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Implementation of Fault Tree Analysis for Production Quality Control Evaluation

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Abstract

This study aims to evaluate the quality control of lightweight brick production at PT XYZ using the Fault Tree Analysis (FTA) method. In the manufacturing industry, product defects are a major challenge that can affect production efficiency, operating costs, and company competitiveness. Based on production data from January to December 2024, the total number of defects identified reached 125,334 units, consisting of three main types, namely cracks (63%), peeling (21%), and imprecision (16%). Through the application of FTA, this study revealed that the two dominant factors that are the root causes of product defects are human error and tools or equipment. Human error is mainly triggered by operator carelessness, overly rapid mold dismantling processes, and errors in installing cutting tools. Meanwhile, machine factors include worn components, excessive vibration, deteriorating cutting wire quality, and lack of regular maintenance. The results of the study emphasize the need for a comprehensive improvement strategy through increasing operator competence, enforcing work discipline, scheduled machine maintenance, and standardizing operational procedures. The implementation of these improvements is expected to reduce the defect rate and improve product quality in a sustainable manner.

Keywords: Fault Tree Analysis, Product Quality, Production Defects, Human Error, Quality Control

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INTRODUCTION

In today's modern era, the business world is experiencing rapid growth, particularly in the manufacturing sector[1] . Companies, both national and international, continue to compete with similar companies to maintain their presence in the industry[2] . The aim of this competition is for companies to win the competition or at least be able to survive in the same market[3] . One important strategy for facing this competition is to pay greater attention to the quality of the products produced[4] . Therefore, improving product quality is essential for companies to compete and maintain their existence in the industrial world[5] . According to[6] , product quality is a description of the physical condition, function, and characteristics of a product that can optimally meet consumer needs and expectations in accordance with its economic value. Meanwhile, according to[7] , product quality is influenced by various factors, including tools and machines as well as human factors . In the production process, the occurrence of defective products is something that cannot be completely avoided[8] . Meanwhile, research conducted by[9] states that product defects are generally caused by two main factors, namely human error and disruptions in production machinery that can affect the final product.

In the production process, every company has the potential to encounter defective products or products that do not meet the established quality standards[10] . The existence of defective products can have a negative impact on the company, both in terms of time efficiency and production costs, because a repair or re-production process is required[11] . This condition can ultimately reduce the company's profit level due to the additional costs that must be incurred[12] . Therefore, this study applies the Fault Tree Analysis method as an approach to control the quality of defective products.

The Fault Tree Analysis (FTA) method is an approach to quality control used to trace the source of damage using a top-down approach, namely through analysis of system errors arising from interactions between components or elements in a process[13] . The use of statistical tools in quality control aims to improve efficiency, so that companies can determine whether to accept or reject the products produced[14] . This process provides an overview of product quality specifications in a populative manner[15] . If the products produced meet quality standards, then the production process can run continuously with the best consistent results[16] .

In this study, the researcher focuses on the process of monitoring, analyzing, and tracing system failures that cause defective products. Quality issues that often arise in companies are an important aspect that needs special attention in order to obtain products with better quality and minimal defects. Products with low defect rates have positive implications for production cost efficiency, as they can reduce additional expenses due to the repair process. The factors causing product defects and the most influential dominant factors will be identified after direct observation at the research site.

METHOD

The data collection method used in this study is a literature review, which is a research method conducted to obtain conceptual understanding and relevant theoretical foundations for analyzing data and research problems. This activity includes various scientific papers, books, journals, and other sources of information related to the research topic, which can be used as a basis for consideration in conducting research. It also uses a data collection method in the form of field observation, which is a research method conducted through direct observation at the company location with the aim of obtaining empirical data. This process involves observing the research object in real life and collecting primary data through interviews with a number of employees who are related to the issues being studied. This approach aims to obtain factual and in-depth information about the actual conditions in the field as a basis for analysis in the research.

Data Sources

The data used in this study consists of primary and secondary data. Primary data was obtained through direct observation in the field for one month, which included documenting production activities and conducting interviews with stakeholders and workers involved in the process. Meanwhile, secondary data was obtained from the company, including data on the types of product defects and daily production reports for one production period, namely from January to December 2024.

Research Flow Chart

The research flowchart is a description of the research steps from the beginning to the end of the research. This research flowchart is shown in Figure 1.

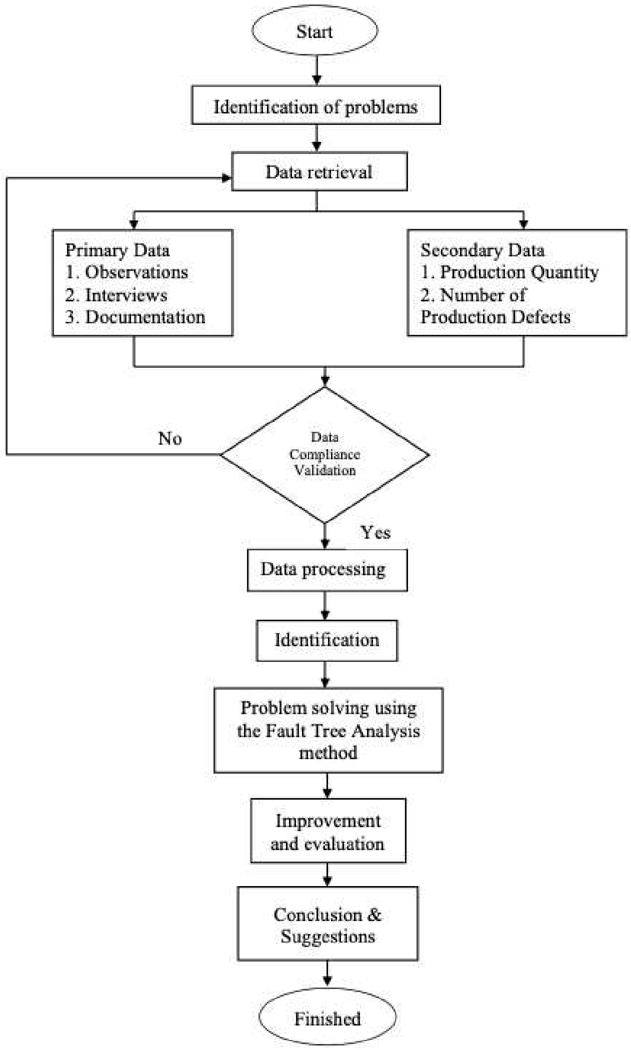


Figure 1. Research Process Flowchart

RESULTS AND DISCUSSION

Production Observation Results

Bricks are composite materials composed of various types of rocks bonded together using a binding agent. This material is formed from a mixture of fine and coarse aggregates which are then mixed with cement paste. Simply put, cement paste serves to bind sand and other aggregates such as gravel, basalt, and so on. The empty spaces between the coarse aggregates are filled with finer particles. This shows that an appropriate ratio between the various types of aggregates is needed so that all constituent materials can play an optimal role in the formation of bricks.

Bricks are generally divided into two main types, namely normal bricks and lightweight bricks. Normal bricks have a density ranging from 2.2 to 2.4 g/cm^3, with strength influenced by the mix design. Meanwhile, lightweight bricks have a density of less than 1.8 g/cm^3, and their strength varies depending on the composition and intended use. Lightweight bricks are divided into two types, namely aerated concrete and non-aerated concrete. The best brick quality at PT XYZ is shown in Figure 2.

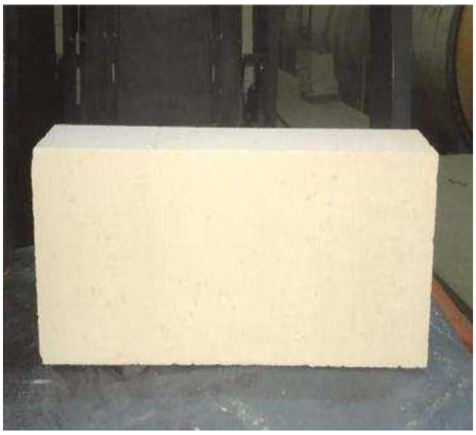


Figure 2. Best Brick Quality

An innovation in aerated lightweight bricks is known as Aerated Lightweight Concrete (ALC) or Autoclaved Aerated Concrete (AAC). This material is also known by various other terms such as Autoclaved Concrete, Cellular Concrete, and Porous Concrete, while in the UK it is often called Aircrete or Thermalite.

Lightweight bricks are a type of brick that has a lower density than conventional bricks. The main purpose of using lightweight bricks is to reduce the dead load on building structures so that supporting elements, such as foundations, can be designed more efficiently and economically.

The production process of lightweight bricks generally involves materials such as cement, sand, gypsum, calcium carbonate ($CaCO_3$), and aluminum catalyst. The reaction between the aluminum catalyst and the cement mixture produces an exothermic hydration process, which produces gas bubbles such as H_2 and CO_2. These bubbles then form pores in the hardened brick mass. The more gas that is formed, the greater the number of pores produced, making the bricks lighter.

The main principle lies in the formation of air cavities, either through porous aggregates, the removal of fine aggregates, or by adding foam-forming materials to the cement paste. Some types of lightweight bricks even combine these two methods.

In addition to being lighter in weight, lightweight bricks also offer advantages in terms of thermal insulation. In general, a decrease in material density is directly proportional to an increase in heat insulation capacity, although this is usually accompanied by a decrease in the mechanical strength of the material.

Production Process

Table 1. Product Production Process

No	**Production process**	**Production Process Documentation**
1.	Raw Material Destruction: In the initial stage of the process, the raw materials, silica and gypsum, are loaded into the tray using a loader. The material is then transported and fed to the ball mill via a conveyor operated by the ball mill's control panel. Inside the ball mill, the material undergoes a grinding process with the addition of a predetermined amount of water. Once the grinding process is complete, the mixture is collected in a	1. The Ball Mill Panel Functions to Control the Bucket and Conveyor. 

No	Production process	Production Process Documentation
	holding well and then pumped to a slurry storage tank for the next stage.	2. The bucket functions as a container for silica materials (gypsum, sand, and stone). 3. The conveyor belt functions  to carry silica material into the ball mill. 4. The ball mill process refines silica material into slurry. 
2.	Density Measurement Level: At this stage, the slurry stored in the holding tank is pumped to the mixing well. Next, the material is mixed with appropriate amounts of mesh and water until it reaches the specified density.	1. Density Wells Work to Measure Density.  2. Mesh Storage Tank. 

No	Production process	Production Process Documentation
		3. Slurry Storage Tank 
3.	Material Mixing Stage: At this stage, all raw materials are weighed and controlled via a Central Control Room (CCR) panel to ensure accurate proportions. The slurry stored in the well is pumped into the mixer using a vacuum pump. Next, other ingredients such as aluminum, lime, cement, and water are added to the mixer, the main mixing components. The mixing process takes place inside the mixer, which serves as a homogenizing vessel for all the lightweight brick components before entering the next stage of the production process.	1. Network Mixer  2. CCR Panel. 
4.	Casting Stage: After the mixing process has been carried out until the mixture reaches a uniform level of consistency, empty molds are prepared to serve as molding containers. The mixture, processed in the mixer, is then poured into these molds to form lightweight bricks of the desired size.	1. Molding  2. Pouring Process 

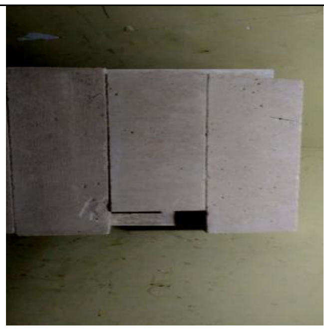
No	Production process	Production Process Documentation
5.	Transfer and Compaction Stages: After the mixture is poured into the mold, the mold containing the material is moved to the curing area using a transfer cart. The mold is then placed in the curing area to undergo the curing process. During this stage, the molded material is allowed to naturally harden for approximately 7 to 8 hours to allow for optimal initial setting.	1. The Process of Transferring Moldings Containing Materials Using a Car.  2. Curing Process 
6.	Light Brick Cutting Level: After curing, the molded material is lifted using crane 1 and moved to the cutting area. During the cutting phase, the material is shaped to the specified dimensions and specifications. Once the cutting process is complete, the material, divided according to dimensions, is lifted using crane 2 and transferred to the autoclave rail for further curing.	1. Lifting Raw Materials to the Train Using a Crank.  2. Raw Material Cutting Process  3. The Process of Lifting Cut Raw Materials Using a Central Crank
7.	Drying Level: After the cut material is transferred to the autoclave rail, it is fed into the autoclave dryer. The drying process is carried out using steam pressure of	The process of inserting cut raw materials into the autoclave

No	Production process	Production Process Documentation
	approximately 12 bar supplied from the boiler through a piping system connected to the autoclave. This drying phase lasts approximately eight hours to ensure optimal hardening and maturation of the material.	
8.	Packing: Once the drying process in the autoclave is complete and the lightweight bricks are removed from the machine, the hardened product, which has achieved optimal physical quality, is ready for packaging. The lightweight bricks can then be distributed and marketed as ready-to-use building materials.	Brick packing process and ready for distribution 

Product Defect Identification Process

Product defects or failures are conditions in which an item does not meet the established quality standards, resulting in deviations from the expected product specifications. In general, in production activities, the level of product defects in companies is still relatively high and in some cases can even exceed the specified tolerance limits. Therefore, to minimize defects, companies need to take corrective and preventive measures quickly and effectively. The types of defects that arise can vary, ranging from simple to complex, depending on the causative factors and stages of the production process. From the analysis process carried out by the researchers, several types of defects were found, which are described in Table 2.

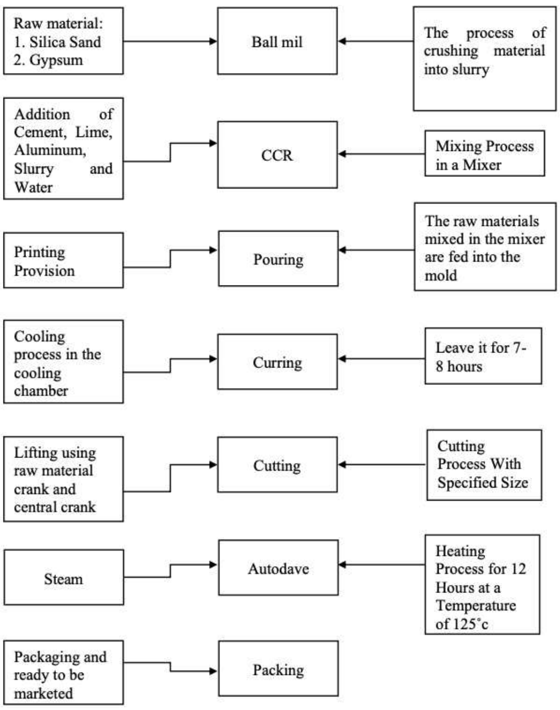
Table 2. Types of Product Defects

No	Type of Disability	Description of Product Defects	Defective Product Documentation
1.	Not Precise	Inaccurate precision is a form of defect that occurs due to several factors, including: a. Inaccurate installation of the cutting tool, resulting in the tool's position or size not conforming to the proper placement standards. b. Using worn or damaged cutting wire, preventing it from functioning optimally. c. Shifting of the cutting wire caused by excessive product hardness, preventing the cutting process from running smoothly.	

2.	Cracked	Cracks are a type of defect that occurs in products due to several factors, including: a. The mold removal process is carried out too quickly, even though the bricks have not yet reached their full hardness and are still damp, making them susceptible to cracking. b. Unstable steam carrier movement causes vibrations in the molding container. These vibrations cause reactions in the material inside the mold, ultimately triggering the formation of cracks in the product.	
3.	Chipped	Peeling is a type of defect caused by the product sticking to the mold surface. This typically occurs due to insufficient oil or lubricant coating on the mold, causing part of the product surface to lift or peel off during the removal process.	

Production Process Flow

The production flow implemented at PT. XYZ includes several important interrelated stages. The process begins with the selection of high-quality raw materials to ensure that the final product meets quality standards. Next, the raw materials go through a series of well-controlled production processes to maintain consistency and efficiency. The final stage is packaging the product using the appropriate method so that it is ready for distribution to consumers safely while maintaining its quality. With this production flow, PT. XYZ can produce reliable products that satisfy market needs. The production process flow from start to finish is shown in Figure 3.



Product Defect Data Collection

This study uses secondary data obtained from the company to identify the level of product defects, with data collected covering the period from January to December 2024. The summary of production defect data is shown in Table 3.

Table 3. Defective Product Data

No	Type of product defect	Number of Defective Products	Percentage of Defective Products
1	Not Precise	19,488	16%
2.	Cracked	78,996	63%
3.	Chipped	26,850	21
Total		125,334	100

Based on Table 3, which displays product defect data, it can be concluded that the defect type with the highest number is cracks, totaling 78,996 units with a percentage of 63%. Meanwhile, peeling defects rank second with 26,850 units or 21%, and the defect type with the lowest number is imprecision with 19,488 units or 16%. Overall, the total number of defective products recorded during the six-month period reached 125,334 units.

Defect Data Processing

Based on Table 3, which contains data on defective lightweight brick products at PT.XYZ, the data was then processed and presented in the form of a histogram to show the distribution of product defect types. This histogram displays the results of data collection over twelve months, from January to December 2024. The histogram illustrating the level of product defects is presented in Figure 4.

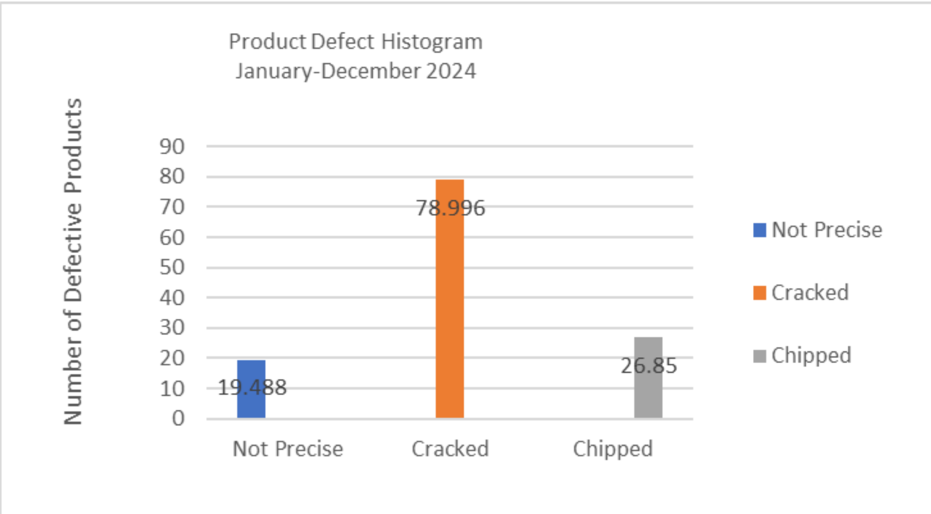


Figure 4. Product Defect Histogram

Referring to Figure 4, the product defect histogram that presents a diagram of product defects at PT. XYZ, three main types of product defects can be identified. Of the three, cracks had the highest frequency and dominated during the twelve-month observation period. The next type of defect was peeling, while the defect with the lowest number was imprecision.

Calculating the percentage of product defects for the twelve-month period from January to December 2024, the total percentage of product defects that occurred at PT. XYZ is as follows:

$$\frac{Number\ of\ Defective\ Products}{Production\ Quantity\ (units)}\ x\ 100 \ldots\ldots\ldots\ldots..(1)$$

$$\frac{478}{9980}\ x\ 100 = 4.789 = 4{,}79$$

$$\frac{477}{9980}\ x\ 100 = 4.779 = 4{,}78$$

$$\frac{246}{12600}\ x\ 100 = 1.952 = 1{,}95$$

$$\frac{247}{12600}\ x\ 100 = 1.960 = 1{,}96$$

$$\frac{427}{10076}\ x\ 100 = 4.237 = 4{,}24$$

$$\frac{425}{10076}\ x\ 100 = 4.217 = 4{,}21$$

$$\frac{429}{7560}\ x\ 100 = 5.674 = 5{,}67$$

$$\frac{431}{7560}\ x\ 100 = 5.701 = 5{,}70$$

$$\frac{196}{4791}\ x\ 100 = 4.091 = 4{,}09$$

$$\frac{198}{4791}\ x\ 100 = 4.132 = 4{,}13$$

The product defects found during the production process consisted of three main types that occurred most frequently. These defects appeared during the production process but could be identified so that defective products could be separated from saleable products. Thus, products that did not meet the standards did not reach consumers. Table 4 shows the number of each type of product defect in the period from January to December 2024. The next stage of analysis uses a Pareto chart, as shown in Figure 5.

Table 4. Number of Defective Product Types

No	**Type of product defect**	**Number of Defective Products**	**Percentage of Defective Products**	**Cumulative (units)**	**Cumulative (%)**
1.	Not Precise	19,488	16	19,488	16
2	Cracked	78,996	63	98,484	79

3.	Chipped	26,850	21	125,334	100
Total		125,334	100	125,334	100

The table above shows the number of product defects sorted from the highest to the lowest number of defects. Based on this data, a cumulative percentage is calculated to show the difference in frequency between the various types of dominant defects. Furthermore, based on the product defect frequency results, a Pareto chart was created to analyze the main factors causing defects in the production process. This chart also helps identify the root causes of product defects at PT XYZ.

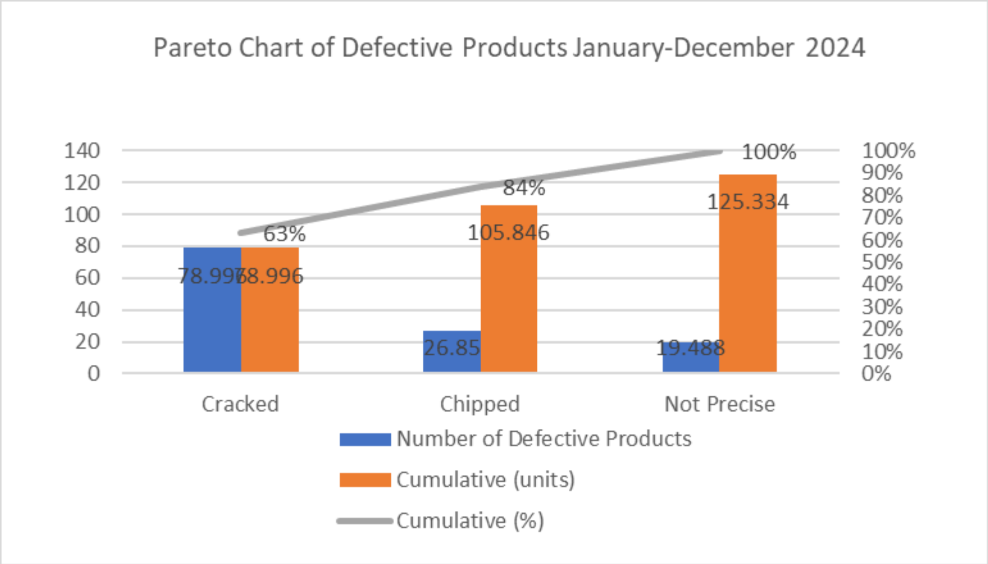


Figure 5. Product Defect Pareto Chart January-December 2024

Based on Figure 5, which shows the Pareto chart of defect types for the period January to December 2024, it can be seen that the defect type with the highest cumulative number is cracks, amounting to 78,996 units or 63% of the total defects that occurred. Meanwhile, the defect type with the lowest cumulative number is imprecision, with 19,488 units or 16%. The Pareto chart is used to identify and analyze the main problems that most influence the level of product defects. In addition, this diagram also serves to trace the factors causing problems in the production process, as has been done in this study on product defects at PT XYZ. After determining the order of defect types based on their dominance, the next step is to make improvements by tracing the causes of each type of defect using the Fault Tree Analysis method.

Based on observations of the production process at PT XYZ, it was found that of the various types of product defects that occurred, there were three main types of defects with the highest frequency, namely imprecision, cracks, and peeling. These three types of defects contribute significantly to the increase in the overall number of defective products, thus requiring special attention in efforts to improve production quality. To gain a deeper understanding of the causes of these defects, an analysis was conducted using the Fault Tree Analysis method. This method aims to trace and map the cause-and-effect relationships of each factor that has the potential to cause product defects. By compiling a fault tree for each type of defect, it is possible to identify the main factors and supporting factors that influence the occurrence of inaccuracy, cracks, and peeling. The results of this analysis are expected to form the basis for formulating systematic and continuous production process improvement measures to reduce product defect rates and improve production quality at PT XYZ. The fault tree analysis for inaccuracy is shown in Figure 6.

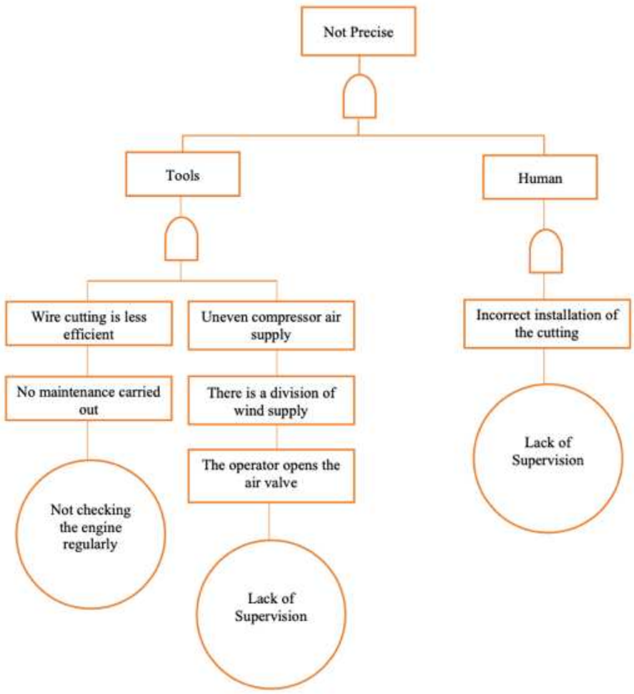


Figure 6. Fault Tree Analysis Not Precise

Based on the analysis results, the potential causes of product defects in the imprecision category are influenced by two main factors, namely equipment (tools) and human error.

Production failures can be caused by suboptimal cutting tool conditions. The cutting wire used in the cutting process experiences a decline in quality due to continuous use, causing the wire to become thinner and more prone to wear. Using wire that has exceeded its usage limit can cause the wire to break during the cutting process, resulting in product dimensional defects. Under ideal conditions, cutting wires must be of uniform thickness and free from damage so that the cutting process can run according to standards. In addition to equipment or tool factors, failure can also be caused by human error due to the operator's lack of precision in installing the cutting tool in the form of wire. In standard operating procedures (SOP), cutting tools must be installed in the correct position and size so that the dimensions of the lightweight brick product, including length, width, and height, remain precise after the cutting process. However, in practice, operators often find it difficult to determine the correct cutting size, especially when there are special requests from consumers for lightweight bricks that differ from the production standard. This condition increases the risk of cutting tool misalignment, which affects the precision of the product.

Therefore, periodic evaluation of the cutting tool condition and increased operator accuracy in carrying out the production process are necessary. Companies are advised to implement a routine maintenance schedule, replace worn cutting wires, and provide spare parts so that the production process is not disrupted. In addition, operator training related to the implementation of SOPs and the determination of cutting sizes also needs to be carried out to minimize human errors that impact product dimensional inaccuracies. Meanwhile, the fault tree analysis for crack production is shown in Figure 7.

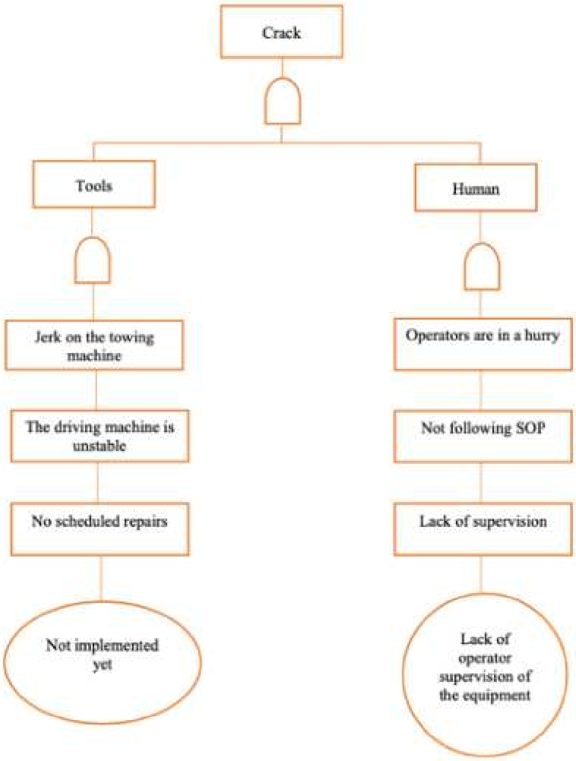


Figure 7. Fault Tree Analysis Cracked

Based on the analysis results, product defects in the form of cracks in lightweight bricks were identified as being caused by two main factors, namely equipment (tools) and human error. One of the tools that has the potential to cause product failure is the crank, which is a tool that functions to transport moldings containing bricks that are still in an imperfect condition to the cutting machine. The problem lies in the crank strap mount, where the movement path does not receive adequate lubrication. As a result, during the transport process, the molding experiences strong shocks or vibrations, causing cracks to form in the bricks.

In addition to equipment factors, defects can also be triggered by human error due to the negligence of operators who rush the process of unloading the moldings (molds). Unloading that is carried out too quickly can cause mechanical stress on bricks that have not completely hardened, making the material structure vulnerable and causing cracks on the surface of the product. In standard operating procedures (SOP), unmolding should be done slowly and carefully to ensure that the bricks are in a stable condition before being moved to the next stage.

To overcome this problem, corrective measures are needed in the form of routine evaluations of equipment performance, particularly the crank system, by ensuring that the movement path is always well lubricated. In addition, improving operator discipline in following the unloading procedure carefully needs to be done through training and stricter work supervision. The implementation of these measures is expected to minimize the occurrence of cracks and improve the quality of the lightweight bricks produced, while the fault tree analysis will be shown in Figure 8.

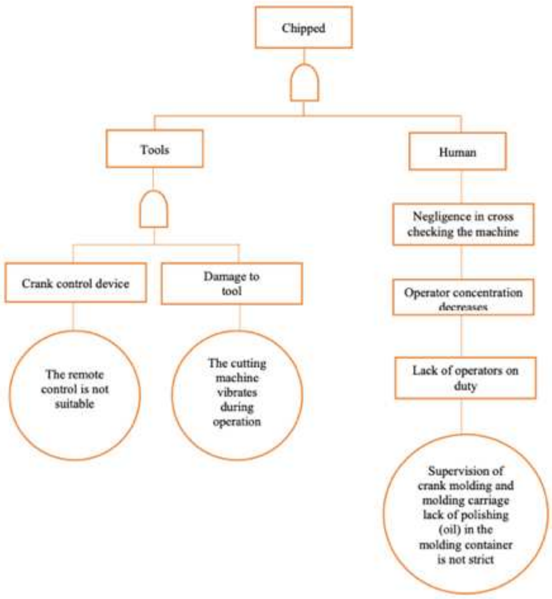


Figure 8. Fault Tree Analysis Chipped

Based on the analysis results, product defects in the form of chipping in lightweight bricks are caused by two main factors, namely equipment (tools) and human error.

From the equipment (tools) side, the main cause of chipping defects comes from the condition of cutting machine 1, which experiences excessive vibration when in use. The cutting machine functions to cut lightweight bricks horizontally, and the vibration is caused by a problem with the carriage puller in the cutting section, which causes jolts during the cutting process. Meanwhile, on cutting machine 2, which functions to cut bricks vertically, the position of the cutting wire is often imprecise because the installation process is still done manually.

The inaccuracy of the cutting wire position has the potential to cause the brick surface to peel off when the wire cuts from the top to the bottom of the brick and returns to its original position.

Overall, the cutting machine begins operating when the cutting carriage carrying the lightweight bricks is moved by the drive dynamo to cutting area 1 for horizontal cutting. Once this stage is complete, the drive dynamo moves the carriage to cutting machine 2 for vertical cutting. At this stage, the stability of the machine's movement and the accuracy of the cutting wire's position are crucial factors in maintaining the quality of the cutting results. Therefore, it is necessary to perform routine maintenance and calibration of the cutting machine and improve the operator's accuracy in operating the machine to prevent chipping defects in lightweight bricks.

Human error is generally caused by operator negligence in performing regular machine checks and maintenance. The checking procedure should include routine checks on the condition of the crank, lubrication of the molding carriage, and special maintenance of the carriage movement path to keep it functioning optimally. In addition, the molding as a container for printing lightweight bricks needs to be lubricated with oil so that the bricks do not stick when the container is opened for to be moved to the cutting stage. Negligence in lubrication can cause the surface of the bricks to stick to the mold, making them easy to peel off during the release process.

Another factor that contributes to peeling defects is an imperfect settling process. Lightweight bricks that have not fully expanded during the settling process will have a less dense and non-homogeneous structure, making their surface layer more fragile and prone to erosion when subjected to friction in the next stage.

Implementation of Evaluation

Improvement is a strategic plan designed by the company as a follow-up to the results of product defect analysis, with the aim of reducing the defect rate and improving the quality of the production process and the products produced. These improvement efforts cover aspects of human resources (employees) as well as production machinery and equipment that play a direct role in the operational process.

1. Machinery and Equipment Aspects

   In addition to human resources, improving the quality of the production process also requires attention to the condition of the machines and equipment used. The improvement measures that can be implemented include:

   a. Improving Machine Maintenance Quality

      Machine maintenance must be carried out systematically and well documented. Companies can create a maintenance log to monitor the most common types of damage and analyze their causes. This allows preventive measures to be taken early on to minimize production downtime and the risk of product defects. Figure 9 shows the evaluation of periodic checks and systematic machine maintenance.

Figure 9. Routine Checks and Maintenance

   b. Replacement of Unsuitable Machine Components.

      Machine components that are worn out or cannot be repaired should be replaced immediately with new components to maintain optimal machine performance. The use of damaged or unsuitable components has the potential to cause product defects ( ) that should be avoided. Figure 10 shows the replacement of unsuitable machine components.

Figure 10. Replacement of Engine Components

c. Standardization and Calibration of Production Engines
   In the event of damage or component replacement, the machine must be returned to its standard condition in accordance with the manufacturer's specifications. The use of non-original components or repair methods that do not comply with standards can reduce machine performance and cause inconsistent production results. Therefore, all maintenance or repair activities must follow the technical procedures established by the manufacturer. Figure 11 shows the routine calibration of production machines after replacing parts in the machine.

Figure 11. Production Machine Calibration

The quality of raw materials also has a significant potential in determining the final quality of the product, so Figure 12 shows (quality control) the selection of quality raw materials.

Figure 12. (Quality Control) Selection of Quality Raw Materials

2. Employee Aspects

   In order to improve employee performance and reduce the possibility of human error, companies need to implement the following improvement measures:

   a. Training and Competency Development
      Companies need to regularly organize training programs for operators, especially regarding the use of equipment and machinery used in the production process. For new employees, training must be supplemented with clear and standardized work instructions in order to minimize the risk of errors caused by a lack of understanding of operational procedures.
   b. Employee Performance Evaluation and Feedback
      Employee performance evaluations need to be conducted periodically to assess work effectiveness and identify obstacles encountered in the field. Through these evaluations, companies can also gather complaints and feedback from employees to create a more comfortable and productive work environment.
   c. Improving Discipline and Compliance with Rules
      Consistent work discipline needs to be enforced by monitoring employee compliance with company rules and regulations. Issuing warnings or sanctions for violations is expected to reduce non-value-added activities and minimize potential losses due to work negligence.
   d. Improvement of Supervisory Functions by Division Heads.
      Department heads play an important role in supervising employee performance, including ensuring that the quality of products meets standards, controlling the use of equipment and machinery, and documenting damage data that occurs in each division. This data can be used as a basis for updating equipment, materials, and work tools that are no longer suitable for use.

CONCLUSION

This study concludes that the defect rate of lightweight brick products at PT XYZ from January to December 2024 was dominated by cracks (63%), followed by peeling (21%), and imprecision (16%), with a total of 125,334 defective units. Through the application of Fault Tree Analysis (FTA), it was identified that the main source of defects came from a combination of human factors (human error) and machine/equipment factors (tools), which contributed to product quality inconsistencies—ranging from operator procedural errors and lack of precision to vibrating, worn, or poorly calibrated machines. Various field findings also indicate that a lack of work discipline, weak monitoring systems, and suboptimal machine maintenance and repair activities contribute to the risk of product defects. Therefore, improving product quality at PT XYZ requires a comprehensive strategy through training and strengthening operator discipline, increasing the effectiveness of supervision, and implementing a planned and sustainable machine maintenance system so that the defect rate can be reduced and production quality consistency can be achieved.

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