Overall Equipment Effectiveness-Driven Process Improvement Through Total Productive Maintenance: Role of Equipment Flexibility

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Abstract

Customer needs for automotive products are still increasing, this has forced the automotive assembly industry to focus more on productivity and make measurement adjustments and improvements to produce products that meet customer demands and improve performance. As one of the largest automotiveare unprepareds in Indonesia, PT Astra Honda Motor faces complex problems related to increasing customer demand which is not in accordance with the plan, reducing component availability and disrupting the production process, while also causing greater performance losses, including operators who unprepared, erratic machine cycles can even be slower because they have to work not according to machine capacity, it can even cause start-up defects in machines used for production processes. All that of course resulted in quality problems becoming more frequent. The overall productivity of the integrated manufacturing system through the overall effectiveness of the equipment regardless of capabilities, and flexibility is considered insufficient as a solution to drive improvements and improve performance. Therefore, PT Astra Honda Motor must pay attention to equipment flexibility and overall equipment effectiveness (OEE_{Flex}) to address customer requests. This study aims to identify losses related to the effectiveness of the equipment as a whole and the possibility of repairs carried out by implementing equipment flexibility that can drive the repair process, this is done by looking at the planning, losses, and availability of parts by eliminating unplanned events by finding the causes and take precautions. This study provides a contextual model of overall equipment effectiveness and equipment flexibility that will help automotive assembly companies meet customer demands through customization.

Keywords
Total Productive Maintenance, Overall Equipment Effectiveness, Process Improvement, Flexible Equipment

1. Introduction
The production process in a manufacturing company is a routine that is always carried out, so it is often assumed that the production process is running properly and correctly, however, it does not rule out the possibility of problems occurring in the production process. This of course can affect productivity. For this reason, companies must examine more deeply regarding efficiency in the production process as an effort so that the company's productivity does not decrease. Efforts that can be made by companies to increase their productivity include humans, machines, and materials. In addition, the company must also optimize the company's resources used and become a benchmark for the company's success in meeting the production targets set by the company.

PT Astra Honda Motor is a multinational company engaged in the motorcycle assembly industry, which is one of the most well-known motorcycle manufacturers in Indonesia. The products produced by PT AHM are processed at five plants, namely the Sunter Plant, the Pegangsaan Plant, the Cikarang Plant, the Karawang Plant and the Kerawang Plant. The products produced by PT AHM are distributed to areas in Indonesia and exported to foreign countries. The products produced by Plant Sunter are Honda PCX and ADV type motorcycles. Meanwhile, the Pegangsaan plant produces all-sport motorcycles. The Cikarang plant produces all-matic type motorcycles. The Karawang Plant produces Beat and Vario type motorcycles, and the Karawang Plant produces all-sport type motorcycles. The products produced from all the plants are then distributed to regions in Indonesia and exported to foreign countries. When researchers made initial observations, problems were identified in the production section, where there was a problem with the company's inability to produce products to reach the machine capacity according to the set standards, causing the company's inability to achieve the set production targets or requiring longer time to achieve production targets.

In automotive assembly, a crank case left (CCL) component is required, which is one of the engine components used as a housing for several components, namely the oil reservoir, transmission gear, and clutch. The manufacturing process for crankcase left is carried out on the high pressure die casting (HPDC) line, which is divided into 3 sub-lines, namely the melting line, injection line and trimming line. In the HPDC line there are 3 HPDC_800 machines in operation, where the capacity of each machine is 800 CCL. When HPDC machines are operating, both when demand is in accordance with production targets and when demand exceeds the set target, the machine sometimes experiences downtime, this causes the production process to be late and the product produced does not meet the set time. This is of course a problem that must get a solution. Efforts made to overcome these problems are stages and steps needed to carry out maintenance (1), apply equipment flexibility, and find the root causes of the problem so that errors/failures that occur in the machine are not repeated.

The issue of globalization and the current competitive environment, forcing companies to strive to be able to produce good quality and cost-effective products. This makes many companies try to adopt certain approaches and techniques in their maintenance and production systems, including TPM, TQM, JIT, and Lean Manufacturing. Gupta and Garg (2012) explained that manufacturing systems often operate not according to their intended capacity and result in low productivity and high production costs. Therefore the company needs to carry out maintenance of the machines used for its production process, because the periodic maintenance of production machines in the company will have a major impact on the company's profitability.

Overall equipment effectiveness (OEE) is an element of the TPM quantitative approach used to compare and analyze each production process. Nayak et al. (2013) explained that OEE has the ability to measure machine efficiency to increase productivity, which is basically a metric for identifying potential areas of productivity to make improvements that will result in increased equipment effectiveness by evaluating the three main OEE factors, namely availability, performance, and quality. OEE's focus is on the six major losses, namely breakdown, setup adjustments, reducing speed, minor stoppages, rework, and yield losses.

OEE is a structured continuous improvement process that can increase a company's productivity and production efficiency by using machines or equipment effectively (Olayinka & Leramo,2012). Meanwhile flexibility is a cycle of improvement in an effort to achieve operational excellence, one way is to increase productivity through increasing equipment effectiveness (Rusev & Salonitas, 2016; Karim & Zaman 2013), through weighing factors namely mobility, uniformity in determining equipment effectiveness, and range or adaptability.

Failure mode and effect analysis (FMEA) was originally a formal design method used in the aerospace industry (Rakesh et al. 2013). FMEA is a technique for conducting risk evaluation and identifying failures by assigning a numerical value (risk priority number/RPN) for each failure that occurs. FMEA is used to improve reliability, security, and customer satisfaction. There are two types of techniques in FMEA, namely design FMEA (used to see potential failures in product design and provide ratings according to the impact they have on the product) and process FMEA (used to identify failures that occur during processes or operations and rank them according to their criticality using RPNs). The FMEA method is used to reduce failures by controlling the occurrence, severity and detection of failures by finding the root causes of failures so that repeated failures do not occur.

Based on previous literature reviews, it was found that the use of FMEA in total productive maintenance is still rarely used. Therefore this research is proposed to fill the gap of previous research by designing flexible overall equipment effectiveness (OEEFles) and failure mode and effect analysis (FMEA), especially in the HHDC process line at PT Astra Honda Motor. What's new in this research is the use of OEEFlex and FMEA techniques as an alternative to improve engine performance and avoid repeated failures on HPDC machines.

1.1 Objectives

This study aims to identify failures related to the effectiveness of the equipment as a whole and the possibility of making improvements by implementing equipment flexibility that can encourage the repair process and prevent recurring failures. This is done by looking at planning, losses, and also the availability of spare parts by eliminating unplanned events by finding the root causes and determining preventive actions. This study provides a contextual model of overall equipment effectiveness and equipment flexibility that will help PT AHM meet customer demands that go beyond planning through customization.

2. Literature Review

When HPDC machines are operating, downtime often occurs which causes the production process to slow down and cannot meet predetermined production targets. Efforts that can be made by the company is to carry out maintenance through the implementation of the total productive maintenance (TPM) program.

2.1 *Total Productive Maintenance* (TPM)

The general approach that is usually used to increase the efficiency and availability of equipment is to apply total productive maintenance (TPM). TPM is not only a promising strategy for dealing with equipment maintenance problems but also eliminating production losses and increasing salable output. This is in line with what was conveyed by Swanson (2001) who explained that TPM not only provides manufacturers with an aggressive but also proactive method of carrying out equipment maintenance. So TPM can be said to be a problem-solving approach that can reduce costs, increase output from limited production capacity. In addition, Total productive maintenance (TPM) is a method developed in Japanese companies that is used to increase the productivity and efficiency of the company's production by using machines and equipment effectively (Herwindo et al., 2014). TPM seeks to optimize production effectiveness by identifying and eliminating equipment losses through the active participation of team-based employees at all operational levels.

2.2 *Overall Equipment Effectiveness* (OEE) and OEE *Flexibility* (OEE_{Flex})

Overall equipment effectiveness (OEE) is a metric or measure of production machine performance in implementing the total productive maintenance program to evaluate the effectiveness of maneuvers in an effort to identify production losses and other hidden costs, but which have a large contribution to the total production cost (Wahid, 2020; Mutaqiem et al. 2022).

Flexibility in manufacturing is the ability to change or react with time, effort, cost, or performance. There are three ways that companies can be flexible, namely the dimensions of change and the time period considered: reach (the ability to produce variations in the characteristics of the main product variations), mobility (agileness within the range of coverage, where the transition period of change is the lower the more flexible), and uniformity (combining productivity with flexibility, regarding productivity consistency). OEEFlex metrics serve as indicators of process improvement leading to higher or maximum levels of actual productivity through equipment effectiveness. Often flexibility requirements result in a negative impact on OEE. Therefore, the flexibility of the equipment cannot be separated from the effectiveness of the equipment. The OEEFlex metrics are described based on mobility, uniformity, and range, and to operate it, it will be necessary to capture data and have a standard operating procedure (SOP) so that the implementation goes well because it complies with the required procedures.

2.3 *Failure Mode and Effect Analysis* (FMEA)

Failure mode and effect analysis (FMEA) is a proactive and structured quality management technique that is used as a determinant of potential system, process, product and/or service failures as well as assessing causes of failure and prevention that can be taken to prevent recurring failures (Huang et al. al. 2019; Liu 2019; Claxton and Campbell-Allen 2017). The risk priority number (RPN) in ranking the potential for failure in the initial development of FMEA, uses a numerical scale of 1-1000 (Stamatis 2019; Cristea and Constantinescu 2017; Yang et al. 2011), but receives much criticism because difficulty level in finding potential root causes of failure on a scale of 1-100 (Subriadi and Najwa 2020). Meanwhile, several other researchers used priority potential failure on a scale of 1 to 10 in determining the risk priority number using three risk factors, namely incident (O), severity (S), and failure detection (D) (Sahno et al. 2015; Zammori and Gabrielli 2012), and explained that a high RPN value indicates a high priority for determining corrective action (Soufhwee et al. 2013). So that it can be said that FMEA is the process of reviewing many interrelated components, assemblies, and sub-systems with the aim of identifying potential failure modes in the system and tracing the effects of their causes. These components are then evaluated for all potential failure modes and the effects they will have on the entire system. Kumru and Kumru (2013) explain that FMEA is a very structured and systematic technique and is effective in analyzing failures, besides that FMEA has also been widely applied by engineers and managers of operational systems and supply chains, such as quality improvement, security, and reliability analysis. products, services, and processes.

FMEA is a qualitative analysis based on expertise and managerial judgment that can also serve as a quantitative assessment of the extent of systematic failure modes when developed and combined with statistical failure model estimates. In addition, FMEA is a risk evaluation and failure identification technique by assigning a risk priority number (RPN) to each failure that occurs. It is used to improve reliability, security, and customer satisfaction. FMEA was originally used in product development cycles, but today it is widely used in manufacturing processes and operations. In addition, FMEA can reduce failures by controlling the occurrence, severity, and also detecting failures. FMEA is used to identify potential failures with risks before failures occur, namely by analyzing the effects of each failure and rating it according to frequency and criticality. Meanwhile, RPN is identified by multiplying three components, namely occurrence, severity, and detection.

2.4 Implementation Flexibility Equipment in Overall Equipment Effectiveness (OOE_{Flex}) on Total Productive Maintenance (TPM) Program

The application of total productive maintenance can be interpreted as a problem-solving approach to reduce costs and increase output from limited production capacity. This application is carried out to identify and resolve the six big losses (BSL) and the causes of their occurrence in the production process. Previous studies on TPM, OEE, and six big losses have had a significant impact and can avoid any cognitive biases or errors observed in decision-making ranges or forming judgments quickly (Purushothaman and Seodon 2021; Alkhars et al. 2019; Dale 2015; Eckerd and Bendoly 2015; Gino and Pisano 2008).

The OEEFlex model in the TPM program is needed to ensure that the implementation of the total productive maintenance program runs effectively. In addition, this model is also needed in assessing the effectiveness of equipment and production systems, so that productivity increases, output quality increases, reduces costs, speeds up delivery, improves environmental safety and increases morale (Ahuja and Khamba 2008). Therefore the application of OEEFlex in the total productive maintenance program is important at PT Astra Honda Motor.3w23we

3. Methods

Data collection techniques in this study used interviews and observation, where at the observation stage the researcher made observations of 3 HPDC 800 machines used to produce CCL directly. Meanwhile the interview phase was carried out before and after conducting the research with the aim of finding out how much production capacity can be produced from each HPDC machine and how often downtime occurs on these machines.

The OEE of the HPDC engine is determined by selecting it based on the downtime that occurred on the three engines used to make the crank case left (CCL), namely the HPDC 800_1 engine, the HPDC 800_2 engine, and the HPDC 800_3 engine in the past year. Meanwhile, HPDC machine data is collected over a period of 30 days. OEE that has been calculated from each machine is then analyzed using the FMEA technique which is used to produce a risk priority number (RPN) for failures that occur during a period of 30 days, by identifying what indicators cause frequent downtime on the previous machine. This is done to make improvements so that there are no repeated failures that lead to increased OEE values, besides that the company can also determine appropriate preventive measures to be applied to the company so that repeated failures can be minimized.

FMEA is a quality management technique for identifying failures in a system, process, product and or service before taking proactive action (Claxton and Campbell-Allen 2017). In determining FMEA, the researcher uses a qualitative inductive approach by using failure effect modes, main failure, sub failure, and the last cause of failure. The success of FMEA can facilitate failure detection and risk control, and its application can be extended to similar products, services or processes.

Claushing and Frey (2005) explained that in the application of FMEA there are three main phases, namely
Phase 1, identify potential failure modes and effects of components used in the HPDC machine process line.
Phase 2, conducts a criticality analysis to determine the level of severity by evaluating the failure risk level of the machines used for CCL production.
Phase 3, take steps to reduce the risk of failure to help improve machine reliability and avoid failure.
Risk evaluation in FMEA is carried out by calculating the RPN of three risk factors, namely incident (O), severity (S), and detection (D) of the failure mode. With the following mathematical model: RPN = O x S x D

4. Results and Discussion

4.1 Problem Situation and Description

The risks that arise from machine downtime in the HPDC line include decreased performance and line disruption in the next process. Decreases in performance that will arise include disruption to processes on the next line, delays in production and delays in delivery and possibly even loss of sales, besides that there is work to add or reserve machines to do overtime in order to meet the planned output volume which is hampered by machine downtime. Another risk that will arise if the process on the next line is disrupted due to machine downtime that is too long will cause the potential for stock parts (components) to run out.

4.2 Flexible *Overall Equipment Effectiveness* (OEE_{Flex})

Before the OEE calculation, the researcher selected one of the 3 available HPDC machines, namely the HPDC 800_1 machine, the HPDC 800_2 machine, and the HPDC 800_3 machine. Based on the previous historical downtime of the three machines, namely machine downtime from January to December 2022, an annual downtime of 122 days was chosen.

a. The initial OEE of the HPDC machine is unknown, therefore 30 days was selected as a sample for the OEE calculation.
b. HPDC machine is an electromechanical equipment, therefore machine downtime can be categorized as mechanical failure, electrical fault and instrument fault.
c. The adjustment time consisting of the melting unit (MU), injection unit (IU), and trimming unit (TU), service failure (SF) is recorded in the engine maintenance management system every time a shift occurs for 30 days. Meanwhile the cycle time of one crank case left (CCL) was generated from the HPDC machine and the machine's monthly scheduling minutes were obtained from the company's PPIC department. Machine downtime data from the production supervisor is always checked by the technician section to ensure daily CCL production is in accordance with equipment downtime, and for equipment reliability and downtime data recorded on worksheets which are distributed to production supervisors in each shift for 30 days.

The following is the initial OEE data from the three HPDC machines before using the failure mode and effect analysis method by looking at three categories of disturbances, namely machine disturbances, electrical disturbances, and instrument errors, as shown in Table 1 below:

Table 1. HPDC Machine Downtime Data for Initial OEE

Mesin	MF (mins)	EF (mins)	IF (mins)	MU (mins)	IU (mins)	TU (mins)	SF (mins)	Total Downtime (mins)	Planned Production Time (mins)	HDPC
HPDC 800_1	2,474	1,424	480	690	1,110	1,350	1,710	9,238	36,718	1,316
HPDC 800_2	2,252	2,522	480	690	1,110	1,350	1,650	10,054	36,718	1,295
HPDC 800_3.	2,120	1,380	480	690	1,110	1,350	1,730	8,860	36,340	1,302
Grand Total								28,152	76,538	3,912

Notes: MF, mechanical fault; EF, electrical fault; IF, instrument fault; MU, melting unit; IU, injection unit;TU, trimming unit; SF, service failure.
Source: sistem manajemen maintenance

4.3 Failure Mode and Effect Analysis (FMEA)

The repeated failures identified in the three HPDC 800 machines were categorized into three failures namely mechanical failure, electrical failure, and instrument failure, as shown in Table 2 below:

Table 2. HPDC Machine Reoccuring Failures

Serial Number	Assembly	Failure	Frequency of Failure
Mechanical Fault			
HPDC 800_1	Central mechanism	Mold damage	5
HPDC 800_2	Central mechanism	Mold damage	5
HPDC 800_2	Vertical mechanism	Broken insert pin	4
HPDC 800_3	Central mechanism	Mold damage	5
HPDC 800_3	Vertical mechanism	Leaky clutch	3
Electrical Fault			
HPDC 800_1	Injection	Drop temperature	4
HPDC 800_2	Injection	Drop temperature	4
HPDC 800_2	Injection	Injection process not optimal	3
HPDC 800_2	Injection	Engine alarm problem	2
HPDC 800_3	Injection	Drop temperature	4
HPDC 800_3	Injection	Low pressure	3
Instrument Fault			
HPDC 800_1	Conerod	Conerod damage	4
HPDC 800_2	Conerod	Conerod damage	2
HPDC 800_2	Colling	Colling problem	3
HPDC 800_3	Ejector	Ejector problem	

A. RPN Selection Criteria

The selection criteria for the identified HPDC machine are defects in the central mechanism, defects in the vertical mechanism, and injection. Conerod defects, colling defects, and ejector defects.

1. Defective central mechanism
   - Failure severity rating = 8, because this failure can cause production to stop
   - Event rating = 10, because the frequency of events on the HPDC 800 machine is frequent (7 times out of 26 failures that occur)
   - Detection rating = 9, in the high category because this failure is difficult to identify by the operator
2. Defective vertical mechanism
   - Failure severity rating = 7, because this failure caused moderate disruption and some production was not completed
   - Event rating = 10, because the frequency of events on HPDC machines often occurs (7 out of 26 total failures that occur
   - Detection rating = 4, because these failures can be identified by operators during the production process
3. Injection defects
   - Failure severity rating = 7, because this failure resulted in part of the production being incomplete
   - Event rating = 8, because the frequency of occurrence of the HPDC 800 machine is frequent (5 times out of 26 failures that occur
   - Detection rating = 7, in the medium category because this failure can be identified by the operator visually
4. Conerod defects
   - Failure severity rating = 9, because this failure causes high disruption and production stops
   - Event rating = 6, medium category because the frequency of events on the HPDC machine does not occur too often (4 out of 26 failures that occur).
   - Detection rating = 8, because these failures are difficult for operators to identify during the production process.
5. Cooling defects
   - Failure severity rating = 3, because this failure causes production to experience slight inconvenience in the process.
   - Event rating = 8, because the frequency of occurrence of the HPDC 800 machine is frequent (8 times out of 26 failures that occur)
   - Detection rating = 9, in the high category because this failure is difficult to identify by the operator.
6. Defect of ejector
   - Failure severity rating = 7, this failure causes moderate disruption and part of the production is not completed
   - Event rating = 5, because the frequency of events on the HPDC machine does not occur too often (4 times out of 26 failures that occur).

- Detection rating = 7, in the medium category because this failure is rather difficult to identify by the operator during the production process
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B. Root Causes of Failures

The causes of failure on the three HPDC 800 machines identified from the defects that occurred were central mechanism defects, vertical mechanism defects, injection defects, conerod defects, and ejector defects as shown in Table 3 below:

Table 3. Root Causes of Failures

No	Failure	Penyebab Utama	Solusi
1	**Defect of the central mechanism** Mold is one of the main components in the HPDC machine process line, because if a crack occurs in the mold it will stop the production process	▪ Incorrect mold installation on the machine ▪ No spare mold available ▪ The screw for the mold is placed untightened so that it does not lock the mold	▪ The mold must be placed in the correct place and secured with screws so that it does not wobble and cracks occur ▪ Ensuring the screw on the mold is tightened and locked properly, so that when the machine is started the mold remains in the set position and does not cause mold cracking.
2	**Vertical mechanism defects** Insert pins and cooling are supporting components of the HPDC machine process line, which will cause the machine to not run properly which causes the production process not to run according to schedule	▪ Installation of the insert pin is not in accordance with its placement, causing the pin to break ▪ Colling is not running perfectly, causing the printout does not meet the requirements	▪ Periodic inspection should be carried out if the insert pin is often broken ▪ The insert pin must be tightened with the help of a spanner ▪ Periodic inspection of cooling should be carried out
3	**Injection Defect** Injection is an electrical support component in the HPDC machine process line	▪ Injection can not be operated because the temperature drops ▪ Low pressure ▪ The engine alarm cannot be operated	▪ Periodic checks should be made for temperature, pressure, and engine alarms ▪ Make repairs for broken engine alarms, low pressure, and dropping temperatures
4	**Conerod and Cooling Defects** Conerod and cooling are instrument supporting components of the HPDC machine process line which will cause the machine to not run properly and cause the production process to not run according to schedule	▪ Installation of the insert pin is not in accordance with its placement, causing the pin to break ▪ Cooling is not running perfectly which causes print results not as required	▪ Periodic inspection should be carried out if the insert pin is often broken ▪ The insert pin must be tightened with the help of a spanner ▪ Periodic inspection of cooling should be carried out.

5	**Ejector Defect** Insert pins and cooling are supporting components in the HPDC machine process line	▪ Conored or the pipe used to enter the liquid to be printed is damaged/torn ▪ The rest of the previous process is still left and sticks to the conored ▪ The copper tube connection is leaking, so that the machine operation is hampered	▪ Periodic checks must be carried out on conored and also copper tube connections at least once every 2 weeks ▪ Clean up the remnants of the previous production process

After carrying out a root causes of failures analysis and carrying out corrective actions according to the solutions to the problems described above on the three HPDC 800 machines, the final OEE data downtime is obtained as shown in Table 4 below:

Table 4. OEE Final Calculation Data Downtime

Mesin	MF (mins)	EF (mins)	IF (mins)	MU (mins)	IU (mins)	TU (mins)	SF (mins)	Total Downtime (mins)	Planned Production Time (mins)	HDPC
HPDC 800_1	1,244	987	1,080	0	1,003	1,230	530	6,074	40,556	2,216
HPDC 800_2	1,022	987	1,080	0	934	1,230	530	5,783	40,558	2,195
HPDC 800_3	1,007	987	1,080	0	956	1,230	530	5,313	40,180	2,202
Grand Total								17,170	121,234	6,613

Notes: MF, mechanical fault; EF, electrical fault; IF, instrument fault; MU, melting unit; IU, injection unit;TU, trimming unit; SF, service failure.
Source: sistem manajemen maintenance

5. Conclusion

OEE is a useful tool for increasing the implementation of the total productive maintenance (TPM) program which is carried out quantitatively, so as to create overall equipment effectiveness and minimize downtime on the HPDC 800 machine. Meanwhile, the flexibility of OEE (OEEFlex) can be continuously increased if there is involvement from management in carrying out equipment (machine) repairs, because with the involvement of repair management carried out on the HPDC process line it can be controlled properly and produce maximum results.

FMEA is a method used to find the root causes of failures that occur in HPDC machines and prevent recurring failures on these machines. The OEE value can be increased if FMEA is carried out, as seen from the increase in production from 2,400 CCL to 3,600 CCL produced or an increase of 38.73% to 61.22% of CCL production. In addition, the FMEA has reduced the downtime of the three HPDC machines as a whole, from 28,152 mins to 17,170 mins.

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Biography

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