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Analysis of Total Productive Maintenance (TPM) Model Development to Increase Overall Equipment Effectiveness (OEE) of CT-scan Tools

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KEYWORDS	ABSTRACT
TPM, Autonomous maintenance, OEE	CT scan is a medical tool used by hospitals to provide radiology patient services. The working principle of a CT scan tool is to utilize ionizing radiation in the form of X-rays and a combination of a computer system. The sophistication of existing equipment does not guarantee that it can be free from disasters such as sudden breakdowns. According to global medical equipment failure statistics, 80% of all failures are caused by preventable factors. Implementation of the Total Productive Maintenance (TPM) model, which is tailored to top management in service provider organizations such as hospitals, is considered a powerful tool for maintenance systems and can minimize the occurrence of failures. The effectiveness of TPM on CT-scan equipment can be measured using the Overall Equipment Effectiveness (OEE) method, this method is able to describe equipment performance in theory and is an accurate calculation of how effectively the machine is used. This type of research is Research and Development (R&D) with an experiment quasi-design and a pretest post-test with a control group design. The researcher used the research stages of the Borg & Gall development model which consists of 10 steps, then the researcher modified it into 6 steps. The research results explain that the TPM model that has been prepared uses the concept of autonomous maintenance with modification and replication of William N. Dunn's policy analysis; The OEE value of the experimental group after the model intervention (36%) was lower than before the model intervention (53%), this was because there were other factors that influenced it.

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INTRODUCTION

Medical equipment is one of the important factors in the implementation of health services in a Health Service Facility (Fasyankes) such as a hospital, the equipment must function properly according to standards (service, quality, security, benefits, safety, and usability). CT-scan is a medical device used by hospitals to provide services to radiology patients, the working principle of the device uses ionizing radiation in the form of X-rays and in combination with a computer system (Hussain et al., 2022). This tool is able to diagnose the presence or absence of a disease disorder in the inner body of the body.

The sophistication of existing equipment does not guarantee that it can be free from disasters such as component failures, sudden breakdowns, and human error (Kletz & Amyotte, 2019). Planned preventive measures and a prompt repair attitude are key to avoiding functional failures of equipment (Prochazkova & Prochazka, 2020). According to medical equipment failure statistics globally, 80% of all failure factors are caused by preventable factors. A daily, continuous, proactive, and preventive maintenance program is needed to keep medical devices functioning properly and effectively. The continuous maintenance program involves elements of planning, management, operation, and implementation of equipment maintenance (Xiang & Chin, 2021).

Total Productive Maintenance (TPM) is an integrated and continuous maintenance method on production machines that involves the active role of all employees, from top management to operators (Agustiady & Cudney, 2018). According to Nakajima, Vice Chairman of the Japan Institute of Plant Maintenance, TPM is defined as an innovative approach to maintenance by optimizing equipment effectiveness, reducing and eliminating sudden breakdowns, and performing autonomous operator maintenance. Haddad (2022) observed that the implementation of TPM in a way that is tailored to top management in service provider organizations, such as hospitals, is considered a powerful tool for maintenance systems. There are 8 pillars that are a reference in implementing the TPM concept, namely autonomous maintenance, quality management, focussed improvement, early equipment maintenance, training and education, safety and environment, and TPM in administration (Rizkya, Sari, Syahputri, & Tarigan, 2021).

Autonomous maintenance is a simple machine maintenance concept that involves production operators as users to perform basic maintenance such as cleaning, lubrication, and inspection (Oyesola, Mpofu, & Kanakana-Katumba, 2024). The application of the concept of autonomous maintenance requires an innovative approach that produces preventive measures and can be developed according to the type of equipment technology (Zonta et al., 2020). The application of the concept of autonomous maintenance can ensure that the machine is in good condition, and if there is potential damage, it can be identified early before more severe damage occurs, which can result in downtime.

Success in the implementation of TPM can be an indicator that the performance of the equipment has reached its optimal performance(Pinto et al., 2020a). There are several methods that can be used to evaluate the performance of a production machine, including mean time to repair (MTTR), mean time before failure (MTBF), mean time to failure (MTTF), and overall equipment effectiveness (OEE). OEE is a measurement tool that can be used to evaluate and improve or improve equipment productivity. Using the OEE method, the performance of equipment can be evaluated periodically to determine whether it is still suitable for use in production activities (Tsarouhas, 2020). The results of the calculation use the OEE method with values that show the level of effectiveness of the tool, so additional calculations are needed to determine the deductive factor for the achievement of the OEE value called six big losses. Six big losses consist of breakdown loss, setup, and adjustment stoppage, idling and minor stoppages, reduced speed, process defect, and reduced yield losses (Burhan & Sari, 2019).

Previous study on "TPM Analysis of Linear Accelerator (Linac) Equipment" reported an Overall Equipment Effectiveness (OEE) value of 58.07%, with each OEE component being Availability (71.60%), Performance (81.1%), and Quality (100%). These findings indicate that equipment performance and TPM program implementation are not yet optimal. While this study provides valuable insights into the current status of Linac equipment performance, it also highlights the need for further research to explore strategies to improve OEE and enhance the effectiveness of TPM programs, particularly in addressing identified deficiencies. This study aims to fill this gap by investigating (specific aspects to be discussed).

The purpose of this study is to compile a TPM model and analyze its effect on improving the performance of CT-scan equipment using the OEE method.

METHOD

This researcher used a type of Research and Development (R&D) research with a quasi experiment design and a pretest post-test with control group design (Wongyai & Patphol, 2014). The researcher used the Borg & Gall model development stages which consisted of 10 steps, then modified to 6 steps. The stages of the research are shown in figure 1.

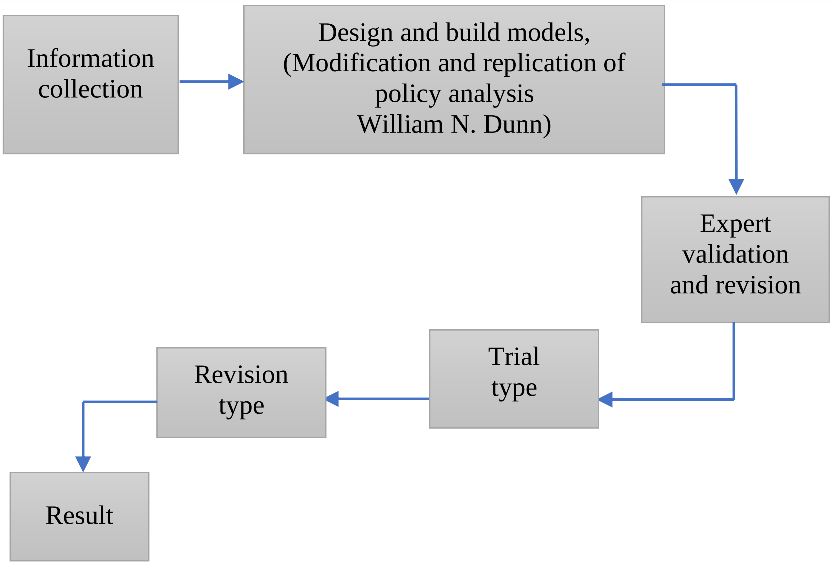

Figure 1. Research and Development (R&D) research stages

RESULT AND DISCUSSION

1. The rise of the TPM model

Researchers have collected data at 2 hospitals (XYZ1 and XYZ2) located in the city of Mataram, West Nusa Tenggara Province. The two hospitals use CT-scan equipment with the same specifications. The first hospital was used for the collection of experimental data, while the second hospital was used for the collection of control data (Maddalena, Müller, dos Santos, Salzmann, & Jones, 2022). The following is an explanation of the stages of research in compiling a TPM model:

a. Information collection
Information collection was carried out through observation, interviews and literature studies about the maintenance of CT-scan equipment. From the results of the information collection, it was concluded that hospital XYZ1 had not implemented TPM, then the researcher conducted a literacy study as a reference in the preparation of the model design.

b. Design and build models
The researcher uses William N. Dunn's policy analysis reference in making model design. The policy analysis includes problem structuring, forecasting, prescription, monitoring, and evaluation.

c. Expert validation and revision
The researcher used expert validators totaling 3 people, including the first senior radiographers as equipment operators, the second as hospital management, and the third Full Service Equivalent Employees (FSE) from one of the medical device manufacturers in Indonesia. The results of the validity of Aiken's v related to the expert assessment items have an average score of 0.92, so it can be said that the instrument used has high validity (>0.6) and is suitable for evaluating the performance of CT-scan equipment.

d. Model trials
The researcher involved 30 respondents in conducting the model test stage. The respondents are CT-scan equipment operators with inclusion criteria including willingness to be a respondent, working period $\geq$ 2 years, having a minimum of DIII radiology education, and being 20-40 years old. The data was then processed using the Wilcoxon signed ranks test and obtained a significance value of p-value 0.000 ($p\text{-value} < 0.05$) so that the conclusion was that there was a significant difference in radiographer's knowledge of the use of the TPM model on improving the performance of CT-scan equipment between pretest and post-test.

e. Model revision
   This stage is actually the transformation of the demo product into the final product. This process involves additional development to ensure that the model can and is ready to function optimally.
f. Result
   The resulting product is in the form of an innovation in the development of a TPM model with the concept of autonomous maintenance on CT-scan equipment. The results of the model development are shown in Figure 2.

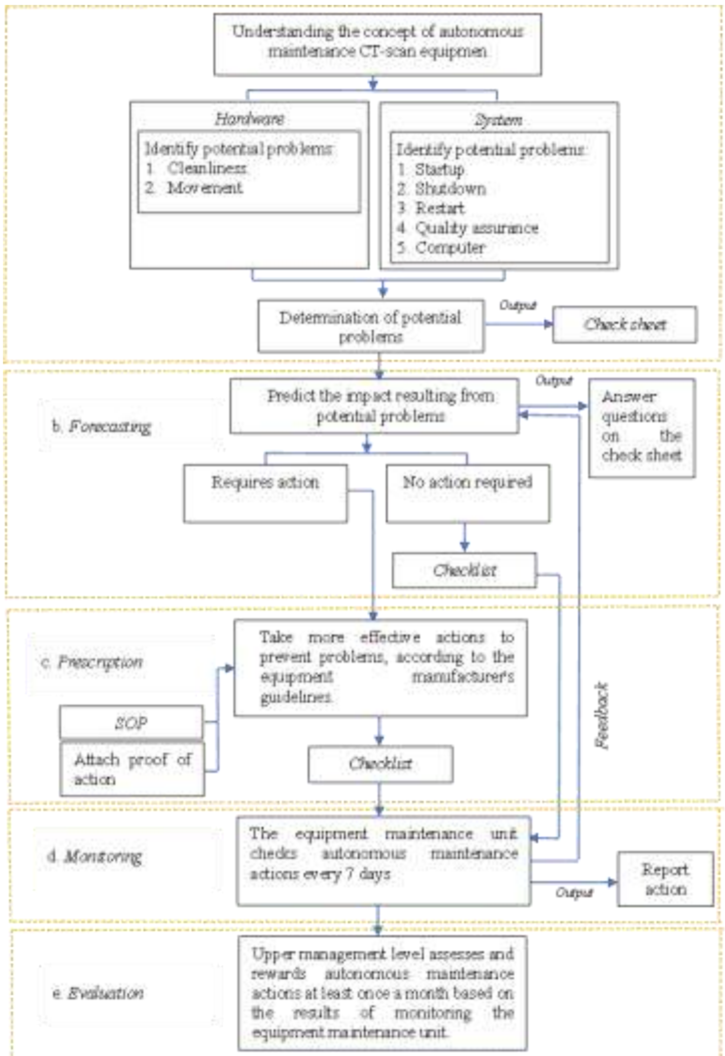

Figure 2. Flowchart of TPM model development with the concept of autonomous maintenance, modification, and replication of William N. Dunn policy analysis.

2. Performance analysis of CT-scan equipment using the OEE method

In this section, we will analyze the OEE values of the CT-scan device of the experimental group before and after the subsequent TPM model intervention compared to the control group (Shahin et al., 2023). OEE is a measurement tool that can be used to evaluate and improve or improve equipment productivity. OEE value is obtained from the results. Multiplication between availability x performance efficiency x rate of quality.

OEE: Availability x performance efficiency x rate of quality

As explained at the beginning, CT-scan device data collection is carried out in 2 hospitals that use the same device specifications (Villarraga-Gómez, Herazo, & Smith, 2019). The collection time will be carried out from January 2024 to March 2024. The results of data collection are as follows:

Table 1.
Comparison of OEE values

Sample	Initial OEE	OEE end
CT-scan device of the experimental group	Availability: 80% Performance efficiency: 66% Rate of quality: 100% OEE: 53% Explanation: The OEE score has not reached the OEE word class (85%); based on the benchmark standard from JPIM, the score is in the low score category.	Availability: 72% Performance efficiency: 50% Rate of quality: 100% OEE: 36% Explanation: The OEE score has not reached the OEE word class (85%). Based on the benchmark standard from JPIM, the score is in the low score category.
Control group CT-scan device	Availability: 94% Performance efficiency: 40% Rate of quality: 100% OEE: 53% Explanation: The OEE score has not reached the OEE word class (85%). Based on the benchmark standard from JPIM, the score is in the low score category.	Availability: 93.6% Performance efficiency: 34,7% Rate of quality: 100% OEE: 32% Explanation: The OEE score has not reached the OEE word class (85%). Based on the benchmark standard from JPIM, the score is in the low score category.

The results of the comparison of OEE values in Table 1 show that the OEE value after the implementation of the TPM model is 36%, and the OEE value before the implementation of the model is 53%. Based on the benchmark set by JPIM, the value has not reached or is still below the world-class OEE standard, which is 85%. This condition is included in the low score category and requires hard efforts to improve it. This means that the application of the TPM model with the concept of autonomous maintenance is not effective, causing losses (Pinto et al., 2020b). The emergence of this phenomenon is possible because there are other factors that have a significant effect on the achievement of OEE scores (Tayal et al., 2021).

The researcher then calculates six big losses to find out the main factors that cause losses. Six big losses are part of OEE and can be interpreted as a deductible factor from the total OEE value. The results of the calculation of six big losses can be seen in Figure 3.

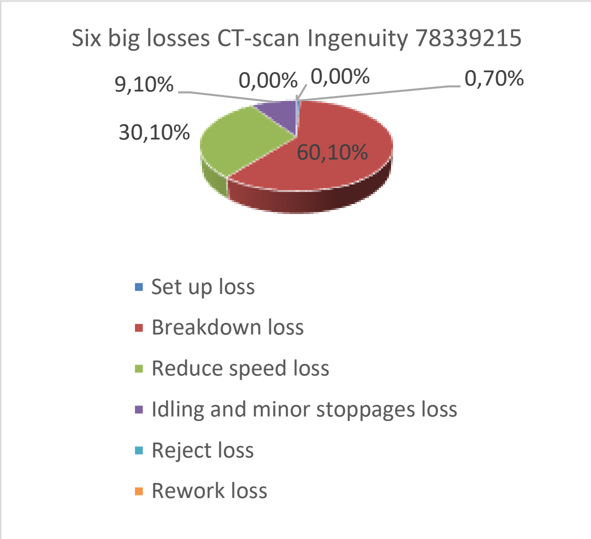

Figure 3. Graph of six big losses CT-scan tool

In Figure 3, the six big losses graph shows that the main factor causing the losses of the CT-scan tool is breakdown. Furthermore, to find out the cumulative percentage of equipment damage from the factors causing losses, analysis was carried out using a pareto diagram (Josiah & Keraita, 2018). The results of the pareto chart analysis can be seen in figure 4.

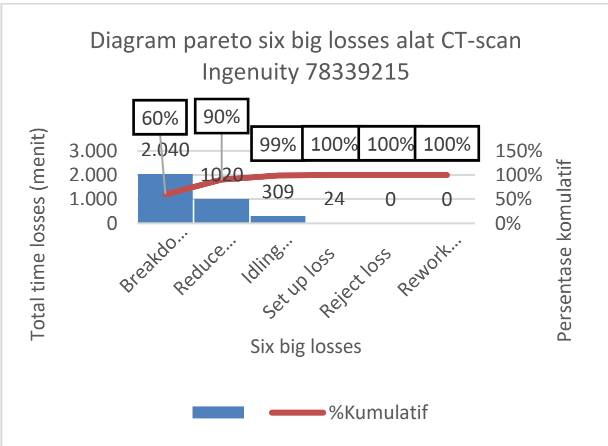

Figure 4. Pareto six big losses diagram of CT-scan tool

In Figure 4, the pareto six big losses diagram above shows that with the problem of breakdown loss, the accumulated damage to the tool can reach 60%. This can be interpreted that breakdown loss is a critical area that causes the most downtime so that it requires more attention and is the top priority for action.

The researcher then conducted a brainstorming Focus Group discussion (FGD) between the operator, the equipment maintenance unit, and the management to analyze the root cause of the problem (breakdown loss) (Nusraningrum & Setyaningrum, 2019). Using a fishbone diagram, the researcher conducted an analysis using a 4M approach (man, material, machine, and method). A fishbone diagram is a systematic analysis tool that looks at the effects and causes that contribute to the effect. The results of the fishbone diagram analysis can be seen in Figure 5.

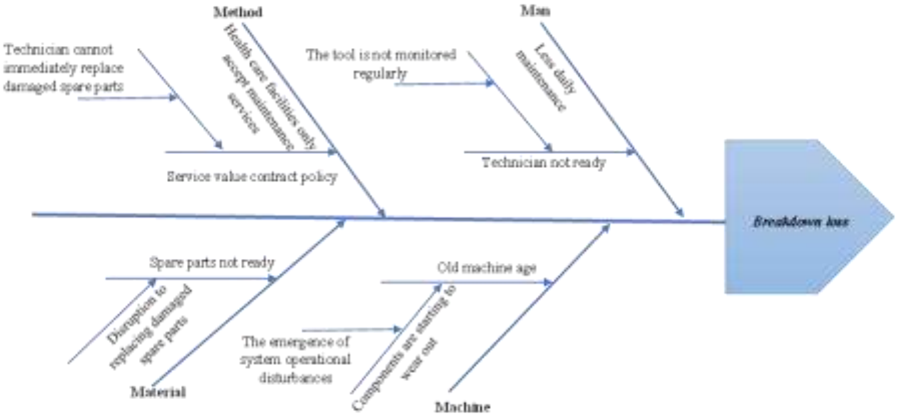

Figure 5. Fishbone analysis diagram causes breakdown problems

The fishbone diagram analysis in Figure 5 revealed several critical factors affecting downtime:

a. Man: Technicians are not adequately prepared, lack necessary daily tools, and tools are not consistently monitored.
b. Material: Unavailability of tool parts, delays in replacing damaged components, and tools not returning to normal function.
c. Machine: Aging machinery with worn components leading to operational issues.
d. Method: Service value contract policies restrict maintenance services to specific actions, preventing immediate replacement of damaged parts by technicians.

Further analysis of the dominant factors identified in the fishbone diagram indicated that breakdown losses primarily stemmed from aging machinery, leading to operational disruptions. Additionally, the service value contract policy prevented timely replacement of spare parts. These findings align with previous studies indicating that poorly managed maintenance processes and aging equipment significantly contribute to reduced Overall Equipment Effectiveness (OEE). This research supports the conclusion that factors not adequately managed can severely impact OEE performance, causing interventions like the Total Productive Maintenance (TPM) model with autonomous maintenance concepts to fall short in improving the performance of CT-scan equipment. These results are consistent with previous literature that highlights the critical role of maintenance practices in achieving world-class OEE standards, such as the 85% benchmark set by JPIM.

CONCLUSION

The TPM model developed in this study incorporates the concept of autonomous maintenance, with modifications and replication based on William N. Dunn's policy analysis. Following the intervention, the OEE value of the CT-scan tool dropped from 53% to 36%. This outcome indicates that the OEE value remains significantly below the world-class standard of 85% set by JPIM. This shortfall can be attributed to several critical factors, including the advanced age of the equipment, which leads to operational disruptions, and the policy adopted by top management to engage in service value contracts. This policy restricts technicians from promptly replacing spare parts when malfunctions occur.

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