Yong, H. H., & Muhd. Ikmal Isyraf Mohd Maulana
Jurnal Mekanikal, June 2026, 49 : 104-124

DEVELOPMENT OF A PERFORMANCE MEASUREMENT TOOL FOR EMPLOYEE INVOLVEMENT IN TOTAL PRODUCTIVE MAINTENANCE

Yong Hua Hee[a], Muhd. Ikmal Isyraf Bin Mohd Maulana[a]*

[a]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding email: muhdikmalisyraf@utm.my

Article history
Received
24th July 2025
Revised
7th February 2026
Accepted
13th April 2026
Published
2nd June 2026

ABSTRACT

Operational excellence in manufacturing depends not only on advanced equipment but also on active employee involvement. This study develops an Employee Involvement Index (EII) to systematically measure employee involvement in Total Productive Maintenance (TPM) and help managers identify actionable improvement measures. Based on pre-survey interviews and structured employee survey in the Assembly Department of a Malaysian stationery manufacturing company, key factors influencing employee involvement were identified and incorporated into the EII. The EII was pilot tested over 11 weeks with nine employees and one production machine alongside targeted initiatives. Results showed an increase in EII from 68% to 84%, with a concurrent improvement in Overall Equipment Effectiveness (OEE) from 50.33% to 82.23%. The findings strongly suggest an association between employee involvement and equipment performance, highlighting the value of a people-centred approach to TPM. Without claiming direct causation, this study contributes a practical tool to evaluate employee involvement and its relationship with equipment performance, supporting sustainable TPM implementation in real manufacturing environments.

Keywords: *TPM, EII, OEE, employee involvement, performance measurement*

1.0 INTRODUCTION

Total Productive Maintenance (TPM) is a systematic maintenance approach aimed at maximizing equipment effectiveness by integrating maintenance into daily operations and fostering a culture of shared responsibility [1,2]. Active involvement from frontline workers is essential for sustaining maintenance practices and preventing production issues [3,4]. Researches have consistently shown that employee involvement enhances equipment reliability, reduces downtime, and drives continuous improvement [5,6].

However, sustaining employee involvement in TPM remains a challenge for many organizations. Common barriers include a lack of motivation, limited awareness, insufficient training, and unclear role expectations [7,8]. With the rapid integration of digital technologies in manufacturing, aligning employee capabilities and involvement with TPM goals has become increasingly critical [9].

Company A, a leading stationery manufacturer in Malaysia, formally introduced TPM in its Assembly Department nearly a decade ago, building upon an established 5S foundation. All eight TPM pillars were introduced at a conceptual level, however implementation depth varied across pillars. In practice, greater emphasis was placed on

Autonomous Maintenance (AM), with the intention of increasing machine operators' involvement in basic maintenance activities previously handled exclusively by technical personnel. Training sessions and workshops were conducted, focusing primarily on TPM tools, procedures, and technical skills, with mandatory participation and significant time investment.

Although short-term improvements in machine performance were observed following these initiatives, management has faced ongoing challenges in sustaining employee involvement and ownership. The department's Overall Equipment Effectiveness (OEE) has averaged only around 50%, remains below the company's 65% target. Observations reveal limited operator involvement in TPM activities, weak maintenance ownership, and recurring quality issues related to machine handling. These conditions suggest that while TPM has been established structurally, its long-term effectiveness has been constrained by insufficient and inconsistent employee involvement.

This study develops and pilot test a performance measurement tool aimed at assessing and support to improve employee involvement in TPM within the Assembly Department. It identifies the key influencing factors, measures current involvement levels, and examines their association with machine performance indicators such as OEE.

By focusing on the human aspect in TPM, this study contributes to existing literature and offers practical guidance for manufacturers seeking to improve TPM sustainability through enhanced employee involvement. The proposed tool offers a structured and quantifiable measure of employee involvement that may also benefit other organizations facing similar challenges in sustaining TPM initiatives.

2.0 LITERATURE REVIEW

2.1 TPM Overview

TPM is widely recognized as a strategic approach to equipment maintenance aimed at achieving zero breakdowns, zero defects, and zero accidents through continuous improvement. Introduced in Japan in the 1970s by Seiichi Nakajima, TPM redefined maintenance as a shared responsibility across all organizational levels rather than a task confined to specialized teams [1,2]. TPM goes beyond traditional maintenance by involving everyone from top management to shop-floor operators. Its framework consists of eight core pillars such as Autonomous Maintenance, Planned Maintenance, and Quality Maintenance. Autonomous Maintenance, in particular, emphasizes frontline worker involvement in daily equipment care and early problem detection. This not only enhances reliability but also builds a sense of ownership and accountability [10,11].

2.2 Performance Metrics Measuring TPM Success

Across the manufacturing sector, numerous studies have demonstrated that TPM contributes significantly to improvements in key performance indicators such as Overall Equipment Effectiveness (OEE), Mean Time to Repair (MTTR), and Mean Time between Failures (MTBF) [1,10,12,13]. Among these, OEE is particularly emphasized, consisting of three standards: 90% availability, 95% performance efficiency and 99% quality, together make up an overall OEE of 85%, which is widely recognized as the benchmark for world-class performance [1,14]. While these studies clearly highlight the technical benefits of TPM, many have placed less focus on the human element, with employee involvement often remaining underexplored or lacking structured measurement.

2.3 Performance Metrics Measuring Employee Involvement

Although the role of employees is acknowledged in TPM models, the actual measurement of their involvement remains underdeveloped. Studies by Ahuja and Khamba [15] and Yang and Yang [4] have recognized employee suggestions and awareness, yet not translate them into consistent, quantifiable metrics. As a result, organizations may struggle to assess how deeply their employees are involved in TPM or identify which areas require targeted improvements.

2.4 Human-Centric Success Factors and Challenges in TPM

In addition to technical tools and methods, the success of TPM often depends on human factors such as employee motivation, effective communication, and leadership support [11,16]. Empowered employees, particularly those involved in Autonomous Maintenance, play a key role in sustaining long term improvements. However, TPM efforts often face setbacks when these human-centric aspects are overlooked. The common human-centric challenges extract from studies are summarized in Table 1. Without a workplace culture that encourages involvement and fosters mutual trust, TPM implementation may become superficial and unsustainable. Establishing TPM as a long-term practice requires more than structured procedures, it demands continuous involvement, recognition of contributions, and strong sense of shared ownership throughout the organization.

Table 1: Common human-centric challenges in TPM

No.	Challenge	Description	Key References
1	Resistance to Change	Employees resist new roles if benefits are unclear or seen as extra work.	[1,3,4,6,10,13, 16,17]
2	Workload and Burnout	Handling both daily tasks and improvement projects can exhaust employees.	[1,6,13,17]
3	Job Complexity	Complicated work can overwhelm and lower performance.	[6,13]
4	Job Security Concerns	Unclear changes make employees fear job loss or added duties.	[1,4,6]
5	Inadequate Training	Lack of training limits employees' ability to contribute.	[1,6]
6	Weak Leadership Support	Poor management support reduces motivation to engage.	[1,6]
7	Misaligned Goals	Unclear or conflicting goals lead to confusion.	[4,6]
8	Lack of Recognition, reward	Employees lose motivation when efforts go unnoticed.	[1,4,6,18]
9	Communication Gaps	Poor communication causes misunderstanding and disengagement.	[1,6]
10	Language Barriers	Language and cultural differences hinder teamwork.	[3,6]
11	Organizational Culture	Strict hierarchies and traditions can block involvement.	[4,6]
12	Sustainability Issues	Interest fades if results take too long to appear.	[1,6]
13	Limited Autonomy	Micromanagement prevents employees from taking initiative.	[4,6]
14	Poor Measurement Strategies	Without clear metrics, it is hard to track involvement.	[1,6]
15	Time Constraints	Employees lack time for training or improvement tasks.	[1,4]

2.5 Towards Human-Centric TPM Metrics

Japanese manufacturing excellence philosophies like TPM, TQM, and Lean emphasize total employee involvement as a key to success [3,15]. Recent researches stress the importance of human element related drivers such as motivation, teamwork, empowerment, and recognition in sustaining TPM [4,13,18]. However, these are rarely made into measurement metrics, leaving a gap between human involvement and operational metrics [3]. Literature review on selected studies uncover nine motivational drivers that interlink with TPM human-centric issues: motivation, teamwork, participation, empowerment, assessment, recognition and reward, work culture, communication, and career development [3-5,13,15,17,19,20] (Table 2). Despite their importance, these factors have rarely systematically integrated into TPM's people performance frameworks.

Table 2: Motivational drivers that interlink with TPM human-centric issues (selected studies)

Area	Metric / Indicator	Count Range
Motivation	Job satisfaction, motivation level, activity participation	6
Teamwork	Team activity rate, teamwork satisfaction, team evaluation, collaboration, 5S	1-6
Participation	Kaizen ideas (proposed and implemented), training rate, brainstorming	1-5
Empowerment	Decision-making, initiative, skill access, upskilling frequency	3-5
Assessment	Evaluation and audit frequency, self-assessment, KPIs	3-5
Recognition & Reward	Recognition count, verbal praise, reward system	1-3
Work Culture	Transparency, fairness, engagement, leadership support	1-5
Clarity and Communication	Management updates, info access, job clarity	3-6
Career Development	Promotion, development planning, training volume	1-6

2.6 Research Gap and Direction Forward

The literature reveals a clear gap in TPM research: a lack of structured tools to evaluate employee involvement in a consistent and meaningful way (Table 3). Particularly in medium size specific industries like Malaysia's stationery manufacturing sector, there is limited guidance on how to measure and connect human involvement with equipment performance such as OEE. Most existing models prioritize technical results, leaving organizations without a practical method to measure and enhance the human contribution to TPM.

To bridge this gap, this study proposes the development of EII, a structured performance measurement tool tailored to Company A's Assembly Department. The EII aims to capture essential human-centric factors and interlink them to TPM results. By addressing both operational and human perspectives, the tool is expected to assess consistently the state of employee involvement and support focused improvement strategies foster a culture of shared ownership and continuous improvement.

Table 3: Research gap analysis of TPM implementation studies

No	(Author , year)	Industry	Country	Focus Area	Performance metrics used	Research Gap
1	[21]	Automotive	India	TPM & AM training	OEE	No metrics for employee involvement (EI)
2	[22]	Manufacturing	Indonesia	8 TPM pillars impact on performance	Q, C, D, F, OEE	No metrics for EI
3	[15]	Steel Manufacturing	India	Maintenance losses, performance improvement	OEE, productivity, safety, costs, employee suggestions	Indirect human metrics; unclear measurement
4	[11]	Manufacturing	India	TPM's role in core competencies	OEE	No metrics for EI
5	[23]	Beverage Manufacturing	Kuwait	13-step TPM scheme for underperforming lines	OEE, output rate, work hours	No metrics for EI
6	[24]	Automotive	Not specified	CNC productivity & maintenance optimization	OEE	No metrics for EI
7	[3]	Manufacturing	Not specified	Barriers to TPM & Lean via survey	Survey (Likert scale)	Human factors discussed; no metrics for EI
8	[25]	Ice Cream Production	Not specified	Improve OEE by identifying losses and performance gaps	OEE, TBF, TTR, Loss %, repair time ratio	No metrics for EI
9	[26]	Hydraulic Parts (SMEs)	China	Light TPM model for SMEs	OEE, employee awareness	No metrics for EI
10	[27]	Manufacturing	Not specified	TPM effects on productivity, maintenance performance, and challenges	OEE, failure/loss %, savings, skill assessment	Human factors discussed; no metrics for EI

3.0 METHODOLOGY

This study employed a structured four-stage approach to identify key factors of employee involvement, develop and validate a performance measurement tool, namely EII, for assessing employee involvement in TPM activities within the Assembly Department of a Malaysian stationery manufacturer (Company A). A mixed-methods approach was adopted to ensure both depth and breadth of analysis.

3.1 Research Design

The methodology is structured into four key stages (Figure 1) aligned with the study's objectives. In the first stage, the research commenced with problem definition and a comprehensive literature review, identifying gaps related to employee involvement in TPM and establishing a theoretical foundation for tool development.

In the second stage, structured and semi-structured pre-survey interview are conducted with employees across functional levels to gain valuable insights. Findings informed the development of a structured employee survey using a 5-point Likert scale. Quantitative analysis on survey data identified key factors influencing involvement.

In the third stage, insights from the survey were used to develop the EII, a practical measurement tool tailored to Company A's TPM. The EII translated employee perceptions into quantitative scores.

Finally, the EII was pilot tested on a specific production machine with total of nine participants. Pre- and post-intervention data were collected for both EII scores and OEE to assess their interdependency. An iterative review would be conducted if the results were found to be suboptimal.

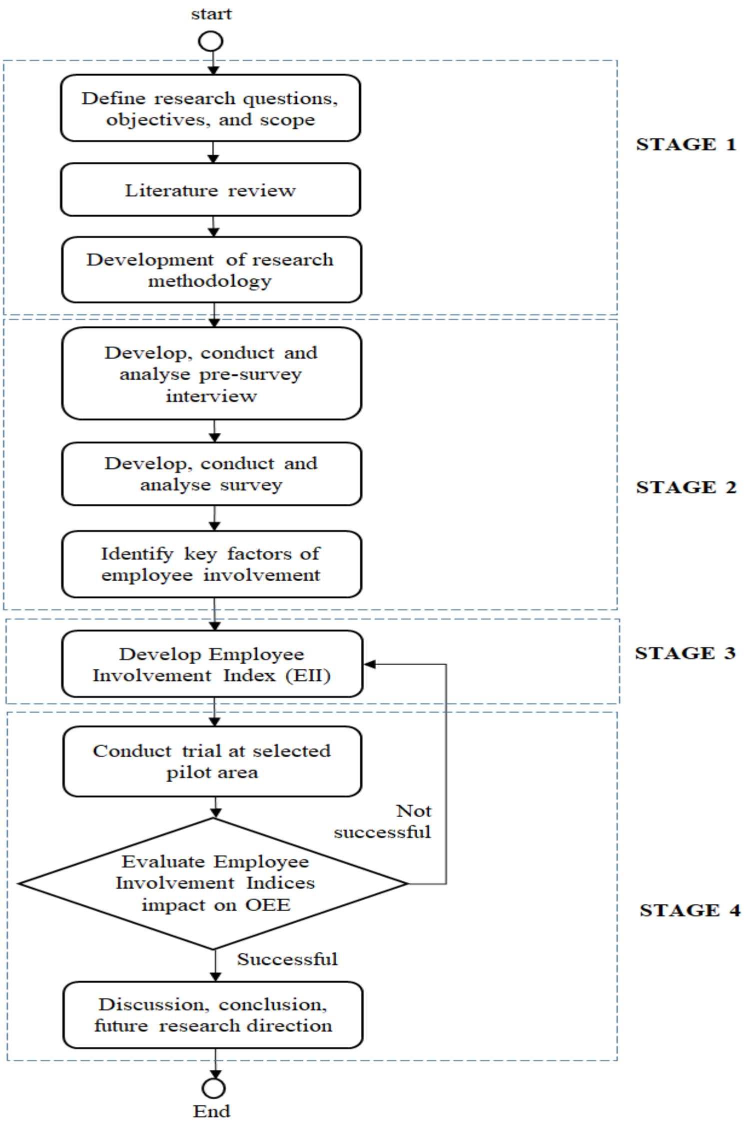

Figure 1: Research methodology flow for the study

3.2 Sampling Approach

A stratified sampling method was applied to both the interviews and surveys to ensure fair and representative participation across six functional categories within Company A's Assembly Department: management, technical, planning, process and quality, local operators, and foreign operators [28]. This approach was selected to capture the diversity of roles and perspectives, enhancing the richness and validity of the findings.

For the pre-survey interviews, nine participants were selected based on proportional stratified sampling to gather qualitative insights that would inform the design of the survey instrument. This sample size aligns with the suggestion by researchers Hennink and Kaiser [29], who indicated that meaningful data saturation in qualitative studies is often achievable within the range of nine (9) to 17 interviews for such population.

For the survey, Yamane's formula was used to determine the appropriate sample size for population of 61 employees, using a 95% confidence level and a 5% margin of error, as shown in Equation (1) [28,30].

$$n = \frac{N}{1 + Ne^2} \tag{1}$$

Where N is 61 (population size), e is 0.05 (margin of error), sampling size (n) computed as 53. The resulting sample size was then proportionally allocated across the six functional categories using the same stratified sampling method as in the interviews. Sample size distribution for both interview and survey are presented in Table 4.

Table 4: Sampling size for interview and survey

Functional Role	Position	Population	Interview Sampling	Survey Sampling
Management	Manager, Executive	2	1	2
Process and Quality	Process Engineer, Quality Assistant	3	1	3
Planning	Schedule Planner	2	1	2
Technical	Technical Engineer, Engineering Assistant	5	1	4
Operational (Local)	Supervisor, Leader, Assistant Leader, First-Grade Operator, Operator	20	2	17
Operational (Foreign)	Assistant Leader, First-Grade Operators, Operators	29	3	25
	Total:	**61**	**9**	**53**

3.3 Data Collection and Evaluation Method

Survey data was collected using a 5-point Likert scale, incorporate self- and/or peer-evaluations, and additional "Not Applicable" option allowed for role-specific relevance [31]. Given the ordinal nature of Likert data, non-parametric analysis was used, focusing on response frequencies and percentage breakdowns [32,33].

Survey responses ratings were further grouped into disagreement (ratings 1 and 2), neutral (ratings 3), and agreement (ratings 4 and 5), with a majority defined as over 50% selecting the same category.

The pilot study evaluated the EII by comparing changes in EII and OEE before and after targeted improvement initiatives in the Assembly Department. The results validated the tool's impact on employee involvement and machine performance.

To assess the reliability and internal consistency of the survey instrument, Cronbach's Alpha analysis was conducted on the collected questionnaire data [34,35]. This reliability test was performed to evaluate the extent to which the survey items consistently measured employee involvement constructs related to TPM. The Cronbach's Alpha was calculated using Equation (2).

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum S_y^2}{S_x^2}\right) \tag{2}$$

Where α represents Cronbach's Alpha, k is the number of tested items, $\sum S_y^2$ is the sum of items variance, and S_x^2 is the variance of the total score. The interpretation of Cronbach's Alpha values used in this study is presented in Table 5.

Table 5: Interpretation of Cronbach's Alpha (α)

Cronbach's value (α)	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Microsoft Excel was used for analysis due to its accessibility and common use in manufacturing.

4.0 RESULT

4.1 Overview of Pre-Survey Interviews

Pre-survey interviews were conducted in accordance with the pre-determined sampling plan, using a mix of open- and closed-ended questions across six thematic areas (Table 6) to refine the clarity, relevance, and alignment of the survey with actual shop floor experiences.

Employees primarily learned about TPM through on-the-job training, focusing more on application than strategy. As key TPM facilitators, management stressed communication gaps, while technical team highlighted TPM's complexity; both of the groups emphasized the needs of dual-perspectives evaluations. Planning personnel reported limited involvement due to their administrative roles, and operators recognized TPM's benefits but noted challenges in sustaining efforts over time.

Common barriers included unclear expectations, low motivation, and lack of recognition. These role-specific insights guided clearer survey design and supported including of both self and peer evaluations for a more accurate assessment of employee involvement.

Table 6: Thematic sections of pre-survey interview questions

No.	Thematic section	Purpose
1	Employee perspectives on TPM implementation	Examines employees' experiences with current TPM practices, including their perceived effectiveness.
2	Understanding of TPM	Assesses employees' level of understanding, sources of knowledge, and exposure to TPM-related training.
3	Employee involvement in TPM	Explores the depth and scope of employees' involvement in TPM-related activities, with reference to TPM eight (8) pillars.
4	Challenges of participation	Assess barriers and difficulties faced by employees in relation to TPM implementation and involvement.
5	Motivation and recognition	Explores employees' perceptions of their motivation, morale, and the recognition or rewards they receive in relation to TPM.

6	Suggestions for improvement	Gathers employees' perspectives on enhancing involvement in TPM, using motivational drivers as a guide for deeper exploration.

4.2 Interviews Survey-Based Analysis of Employee Involvement

The survey, developed from literature and pre-survey insights, assesses TPM understanding, participation challenges, motivational drivers, and satisfaction state. Structured into four sections, using 5-point Likert scales, it incorporates both self and peer evaluations where relevant (Table 7). Data analysis employs non-parametric methods to reflect frequency patterns and majority opinions.

4.2.1 Respondent Demographics

Out of 61 distributed survey questionnaires, 56 valid responses were collected, exceeding the required sample size of 53. This yielded a high response rate, fulfilling statistical reliability of 95% confidence level and 5% margin of error. Respondents came from six functional roles in the Assembly Department, with an overall average service length of 9 years, reflecting a stable and experienced workforce supportive of TPM initiatives (Table 8). This distribution demonstrates a healthy mix of long-serving and newer employees, contributing to both continuity and adaptability in TPM practices.

Table 7: Summary of survey design

Section	Focus Area	Evaluation	Questions	Purpose
A	Understanding of TPM	Self & Peer	8	Assess basic TPM knowledge
B	Challenges in TPM participation	Self & Peer	17	Identify barriers to involvement
C	Motivational driver elements	Self & Peer	10	Explore key drivers of involvement
D	Job satisfaction & involvement	Self Only	26	Gauge satisfaction and involvement level

Table 8: Summary of survey respondents by functional role

Functional Role	Respondents	Average Years of Service
Management	2	12
Process & Quality	3	14
Planning	2	29
Technical	5	13
Operational (Local)	18	11
Operational (Foreign)	26	4.3
Total / Overall Average	**56**	**9**

4.2.2 Understanding of TPM

Survey results showed that the majority of respondents had an understanding of TPM, with both self and peer evaluations exceeding 50%. However, a perception gap was observed between self-evaluation (64%) and peer evaluation (52%), indicating a possible overestimation of personal knowledge.

By functional role, management (81%) and technical team (70%) reported strong self-ratings, reflecting their facilitator's roles in TPM, but their significant lower peer ratings (0% and 17%) indicating a potential disconnect between individual understanding and team perception. Planning staff recorded lowest ratings likely due to limited TPM involvement. In contrast, foreign operators rated themselves and co-worker positively (68% and 71%) reflecting shared confidence within the group (Table 9).

Topic-wise, employees showed strong awareness in 5S, autonomous maintenance, and machine issue response. However, significant self-peer gaps emerged in technical areas like maintenance types and machine parameters, pointing to a need for more balanced and transparent knowledge sharing (Table 10).

These findings suggest the importance of role-specific training, relook planning roles, and greater involvement of support functions to strengthen overall understanding and collaboration.

Table 9: TPM understanding – survey result by functional roles

No.	Functional Role	Self, High (4&5)	Peer, High (4&5)
1	Management	81%	0%
2	Process & Quality	46%	33%
3	Planning	0%	0%
4	Technical	70%	17%
5	Operational (Local)	65%	48%
6	Operational (Foreign)	68%	71%
	Overall:	**64%**	**52%**

Table 10: TPM understanding – survey result by topic

No.	Topic	Self, High (4&5)	Peer, High (4&5)
1	TPM concepts	55%	46%
2	Maintenance types	68%	43%
3	Autonomous Maintenance	64%	55%
4	5S importance	70%	63%
5	Role in TPM	55%	46%
6	Machine parameters	61%	46%
7	Response to machine issues	70%	54%
8	Detect abnormal condition	70%	59%

4.2.3 Challenges to Participation in TPM Activities

Section B of the survey examined 17 challenges related to TPM involvement through both self and peer evaluations. As shown in Figure 2, the most prominent challenge was difficulty in sustaining TPM efforts, rated highly by both self (52%) and peer (59%) evaluation. The remaining challenges were rated by a minority. Four second-ranked challenges (40–49%) include language barriers, workload burnout, limited management support, and uncertainty in contributing to improvement, were more strongly recognized by peers than by self-evaluations. Eight additional challenges (30–39%) such as unclear feedback, time constraints, and lack of training signal practical and motivational gaps. Lastly, four items including poor communication and unclear responsibilities, received less than 30% agreement.

Notably, peer evaluations report higher concern consistently, suggesting underreporting of personal difficulties. These insights emphasize the need for targeted training, inclusive leadership, and open communication to support long-term TPM engagement.

4.2.4 Key Drivers for TPM Involvement

As shown in Figure 3, the survey results indicate strong consensus among employees that all listed motivational drivers are important for fostering TPM involvement. Both self and peer evaluations consistently identified six key elements as most influential: clarity and communication, career development, teamwork, motivation, participation, and work culture, each receiving over 68% agreement. Clarity and communication ranked highest (84% self, 82% peer), highlighting its central role. While empowerment, recognition, reward and assessment received slightly lower ratings (55%–66%), they remain relevant contributors. These findings support previous studies and align well with established motivational drivers in manufacturing excellence.

4.2.5 Current Involvement and Satisfaction on TPM Drivers

Survey findings revealed the current state of each key motivational driver. As shown in Figure 4, employees reported high satisfaction on several key motivational drivers, such as motivation (77%), assessment (73%), clarity and communication (73%), teamwork (71%), and career development (70%). Empowerment (65%), work culture (61%), and participation (63%) were rated moderately, indicating opportunities for consistent reinforcement. The most concerning areas were recognition and reward, where both receiving only 43% of agreement. Despite being moderately valued in importance (66%), these elements showed the lowest satisfaction levels, highlighting a critical gap. Addressing recognition and reward systems is essential to sustaining employee involvement and morale in TPM.

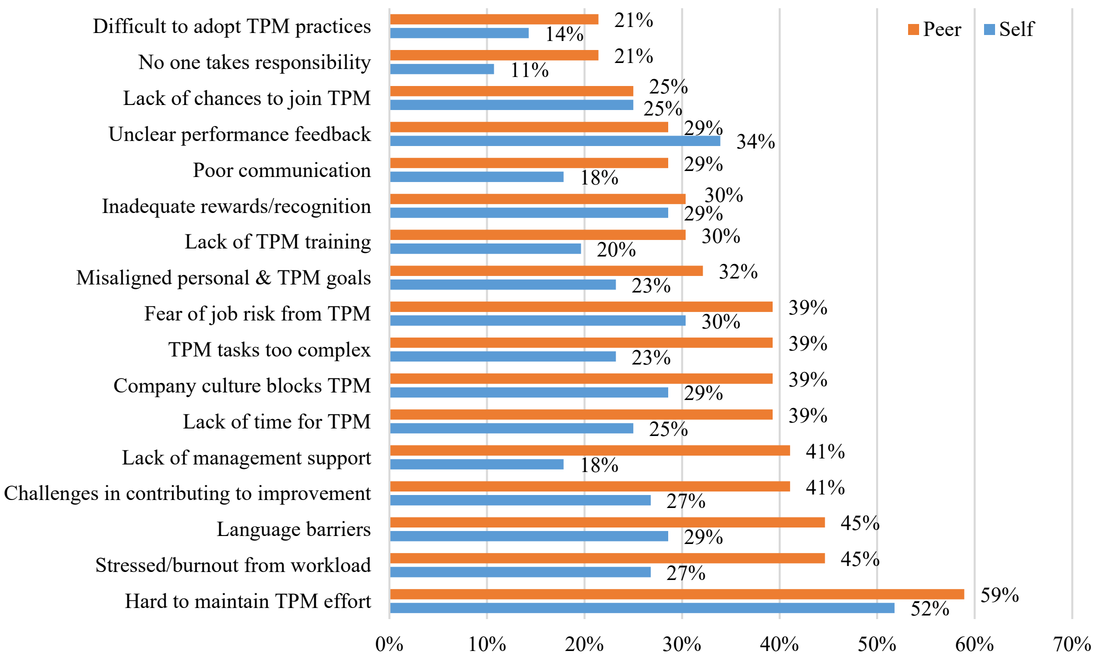

Figure 2: TPM involvement challenges agreement ratings (ratings 4 and 5)

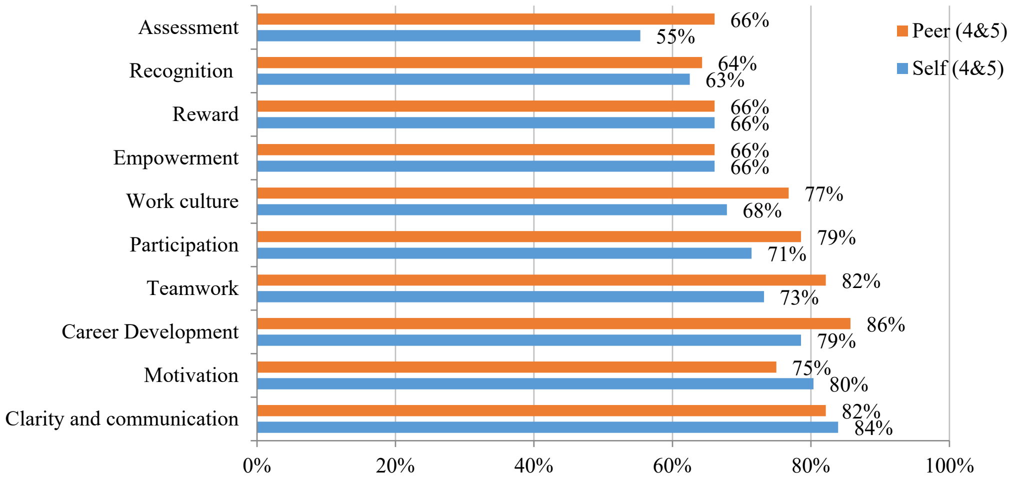

Figure 3: Key motivational drivers agreement ratings (ratings 4 and 5)

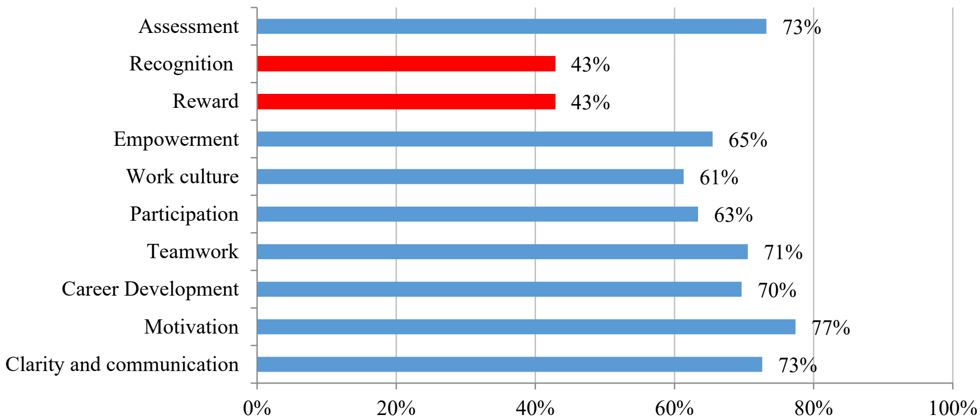

Figure 4: Current state of involvement satisfaction for key motivational drivers

4.3 Key factors Influence Employee Involvement

Table 11 summarizes all the factors influencing employee involvement in TPM in the case study, with three key factors identified among them.

Survey results revealed that all ten motivational drivers commonly cited in previous studies were also considered important by employees in the case study However, a notable gap was observed in satisfaction levels related to recognition and reward systems, indicating a need for focused attention.

Although the majority of employees rated themselves as having a good understanding of TPM, a perception gap was evident, with peer evaluations consistently lower than self-evaluations. This highlights the need to align perceptions and expectations through improved training and communication.

The most prominent challenge identified was sustaining TPM effort over time. Other challenges such as workload stress, language barriers and difficulty contributing to improvement were reported by a minority but remain relevant.

In conclusion, three key factors were identified: weak recognition and reward satisfaction, a perception gap in understanding of TPM, and constraints in sustaining TPM efforts. Addressing these gaps through targeted improvements in communication, training, and the recognition and reward systems is essential to strengthening employee involvement in TPM.

Table 11: Factors influencing TPM employee involvement for Assembly Department

Category	Factor	Remark
Motivational Driver Elements	Clarity and communication Motivation Career Development Teamwork Participation Work culture Empowerment Reward Recognition Assessment	All drivers rated by majority as important element
Knowledge and Awareness	TPM understanding	Perception gap, need for targeted training and clearer communication
Challenges	Hard to maintain TPM effort	Top rated factor by majority
	Stressed/burnout from workload Language barriers Challenges in contributing to improvement Lack of management support Unclear performance feedback Fear of job risk from TPM Company culture blocks TPM TPM tasks too complex Inadequate rewards/recognition Lack of time for TPM Lack of TPM training Misaligned personal & TPM goals Poor communication Lack of chances to join TPM Difficult to adopt TPM practices No one takes responsibility	The rest not rated by majority, but do considered for improvement
Drivers gap	Recognition and reward	Significant satisfaction gap with rating below majority benchmark

4.4 Development and Composition of the Employee Involvement Index (EII)

The EII quantifies employee involvement in TPM using responses from Section A (8 questions) and Section D (26 questions) of the earlier survey (see Table 7). A new EII survey questionnaire incorporating these two sections was developed for pilot testing and future application.

As shown in Table 12, the EII comprised 10 elements and converts qualitative perceptions into measurable scores based on the percentage of agreement (ratings of 4 or 5). For the "TPM understanding" element, a weightage of self-evaluation (0.4) and peer evaluation (0.6) was applied, determined by Assembly Department's management to balance individual confidence with peer perception.

The calculated EII score for Assembly Department is 65%, with key improvement areas identified as recognition and reward, and TPM understanding. The EII result is also visualized in the radar chart (see Figure 5).

Table 12: EII composition

No.	Elements	Description	Self-Agreement Rating % (1)	Self-Agreement Weight (2)	Peer Agreement Rating% (3)	Peer Agreement Weight (4)	Score (1x2) + (3x4)
1	TPM understanding	Having TPM fundamental knowledge	64%	0.4	52%	0.6	**57%**
2	Motivation	Feeling encouraged and energized to take part in the activities.	77%	1			**77%**
3	Teamwork	Having strong cooperation and team spirit in the activities.	71%	1			**71%**
4	Participation	Having opportunities to share ideas and be involved in decision-making.	63%	1			**63%**
5	Empowerment	Being trusted and given responsibility to solve problem in the activities.	65%	1			**65%**
6	Assessment	Having a clear feedback and fair evaluation of my performance	73%	1			**73%**
7	Recognition & Reward	Receiving appreciation and rewards for my involvement and contribution.	43%	1			**43%**
8	Work culture	Working in an environment that support open communication and respect.	61%	1			**61%**
9	Clarity and communication	Getting clear instructions and updates about tasks and goals.	73%	1			**73%**
10	Career Development	Having opportunities to grow professionally or learn new skills.	70%	1			**70%**
	EII	**Overall employee involvement index**					**65%**

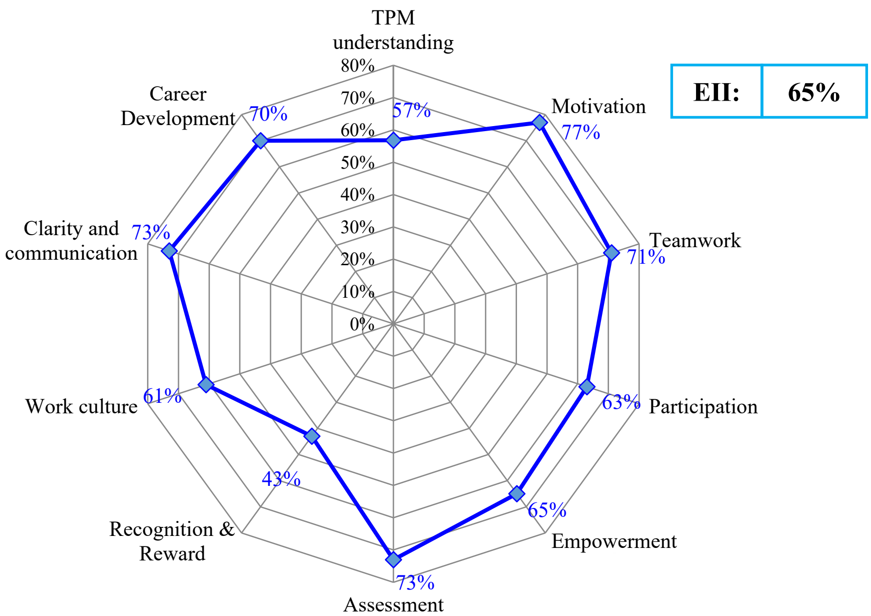

Figure 5: EII score in radar chart

4.5 Pilot Test Implementation and Results

A pilot test was conducted to evaluate the interdependency between employee involvement (EII) and equipment performance (OEE). The test followed seven structured steps, including selection of machine and participants, determination of EII and OEE baselines, establishment and implementation of targeted improvements, and monitoring and analysis of results. This process aimed to assess the association between EII and OEE, thereby validating the practical application of the tool for supporting continuous TPM improvement in the Assembly Department.

4.5.1 Selected Machine and Participants

Machine Z, a high-utilization printing machine in the Assembly Department, was selected for its operator-dependent performance and stable workload. Six machine operators across two shifts participated, supported by each of technical, process and quality, and management representatives. This focused setup ensured consistency and allowed close monitoring of the EII's influence on machine performance during the pilot period.

4.5.2 Targeted Improvements

Based on baseline data and earlier survey findings, five (5) targeted initiatives were implemented to address key gaps in employee involvement and support TPM progress in the Assembly Department. Each initiative was aligned with the identified challenges and mapped to specific EII elements to ensure a structured improvement approach.

(1) Kaizen program: A department-wide Kaizen program was introduced to address challenges in sustaining TPM efforts while strengthening empowerment, participation, motivation and work culture. Three guiding principles "every idea matters", "total involvement", and "ownership" were emphasized to encourage frontline contributions regardless of idea scale. The idea validation process was simplified and led by the department manager to enable rapid approval and implementation, embedding continuous improvement into daily routines and fostering ownership.

(2) Recognition and reward system: To address gaps in recognition and reward satisfaction, a structured incentive system was implemented alongside the Kaizen program. Approved ideas and implementations were rewarded through standardized cash incentives, complemented by monthly recognition of high contributors displayed on departmental notice boards and endorsed by top management. This reinforced positive behaviors and enhanced motivation, participation, and empowerment.

(3) Role-specific TPM training enhancement: To address perception gaps in TPM understanding, training materials were revised to reflect role-specific responsibilities. Operators received focused training on Autonomous Maintenance tasks, while technical and process personnel were trained to support standard setting, troubleshooting, and feedback support. Visual aids and real machine examples were incorporated to improve comprehension and mitigate language barriers, strengthening TPM understanding.

(4) OEE awareness and performance feedback: To address perception gaps in TPM understanding and support sustained TPM effort, operators were briefed on Machine Z's OEE components, and how daily production activities influence these measures. Structured discussions and simplified visual displays were used to align understanding of machine issues and performance. Daily output and OEE trends were reviewed during

shop floor meetings to reinforce the link between TPM activities and equipment performance, strengthening the EII assessment element through consistent performance monitoring and improved workers accountability.

(5) Enhanced communication flow across shifts and functional levels: To improve continuity and coordination, a dedicated WhatsApp group involving operators, technical teams, supervisors, and management was established. The platform enabled real-time sharing of machine conditions, abnormalities, corrective actions, and Kaizen progress, reducing information loss and supporting faster issue resolution. This initiative strengthened the EII elements of clarity and communication, teamwork, and work culture.

Collectively, these initiatives addressed gaps in recognition and reward, TPM understanding, TPM sustainability, while strengthening key EII elements. By systematically aligning improvement actions with EII elements within the case study context, the pilot test provided a structured basis for examining the association between employee involvement and equipment performance.

4.5.3 Post-Intervention Changes

The 11-week pilot test demonstrated significant improvements in both equipment performance and employee involvement. As shown in Table 13, Figure 6, and Figure 7, Machine Z's OEE rose 31.9% from 50.33% to 82.23%, driven by improvements in availability, performance, and quality. These gains were largely attributed to proactive employee actions including correction machine speed settings to counter speed loss, refinement of ink mixing methods to enhance process efficiency, and stabilization of the packaging process.

As presented in Table 14 and Figure 8, the EII improved 16% from 68% to 84%. Notable improvements were observed in the targeted areas: recognition and reward (from 52% to 70%), and TPM understanding (from 55% to 76%). Interestingly, significant increases were also recorded in motivation (74% to 100%), teamwork (69% to 94%), and communication clarity (85% to 96%). These outcomes reflect the positive impact of revised training, Kaizen initiatives, recognition systems, and enhanced communication. However, areas such as empowerment and career development showed minimal change, indicating the need for continued focus in future improvement efforts.

4.5.4 Interdependency between EII and OEE

The pilot test demonstrated a strong relationship between EII and OEE. As the EII increased 16% from 68% to 84%, OEE improved 31.9% from 50.33% to 82.23%. Improved understanding, motivation, and communication enabled employees to prevent errors, solve problems efficiently, and sustain improvements. These findings indicate that employee involvement is not merely supportive but essential in driving equipment performance, fostering a positive cycle of both technical and human-centric progress in TPM implementation.

Table 13: OEE of Machine Z pre- and post-intervention

		OEE	Availability (A)	Performance (P)	Quality (Q) (1-R)	Reject (R)
World Class Standard:		**85%**	**90%**	**95%**	**99%**	**-**
Baseline	Nov'24	50.49%	74.98%	68.67%	98.08%	1.92%
	Dec'24	57.09%	82.06%	71.32%	97.54%	2.46%
	Jan'25	51.33%	74.49%	69.57%	99.04%	0.96%

	Feb'25	46.85%	74.81%	63.86%	98.06%	1.94%
Average (Baseline):		50.33%	75.90%	67.50%	98.23%	1.77%
Pilot Test	Mar'25	62.49%	82.44%	76.54%	99.03%	0.97%
	Apr'25	71.24%	88.43%	81.13%	99.30%	0.70%
	May'25	82.23%	94.62%	87.22%	99.64%	0.36%

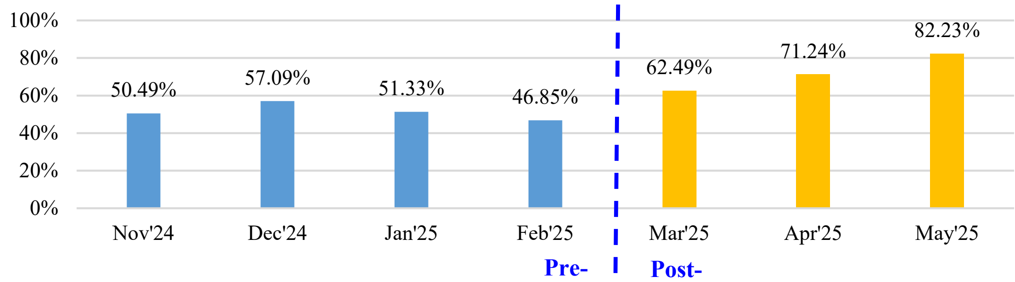

Figure 6: OEE Machine Z pre- and post-intervention

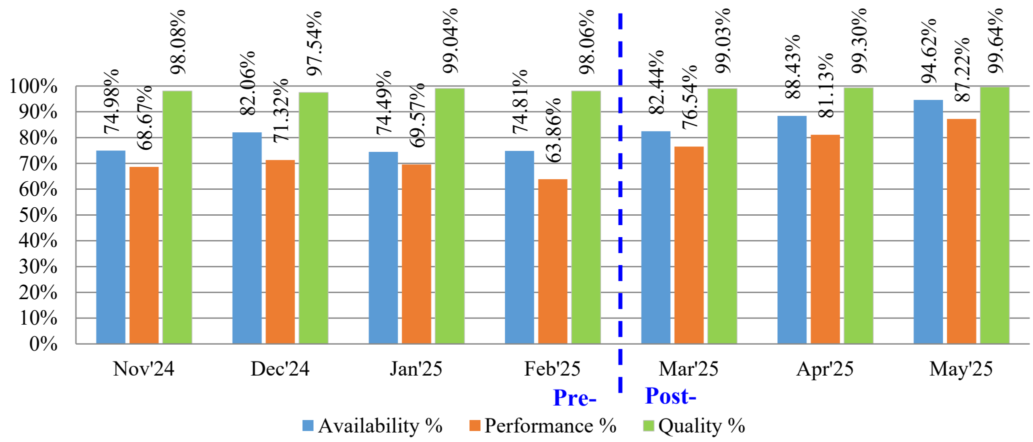

Figure 7: Availability, Performance, and Quality Machine Z pre- and post-intervention

Table 14: EII pre- and post-intervention

		Weighted Score	
No	**Elements**	**Pre-**	**Post-**
1	TPM understanding	55%	76%
2	Motivation	74%	100%
3	Teamwork	69%	94%
4	Participation	67%	78%
5	Empowerment	67%	70%
6	Assessment	67%	100%
7	Recognition & Reward	52%	70%
8	Work culture	74%	85%
9	Clarity and communication	85%	96%
10	Career Development	72%	72%
	EII	**68%**	**84%**

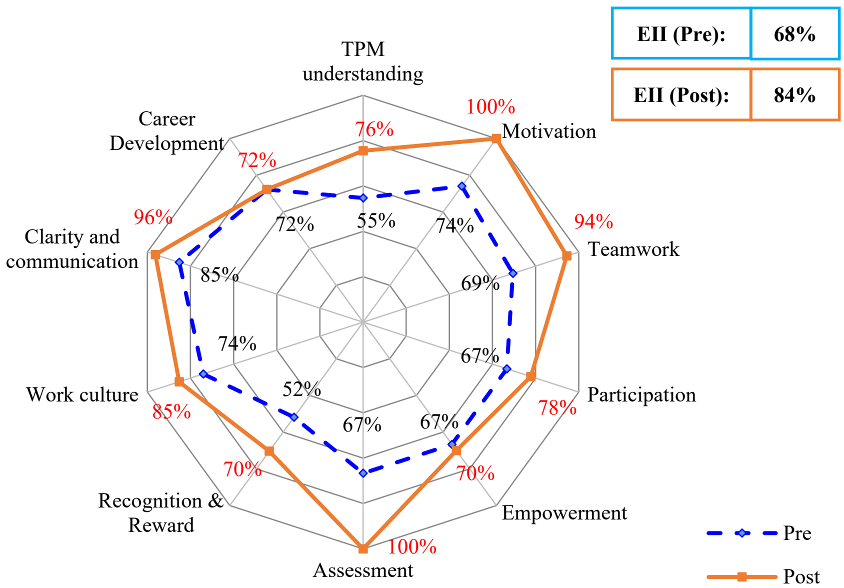

Figure 8: EII pre- and post-intervention in radar chart

4.5.5 Reliability Analysis

Cronbach's Alpha for the EII questionnaire was 0.946, indicating excellent internal consistency. As the value remains below commonly cited redundancy thresholds, it suggests strong coherence without excessive overlap, confirming that the items reliably measure employee involvement in TPM.

5.0 DISCUSSION

This study demonstrates that structured enhancement of employee involvement is strongly associated with improved equipment performance within a TPM context. The targeted improvements implemented in the case study align with core TPM pillars, particularly Autonomous Maintenance, Focused Improvement (Kaizen), and Education and Training, reinforcing prior findings that frontline ownership and role clarity are critical to TPM sustainability [1,4,11].

Improvements in OEE can be interpreted through reductions across the six major OEE losses. Increased operator awareness, clearer communication, and structured performance feedback enabled faster abnormality response (availability), improved operating discipline (performance), and earlier detection of quality deviations (quality). These outcomes support existing literature that positions employee involvement as a key enabler in translating TPM practices into measurable operational performance [10,12,15].

From a human-centric perspective, the findings align with studies emphasizing empowerment, recognition and reward, teamwork, and communication as drivers of sustained employee involvement in TPM environments [4,6,18]. Role-specific training, structured recognition mechanisms, and transparent communication addressed common barriers, including motivation decline and perception gaps in TPM understanding.

The main contribution of this study is the development and application of the EII as a practical, internally consistent tool that complements traditional equipment-based metrics. While the findings indicate a strong association between employee involvement and equipment performance, no direct causality is claimed, consistent with the case-based pilot design.

6.0 CONCLUSION

6.1 Conclusion

This study developed and pilot-tested the EII as a practical tool for measuring and improving employee involvement in TPM. The study achieved its three research objectives by identifying three key factors influencing employee involvement in TPM, developing the measurement tool known as EII, and validating its effectiveness in a real manufacturing environment. Pilot test demonstrated a strong association between employee involvement and equipment performance, with improvements observed in both EII and OEE. These findings underscore the importance of people-centric strategies in sustaining TPM and advancing manufacturing excellence.

6.2 Contributions

Practically, this research offers a quantifiable and adaptable measurement tool, the EII, for assessing employee involvement in TPM. The EII provides actionable insights to guide targeted interventions that enhance employee involvement, support TPM activities, and improve equipment performance. Theoretically, the study reinforces the significance active employee involvement in relation to improved equipment performance, specifically OEE. Contextually, this research contributes to the TPM literature by presenting a real-world case study from a mid-sized Malaysian manufacturing environment, offering industry and culture specific insights that remain underrepresented in existing TPM literature.

6.3 Limitations

This study focused on a single department within one company and a sample size approximately 60 may limit generalizability and statistical power. The short evaluation period, an 11-week pilot test captures only immediate effects without assessing long-term sustainability. Additionally, some reliance on self-reported data introduces potential bias.

6.4 Recommendations

Future studies should consider to expanding the application scope of the EII across multiple departments, organizations, and industries to validate its adaptability. Longer-term evaluations are recommended to assess sustained impact. Advanced statistical analysis of perception data could provide deeper insights. Integrating digital platforms for real-time data collection could enhance data accuracy and support more informed decision making. Finally, examining leadership or managerial roles could further clarify how leadership influences employee involvement and TPM success.

ACKNOWLEDGEMENT

I sincerely thank my supervisor, Ts. Dr. Muhd. Ikmal Isyraf Bin Mohd Maulana, for his guidance and support. Appreciation also goes to my fellow postgraduates, colleagues, and family for their encouragement. Special thanks to the organization's participants for their cooperation during interviews, surveys, and the pilot test. Their contributions and insights were vital to the success of this research.

REFERENCES

1. Ahuja, I. P. S. & Khamba, J. S. 2008b. Total Productive Maintenance: Literature Review And Directions. *International Journal Of Quality And Reliability Management,* 25**,** 709-756.
2. Nakajima, S. 1988. Introduction To TPM: Total Productive Maintenance.(Translation). *Productivity Press, Inc., 1988***,** 129.
3. Slavina, T. & Štefanić, N. 2024. Facing Challenges Of Implementing Total Productive Management And Lean Tools In Manufacturing Enterprises. *Systems,* 12**,** 52.
4. Yang, Y. & Yang, B. 2024. Employee Participation In Total Productive Maintenance–A Bottom-Up Perspective. *International Journal Of Quality & Reliability Management,* 41**,** 269-290.
5. Chaurey, S., Kalpande, S. D., Gupta, R. C. & Toke, L. K. 2023. A Review On The Identification Of Total Productive Maintenance Critical Success Factors For Effective Implementation In The Manufacturing Sector. *Journal Of Quality In Maintenance Engineering,* 29**,** 114-135.
6. Knapić, V., Rusjan, B. & Božič, K. 2023. Importance Of First-Line Employees In Lean Implementation In Smes: A Systematic Literature Review. *International Journal Of Lean Six Sigma,* 14**,** 277-308.
7. Singh, R. K. & Gurtu, A. 2022. Prioritizing Success Factors For Implementing Total Productive Maintenance TPM). *Journal Of Quality In Maintenance Engineering,* 28**,** 810-830.
8. Tortorella, G., Saurin, T. A., Fogliatto, F. S., Tlapa, D., Moyano-Fuentes, J., Gaiardelli, P., Seyedghorban, Z., Vassolo, R., Mac Cawley, A. F., Sunder M, V., Sreedharan, V. R., Sena, S. A. & Forstner, F. F. 2022. The Impact Of Industry 4.0 On The Relationship Between TPM And Maintenance Performance. *Journal Of Manufacturing Technology Management,* 33**,** 489-520.
9. Samadhiya, A., Agrawal, R. & Garza-Reyes, J. A. 2024. Integrating Industry 4.0 And Total Productive Maintenance For Global Sustainability. *The Tqm Journal,* 36**,** 24-50.
10. Ahmed, S., Hassan, M. H. & Taha, Z. 2005. TPM Can Go Beyond Maintenance: Excerpt From A Case Implementation. *Journal Of Quality In Maintenance Engineering,* 11**,** 19-42.
11. Ahuja, I. P. S. & Khamba, J. S. 2008a. Justification Of Total Productive Maintenance Initiatives In Indian Manufacturing Industry For Achieving Core Competitiveness. *Journal Of Manufacturing Technology Management,* 19**,** 645-669.
12. San, S. 2021. A Systematic Literature Review of Total Productive Maintenance On Industries. *Performa: Media Ilmiah Teknik Industri,* 20**,** 97-108.
13. Wolska, M., Gorewoda, T., Roszak, M. & Gajda, L. 2023. Implementation And Improvement Of The Total Productive Maintenance Concept In An Organization. *Encyclopedia,* 3**,** 1537-1564.
14. Mckone, K. E., Schroeder, R. G. & Cua, K. O. 2001. Impact of total productive maintenance practices on manufacturing performance. *Journal of Operations Management,* 19**,** 39-58.
15. Ahuja, I. P. S. & Khamba, J. S. 2007. An Evaluation Of TPM Implementation Initiatives In An Indian Manufacturing Enterprise. *Journal Of Quality In Maintenance Engineering,* 13**,** 338-352.
16. Singh, A. P. & Awoke, N. F. 2023. Relationship Between TPM Practices And Operational Performance In Soft Drinks Manufacturing Industry. *Journal Of Quality In Maintenance Engineering,* 29**,** 729-762.
17. Yang, Y., Yang, B., Onofrei, G., Nguyen, H. & Hlaciuc, E. 2024. The role of employees in continuous improvement: a study on employee participation. *European Journal of Training and Development*.
18. García-lorenzo, A., Carlos Prado Prado, J. & García Arca, J. 2000. Continuous improvement and employee participation in SMEs. *The TQM Magazine,* 12**,** 290-294.
19. Daniel Kitaw, E. B., Mulatu Tilahun Gelaw 2024. Assessment Of Critical Success Factors, Barriers And Initiatives Of Total Productive Maintenance (~~Tpm~~ TPM) In Selected Ethiopian Manufacturing Industries.
20. Charles, E., Okpala, C. & Onyekachi, E. 2016. Benefits and Challenges of Total Productive Maintenance Implemention. *Int. J. Adv. Eng. Technol,* 7**,** 196-200.
21. Acharya, A., Garg, D., Singh, N. & Gahlaut, U. 2018. Plant Effectiveness Improvement Of Overall Equipment Effectiveness Using Autonomous Maintenance Training:—A Case Study. *Int. J. Mech. Prod. Eng. Res. Dev,* 9**,** 103-112.
22. Adesta, E. Y., Prabowo, H. A. & Agusman, D. Evaluating 8 pillars of Total Productive Maintenance (TPM) implementation and their contribution to manufacturing performance. IOP conference series: materials science and engineering, 2018. IOP Publishing, 012024.
23. Bataineh, O., Al-hawari, T., Alshraideh, H. & Dalalah, D. 2019. A sequential TPM-based scheme for improving production effectiveness presented with a case study. *Journal of Quality in Maintenance Engineering,* 25**,** 144-161.
24. Gherghea, I. C., Bungau, C., Indre, C. I. & Negrau, D. C. 2021. Enhancing Productivity of CNC Machines by Total Productive Maintenance (TPM) implementation. A Case Study. *IOP Conference Series: Materials Science and Engineering,* 1169**,** 012035.

25. Tsarouhas, P. H. 2020. Overall Equipment Effectiveness (Oee) Evaluation For An Automated Ice Cream Production Line. *International Journal Of Productivity And Performance Management,* 69**,** 1009-1032.
26. Xiang, Z. T. & Feng, C. J. 2021. Implementing total productive maintenance in a manufacturing small or medium-sized enterprise. *Journal of Industrial Engineering and Management,* 14**,** 152-175.
27. Zlatić, M. 2019. TPM-total productive maintenance. *Proceedings on Engineering Sciences,* 1**,** 581-590.
28. Nanjundeswaraswamy, T. S. & Divakar, S. 2021. Determination Of Sample Size And Sampling Methods In Applied Research. *Proceedings On Engineering Sciences,* 3**,** 25-32.
29. Hennink, M. & Kaiser, B. N. 2022. Sample Sizes For Saturation In Qualitative Research: A Systematic Review Of Empirical Tests. *Social Science & Medicine,* 292**,** 114523.
30. Uakarn, C., Chaokromthong, K. & Sintao, N. 2021. Sample size estimation using Yamane and Cochran and Krejcie and Morgan and Green formulas and Cohen statistical power analysis by G* power and comparisons. *Apheit Int J,* 10**,** 76-88.
31. Queirós, A., Faria, D. & Almeida, F. 2017. Strengths and limitations of qualitative and quantitative research methods. *European journal of education studies*.
32. Allen, I. E. & Seaman, C. A. 2007. Likert scales and data analyses. *Quality progress,* 40**,** 64-65.
33. Harpe, S. E. 2015. How to analyze Likert and other rating scale data. *Currents in pharmacy teaching and learning,* 7**,** 836-850.
34. Al-baldawi, Z., Kassam, A., & Al-Zubaidi, S. S. A. (2024). Investigation and assessment the level of adoption lean philosophy in SMES under uncertainty by EFA/FAHP/FTOPSIS integrated model. *Management Systems in Production Engineering*, 32(2), 280-293.
35. Izah, S. C., Sylva, L., & Hait, M. (2023). Cronbach's alpha: A cornerstone in ensuring reliability and validity in environmental health assessment. *ES Energy & Environment*, 23, 1057.