factor loading of the indicator, CR and the AVE have to be considered (Hair *et al.*, 2017). The value ranges from 0 to 1. AVE value should exceed 0.50, CR and the indicator's outer loadings should be higher than 0.708 so that it is adequate for convergent validity (Henseler *et al.*, 2009; Ab Hamid *et al.*, 2017; Hair *et al.*, 2013). As shown in Table 7, all values of AVE are greater than 0.5. The factor loading and CR values are > 0.708 showing the convergent validity of the measurement model.



Source(s): Figure created by author

Figure 6.
The PLS-SEM factor
loadings, correlations
and R^2 values of TPM
pillars and OEE

Latent variable	Indicators	Loadings	Collinearity statistics (VIF)	Construct reliability Cronbach's alpha (α)	Composite reliability (CR)	Average variance extracted (AVE)
Autonomous Maintenance (AM)	AM1	0.850	1.634	0.779	0.871	0.693
	AM2	0.850	10.646			
Focused Improvement (FI)	AM3	0.828	10.560	0.863	0.901	0.646
	FI1	0.820	2.264			
	FI2	0.836	2.450			
	FI3	0.778	1.923			
	FI4	0.8313	2.405			
Earl Equipment Management (EEM)	FI5	0.770	2.036	0.865	0.908	0.712
	EEM1	0.860	2.344			
	EEM2	0.874	2.508			
	EEM3	0.782	10.650			
Planned Maintenance (PM)	EEM4	0.857	2.155	0.850	0.892	0.625
	PM1	0.747	10.607			
	PM2	0.838	2.454			
	PM3	0.851	20.669			
	PM4	0.729	1.373			
Quality Maintenance (QM)	PM5	0.779	2.033	0.899	0.929	0.767
	QM1	0.872	20.699			
	QM2	0.880	2.727			
	QM3	0.884	2.599			
Office TPM (OTPM)	QM4	0.866	2.302	0.893	0.921	0.700
	OTPM1	0.866	2.753			
	OTPM2	0.790	2.132			
	OTPM3	0.854	2.738			
	OTPM4	0.821	2.141			
Safety, Health and Environment (SHE)	OTPM5	0.852	2.787	0.843	0.895	0.681
	SHE1	0.813	1.787			
	SHE2	0.778	10.639			
	SHE3	0.864	2.331			
Education and Training (EduT)	SHE4	0.843	2.200	0.730	0.850	0.656
	EduT1	0.821	1.862			
	EduT2	0.897	2.161			
Overall Equipment Effectiveness (OEE)	EduT3	0.699	1.266	0.900	0.938	0.834
	OEE1	0.908	2.827			
	OEE2	0.951	4.480			
	OEE3	0.880	2.755			

Table 7.
Construct reliability,
validity and
collinearity test result

Source(s): Table created by author

4.2.4 Discriminant validity. Discriminant validity is the extent to which a construct is truly distinct from other constructs by empirical standards. Thus, establishing discriminant validity implies that a construct is unique and captures phenomena not represented by other constructs in the model. The Fornell–Larcker criterion is a conservative approach to assessing discriminant validity. It compares the square root of the AVE values with the latent variable correlations. Specifically, the square root of each construct’s AVE should be greater than its highest correlation with any other construct. This criterion can also be stated as the AVE should exceed the squared correlation with any other construct. The logic of this method is based on the idea that a construct shares more variance with its associated indicators than with any other construct (Hair *et al.*, 2013) (Hair *et al.*, 2017). As shown in Table 8: the diagonal (italic) values are $\sqrt{AVE}$ and the other values are correlations. The

Table 8.
Discriminant validity

	AM	EEM	EduT	FI	OEE	OTPM	PM	QM	SHE
AM	<i>0.832</i>								
EEM	0.493	<i>0.844</i>							
EduT	0.647	0.567	<i>0.810</i>						
FI	0.568	0.803	0.660	<i>0.804</i>					
OEE	0.473	0.548	0.547	0.698	<i>0.913</i>				
OTPM	0.504	0.551	0.546	0.665	0.500	<i>0.837</i>			
PM	0.372	0.584	0.535	0.684	0.603	0.573	<i>0.790</i>		
QM	0.524	0.688	0.565	0.754	0.719	0.658	0.704	<i>0.876</i>	
SHE	0.550	0.467	0.571	0.634	0.654	0.599	0.684	0.753	<i>0.825</i>

Note(s): The diagonal (italic) values are $\sqrt{AVE}$

Source(s): Table created by author

square root of each construct's AVE is greater than its highest correlation with any other construct. Therefore, discriminate validity criteria are fulfilled.

4.3 Assessment of structural model

The structural model is evaluated by examining at its predictive capabilities as well as the relationships between the constructs. The significance of the path coefficients, level of R^2 values, f^2 effect size, predictive relevance Q^2 and q^2 effect size, are the key criteria for evaluating the structural model in PLS-SEM. According to (Hair *et al.*, 2013) assessment of structural model has five steps including: assessment of structural model for collinearity issues, assessment of the significance and relevance of the structural model relationships using structural model path coefficients, assessment of the level of R^2 , assessment of the effect sizes f^2 , assessment of the predictive relevance Q^2 and the q^2 effect sizes.

4.3.1 Collinearity assessment. Before conducting the analyses, the structural model must be examined for collinearity. The path coefficients might be biased if the estimation involves significant levels of collinearity among the predictor constructs. If the level of collinearity is extremely high as indicated by a variance inflation factor (VIF) value of five or higher, one should consider removing one of the corresponding indicators (Hair *et al.*, 2013). As shown in Table 7, all constructs have a VIF value of less than five showing there is no collinearity issue. OEE2 has a relatively highest value of VIF (4.480) but still within the limit.

4.3.2 Structural model path coefficients. After running the PLS-SEM algorithm, estimates are obtained for the structural model relationships, which represent the hypothesized relationships among the constructs. The bootstrapping result shows that except the two paths (EEM→OEE and OTPM→OEE), all paths have a positive relationship with their dependent variable; however, not all variables are statistically significant (See Figure 7 and Table 9). As indicated by the bootstrapping results of PLS-SEM in Table 9: the direct effect of the five pillars of TPM namely AM, EEM, PM, OTPM and SHE was not significant. The total indirect effect of EduT pillar on OEE was found to be significant. Moreover, the direct effect of two pillars of TPM namely FI and QM were found to have a significant direct effect on OEE. The hypotheses H2, H5, H8b, H8c, H8d, H8e, H8f, H8g, H8h and H9 were accepted and H1, H3, H4, H6, H7 and H8a were rejected (See Table 9).

As shown in Table 9, the direct effect of EduT on OEE is not significant. Accordingly, hypotheses H8a was rejected. But the total indirect effect of EduT on OEE as mediated by AM, EEM, FI, OTPM, PM, QM and SHE is positive and significant supporting hypothesis H9 (see Table 10).

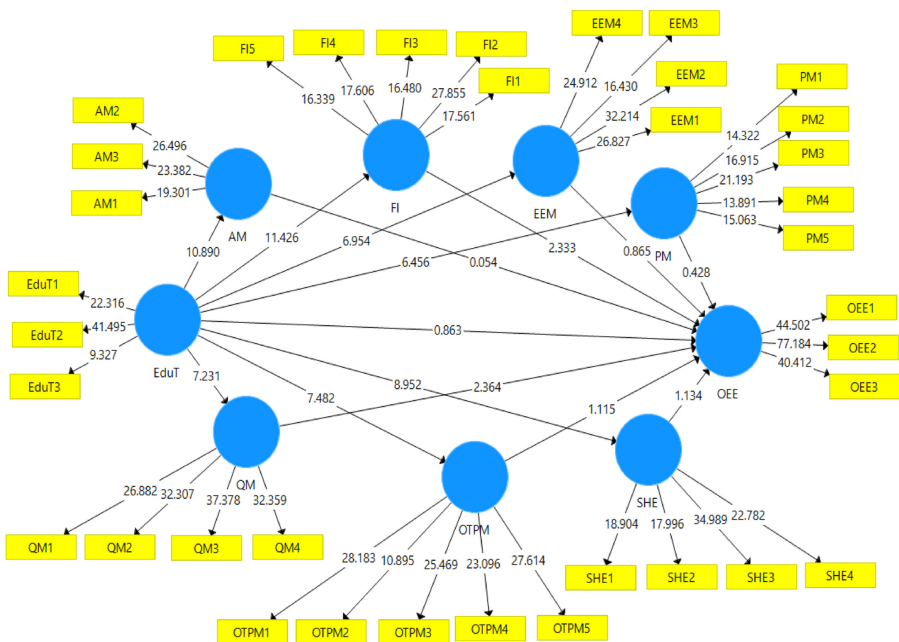


Figure 7.
Bootstrapping for
TPM pillars and OEE
(*t*-values)

Source(s): Figure created by author

Hypothesis	Path	Path coefficient	Standard deviation	<i>T</i> statistics	<i>P</i> values	Decisions
H1	AM → OEE	0.040	0.079	0.501	0.616	Rejected
H2	FI → OEE	0.409	0.154	20.645	0.000	Accepted
H3	EEM → OEE	-0.104	0.128	0.813	0.416	Rejected
H4	PM → OEE	0.059	0.107	0.553	0.580	Rejected
H5	QM → OEE	0.364	0.153	2.380	0.017	Accepted
H6	OTPM → OEE	-0.112	0.104	1.079	0.281	Rejected
H7	SHE → OEE	0.174	0.139	1.248	0.212	Rejected
H8a	EduT → OEE	0.090	0.105	0.863	0.388	Rejected
H8b	EduT → AM	0.647	0.059	10.953	0.000	Accepted
H8c	EduT → EEM	0.567	0.082	6.949	0.000	Accepted
H8d	EduT → FI	0.660	0.058	11.434	0.000	Accepted
H8e	EduT → OTPM	0.546	0.074	7.377	0.000	Accepted
H8f	EduT → PM	0.535	0.084	6.361	0.000	Accepted
H8g	EduT → QM	0.565	0.078	7.214	0.000	Accepted
H8h	EduT → SHE	0.571	0.065	8.736	0.000	Accepted

Table 9.
Path analysis result:
direct effects

Source(s): Table created by author

4.3.3 Coefficient of determination (R^2 value). The coefficient of determination (R^2 value) is the metric that is most frequently used to assess the structural model (Hair *et al.*, 2013; Hair *et al.*, 2021; Henseler *et al.*, 2009). This coefficient, which is determined as the squared correlation between the actual and anticipated values for a certain endogenous construct, serves as a

gauge of the model's predictive efficacy. The coefficient shows how the endogenous latent variable is affected by the combined impact of the exogenous latent variables. The amount of variance in the endogenous constructs that is explained by all of the exogenous constructs linked to it is also represented by the coefficient, which is the squared correlation of the actual and predicted values.

The R^2 value ranges from 0 to 1 with higher levels indicating higher levels of predictive accuracy. In general, R^2 values of 0.75, 0.50 or 0.25 for the endogenous constructs can be described as substantial, moderate and weak, respectively (Hair *et al.*, 2013; Hair *et al.*, 2021; Henseler *et al.*, 2009). Table 11 shows the R^2 values for all endogenous variables. The TPM pillars collectively explain 60.2% of the variance of OEE, while the remaining 39.8% is explained by some other variable, according to the OEE's significant R^2 value (0.602). Similar to AM, EEM, FI, QM and SHE all have R^2 values that are near to moderate (0.320, 0.437, 0.318 and 0.326, respectively). The R^2 values for OTPM (0.299) and PM (0.288) are weak. These results demonstrate that the EduT pillar of TPM may predict differences in 41.9% of AM, 32.20% of EEM, 43.7% of FI, 31.8% of QM, 32.6% of SHE, 29.9% of OTPM and 28.8% of PM. Other factors are responsible for the remaining percentages for each TPM pillar.

4.3.4 Effect size f^2 . The change in the R^2 value when a certain exogenous construct is excluded from the model can be used to assess if the excluded construct has a significant impact on the endogenous constructs in addition to analyzing the R^2 values of all endogenous constructs. The f^2 effect size is the name given to this metric. According to the guidelines for calculating f^2 , values of 0.02, 0.15 and 0.35, respectively, correspond to the minor, medium and large effects of the exogenous latent variable (Salkind, 2012).

The f^2 values of AM→OEE (0.002), EEM→OEE (0.008), OTPM→OEE (0.016), PM→OEE (0.003) are less than 0.02 showing the small effect of these pillars if we remove them from the model. The f^2 values of QM → OEE (0.086) and SHE → OEE (0.024) shows the variables have medium effect on OEE. The f^2 value of EduT → AM (0.719), EduT → EEM (0.474), EduT → FI (0.772), EduT → OTPM (0.425), EduT → PM (0.402), EduT → QM (0.468) and EduT → SHE (0.484), shows that EduT will have a large effect on the endogenous corresponding variables if removed from the model (See Table 12).

4.3.5 Blindfolding and predictive relevance Q^2 . Researchers should look at Stone–Geisser's Q^2 value in addition to the size of the R^2 values when determining the predictive accuracy

Hypothesis	Path	Path coefficient	Standard deviation	T statistics	P values	Decisions
H9	EduT → OEE	0.512	0.065	7.838	0.000	Accepted

Source(s): Table created by author

Table 10.
Path analysis result:
total indirect effects

Latent variable	R^2	R^2 adjusted
AM	0.419	0.412
EEM	0.320	0.315
FI	0.437	0.430
OEE	0.606	0.571
OTPM	0.299	0.290
PM	0.288	0.279
QM	0.318	0.312
SHE	0.326	0.319

Source(s): Table created by author

Table 11.
 R^2 and R^2_{adjusted}
results

Table 12.
f² values

	AM	EEM	EduT	FI	OEE	OTPM	PM	QM	SHE
AM					0.002				
EEM					0.008				
EduT	0.719	0.474		0.772		0.425	0.402	0.468	0.484
FI					0.097				
OEE									
OTPM					0.016				
PM					0.003				
QM					0.086				
SHE					0.024				

Source(s): Table created by author

(Geisser, 1974). The predictive relevance of the model is indicated by this metric. The external constructs have predictive relevance for the endogenous construct under examination, as indicated by Q² values larger than 0. As a relative measure of predictive importance, the values of 0.02, 0.15 and 0.35, respectively, imply that an external construct has a minor, medium or strong predictive relevance for a certain endogenous construct (Q²) (Geisser, 1974) (Hair *et al.*, 2013). Table 13 shows that all variables have medium predictive relevance.

The key constructs that are most relevant to explaining the endogenous latent variable(s) in the structural model can be determined by interpreting these findings. As a result, Table 13 shows that AM, EEM, FI, OTPM, PM, QM and SHE have medium relevance to the endogenous variable OEE.

5. Conclusion and recommendation

5.1 Conclusion

The main outcome of this study offers empirical support for the case companies' TPM implementation initiatives. From the findings of descriptive statistics and multivariate analysis using PLS-SEM, the TPM implementation initiative of the case manufacturing industries is at its earliest stage. To reach the OEE level for the world-class production, a greater effort needs to be done.

The research also discloses the barriers and critical success factors of TPM implementation in the selected manufacturing companies. Regarding the implementation of the eight TPM pillars and their effect on OEE, only three pillars namely FI, QM and EduT have significant effect on OEE of the selected companies. The other five TPM pillars—AM, EEM, Planned Maintenance (PM), OTPM and SHE—had no appreciable impact on the situation. Although EduT have a small direct impact on OEE, they have a considerable indirect impact on OEE through the mediation of AM, FI, PM, EEM, QM, SHE and OTPM. The fact that OEE's $R^2 = 0.606$ indicates that the total effect of TPM pillars accounts for 60.6% of OEE's explanation, with other variables accounting for the remaining 39.4%.

The originality of this study is in its thorough analysis of the connection between TPM pillars and OEE in manufacturing industries, particularly in Ethiopia, by creating a unique

Table 13.
Q² values

	AM	EEM	EduT	FI	OEE	OTPM	PM	QM	SHE
Q ²	0.274	0.215		0.265	0.474	0.199	0.169	0.236	0.214

Source(s): Table created by author

conceptual model that is extremely distinct from previous studies. This study filled up the gaps left by earlier research by examining important data about critical success factors and barriers of TPM implementation as well as by identifying the weak and strong pillars of TPM in the instance manufacturing companies. Managers of the organizations can use this knowledge to focus their limited resources on the particular issues that need their attention. Future research in the topic can be built on the findings of this study as well.

5.2 Recommendation

TPM is not a quick fix. It necessitates a change in both the company's and employee's attitude and their values. Bringing about this change requires time, long-term planning, the dedication of top managers, as well as EduT. The management of the organizations should focus on:

- (1) Eliminating the barriers of TPM implementation.
- (2) Taping to critical success factors facilitation of the implementation of the weak pillars.
- (3) Maintaining and improving TPM pillars that have good implementation.
- (4) Identifying the skill gaps and filling the gap through appropriate EduT programs.

6. Limitations and future study directions

Despite the fact that great effort has been done to maintain the quality of this study and the study investigated helpful information to the practitioners and researchers, this study is not without limitations. First, the limitation of this research is the small sample size. Due to limitation of time and budget, this research focused on 18 purposely selected manufacturing industries in Addis Ababa, Ethiopia. Accordingly, it is difficult to generalize the research finding to the other sectors. Second, the manufacturing performance KPI used in this study is only OEE. Future studies should focus on enlarging the coverage of the case companies to get generalizable result. Other measures like MTBF, MTTR and mean down time (MDT) can be included to the manufacturing performance measurement KPI (OEE).

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Further reading

- Ranatunga, P. and Megama (2020), "Methods and rule-of-thumbs in the determination of minimum sample size when applying structural equation modelling: a review", *Journal of Social Science Research*, Vol. 15, pp. 102-109.

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Appendix 1
Addis Ababa University.
Institute of Technology.
School of Mechanical and Industrial Engineering.

Questionnaire.

Dear respondent,

Firstly, we express our gratitude for your kind support and sharing your knowledge while answering a few questions below.

Nowadays, extensive study is being conducted to identify various strategies and processes that might help a company enhance its quality and productivity to cope up with the global competition. One such method is Total Productive Maintenance (TPM). It is a Japanese philosophy that focuses on obtaining ZERO breakdowns, ZERO defects and ZERO accidents by properly maintaining equipment throughout its lifetime. Total productive maintenance (TPM) is a strategy that operates according to the idea that everyone in a facility should participate in maintenance, rather than just the maintenance team only. TPM integrates all areas of an organization.

Dear respondent, we are conducting research entitled “Assessment of critical success factors, barriers, and initiatives of Total Productive Maintenance (TPM) in Selected Ethiopian Manufacturing Industries”. Your responses in this regard: shall help us to complete this research in efficient way, will be strictly kept confidential and used for academic purpose only. The results of this study will be reported only in aggregate form (no individual names and company will be reported). You can also be informed of the outcome of the research study, if you desire.

It will be a great favor for us and the case companies if you can fill and submit this survey as early as possible.

If you have any doubt, please don't hesitate to contact us at:

Mulatu Tilahun

E-mail: MTBT2017@gmail.com

Mobile: +2519282879 66.

Many thanks in anticipation for all your help, time and effort without which this research is not effectively possible!

With best regards!

Part I: General Information

- 1. Gender: ☐ Male ☐ Female
- 2. Age: ☐ <25 ☐ 26-30 ☐ 31-35 ☐ 36-40 ☐ >40
- 3. Education Level: ☐ Certificate ☐ Diploma ☐ First Degree ☐ Masters ☐ PhD
- 4. Work experience: ☐ <2 years ☐ 2-5 years ☐ 6-10 years ☐ 11-15 years ☐ >15 years
- 5. Position: ☐ General Manager ☐ Technical Manager ☐ Maintenance technician ☐ Supervisor ☐ Operator ☐ Quality Assurance ☐ Production manager Other (Please Specify) ---
- 6. Company Type: ☐ Manufacturing ☐ Service
- 7. Company Size/Scope: ☐ Small ☐ Medium ☐ Large
- 8. Company Name (Optional)-----
- 9. What type of maintenance policy best describes your company’s maintenance practice? **[You can Tick more than 1 Answer]** ☐ Breakdown /Corrective/ Maintenance ☐ Condition Based Maintenance ☐ Time based Maintenance ☐ Predictive Maintenance ☐ Prescriptive Maintenance ☐ Total Productive Maintenance (TPM)

Part II: Structural equation model items

Construct	Item code	Items
Autonomous Maintenance (AM)	AM1	In our company, machine operators have given the responsibility/autonomy/for basic maintenance tasks, rather than relying on dedicated maintenance technicians. Operators perform maintenance tasks on their own equipment emphasizing proactive and preventative maintenance
	AM2	The operators are empowered and able to do simple maintenance tasks (cleaning, lubrication, fixing minor errors, tightening nuts and bolts and safety checks) themselves
	AM3	Our company tools required to perform routine maintenance, checks, setups, etc., are identified and stored using 6S (sort, set in order, shine/sweep, standardize, sustain and safety) principles
Education and Training (EduT)	EdT1	In our company, operators are given necessary education and training on maintenance engineering practices timely
	EdT2	All employees associated with the focus equipment value stream (operators, supervisors, management, quality assurance, engineering, maintenance, etc) received proper training and they have the necessary skills and knowledge
	EdT3	In our company, all maintenance related training/operating materials are available and accessible to the concerned person
	EdT4	In our company, maintenance skills gaps are identified, prioritized and filled through training timely
Safety, Health and Environmental Management (SHE)	SHE1	In our company, there is good maintenance management which avoids accidents during maintenance activities
	SHE2	In our company, all maintenance activities are environmentally friendly
	SHE3	Environmental, health and safety (EHS) risk assessment associated with the equipment (machine guarding, electrical hazards, personal protective equipment (PPE) assessments, etc) is reviewed and updated timely
	SHE4	All operators, mechanics, technicians (and others as appropriate), have been informed of all specific environmental, health and safety (EHS) hazards and associated control measurements that must be maintained
Overall Equipment Effectiveness (OEE)	OEE1	Our machines produce high quality/defect free/products
	OEE2	The performance of our machines is very high. Our machines are effective and efficient
	OEE3	Our machines run for a long time without failure. The availability of our machines is high
Planned Maintenance (PM)	PM1	In our company, problems are fixed at the right time while they are minor to reduce repair costs
	PM2	Properly planned maintenance practices are being performed
	PM3	Preventative maintenance requirements have been established for the equipment at a defined frequency
	PM4	Critical spare parts have been identified and are stored near the equipment (as appropriate)
	PM5	There are sufficient signs and labels that play a crucial role in a successful planned maintenance system. For example, every lubrication points have been labeled to identify the type of lubrication that should be used

(continued)

Table A1.
The item measures of
the TPM pillars
and OEE

Construct	Item code	Items
Early Equipment Management (EEM)	EEM1	When it's time to choose new equipment or develop new products, we consider previous experiences to make maintenance easier in the new machine
	EEM2	There is an effort to design our machines for easy, infrequent and inexpensive maintenance
	EEM3	Life cycle costs are considered in early management process with variable results
	EEM4	There is an effort to design our machine for safety. For example, an effort to protect an operator from injury during machine breakdown
Quality Maintenance (QM)	QM1	In our company, cost of poor-quality losses is measured and addressed linking back to the process
	QM2	In our company, process capability issues are analyzed and investigated timely
	QM3	In our company, product quality risks are managed timely and appropriately
	QM4	Existing quality management systems and tools are used to identify and resolve issues affecting the quality factor of OEE
Office TPM (OTPM)	OTPM1	In our company, administrative workers and managers work in harmony with other employees
	OTPM2	Our administrative offices are responsive and flexible to respond to changes in our customer requirement and that ensured a strong brand image of the company
	OTPM3	In our company offices, all tasks completed on time within standard working hours
	OTPM4	There is clear and consistent communication between managers and employees about strategies and goals of maintenance which builds a strong foundation of manager-employee relationship in our company
	OTPM5	There is continuous process improvement practice in administrative offices
Focused Improvement (FI)	FI1	In our company, there are team-based, structured improvement activities, aimed to eliminate or reduce all possible losses to improve safety and productivity and reduce defects and production costs
	FI2	The maintenance team is proactive, willing to try new methods
	FI3	There is great effort aiming at creating a continuous improvement culture in maintenance related activities
	FI4	There is comprehensive loss analysis to measure and analyze the current maintenance related losses contributing to productivity, efficiency or cost loss
	FI5	In our company, standards established for cleaning, inspection, lubrication and tightening operations

Table A1. Source(s): Adapted from (Al-refaie *et al.*, 2022; Ahuja, 2009)

Parts III: Opinions of respondents towards Implementation of TPM, Critical success factors, and barriers of TPM implementation initiatives

10. Do you think Total Productive Maintenance (TPM) is implemented in your company?

- ☐ Yes ☐ No ☐ Partially

11. If TPM is not implemented in your organization yet, what were the Barriers (Obstacles)? [more than 1 answer is possible, Tick all the possible Barriers] (Source: Adapted from (Hassan, 2020; Khamba, 2008; Panneerselvam, 2012; Shen, 2015; Tyagi et al., 2009)

i. **Behavioral:**

- ☐ Lack of top management commitment
☐ Employee resistance
☐ Poor coordination between maintenance and production
☐ Lack of clear vision

If any other (Please specify) -----

ii. **Strategic:**

- ☐ Ineffective long-term planning
☐ non-clarity of organizational objectives
☐ Non clarity of organization policy on TPM
☐ Failure to allow sufficient time for evolution
☐ Poor structure to support TPM initiatives

If any other (Please specify)-----

iii. **Technical:**

- ☐ Lack of technical knowledge
☐ Lack of educated workforce
☐ Lack of training and development
☐ Lack of understanding of TPM concepts and principles
☐ Absence of computerized maintenance management system (CMMS).

If any other (Please specify)-----

iv. **Human and Cultural:**

- ☐ Lack of motivation

- ☐ Lack of coordination
- ☐ Inability to change organizational culture
- ☐ Unwillingness of human resources to adopt TPM
- ☐ Less empowerment.

If any other (Please specify-----

v. **Operational:**

- ☐ Lack of standard operating procedure
- ☐ Absence of preventive maintenance schedule
- ☐ Poor workplace environment
- ☐ Inadequate use of tools, techniques and methodologies
- ☐ Lack of follow up of progress of TPM initiatives. If any other (Please specify-----

vi. **Financial:**

- ☐ Lack of sufficient budget
 - ☐ TPM is too expensive to implement
 - ☐ Return on investment from TPM is not immediate
- If any other (Please specify-----

12. If TPM is implemented in your organization, Please Tick all the critical success factors.
(Source: Adapted from:(Hassan, 2020; Khamba, 2008; Panneerselvam, 2012; Shen, 2015; Tyagi et al., 2009)

- ☐ Long-term commitment and support to TPM by senior managers
- ☐ The properly Promoted and established team culture
- ☐ Full empowerment to the employees
- ☐ Overall employee involvements in TPM implementation Activities
- ☐ high involvement willingness of the operators to the maintenance works
- ☐ Acquired consensus of all employees within the company about TPM
- ☐ The Launched 6S(5S+Safety) movement and carried out complete implementation
- ☐ Continuous educational trainings, and cooperate with the carrying out of TPM
- ☐ Established thoughtful preventive maintenance policies
- ☐ The obtained full understanding on the basic conditions that equipment should possess
- ☐ Good maintenance data record or maintenance status
- ☐ Upgraded maintenance management technologies.

If any other (Please specify-----