IOP Conf. Series: Materials Science and Engineering **290** (2018) 012024 doi:10.1088/1757-899X/290/1/012024

Evaluating 8 pillars of Total Productive Maintenance (TPM) implementation and their contribution to manufacturing performance

E Y T Adesta[1], H A Prabowo[2], D Agusman[3]

[1]Department of Manufacturing and Materials Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia.
[2]PhD Student at Manufacturing and Materials Engineering Department, International Islamic University Malaysia (IIUM), Gombak, Malaysia and a Lecturer staff of Industrial Eng. Dept. Mercu Buana University Jakarta, Indonesia.
[3]Department of Mechanical Engineering, Universitas Muhammadiyah Prof. Dr. HAMKA (UHAMKA), Jalan Limau 2 Kebayoran Baru, Jakarta Selatan, Indonesia

Email: herryagung@gmail.com

Abstract. TPM is one method to improve manufacturing performance through an emphasis on maintenance that involves everyone in the organization. Research on the application of TPM and its relevance to the manufacturing performance has been performed quite a lot. However, to the best of our knowledge, a study that deliberates how the application of 8 pillars TPM (especially in developing countries) is still hard to find. This paper attempts to evaluate in more detail about how the 8 pillars of TPM are applied in Indonesia and their impact on manufacturing performance. This research is a pilot study with a target of 50 companies. From the results of data collection, only 22 companies (44%) are eligible to process. Data processing was performed using SPSS and Smart PLS tools. From the validity and reliability tests, it can be seen that all items/indicators for TPM pillars are valid and reliable with correlation value (R) of 0.614 - 0.914 and with Cronbach's alpha equal to 0.753. As for the Manufacturing Performance construct, the Delivery indicator was not valid. In overall, the model is reliable with Cronbach's alpha of 0.710. From the results of Confirmatory Factors Analysis (CFA) for TPM, it can be seen that four indicators (pillars) are highly significant while four other indicators are less significant. For MP, three indicators are significant, and two are not significant. In general, the structural model of the relationship between TPM and MP is relatively strong and positive with values R = 0.791, and R squared = 0.626. This means that the TPM Pillars can explain 62.6% MP variability construct variable, while the other 37.4% can be explained by unrelated variables.

1. Introduction
With the challenges of tight competition worldwide, manufacturing industry is under pressure to provide high levels of performance and commitment. To face the ever-changing customer demands, manufacturing companies opted to adopt strategic changes in management approaches, production process and technologies, supplier attitudes and customer behavior. Lean manufacturing principles have been widely used by manufacturing companies to achieve these changes and gain competitive advantage. It also has emphasized the re-examination of the role of improved maintenance

management towards enhancing the organization's competitiveness [1]. One approach to improving the performance of the maintenance activities is by implementing Total Productive Maintenance (TPM) strategy [1]. It is required in modern manufacturing for companies to be successful organizations, and it has to be supported by both effective and efficient maintenance program, which is TPM [2].

The basic practices of TPM are often called the "pillars" or "elements" of TPM. The entire edifice of TPM is built and stands on eight pillars [3]; [4]; [1] and [5]. The eight pillars of TPM is a system for maximizing production effectiveness and efficiency. Many researchers have investigated and explained the application of those eight pillars in the industry that are mostly located in developed countries, but very few had examined their implementation in developing countries (such as Indonesia) and their effect on the operating performance. Some Indonesian researches in TPM focused mostly on the impact of TPM implementation on Six Big Losses and Overall Equipment Effectiveness (OEE) regardless of how the execution of the 8 pillars was implemented. For example [6], uses OEE to measure the effectiveness of production machinery and uses 5S methodology as a tool to progress existing maintenance processes and suggested to implement TPM Pillars [7]. Many researchers [8], [9], [10], [11] also only examine Six Big Losses and OEE for measuring performance machine regardless of how TPM pillars are running. Though Six Big Losses and OEE are only 'Results' or "Effects" of TPM implementation. A little progress is made by [12] with examining one of the TPM pillars: Autonomous Maintenance and its impact on OEE machines. From this background, this study aims to evaluate the employment level of 8 TPM pillars and their impact on manufacturing performance in the Indonesian manufacturing industries.

2. Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a productive maintenance concept designed to achieve a comprehensive effectiveness of the production system by involving everyone within the organization [3] and [13]. In more detail, TPM is divided into three important concepts:

1. Total, which means the involvement of all personnel/employees of the company.
2. Productive, which means TPM activities/activities is executed as much as possible, does not interfere with the productivity of the company,
3. Maintenance, which means the selection of the most appropriate/effective method of maintenance.

The eight pillars of TPM is a system for maximizing production effectiveness of any industry. The summary of eight pillars is given in table 1.

Table 1. Brief Summary of Eight Pillars [1]**;** [5]

TPM Pillars	Description	Advantages
Autonomous Maintenance	Hands operators of equipment responsible for carrying out basic maintenance of equipment	Operators feel responsible for their machines; equipment becomes more reliable
Planned Maintenance (Keikaku-Hozen)	Maintenance scheduled using the historical failure rate of equipment	Maintenance can be scheduled when production activities are few
Quality Maintenance	Quality ingrained in the equipment to reduce defects	Defect reduction & consequent profit improvement
Continuous Improvement (Kaizen)	Use of cross-functional teams for improvement activities	Improves problem-solving capabilities of the workers
Early Equipment Management	Design of new equipment using lesson learned from previous TPM activities	New equipment achieves full the potential in a shorter period
Education & Training	Bridging of the skills and knowledge gap through training of all workers	Employees gain the necessary skills to enable them to solve the problems within the organization
Health. Safety & Environment	Providing of an ideal working environment devoid of accidents and injuries	Elimination of harmful conditions & healthy workforce

TPM in the Office	Spread of the principles to administrative functions within an organization	Support functions understand the benefits of these improvements

The definition of the 8 pillars of TPM above is the basis of this research which is about the evaluation of the application of 8 pillars of TPM in Indonesian manufacturing industries and its effect on their performance.

3. Manufacturing Performance (MP)

In this research, only 5 MP indicators are used, 4 indicators were taken from [14] namely: 1) Quality (Q), 2) Cost (C), 3) Delivery (D), and 4) Flexibility (F) performances and 1 (one) indicator taken from [1] and [15] which is OEE (Overall Equipment Effectiveness) value.

4. Research Methodology

To achieve the objectives of this study and to obtain a valid result, a series of research activities were systematically constructed. These activities can be described as follow:

i. Identifying TPM Pillars and MP indicators according to previous studies (based on literature reviews).
ii. Generating a questionnaire to measure variables and conducting pilot study (n=50)
iii. Performing Validity and Reliability Test.
iv. Formulating the models (CFA models and Structural Model) using SEM tools.
v. Data processing using PLS/Amos software.
vi. Analysing and comparing the results with SEM standard values.
vii. Making conclusion, documentation, and publication.

5. Results and Discussion

Out of the 50 companies targeted for the delivery of questionnaires, only 25 companies responded, and only 22 companies (44%) were eligible for processing which considered to be sufficient. The collected data is then processed using SPSS to test the validity and reliability of the questionnaire. Only valid and reliable data are then processed using Smart-PLS 3.0 program.

Validity and Reliability Tests.

- **Results for TPM Pillars:**

Table 2. TPM pillars validity test

Indicators	Correlation (R)	Conclusion
1st Pillar	0.707	Valid
2nd Pillar	0.658	Valid
3rd Pillar	0.644	Valid
4th Pillar	0.867	Valid
5th Pillar	0.914	Valid
6th Pillar	0.614	Valid
7th Pillar	0.668	Valid
8th Pillar	0.708	Valid

From the above validity test, all TPM pillars indicators have correlation values (R) between 0.614 to 0.914 which is greater than 0.5, so that all question items in the questionnaire are considered valid [16] and can extract the desired latent variable (TPM pillars).

Table 3. TPM Pillars reliability test

Cronbach's Alpha	N of Items
.753	25

From the reliability test, it can be seen that the questionnaire used is reliable because it has a value of Cronbach's alpha greater than 0.7 [16], so it can be continued to the next stage of data processing using Smart PLS to get the indicators that form TPM Pillars in Indonesia.

- **Manufacturing Performance (MP) Test Results:**

Table 4. MP Validity test

Indicators	Correlation (R)	Conclusion
Quality	**0.587**	Valid
Cost	**0.616**	Valid
Delivery	**0.253**	Not Valid
Flexibility	**0.509**	Valid
OEE	**0.595**	Valid

From the result of the validity test above, not all of manufacturing performance indicators are valid as the delivery indicator has R value count less than 0.5 [16], so it was revised for further data retrieval process.

Table 5. MP Reliability test

Cronbach's Alpha	N of Items
.710	5

From the reliability test, it was observed that Cronbach's alpha for MP is greater than 0.7 which revealed the reliability [16]. Then all indicators were further processed using Smart PLS program to determine the significance level of each indicator in forming the latent variable.

Smart PLS Analysis Results

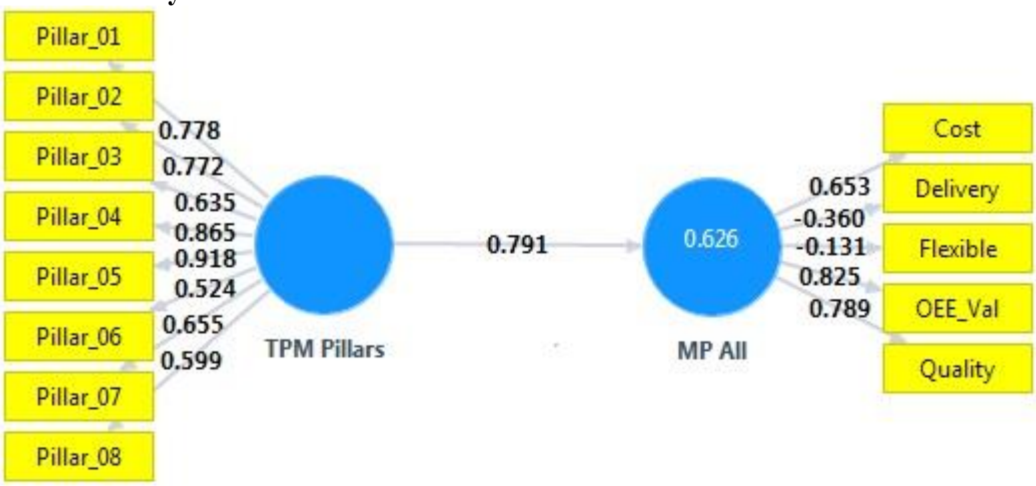

Figure 1. CFA and SEM (Structural Equation Modelling) for TPM Pillars and MP

Confirmatory Factors Analysis (CFA) for TPM Pillars (Outer model)

From the calculation results using Smart-PLS program (Figure.1), it is observed that 4 indicators have been applied and run very well. Those are Pillar 01, Pillar 02, Pillar 04 and Pillar 05 which had loading factor values greater than 0.7 [16]. While Pillar 03, 06, 07 and 08 have been applied but not running maximally as the loading factor values were less than 0.7. However, according to [16], loading factor on the level of development values of 0.5-0.6 can still be considered adequate.

Table 6. TPM Indicators/Pillars

Indicators	Loading factor	Conclusion
1st Pillar: Autonomous Maintenance	0.778	Significant
2nd Pillar: Continuous Improvement	0.772	Significant
3rd Pillar: Planned Maintenance	0.635	Less Significant
4th Pillar: Quality Maintenance	0.865	Significant
5th Pillar: Education and Training	0.918	Significant
6th Pillar: Safety, Health, Environment	0.524	Less Significant
7th Pillar: Office TPM (Supporting)	0.655	Less Significant
8th Pillar: Development Management	0.599	Less Significant

From table 6, it can be explained in detail the activities that have been executed as part of the implementation of 8 pillars TPM as follows:

- 1st Pillar: Autonomous Maintenance, that the operator has done simple machine maintenance activities include cleaning, lubrication, adjustment and tightening and inspection. The operator also has a sense of ownership of the machines/equipment they operate.
- 2nd Pillar: Continuous Improvement (Kaizen), the PDCA process (Plan, Do Check, Act) has been running well, various types of losses have been identified to be systematically eliminated, and the efficiency and effectiveness of the system are continually enhanced.
- 3rd Pillar: Planned Maintenance, preventive, predictive and corrective maintenance have been planned. All maintenance activities have been carried out regularly. The maintenance program tries to optimize the MTBF (Mean Time Between Failures) and MTTR (Mean Time To Repair) engines but still needs improvement.
- 4th Pillar: Quality Maintenance, zero defects targets have been applied, causes of quality issues have been identified appropriately. Machinery, materials, operators have been prepared to achieve the best performance.
- 5th Pillar: Education and Training, human resource competencies have been adapted to organizational goals, multi-skilled workers have been developed as needed. Human resources also have been evaluated, and it updates the skill of employees on a regular basis
- 6th Pillar: Safety, Health, Environment (SHE). SHE standard operating procedures (SOPs), safe and healthy working environment, and the availability of adequate sewage treatment facilities are still being developed. It has not run perfectly because it requires many investment costs.
- 7th Pillar: Office TPM (Supporting), 5S program has been implemented in the office area, work procedure/bureaucracy have been minimized, and synergy between departments have been built, but still, needs improvement.
- 8th Pillar: Development Management, problems in the installation of new equipment have been minimized, the experience of previous machine/system has been utilized for repair, Machine maintenance system has been developed in a better way. This pillar still needs enhancement.

Confirmatory Factors Analysis (CFA) for Manufacturing Performance (Outer model)

For MP indicators, only three indicators that significantly represent them, namely: Quality, Cost, and OEE, which were significant; whereas the other two indicators, Delivery and Flexibility, were not significant because their value of loading factor was below 0.5 [16] as can be seen in table 7.

Table 7. MP Indicators/Pillars

Indicators	Loading factor	Conclusion
Quality	0.789	Significant
Cost	0.653	Significant
Delivery	-0.360	Not Significant
Flexibility	-0.131	Not Significant
OEE	0.825	Significant

Since the study is still in the pilot project stage, the insignificant variables would not be abandoned but might be revised through the detailed questionnaires. In addition to the loading factors, to assess the validity of reflective indicators, it is also necessary to see the discriminant validity and average variance extracted (AVE) values.

Table 8. Discriminant Validity

Fornell-Larcker Criterium		
	MP All	**TPM Pillars**
MP All	0.612	
TPM Pillars	0.791	0.730

Table 9. Average Variance Extracted (AVE)

	AVE
MP All	0.375
TPM Pillars	0.532

Discriminant validity shows that the relationship between the construct (latent variable) of TPM Pillars with the construct of MP with a value of 0.791 is slightly higher than the correlation between the construct indicator (TPM Pillars = 0.730 and MP indicators = 0.612). As a result, the correlation between constructs is greater than the correlation in the construct. From the AVE value, it appears that AVE for MP has a value below 0.5 which is not valid. This can be explained by the discriminant value where only 3 indicators are valid with values above 0.5. For further analysis, the related questionnaire needs some improvements/revisions.

Table 10. Model's Reliability

	Composite Reliability (CR)
MP All	0.502
TPM Pillars	0.898
	Cronbach's Alpha (CA)
MP All	0.323
TPM Pillars	0.872

From the above values (CR and CA), it appears that TPM Pillar construct variables have excellent reliability because the value is above 0.70, while MP construct variables are less reliable.

Structural Equation Model (Inner Model) for TPM and MP

Table 11. Path coefficient

	MP All
TPM Pillars	0.791
	R Square
MP All	0.626

The relationship between TPM Pillars with MP appear to be STRONG POSITIVE based on Path Coefficient (R value) of 0.791. This is in line with previous studies such as [13], [17] and [18] which reported that there is a strong and positive relationship between TPM implementation and manufacturing performance. From the R squared value, 62.6% MP variability can be explained by the TPM Pillars construct variables, while unrelated variables can describe the other 37.4%.

6. Conclusion

In summary, it can be concluded that the implementation of 8 TPM's pillars in Indonesia manufacturing industries was relatively good. Where the 4 pillars, namely: Autonomous Maintenance, Continuous Improvement, Quality Maintenance, and Education and Training, are running very well. The other 4 pillars, namely: Planned Maintenance, Safety-Health & Environment (SHE), Office TPM (Supporting), and Development Management, need to be further improved, particularly SHE pillar which has the smallest loading factor. The insignificant variables in Manufacturing Performance should also be revised through related questionnaires. From the structural model, it can also be concluded that the model of TPM Pillars and MP relationship is reliable, positive and strong, as TPM pillars can explain 62.6% variability of MP, while other factors influenced the rest (37.4%).

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