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Evaluating the quality of pole concrete production through the integration of Six Sigma and Kaizen

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ABSTRACT

Competitive industries can thrive by emphasizing quality, which is essential for a company's growth. This study examines the quality control of a concrete manufacturer's precast concrete electric pole products. The research aims to detect product defects and assess quality levels using the sigma level, while also suggesting improvements. However, some manufactured products still exhibit defects. To address this, Six Sigma is employed to enhance quality. The Six Sigma methodology follows five steps: Define, Measure, Analyze, Improve, and Control (DMAIC). In the Define stage, issues such as cracks, pole alignment, fin breadth, skin stickiness, lumps, ovals, and through holes are identified. According to the Pareto diagram, defects related to cracks, fin width, and skin stickiness have dominated the measurement stage over the past seven years. In the Analyze stage, factors such as insufficient supervision, failure to maintain aging machines and equipment, and uncontrolled raw materials are identified as causes. During the Improve stage, Kaizen's 5W+1H approach is used to propose improvements. By adopting these improvement recommendations, the company can significantly reduce defects.

1. Introduction

Generally, the main objective of the manufacturing industry is to produce goods efficiently to gain profit and deliver products on time. Additionally, the manufacturing industry needs to maintain sustainability, innovation, and growth in production. Industries are encouraged to become more competitive in gaining market share. Hence, they must possess the capability to implement relevant business strategies, not only to withstand prevailing competition but also to accommodate technological advancements and a highly dynamic environment [1], [2].

Focusing on quality improvement would undoubtedly help companies survive in highly competitive markets. Quality is a crucial factor that drives the success and expansion of companies [2]. A corporation's size and characteristics directly influence its product quality. Therefore, adaptive companies allocate resources toward the integration of cutting-edge technology, research and development [3], human capital, and, particularly, core operations that directly pertain to quality management [4]. Naturally, this is done in anticipation of potential deterioration in the manufacturing process and the final product. Despite the efficient execution of the production process, errors still occur, and the products may not meet the company's requirements, indicating a flaw in their quality.

Product quality evaluation can be carried out in various ways. The Six Sigma approach is an effective strategy that can be utilized to analyze and improve product quality. Six Sigma is an integrated quality approach that is part of Total Quality Management (TQM). TQM is a strategic initiative that ensures all functional components of an organization meet standards and continuously improve. The main objectives of TQM are to meet customer expectations and enhance productivity [5]. It has gained significant popularity and has been implemented in a wide range of products, including agricultural products [6], food networks [7], electronics [8], filters [9], machining processes [10], chemical products [11], marine products [12], bogie assembly processes [13], additive manufacturing [14], and the health industry [15]. Quality control systems generally emphasize

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continuous improvement, often driven by the independent awareness of management. However, this approach does not provide appropriate solutions when it comes to making significant breakthroughs toward achieving zero defects. Six Sigma, which is one of the most widely used methodologies today, represents a significant advancement in quality management and serves as an alternative to traditional quality control principles [10], [11], [16], [17].

As previously described, Six Sigma is generally accepted as a technique for evaluating product quality and offering recommendations for enhancement. Six Sigma employs several stages, including DMAIC (Define, Measure, Analyze, Improve, Control). In the Define stage, problems are identified; in the Measure stage, process performance is assessed; in the Analyze stage, defect causes are identified; in the Improve stage, solutions are proposed; and finally, in the Control stage, progress is monitored. Six Sigma is a Statistical Quality Management System [18], [19], [20]. By integrating Six Sigma with the green lean concept, the latest approaches in quality evaluation are being developed [15], [21], [22], [23], [24], [25].

With a market share spanning Southeast Asia, a concrete manufacturer produces a wide range of precast concrete products that excel in their respective categories. This manufacturer must uphold and continuously improve the quality of its products. Among its concrete production products for electrical poles, there are still instances of non-compliance with the stipulated criteria. An enterprise that has achieved global reach must maintain high standards for its manufactured goods. However, some precast concrete power poles still exhibit defects, such as cracks or deficiencies in fin width. By preventing production defects, manufacturers can ensure the high quality of their products, leading to customer satisfaction and attracting new customers.

Based on the explanation above, this study was conducted in a concrete industry specializing in power pole production. Prior studies assessed the quality of concrete manufacturing for electrical poles using quality tools such as the 7 quality tools and the 7 new tools of quality [26]. This study proposes a case study to explore the main problems in the concrete pole production process. The research uses the general Six Sigma framework to identify the main issues, generate causes, and offer alternative solutions. In Six Sigma, technical approaches are integrated within each stage. The key difference between this study and previous research is the use of technical approaches tailored to the context and specification of the case study. One study incorporated Sus-VSM (Sustainable Value Stream Mapping) into Six Sigma [27]. Other studies have integrated FTA (Fault Tree Analysis) and FMEA (Failure Mode Effect Analysis) into Six Sigma in the tire [28], rubber [18], and automotive industries [29]. Lean Six Sigma has also been used to minimize waste in the food industry [30]. More advanced studies have integrated Machine Learning with Six Sigma in clinical practice [31] and evaluated the lifespan of LED bulbs with the integration of Weibull distribution [32]. Multi-criteria decision-making (MCDM) within Six Sigma has been used to evaluate the microlens process [33]. Six Sigma has also been integrated with process modeling in wind blade factories [34] and ergonomics [35]. Meanwhile, this study proposes the integration of Kaizen into Six Sigma to identify and prioritize defects in precast concrete electrical pole production. The Six Sigma and Kaizen methods will be used to determine the sigma level of the concrete and provide recommendations to improve the quality of the precast.

2. Material and method

Data collection was conducted using both primary and secondary data sources. The research followed a series of preliminary steps, including interviewing industry experts, making restricted observations, and documenting relevant information. The secondary data collected consists of the company's historical production figures and manufacturing failure data. The analysis was performed using the Six Sigma methodology, which quantifies defects per million opportunities (DPMO). Continuous improvement was implemented through the Six Sigma methodology, specifically the DMAIC approach (Define, Measure, Analyze, Improve, and Control), as supported by the available data [35], [36].

2.1. Define

During this phase, interviews and observations are conducted about the entire manufacturing process, starting from the receipt of materials to the delivery of the final product. This includes examining standard operating procedures, quality criteria, and standards and assessing the human resources involved. Next, critical defects that primarily cause multiple damages leading to production failure must be identified. This can be achieved by:

- Identifying deficiencies in producing products that do not meet the company's quality standards.
- Formulating and implementing action plans based on research findings and analysis.
- Establish Six Sigma quality improvement goals and targets derived from the findings of observations.

2.2. Measure

Several stages of measurement are carried out as follows:

a. Collecting sample or population data. Data obtained from the company, including production data and production defect data, will be presented in tabular form to make it more structured and easier to analyze. From the product defect data, a Pareto diagram will be created to identify the defects. By examining the Pareto diagram, we can observe the ranking of defect types and identify the dominant ones.

b. Determning the DPMO value and Six Sigma level. A higher sigma level will result in a lower number of defects per one million opportunities (DPMO), indicating that the company's quality control is more effective.

2.3. *Analysis*

First, identify the most prevalent key problem. Next, analyze the factors contributing to product damage using a fishbone diagram to examine the components that lead to product damage.

2.4. *Improvement*

The improvement stage is the stage of improving quality using the Kaizen method to provide improvement recommendations. The application of the Kaizen method uses 5W+1H (What, Why, Who, When, Where, How). Once the cause of product damage is known, a recommendation or proposed action can be prepared to improve product quality.

2.5. *Control*

In the last phase, the task entails overseeing and tracking the repairs that have been planned and formulated in the preceding stage. The results can be determined by assessing if the ongoing process falls within the defined quality tolerance limits or range.

3. Results and discussions

WKB is the largest precast concrete producer in Indonesia and Southeast Asia. An additional advantage of this company is that it operates 10 factories across Indonesia, a region with high growth in the construction industry, and applies the Precast Engineering-Production Installation (EPI) pattern. In particular, the factory located in Makassar City produces an average of approximately 18,000 electricity poles per year.

This industry adheres to high and strict quality standards in the production process. The electric pole production process consists of several stages, which will be further explained in the Six Sigma stages. Based on these stages, the following are the results of the study according to the DMAIC approach.

3.1. *Define*

WKB manufactures electric poles in various sizes, including 7/100, 7/150, 9/100, 9/150, 9/200, 11/200, 11/350, 13/350, 14/350, and 14/500. The 10 types are distinguished by the dimensions of the concrete thickness, top diameter, bottom diameter, and the number of wires. To access more comprehensive specifications regarding electricity pole types, please refer to Table 1.

In preparation for manufacturing electric pole products, two main materials are used: reinforcement material and concrete material. The first phase of electric pole manufacturing involves the preparation of reinforcement materials. This preparation includes creating spirals, forming rings, severing prestressed iron, constructing heads, and fabricating grounding conductors.

The next phase involves the assembly of the reinforcement. The results of the reinforcing process are carefully organized and connected within a mold, while the necessary accessories are added. The reinforcement assembly uses a concurrent stressing system.

The subsequent phase involves the production of concrete. Concrete is made by combining specific quantities of ingredients sourced from the material storage area. The components are thoroughly mixed in about five minutes using a scraper machine. A single operator is sufficient to operate the screener machine. After mixing, the concrete is poured into the mold, with approximately 2-3 individuals involved in compressing the material.

The third phase involves extracting the prestressed iron. A pulling machine is used to apply force to the reinforcement, while a siren alerts workers that the reinforcement pulling operation is in progress. The primary purpose of the siren is to signal workers in proximity to the reinforcement pulling stage. To reduce the frequency of work accidents, it is important to ensure that the wire used during the pulling stage has sufficient flexibility. If the wire is too rigid, it may come out of the mold and potentially cause injuries to workers nearby.

Table 1.
Power pole specification

No	Type	Width (mm)		Top Diameter (mm)	Bottom Diameter (mm)	Quantity of Wire (pc)
1	7/100	40	50	124	217	4
2	7/150	40	50	124	217	5
3	9/100	40	55	157	277	4
4	9/150	40	50	124	224	5
5	9/200	40	55	157	277	6
6	11/200	45	70	190	335	6
7	11/350	45	70	190	335	8
8	13/350	45	80	190	363	10
9	14/350	45	80	190	377	10
10	14/500	45	80	190	377	12

Table 2.
Indicator and quality attributes

No.	Defect types	Quality indicator		
		Good	Defect	Failed
1	Pole straightness (PS)	PS < 2 per mil.	-	PS > 2 per mil.
2	Fin width (FW)	Fin width ≤ 1mm	1mm < FW ≤ 5mm.	FW > 5mm
3	Skin sticking (SS)	SS ≤ 1mm	1mm < SS ≤ 4mm	SS > 4mm
4	Blockage (BL)	BL ≤ 2mm	2mm < BL ≤ 30mm	BL > 30mm
5	Cracks (CR)	No CR	-	CR is observed, CR area > 0,25mm2
6	OVL (Oval)	OVL ≤ 3mm	3mm < OVL ≤ 15mm	OVL > 15mm and wire observed
7	Sign (SN)	Completed	-	Uncompleted
8	Dent (DT)	DT ≤ 1,5% pole diameter	-	DT > 1,5% pole diameter
9	Through-hole (TH)	TH		No hole, hole unsimetric
10	TRG (Terminal grounding)	Good condition	-	No good condition.
11	Visual (VL)	Visual (accuracy of position in place)	-	Visual (position is not accurate)
12	Finishing	The hat is firmly attached to the concrete, there is no metal protruding on the top, the fins are clean and even	-	The hat is not firmly attached to the concrete, there is metal protruding on the top, the fins are not clean and uneven

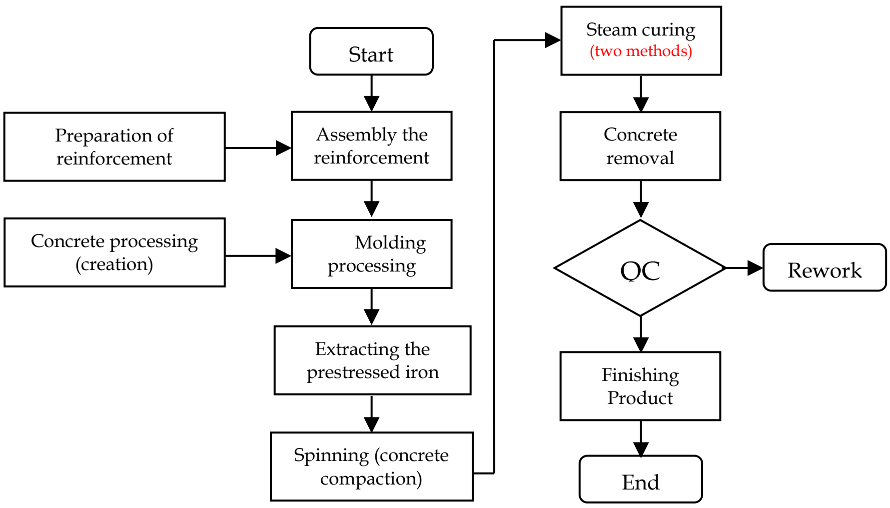

Figure 1. Flowchart of the production process

The process of compacting concrete, also known as spinning, takes place during the fourth step. During this phase, the machine rotates the mold at a speed of 1,300 revolutions per minute. In a single screening, two molds can be accommodated, and the process can be completed within 10 minutes by a single operator. In the fifth phase, steam treatment (Steam Curing) is conducted. Steam treatment can be performed using two methods: one involving steam and the other without it. The mold will be subjected to steam at a temperature range of 65°C–70°C to apply pressure. If steam is not used, the mold will remain at the ambient temperature of the room.

The demolding stage, which is the sixth stage of concrete removal, is a crucial step in the overall production process. It involves opening the mold with the assistance of 2-3 workers. Once the mold is separated from the electric pole product, an inspector examines it to ensure that there are no defects. If any defects are found, the product moves on to the finishing stage, where it will be repaired according to the specific type of defect. The final stage is the finishing stage, which involves marking the product. If the product is free from defects, it will be labeled with the company's product label, logo, product type, date of manufacture, production number, and grounding marker. The production process for making electric pole products is shown in Fig. 1.

The company has quality requirements for defects that arise during the production process. The quality requirements are divided into three categories: good (the product does not experience defects), defective (the product experiences defects that can be tolerated), and failure (the product experiences defects that cannot be tolerated). Several quality requirements determined by the company are listed in Table 2.

The data gathered at WKB represents the company's authentic historical records spanning the past seven years. During the entire process of manufacturing electric poles, defects are inevitably generated. These defects are categorized into 12 distinct types, including pole straightness defects, fin width defects or fin loss, skin sticking defects, block defects, crack defects, oval defects, sign defects, dent defects, grounding terminal defects, through hole defects, visual defects, and final finishing defects (see Table 2).

(a) Straightness of the pole

(b) Fin width

(c) Skin stickiness

(d) Blockage

(e) Cracks

(f) Oval

(g) Through hole

Figure 2. Types of defects

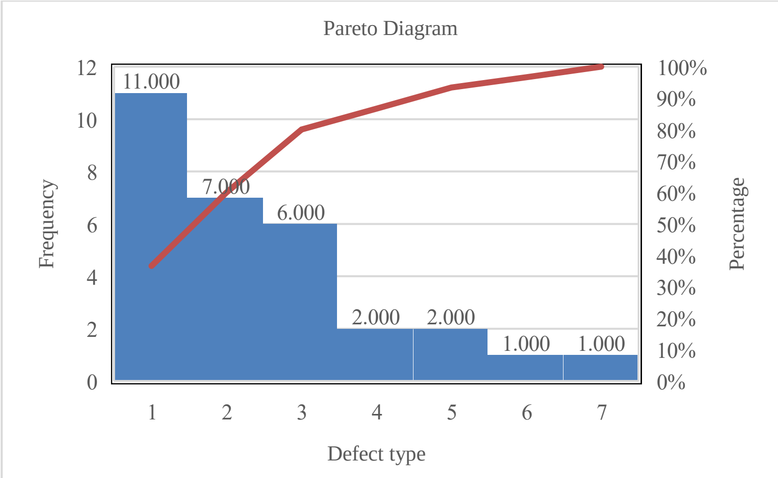

Figure 3. Pareto diagram

Table 3.
Critical to Quality

No	Type of Defect	Number of Defect (pc)	Percentage (%)	Cumulative (%)
1	Cracks	11	36,7	36,7
2	Fin width	7	23,3	60
3	Skin Stickiness	6	20	80
4	Blockage	2	6,7	86,7
5	Through-hole	2	6,7	93,3
6	Straightness of the pole	1	3,3	96,7
7	Oval	1	3,3	100
Total		30	-	-

Table 4.
Internal failure cost

No	Type	Cost (IDR)	Defect (pc)	Total cost (IDR)
1	7/100	928193	0	0
2	7/150	1009796	2	2019592
3	9/100	1244454	1	1244454
4	9/150	1238690	0	0
5	9/200	1295219	12	15542628
6	11/200	1734743	7	12143201
7	11/350	1893956	1	1893956
8	13/350	2572569	7	18007983
9	14/350	2843765	0	0
10	14/500	3251236	0	0
	Total		30	50851814

However, over the past seven years, only 7 specific product defects have emerged. Notably, these 7 types of defects represent only a portion of the 12 types of faults classified in the electricity pole production process (Fig. 2).

3.2. *Measure*

In the measure stage, calculations are carried out to assess product quality. The first step is to determine and sort the Critical to Quality (CTQ) factors. Based on historical data on electricity pole concrete production over the past seven years, the defects with the largest percentages, as shown in Figure 3's Pareto Diagram, are crack defects (36.7%), fin width defects (23.3%), and skin sticking defects (20%). Therefore, these three types of defects will be the focus of this research.

According to the Pareto diagram in Fig. 3, the crack defect type accounts for 36.7% of the flaws, indicating that it has a higher percentage compared to the other defect types. Table 3 displays the percentage of defects over the past seven years. Table 3 reveals that the crack defect type accounts for the largest proportion, at 36.7%. The fin width defects follow at 23.3%, while skin stickiness accounts for 20%. Blockage, through holes, pole straightness, and oval defects each represent 6.7%, 6.7%, 3.3%, and 3.3%, respectively. Moreover, according to the DPMO calculations, the manufacture of electricity pole concrete at WKB has a potential defect rate of 24 units per million units produced. While the results may appear favorable from this perspective, when considering the losses incurred, the associated expenses have a significantly negative impact on the organization. Refer to Table 4 to determine the internal costs related to failures.

The achieved sigma level is satisfactory; however, when considering internal failure costs, the incurred losses are substantial. The company has suffered losses amounting to IDR 50,851,814. Failure to manage these significant expenses can lead to substantial financial losses. Additionally, an increase in defective products during the production process will result in higher production costs for the company.

3.3. Analyze

The analyze stage is the subsequent phase in the Six Sigma methodology, during which the causes of problems are identified. A fishbone diagram is used to identify the factors that contribute to the occurrence of production errors in electric poles. Through the implementation of the Six Sigma approach, precise calculations have identified several factors that contribute to defects in electricity pole concrete products during quality control. The three main factors are Man, Machine, and Material.

The Man (worker) aspect is a common element seen in all three prevailing types of problems. Workers exert a significant impact on job inefficiencies throughout the production process. Negligence typically arises when personnel improperly position the sponge during installation. If an error occurs during the installation of the sponge at the mold closing workstation, it will result in the concrete liquid leaking out of the mold.

Additionally, at the mold opening workstation, a fault occurred due to prematurely opening the mold. To address the issue of the mold opening too quickly, it is recommended to incorporate time measurement equipment to effectively manage the minimum time required for mold opening. Alternatively, additional workers can be assigned the task of accurately recording the minimum time needed for mold opening. Moreover, there are worker errors related to failing to apply lubricant to the mold. The absence of lubricant on the mold's surface results in the adhesion of the concrete liquid, which could harm the structural integrity of the electricity pole. A recommended course of action would be to develop a customized dosage specifically for the application of mold lubricants to ensure uniform and quantifiable distribution within a single mold. Factors such as rapid mold opening, insufficient mold cleanliness, and inadequate lubrication contribute to the occurrence of sticky skin problems.

Inadequate oversight contributes to the occurrence of crack defects. The disparity in the amount of time allocated for supervision at each workstation is evident. Supervision is occasionally lacking during the third shift at the foundry workstation. The workers' lack of focus on their tasks is due to the absence of physical compaction of the concrete mixture poured into the mold. The production process of electric pole concrete is primarily supported by machinery. However, there are inadequacies in the maintenance of machinery and industrial auxiliary equipment. The base for the electrical pole was compromised due to its inability to bear the weight of the final concrete product. Given this issue, it is imperative to develop a maintenance strategy for the machinery and auxiliary equipment used in production to enhance the efficiency of their daily utilization.

The level of control over raw materials upon their arrival at the factory is relatively low. Based on observations, several raw materials were promptly stored in the material storage area, prepared for use in manufacturing. The incoming material section should implement more stringent measures to guarantee that raw materials conform to the company's required criteria. Therefore, it is essential to implement a process for conducting inspections of imported raw materials by sampling them from vendors.

3.4. Improve

The enhance stage involves improving quality through the implementation of improvement recommendations using the Kaizen approach. The Kaizen technique applies the 5W+1H approach, which includes the questions: What, Why, Who, When, Where, and How. In the fishbone diagram, several causes can be categorized, such as Man, Machine, Method, and Material. However, for the case studied, the emergence of defects is mainly influenced by three factors: Man, Machine, and Material. Therefore, the Method factor is not included in this discussion. The proposed improvements are based on these three primary factors—Man, Machine, and Material—that contribute to the occurrence of defects in electric pole concrete products.

Enhancing the caliber of human resources primarily involves increasing expertise and disseminating knowledge related to the manufacturing process. Additionally, rigorous oversight is required to ensure that the production process adheres to operational protocols, particularly at crucial workstations.

Systematic and periodic maintenance planning is conducted for machines and production auxiliary equipment. Maintenance procedures include preventative maintenance, corrective maintenance, maintenance following damage, and emergency maintenance.

Material handling involves conducting comprehensive and quantifiable inspections of raw materials using the most up-to-date inspection methods, which include examining samples received from suppliers. A supplier review should be conducted to choose the most suitable supplier based on the company's requirements, and subsequently, permission should be issued for their use in the ready-to-use material storage area.

3.5. Control

The control stage is the ultimate phase of the Six Sigma methodology. Continued progress in the improvement process requires a dedicated commitment to supervision. This control aims to elevate the company's sigma level to perfection and eliminate any occurrences of defects in electricity pole concrete. We concluded that the proposed method can be implemented by a manufacturing company that implements a just-in-time production system.

4. Conclusions

It is imperative for the industry to consistently enhance competition, effectively manage relationships across the supply chain, and continuously improve production quality. WKB is a company that manufactures precast concrete in various forms of electrical poles. An assessment of both the manufacturing process and the resulting goods is conducted to oversee and maintain production quality. The DMAIC approach, when implemented in conjunction with Six Sigma, is a highly effective method for managing and improving production quality. Using this methodology, we acquired historical production data, as well as information on the types and frequency of defects in production over the past few years. The defects that arose during the production of electricity pole concrete included 11 instances of cracks, 7 instances of defects related to fin width or fin loss, 6 instances of sticky skin defects, 2 instances of block defects, 2 instances of through-hole defects, and defects related to straightness.

The data processing results obtained through the implementation of the Six Sigma method revealed that the highest proportion of defects, specifically in relation to the Critical to Quality metric, was 36.7% for crack defects. Moreover, according to the findings of the Six Sigma analysis, the production of electricity pole concrete yielded an average damage rate of 24 units per one million units produced. Alternatively, when considering the negative impact on concrete production for electricity poles, the total loss amounts to IDR 50,851,814.

The recommendations provided in the improvement stages encompass a range of suggestions aimed at minimizing product defects. The proposal is categorized into distinct factors: Man, Machine, and Material. To enhance the Man factor, it is imperative to improve the caliber of human resources, particularly the workers involved in the critical path. This can be achieved through increased supervision time at each workstation and conducting regular briefings prior to commencing work on each shift. Special attention needs to be given to the Machine factor, specifically the upkeep of machines and industrial ancillary equipment. A well-organized maintenance schedule should be developed. For the Material factor, raw material inspection activities are required, including taking samples directly from suppliers and creating a more measurable material requirements plan.

The findings of this research succeeded in identifying the specific problem, exploring the cause of defects, offering alternative solutions, and determining the priority solution. Additionally, the findings will be utilized to identify areas that require development to achieve the highest possible level of quality and productivity. Lastly, it is recommended that a study be conducted focusing more specifically on the machine and human factors to improve the quality level of the process, as this area is still rarely studied.

Declaration statement

Armin Darmawan: **Conceptualization, Methodology, Supervision, Formal Analysis**. Syamsul Bahri: **Supervision, Project Administration**. Ilham Fansuri: **Resources, Visualization, Documentation, Investigation**. Nurfaidah Tahir: **Data curation, Validation**. Armin Darmawan, Ilham Fansuri: **Writing - Original Draft**. Armin Darmawan: **Writing - Review & Editing**.

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

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