Improving Overall Equipment Effectiveness of the Plaster Mold Process using Lean Manufacturing Principles

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Abstract. *The purpose of this research was to improve the production process for plaster molds by utilizing overall equipment effectiveness (OEE). Data collected prior to the improvement revealed low performance due to lost time during preparation, movement, and waiting. Lean tools such as work studies, flow process charts, and man-machine charts were used to identify the root causes of these issues. The issues can be categorized using seven waste principles, including transportation and walking that is excessive. Defects occurred during the process. A machine idles occurred during the process. There was too much worker motion in the process. An extra-process was taken because the defective parts had to be repaired. Improvements were made using lean manufacturing, separating internal and external work, and ECRS principles, resulting in an increase in performance rate from 42.27% to 90.34%, an increase in overall equipment effectiveness from 38.18% to 81.56%, and a 25% decrease in the number of workers from 8 to 6. The labor productivity rate increased from 0.140 to 0.145 set per person per hour. Improved overall equipment effectiveness leads to increased process efficiency and productivity. As a result, it is one of the most effective tools for process improvement.*

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1. Introduction

The world in the 21st century has transformed into a very complicated world in many dimensions, including its technological scope. With the introduction of new technologies in various industries, one of the most important goals of all companies is to increase or maintain their market share in order to remain competitive. [1]

Companies are attempting to make their business operations more sustainable in the face of today's intense competition. In an aggressive competitive environment, industrial firms must meet their customers' needs in terms of quality (Q), cost (C), on-time delivery (D), and agility in manufacturing processes. As a result, they should develop strategies to increase the flexibility and efficiency of their processes. In addition, pay attention to minimizing overall production costs. increase profitability and improve the efficiency and productivity of the production process. [2]

In 1971, the Japan Institute of Plant Maintenance (JIPM) was the first to define TPM. TPM is used to improve the overall effectiveness of the production environment, particularly through methods for increasing the effectiveness of the equipment. Currently, TPM is still widespread in many countries around the world.

TPM implementation entails using continuous approaches to minimize losses. TPM focuses on reducing equipment-related losses because most value additions to products involve machines and equipment. TPM is concerned with machines. [3]

TPM discusses six types of losses known as six big losses, which are classified into three categories: downtime losses, speed losses, and quality losses. Low availability is made worse by downtime losses, whereas speed and quality losses result in reduced performance and product quality, respectively. The six big losses are breakdowns of equipment, set-up and adjustments, idling and minor stoppages, reduced speed operation, start-up losses, and scrap including rework. The objective of evaluating OEE is to increase the equipment's effectiveness. [3] Workers on the production line participate in monitoring OEE as well as planning and implementing equipment improvements to reduce losses.

Toyota is a Japanese automaker that pioneered lean manufacturing, often known as the Toyota Production System (TPS), which has now been adopted by most nations due to its demonstrable benefits in terms of quality improvement, cost savings, flexibility, and quick reaction. Lean manufacturing is best described as the elimination of waste in a production system that may be connected to labor costs and time inventories at different stages of production. In most of the manufacturing and service industries, lean manufacturing is a popular and successful strategy for addressing non-value-added operations and waste [4].

The case study factory is a metal mold production industry for tire casting. The production process of plaster molds is another production process for creating molds for the company. From the data collection of the production process before the improvement, it was found that the availability rate, performance rate, and quality rate were 91.71%, 41.93%, and 98.57%, respectively. The overall equipment effectiveness was 37.90%, there were 8 workers in the process, and the labor productivity rate was 0.140 set per person per hour. When analyzing jobs using work studies, flow charts, and man-machine relationship charts, there was a problem with wasting time during preparation due to a loss of movement time and an unbalanced hierarchy of workflows. There was a wait during the process, causing waste in the process. Due to the baseline OEE and the world-class target of 85%, it is therefore necessary to improve the overall efficiency equipment (OEE) to increase process efficiency by applying lean manufacturing principles, separation of outside work and inside work, and ECRS principles as tools to help improve.

2. Theory and Literature Review

2.1 Overall Equipment Effectiveness

Overall Equipment Effectiveness (OEE) was introduced in 1989 in a book titled TPM Development Program: Implementing Total Productive Maintenance, edited by Seiichi Nakajima of the Japan Institute of Plant Maintenance. This was translated from the 1982 Japanese book TPM Tenkai. [5]

Prior to OEE, people measured equipment performance by its availability or interruptions. This was fine until it was discovered that having the same interruptions for the same item of equipment over various periods could result in different results.

According to Nakajima, effectiveness can be calculated using the following formula in the equation (1):

$$OEE = A \times P \times Q \quad (1)$$

where A is the operating rate (Availability), P is the efficiency rating of the machine. (Performance), and Q is the quality rate (Quality).

The operating rate can be obtained from equation (2):

$$A = \frac{Operating\ time}{Loading\ time} \quad (2)$$

where operating time is the loading time minus all recorded downtime, and loading time is the day or shift time.

The performance rate can be obtained from equation (3):

$$P = \frac{Net\ Operating\ time}{Operating\ time} \quad (3)$$

where net operating time has been subtracted from the minor stopped and idling loss time, or speed loss.

The quality rate can be obtained from equation (4):

$$Q = \frac{Good\ output\ produced}{Total\ produced} \quad (4)$$

Where good output means only good product and total product means the entire product that was processed.

However, there are six major losses associated with OEE: losses from equipment failures, losses from machine adjustments, minor stopping losses such as stopping to pick up chips or pull chips, speed losses referring to operating the machine at a slower than designed speed, waste from scrap and work repair, and losses from starting a new job. Table. 1. categorizes the six major losses that affect OEE.

OEE losses have expanded to include additional losses. Planned downtime under the run rate This results in seven losses, as shown in Fig. 1. The seven losses aim to capture all possible losses that can be improved in operations, such as planned outages. meal break Regular maintenance intervals shift start Pre-work meetings, etc.

Availability rate	Performance rate	Quality rate
Breakdown losses	Idling and minor stoppage losses	Quality defect and rework losses
Setup and adjustment losses	Reduced speed losses	Start-up (yield) losses

Table 1 Six major losses affecting OEE [4]

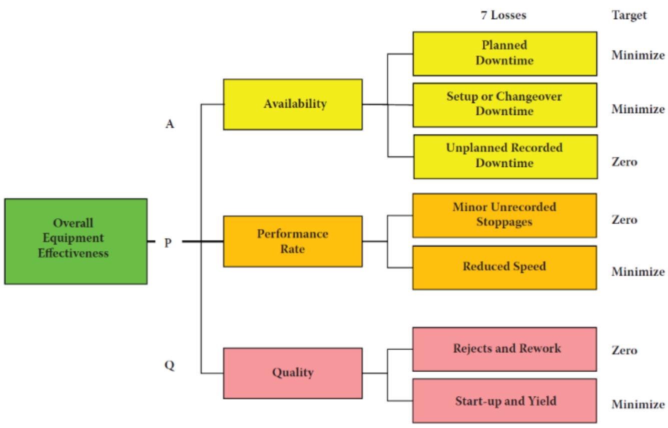


Fig. 1 Seven losses [5]

2.2 Lean Manufacturing

Lean manufacturing is a systematic approach to categorizing and discarding waste (non-value-added activities) in the manufacturing process to supply perfect products to customers. The lean manufacturing process is a comprehensive approach to reducing all types of waste. Under the lean process, material and time waste are both considered waste. [6], [7]

To be successful, lean manufacturing must involve employees and focus on improving lead times, quality, and operating costs. The lean principles are not a tactic or a cost-cutting program, but rather ways of thinking and acting for an entire organization. Lean manufacturing is a manufacturing philosophy that eliminates waste to reduce the time between a customer's order and the shipment of a product.[6], [8]

2.3 ECRS Principles

The ECRS principles are simple principles that can be used to effectively reduce waste [9].

1. E (eliminate) means eliminating all seven wastes found in production.

2. C (combine) is to consider whether the steps can be combined or not. If combined, it will reduce the workflow.

3. R (rearrange) is a new production process to reduce unnecessary movement.

4. S (simplify) means to make work easier and more convenient.

2.4 Literature Review

Tamer Haddad et al. [8] used SMED techniques as a lean manufacturing approach at a leading Palestinian aluminum and aluminum extrusion company. Reduced set-up time and improved overall machine effectiveness (OEE) of compression molding machines. It also introduces a guide for operators to improve the extrusion process of mold changers in similar industries. Overall, SMED adoption resulted in a 3.26% increase in OEE resulting from a 4.86% increase in machine availability.

N. Sriputtha and B. Nadondu [9] used industrial engineering approaches to research work, assess the relationship between man and machine by applying the man-machine chart, ECRS principles, machine layout to balance production processes, and eliminate the work that does not create value (non-value added). Data collecting revealed that the production process had a lot of waste and was only 41.17% effective. Improvements resulted in the waste time dropping from 40 to 13 seconds, or 67.50%, the operator count in the manufacturing process dropping from 5 to 3, or 40%, the production efficiency rising to 85.39%, and the production cost dropping by 232,320 baht.

Shreeja Basak et al. [10] presented a framework for measuring OEE within additive manufacturing and systematically mapped six production losses to AM process workflows. The main problem of inefficiency was performed to examine how AM implementation practices, product diversity requirements, and lead times affect the OEE of AM processes. OEE can indeed be used in the context of AM. It also identifies AM's operational practices as a key factor in its performance in terms of OEE success.

Tahir Hussain Lakho et al. [11] studied the overall equipment effectiveness (OEE) measure of the heavy engineering industry and compared it to global standards. Primary data is gathered from the production line of the case study industry. Secondary data is obtained from the maintenance department of the company. Previous six months data and Internet resources Data includes planned and unplanned downtime, number of shifts, shift duration, plant operating hours, and actual working time. Rework and repair This is necessary for calculating OEE indicators. The time between failure and repair is also collected from the company's maintenance department. The data was analyzed in MS Excel and Minitab. Availability, Efficiency, Quality, and OEE were calculated as 77.50%, 58.94%, 97.42%, and 44.5%, respectively, while the global benchmarks were Availability (90%), Efficiency (95%), Quality (99.90%), and OEE (85%). Acting like a global manufacturing system is a challenge. The authors provide guidance on calculating OEE and comparing it with global standards. Further research can be conducted on OEE and other lean tools. in case studies and other industries.

M. Suryaprakash et al. [3] presented a case study on overall equipment effectiveness (OEE) improvement in a steering housing manufacturing company and identified the facets that hinder TPM implementation in the field. The main problems this company faces are the lack of stock and the time it takes to change tools. This reduces machine availability, resulting in a significant decrease in OEE. The current level of OEE for machinery is 54.09%. Implementing lean concepts such as TPM and Single Minute Exchange of Dies (SMED) will improve OEE by 6.06%.

Yogi Tri Prasetyo and Felix Concepcion Veroya [12] use overall machine effectiveness (OEE) to identify bottlenecks. It can be integrated with other continuous improvement tools and techniques. OEE is implemented through Lean Six Sigma DMAIC and is applied to process bottlenecks at multinational semiconductor companies in the Philippines. The conceptual framework covers the integration of different approaches. This has been proven by relevant studies such as Total Productive Maintenance (TPM), FMEA, Visual Management, Mistake-Proofing, Single Minute Exchange of Dies (SMED), and DOE. Results show an overall OEE increase of 68% to 87%, which indicates an improvement of 30%. The maximum improvement comes from the operating efficiency component, which went from 24% to 67%. The conceptual framework obtained from this study can guide the improvement of bottleneck processes in similar industries.

Panagiotis H. Tsarouhas [13] conducted a study to determine strategic management tools and techniques for the OEE assessment of ice cream production lines. By collecting and analyzing data for ice cream production under real working conditions. The data spans an eight-month period. A process framework has been proposed to improve the OEE of automated production systems. The six major downtime losses are equipment failures. Settings and customization Little idling and downtime reduced speed, process flaws, and productivity. By using Pareto chart analysis to help. It also shows actual availability (A), performance (P), and quality rate (Q) metrics along with the complete OEE for each workday, week, and month of the production line.

3. Methodology

The study to carry out the plaster mold manufacturing process efficiency improvement activities is shown in Fig. 2, starting from the data collection process to the conclusion of the study.

3.1 Current Situation Study

This study aims to eliminate non-valued waste within the plaster mold manufacturing process. to increase production efficiency Data were collected from the plaster mold manufacturing process per day for 30 days. Working time was from 8:00 a.m. to 5:00 p.m. The actual working time per day was 8 hours, and 30 days (including overtime) were 240 production hours.

The production of plaster molds is a continuous process with three main steps: as shown in Fig. 3. From the data collection, there was a lot of waiting time, causing the molds to be produced late. To reduce the waiting time in production. As a result, lean manufacturing techniques are used to keep the manufacturing process running smoothly and continuously. The data collected during the plaster mold manufacturing process was then analyzed.

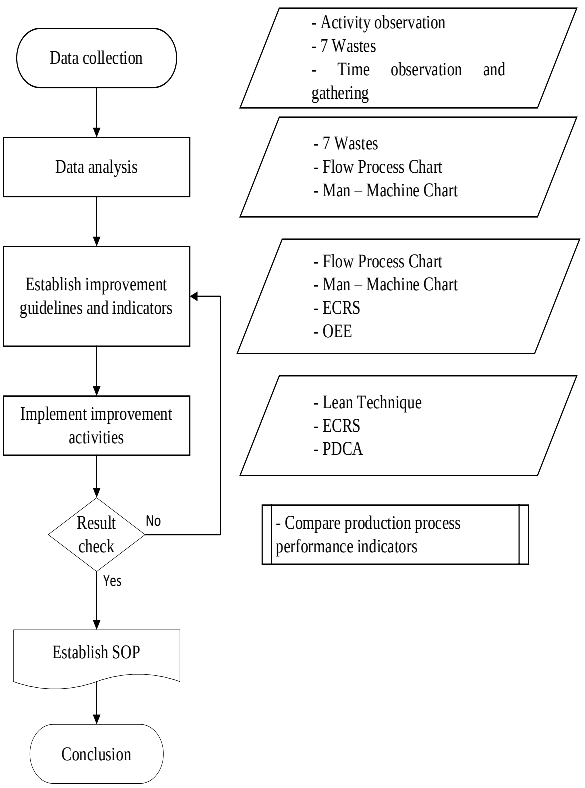


Fig. 2 procedures for carrying out improvement activities.

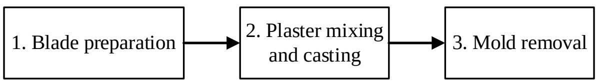


Fig. 3 Plaster mold process

3.1.1 Seven Wastes

Table. 2 summarizes the collection and analysis of seven wastes generated during the plaster mold making process.

3.1.2 Flow Process Chart

At each stage of the plaster mold manufacturing process, flow process charts are used to collect sub-activity data. Table 3 summarizes the number of activities and time spent. Prior to improvement, the total time spent in plaster mold production per cycle was 3,135 seconds, the working time was 3,135 seconds, the working time was 1,464 seconds (46.70%), and the workpiece movement was 121 seconds (3.86%). There was a wasted waiting time in the process of 1,530 seconds, representing 48.80%, and an inspection time of 20 seconds, representing 0.63%. This process employed 8 people and had a labor productivity rate of 0.140 pieces per person per hour.

7 Wastes	Waste characteristics
Over production	No
Inventory	No
Transportation	- Use human power to assisted material transportation. - Transportation and staff walked too much.
Defect	A defect occurs during the production process.
Waiting	- Unemployed from waiting in the process. - The machine became idle from waiting in the process.
Motion	- The motion of the employees was too much. - There was no clear operating standard.
Extra-processing	A special process has been established to repair damaged parts.

Table 2 Wastes data

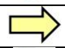
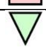
Symbols	Production process			Total
	Blade preparation	**Mixing and casting**	**Mold removal**	
	1	16	28	45
	-	13	13	26
	-	4	-	4
	-	-	1	1
	-	-	-	-
Total	1	33	42	76
Time (sec)	360*	1,862	913	3,135

Table 3 Summarizes the activities obtained from the process flow chart (before improvement).

*In the blade preparation process, three blades can be inserted per working cycle.

3.1.3 Man-Machine Chart

Table 4, a man-machine chart shows the performance time of employees working with machines to produce plaster mold. It was found that the plaster mold process, which has a mold removal (included baking process) as the main machine in the process, has a working cycle time (machine cycle time) equal to 1,862 seconds. A working rate of worker, blade preparation, mixing and casting, and mold removal process was 17.83%, 14.07%, 0.54%, and 64.45%, respectively. (Note: The man-machine chart is extracted from the whole chart only. because the table is too large to display.)

Item	Man	Blade preparation	Mixing and casting	Mold removal
Operation time (sec)	332	262	10	1,200
Idle time (sec)	1,530	1,600	1,852	652
Cycle time (sec)	1,862	1,862	1,862	1,862
Working rate (%)	17.83	14.07	0.54	64.45

Table 4 Summarizes time from the man-machine chart (before improvement).

3.2 Improvement

When analyzing the waste data in Table 2 to find the best corrective actions, 5-why analysis approaches were employed. Table 5 depicts the five-why analysis. The response measures can be summarized as follows: Study work and movement (motion and time study) and lay out new processes, rearrange procedures, and allocate work to the employee properly.

The ECRS was used to improve the process to reduce wait time and increase production efficiency. 1. Combine (C) tasks and assign them to employees who have equivalent workloads, 2. Rearrange (R) a new activity sequence to be appropriate; after these improvements, the employees were reduced from 8 to 6 people, and 3. To simplify (S) activities, a standard operating procedure (SOP) was established. In addition, SMED techniques have been used to reduce time lost from outside work. Following improvement, use flow process charts to collect sub-activity data at each step of the plaster mold manufacturing process. Table. 6 summarizes the number of activities and their durations.

Wastes	Why1	Why2	Why3	Why4	Why5	Measures
Human transportation and walked too much.	Work according to predetermined processes	process layout according to ease and low production capacity	As demand rises, add more equipment and workflows	There is no study of the work before laying out the process	Lack of knowledge, and no one does.	Study work and movement and lay out new processes
A defect occurs	Human errors	There has been work done without following norms	The work process is inappropriate	There is no study of the work	Lack of knowledge, and no one does.	Study work and movement and rearrange procedures
Waiting in the process.	Machine time is greater than human time	Too many employees in the process	There will be more employees as demand rises	There is no study of the work	Lack of knowledge, and no one does.	Study work and movement and allocate work to the employee properly.
Excessive motion	Work according to predetermined processes	process layout according to ease and low production capacity	There is no study of the work	Lack of knowledge, and no one does.	-	Study work and movement and rearrange procedures
Repair part	Defects will be re-inspected to decide	repaired to become good parts	Refer to quality procedure	-	-	Need to quality improvement

Table 5 The 5-Why analysis to reduce waste.

Symbols	Production process			Total
	Blade preparation	Mixing and casting	Mold removal	
○	1	31	28	59
⇨	-	9	4	13
D	-	1	-	1
□	-	-	1	1
▽	-	-	-	-
Total	1	41	33	74
Time (sec)	610*	1,527	913	3,050

Table 6 summarizes the activities obtained from the process flow chart (after improvement).

* In the blade preparation process, six blades can be inserted per working cycle.

4. Result and Discussion

After improvement, it was found that the total time spent on plaster mold production per cycle was reduced from 3,135 seconds to 3,050 seconds, a decrease of 85 seconds. Although the time per cycle was slightly reduced, the number of workers could be reduced from 8 to 6. The labor productivity rate was 0.145 set per person per hour, an increase of 3.57%, with a working time of 1,524 seconds, representing 92.70%, workpiece movement of 161 seconds, representing 5.08%, and a process waiting time of 120 seconds, representing 3.79% as shown in table 7 and table 8.

Parameter	Improvement		Diff	%
	Before	After		
Total time (sec)	3,135	3,050	85	2.71
labor productivity rate	0.140	0.145	0.005	3.57
Worker	8	6	2	25
Productivity (Piece/man/hour)	0.140	0.145	0.005	

Table 7 Total time spent on plaster mold production.

The man-machine chart was once again utilized to compare the working rates of both labor and machines following progress. It was found that the plaster mold process, which has mold removal (including baking) as the main machine in the process, has a working cycle time (machine cycle time) reduced to 1,644 seconds. The working rates of workers, blade preparation, mixing and casting, and mold removal processes were 92.70%, 31.36%, 1.22%, and 72.99%, respectively, as shown in Table 8.

Item	Man	Blade preparation	Mixing and casting	Mold removal
Operation time (sec)	1,524	516	20	1,200
Idle time (sec)	120	1,128	1,632	1,444
Cycle time (sec)	1,644	1,644	1,644	1,644
Working rate (%)	92.70	31.36	1.22	72.99

Table 8 Summarizes time from the man-machine chart (after improvement).

4.1 OEE Calculation

Following improvement, each parameter is measured and calculated. Before and after improvements in operating time, it was 440 and 445 minutes, respectively. The net operating time was 186 and 402 minutes, respectively. The productivity before improvements was 415 pieces; it had defects of 6 pieces. After improvement, the productivity increased to 575 pieces and 15 pieces in defects. As a result, it was found that the availability rate, performance rate, and quality rate were 92.71%, 90.34%, and 97.39%, respectively. Therefore, the OEE and its parameter can be calculated using equation (1), (2), (3), and (4) as previously mentioned.

$$Availability\ rate = \frac{Operating\ time}{Loading\ time}$$

Before improvement

$$Availability\ rate = \frac{440}{480} = 0.9167(91.67\%)$$

After improvement

$$Availability\ rate = \frac{445}{480} = 0.9271(92.71\%)$$

$$Performance\ rate = \frac{Net\ operating\ time}{Operating\ time}$$

Before improvement

$$Performance\ rate = \frac{186}{440} = 0.4227(42.27\%)$$

After improvement

$$Performance\ rate = \frac{402}{445} = 0.9034(90.34\%)$$

$$Quality\ rate = \frac{Good\ output\ produced}{Total\ produced}$$

Before improvement

$$Quality\ rate = \frac{415-6}{415} = 0.9855(98.55\%)$$

After improvement

$$Quality\ rate = \frac{575-15}{575} = 0.9739(97.39\%)$$

$$OEE = A \times P \times Q$$

Before improvement

$$OEE = 0.9167 \times 0.4224 \times 0.9855 = 0.3816(38.16\%)$$

After improvement

$$OEE = 0.9167 \times 0.4224 \times 0.9855 = 0.3816(38.16\%)$$

Table 9 shows a comparison of OEE before and after the improvement.

Parameter	Before improvement	After Improvement	Diff
Availability	0.9167	0.9271	0.0104
Performance	0.4227	0.9034	0.4807
Quality	0.9855	0.9739	-0.0116
OEE	0.3819	0.8156	0.4337

Table 9 OEE before and after the improvement.

4.2 Discussion

The improvement of overall equipment effectiveness (OEE) through the Lean Manufacturing approach improved the performance rate by 48.07% and resulted in a 43.37% improvement in overall equipment effectiveness (OEE).

There has been a slight 3.44% gap between the baseline OEE and the world-class target of 85%. [14] The main contributors are performance with 10%, availability with 8%, and quality with no significant contribution.

Low performance is addressed by implementing lean manufacturing tools such as ECRS and the SMED technique to separate internal and external tasks. The standard operating procedure was used to ensure that employees could carry out their responsibilities properly. The findings concluded that implementing the lean manufacturing concept resulted in significant improvements in OEE in the plaster mold process.

5. Conclusion

Overall equipment effectiveness (OEE) is an effective tool for determining production system efficiency based on practices in complex manufacturing systems. Many tools are strongly recommended to improve the manufacturing industry's production productivity performance, including the IE technique, OEE, SMED, ECRS, Visual Management, Value Stream Mapping, Total Productive Maintenance, Poka Yoke, and others. Improvement opportunities were identified and addressed using the lean manufacturing concept, resulting in a 52.42% improvement in the OEE of the plaster mold process. According to the researcher's suggestion, more research is needed to continuously improve the OEE and expand it to other processes in the factory. [15], [16]

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