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Original Research Paper

FMEA-Based Risk Assessment in Filter Tank Production

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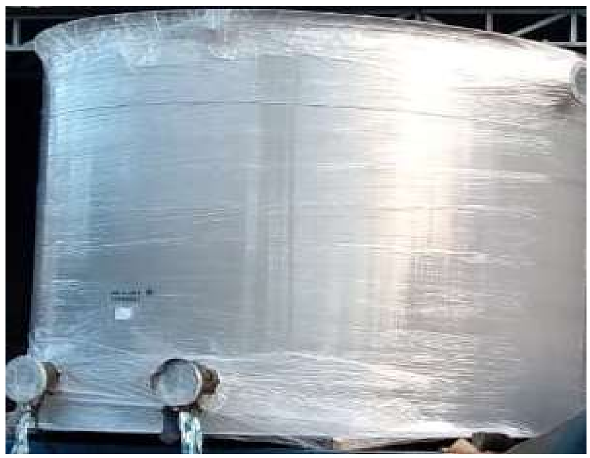
Abstract: Quality assurance is an action to maintain customer satisfaction. As a prominent fabrication producer, Firm A, which receives regular orders from corporate clients, has been challenged with maintaining quality consistency during the production process of filter tanks. This study aims to identify risks and evaluate failures that occur during the filter tank production process based on the Failure Mode and Effects Analysis method. The FMEA stage was started with a walkthrough survey to identify defects, followed by brainstorming sessions with two expert respondents to determine the severity, occurrence, and detection score. Subsequently, the Risk Potential Number score was calculated. Research findings distinguished three types of defects during production stages, namely welding, asymmetric, and painting. Based on risk quantification, it was found that the highest defect score, 392, was attributed to the painting failure category, characterized by excessively thick paint results. This finding was followed by the second-highest score of 336, and the third with value of 294 as failure of asymmetric joints. The practical implication in complementary of the FMEA finding showed that systematic training, audits, and briefings are suggested to address the issues that cause the highest number of failures on fabrication process.

Keywords: Defect Analysis, Fabrication Process, Failure Mode and Effects Analysis (FMEA), Filter Tank Production, Risk Assessment.

1. Introduction

Maintaining the characteristics of products and services demanded by customers is a fundamental element of a sustainable business [1]. It is crucial to maintain stability during the production process in order to produce a high-quality product or service. Empirical evidence shows that consumers are not only considering the price in deciding a procurement, but also highlighting quality [2].

Company A, a general contractor service company, has been established for eighteen years, evolving from small project work, such as welding, to a company that supplies products like filter tanks to various multinational companies across Indonesia. The Filter Tank, a key product of Company A, is a tank equipped with a filter instrument that processes liquid waste into clear water suitable for daily use in households, industries, and office buildings. The filter tank product can be seen in Figure 1.



Source: authors' documentation

Figure 1. Filter Tank

The quality assurance of Firm A ensures that once the finished product is placed in the warehouse, the quality control department performs an inspection to validate that the product meets specifications before distribution to customers. However, the finished product is yet out of specification, resulting in the quality control department requiring rework because the goods do not meet established standards. Repairing product defects has consequences and problems that can be described as follows.

The first identified problem during inspection was the frequent defects that caused production delays, preventing the product from being completed on time. These defects, including welding defects, symmetry defects, and painting failures, frequently cause component defects. Despite systematic concerns with the same product and the implementation of new approaches to eliminate the cause, quality audits consistently discover the same errors. The impact of reworking these defective products leads to delays in the contractually stated product completion and contributes to rework costs. Additionally, the firm incurs losses if the defective product cannot be repaired, resulting in the reproduction of new components, which significantly impacts the company's operations and financial issues.

A comprehensive approach used to control process failure risk is the Failure Mode and Effects Analysis (FMEA) approach [7]. This practical approach integrates qualitative and quantitative methods. It begins by identifying process failures, then measures the risks, and designs solution scenarios based on the risk measurements in a production process. FMEA implementation is also flexible when combined with quantitative theories, such as maintenance management theory and statistical-based quality management theory [19] [20]. FMEA is a complementary theory at the Analyze stage of a series of Define, Measure, Analyze, Improve, and Control (DMAIC) stages, also known as the Six Sigma cycle [20]. Moreover, the FMEA method is used to evaluate failures that occur in a system and is a structured procedure to identify and prevent failure modes, and can be used to specify root causes of quality cases [12]. FMEA is used to identify the sources and root causes of a quality problem. Empirical evidence shows that the FMEA approach is practical in analyzing functional or component failures in manufacturing and service companies [3] [16] [21]. Although the implementation of FMEA has been empirically proven and validated through various case studies, the use of FMEA remains relevant in addressing white spots in terms of object fabrication and construction-based projects.

This research aims to evaluate the risk in the filter tank production process using the Failure Mode and Effects Analysis method. The first objective of this study is to identify the types of defects, the causes of defects, and the consequences of their occurrence. The second objective is to quantify risk based on the potential number score and design improvement scenarios to mitigate risk during the filter tank's production process.

2. Literature Review

Quality can vary because consumer expectations continuously transform. Every time a new standard is found, consumers will require a better standard [3]. The production process is an activity that involves humans, materials, and equipment to produce valuable products [4] [5]**.** A product that does not meet quality standards can be economically refined into a non-functional product, resulting in spending on rework costs to fix it [6]. Meanwhile, a defective product is a product produced in the production process, where the resulting product does not comply with the quality standards [7].

Failure in the production process is a risk that occurs in both manufacturing and service companies. Empirical evidence shows that risk factors are categorized not only in the financial sector, but also in operational, environmental, and even supply chain categories [8] **-** [13]. Research by [13] [14] indicates that financial risk is primarily attributed to internal company factors. Meanwhile, researchers [15] state that operational risk can be mitigated to improve the business. In addition, scientific approaches to failure management generally use approaches such as Fault Tree Analysis (FTA), Ishikawa Diagrams, Multicriteria Analysis, and quantitative-based approaches to statistical process control, which have proven effective in analyzing the causes and impacts of process and product failures [10] [16] [17] [18].

Failure Mode and Effect Analysis (FMEA) approach is an engineering technique used to determine, identify, and eliminate failures, problems, and errors from a system before it reaches the customer [7]. FMEA is a tool used to analyze the reliability of a system and its causes of failure to meet the reliability and safety requirements of the system, design, and process by providing basic information regarding the prediction of system reliability [22]. Companies can achieve their goals by utilizing FMEA, which involves identifying failure modes and their severity, pinpointing critical and significant characteristics, sorting potential design and process deficiencies, and helping engineers focus on reducing attention to products and processes to prevent problems [23]. FMEA is a structured procedure to identify and prevent as many failure modes as possible. FMEA is used to identify the sources and root causes of a problem, as well as to develop analytical techniques [19]. The purpose of the FMEA approach analysis is to determine the precise causalities of equipment, supplies, processes, and raw materials used and to determine preventive measures to prevent recurrence [24].

The stages that must be carried out in the FMEA method are as follows [11] [12] [16] [17] [18] [22]. First, observe the process, and then identify potential failure modes of the observed process. The third stage involves assessing the potential effects of the failure mode and determining the severity, which evaluates the seriousness of the failure mode. The fourth stage involves identifying the potential causes of the failure mode in the ongoing process, which indicates the frequency of a problem that occurs due to a potential cause. The next stage involves identifying the current process control to prevent the possibility of causing the failure mode, and then specifying detection to prevent the occurrence of the failure mode. Finally, determining the risk priority number, which indicates the seriousness of the potential failure, helps prioritize scenario improvements.

3. Methodology

The This research employs a mixed-method approach, starting with a qualitative cycle to identify the failure of the production process, followed by a quantitative stage. In this stage, the potential effect of failure, the potential causes, and current detection methods were quantified to determine the risk priority number value. Furthermore, data were obtained through direct observations conducted over six months in Firm A's workshop. Furthermore, the technique for identifying the impact of failure and quantifying the risk potential value was obtained through brainstorming with the Owner, who has 20 years of work experience. Meanwhile, quantifying severity, occurrence, and detection was conducted with two participants, including the Supervisor and Owner of Firm A.

The FMEA implementation stages began with observing the shop floor and the filter tank production to understand the stages of the production process, followed by identifying potential failures and their potential effects. The next stage was determining the severity value (S), which was an assessment of how profound the effect of the failure mode was, and identifying the potential cause of the failure mode in the ongoing process, followed by determining the accuracy value (O), and the frequency value of a problem that occurs due to a potential cause. The next stage involved identifying the operation control and determining the detection value (D) to measure the control process's capability. The next stage was calculating the Risk Priority Number (RPN) using the Formula [7]:

$$RPN = S \times O \times D \tag{1}$$

Where,
RPN = Risk Priority Number
S = Severity
O = Occurrence
D = Detection

The severity score represented the event's impact on the output of the impact process, ranked on a scale of 1 to 10. A scale of 1 indicates the lowest score, and a scale of 10 indicates the highest. The scale is based on an ordinal qualitative scale. The degree of severity from 1 to 10 for each scale can be seen in Table 1[15].

Table 1. Severity Rating Scale

Consequence	Scale	Criteria
Not significant	1	No effect on quality
Extremely slight consequence	2	The quality of the appearances of resources is not interrupted
Minimal significance	3	The influence is slight on the value of items.
The concerns are insignificant	4	The feature of raw materials is marginally interrupted.
Moderately substantial	5	Malfunction occasioned by dissatisfaction with the value of raw materials.
Somewhat substantial	6	Failure results in discomfort
The significance is enormous	7	The characteristics of raw materials are not adequate
Excessive consequence	8	The quality of raw materials is exceedingly inadequate
Severe, significantly consequential	9	Possibly cause opposing outcomes in the production process
Extremely at risk	10	The effect of failure in the quality of raw materials results in an imperfect production process.

Source: [15]

Occurrence is the probability of a failure during the production process. Occurrence scale using an Ordinal qualitative scale from 1 to 10. In addition, one scale indicates the lowest whilst 10 indicates the highest score. The occurrence scale can be seen in Table 2 [25].

Table 2. Occurrence Rating Scale

Consequence	Scale	Criteria
Never	1	The record demonstrates no losses
Infrequently,	2	The probability of loss is irregular
Minimal	3	The possibilities of negligence exist in the tiniest
Relatively small	4	Some likely losses
intermediate	5	The potential of loss exists
moderate	6	The likelihood of loss stands medium
Increased adequately	7	The likelihood of loss is particularly increased
Elevated	8	Elevated number of losses
Enormously increased	9	A significantly increased number of potential losses.
Inevitable	10	Loss is practically unavoidable

Source: [25]

Detection is a measurement of control performance that can detect failures in a process. Information regarding the detection assessment scale is presented in Table 3 [26].

Table 3. Detection Rating Scale

Consequence	Scale	Criteria
Practically unquestionable	1	The control must notice
Significantly elevated	2	The control practically clearly notices
Elevated	3	Control includes an increased possibility of detecting
Increased sufficiently	4	Controls may notice increased adequacy
moderate	5	The control may detect moderate
Low	6	Control may detect a subordinate
Small	7	Controls include a minimal possibility of detecting
The smallest	8	Controls have a minimal chance of detecting
Infrequently	9	Control may not notice
Unattainable	10	The control did not notice

Source: [26]

4. Finding and Discussion

4.1. Finding

Historical data from the production and quality department at Company A revealed three types of defects caused by failures during the welding process, the joint process, and the painting process. An image of a product defect caused by welding failure can be seen in Figure 2.

Figure 2. Defect due to Welding Failure

It can be seen from Figure 2 that welding failure occurs during the process of joining two metals. This welding error results in an uneven metal joint and is classified as an out-of-spec product.

Visualization of Symmetrical failure shows in Figure 3. It can be seen in Figure 3, Symmetrical defects occur when one metal is joined to a second metal, but the two metals are not perfectly aligned. The last defect related to Painting failure can be seen in Figure 4.

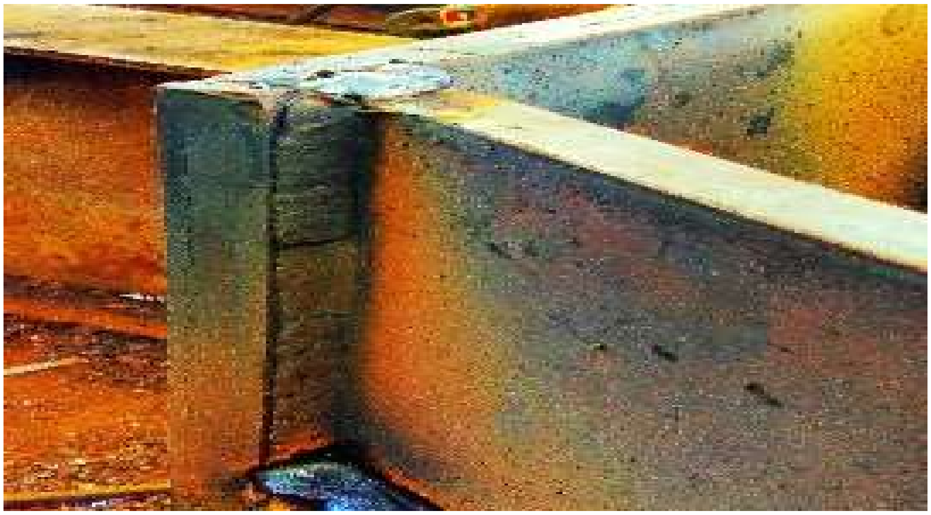


Figure 3. Symmetrical failure

Painting defects depicted in Figure 4 and visualized as characterized by uneven surface shapes, such as orange peel, were caused by rough granules that were not fully atomized. The paint granules dried before the layer was even. This defect was also known as poor flow, poor leveling, and pebbling.

Figure 4. Painting

The results of failure identification and quantification of RPN values can be seen in Table 4. It can be seen from Table 4. There was a failure in the painting process. The out-of-spec painting was caused by several factors, as follows. First, the painting failure occurred because the paint layer was too thick, and the thinner used was not suitable. Second, the second priority was that the welding error layer was too thick; the plate used was not suitable for the connection due to its excessive thickness. Third, the Physical shape error was symmetrical due to the lack of tools to place the plates, resulting in the first plate being asymmetrical with the second connecting plate.

Table 4. Failure Mode and Effect Analysis Result

Process	Potential Failure Mode(s)	Potential Effect(s) of Failure	Severity	Potential Cause(s)	Occurrence	Current Design Controls	Detection	R P N	Recommended Action(s)	Responsibility	Action Taken
What is the procedure for examination?	In what procedures could the stage be shifted?	What is the consequence for the buyer if this loss is not fixed?		The casualties emerge?		What controls are in place to detect the loss?			What are the advised activities for enhancing detection?	Who is responsible for completing the measures?	What efforts were completed, and when did they affect the RPN?
Welding: Failure when carrying out the metal joining process, exceeding natural mechanics, such as tensile strength, hardness, and toughness compared to the parent metal.		Missing a crucial time in joining two sheets	4	Worker negligence	4	visual inspection	7	112	Regular supervision	QC supervisor	Create new SOPs
		Coating of welding too thick The plate used is wrong	7	Fundamental knowledge of welding skills	8	visual inspection	6	336	Upgrade knowledge about welding techniques.	Welding trainer	update welding skills periodically
		Air pressure is too Elevated.	3	Lack of communication	4	visual inspection	9	108	Prechecking SOP	Operator	Perform regular maintenance
		Temperature level is too low	5	Blender unclean	4	visual inspection	6	120	Recheck regularly	Welding operator	Regular maintenance
Physical form unsymmetrical: Failure during the merging process between one plate and another plate to form the proper shape		Unmatched spare parts	6	Lack of a tool	7	visual inspection	7	294	Maintain the availability of spare parts	Management	Regular audit
		Measurement The plate does not match	5	The lack of measuring tool	5	visual inspection	7	175	Give An appropriate measuring tool	Management	Audit workshop daily
		negligence worker	6	Insufficient workers	5	visual inspection	8	240	Given input	QC supervisor	Carry out short briefing daily
		Unavailability of a spare part	5	Worker underperforms	6	visual inspection	7	210	Should use	Operator	Provide SOP about use facility
Painting: Error while Painting cannot cover the product completely		Flash time off less between layers to	6	Worker negligence	7	visual inspection	7	294	More often Pay attention to the spray tool	Operator	Fill in the logbook daily.
		paint layer too thick	7	The worker's capability is inadequate.	7	visual inspection	8	392	Given supervision regularly	Painting trainer	Update the painting operator periodically.
		Tire pressure was too low.	5	Not enough inspection	6	Visual inspection	6	180	Precautions during the preparation stage	Operator	Regular technical training
		The temperature level begins too low.	5	Worker negligence	6	visual inspection	8	240	Check the temperature level before use	Operator	Technical training of painting regularly

Based on the FMEA quantification results in Table 4, it can also be seen that the highest RPN score from welding error was 336. In addition, the highest RPN value based on asymmetrical failure was marked with a 294 score. The painting process experienced a failure with the highest RPN score of 392. The proposed improvement to improve failure can be described in Table 5.

Table 5. Proposed Improvement Based on the Highest Risk Potential Number

Proposed Improvements	
Welding (RPN score = 336)	It is best to adjust the welding layer to the plate used, so that it is suitable. It is recommended to avoid unwanted defects to ensure a more focused welding process.
Physical Form is asymmetrical. (RPN score = 294)	It is better for the two plates to fit and to avoid misplaced plates. The improvements can be done by providing additional plates or welding assistance on both plates before welding or locking. If the procedure is correct, join the two plates to prevent an asymmetrical shape.
Painting (RPN score = 392)	For painting, the thickness and thinness should be adjusted according to the needs and type of plate used. The thinner used should be selected based on the specific needs, rather than relying on a single type of thinner. The oven temperature level used should be suitable.

The proposed improvements stated in Table 5 can potentially reduce the severity and occurrence of defects during the Filter Tank production process.

4.2. Discussion

In Empirical evidence indicates that enhancing human resource competency leads to improved performance in industrial workplaces, which can be adopted to address the skills gap faced by Company A's employees [27]. For instance, the effectiveness of briefings in the construction sector confirms that regular briefings can strengthen employee understanding of work responsibilities and procedures, improve cross-team coordination, and encourage active participation in operational discussions [28]. The second improvement for workers to upgrade their competency can be achieved through a training program, specifically, a competency-based training program [29]. Empirical evidence shows that the training demonstrates increased machine efficiency and quality, while also demonstrating the positive impact on operator competency improvement on overall production line performance [27].

To improve painting competency, Management of Firm A can adopt an empirical case study focusing on painting techniques in automotive manufacturing[30]. Moreover, this study employs an intensive practical program that integrates in-depth theory with hands-on practice for engineering students, aiming to bridge the gap between the foundational knowledge taught in school and the specific skills required by the automotive industry [30]. This method can be adopted by firm A to increase workers' competency in painting technique, including theory that provides a basic understanding of the painting process from technology, material characteristics, quality standards, and equipment principles, as well as practical sessions with direct practice of proper paint mixing, spray gun parameter settings, and mastering various spraying techniques. The implementation of the Project-Based Learning model, particularly in the Metal Welding Technology course, has proven highly effective in transforming conventional learning into student-centered learning through real-world projects based on industry [29]. This approach not only enhances the students' understanding of welding but also fosters their problem-solving skills and creativity. Management of Firm A can adopt this project-based learning program, which can lead to an upgrade in knowledge of welding, encompassing not only material analysis and technological application but also fundamental engineering principles of design and fabrication.

Additionally, fabrication activities such as welding and the painting process have significant safety implications and can lead to accidents. Management of Firm A may adopt the Job Hazard Analysis (JHA) method. This systematic approach has the potential to significantly mitigate accidents that impact the blasting and painting processes in the steel fabrication industry [31]. The JSA approach can identify potential hazards by documenting the types of mechanical, chemical, physical, and ergonomic risks in each work stage, from the preparation process, core processes, and housekeeping. Empirical evidence on six aspects of improving employee competency, ranging from structured briefings, competency-based training, integrative learning, systematic hazard analysis, to the systematic and measurable implementation of SOPs, is expected to improve employee skills in the manufacturing environment. These activities directly target the improvement of technical competencies, such as machine handling, welding, painting, and understanding. Each aspect plays a crucial role in enhancing employee competency. Structured briefings improve understanding of work responsibilities, competency-based training enhances specific skills, integrative learning bridges the gap between theory and practice, systematic hazard analysis ensures workplace safety, and the implementation of SOPs increases efficiency and customer satisfaction.

5. Conclusion

This study presents a comprehensive approach to assessing failure and strategy improvements on the production process of filter tanks. Four conclusions can be explained as follows. The first conclusion identifies three defect components due to failure in the welding process: a physical form defect, defects in the process, and defects in the painting process. The second conclusion is that the highest RPN score is 392, related to painting defects. The second-highest score was 336, for welding defects. The third highest score is 294, for physical form defects that are asymmetrical. The third finding concluded that the cause of defects is related to human capability. Specifically, welders have minimal knowledge of welding techniques, leading to physical form defects due to inadequate tools for plate placement. Additionally, painting defects result from workers' inadequate knowledge of painting techniques. The fourth finding related to proposed improvements for Enterprise A includes addressing physical shape and Painting Defects.

A future research agenda can be developed based on three key areas as follows. First, expand empirical scope through multi-site studies of diverse companies to validate findings. Second, implement a longitudinal study over three to five years to assess the impacts of policy on preventive maintenance costs, downtime, and asset lifetime value. Third, use a mixed-methods approach, including qualitative studies like interviews, to explore employee psychosocial factors and learning capacity. Finally, establish a product comparison framework through controlled experiments to identify maintenance-sensitive variables. This research will enhance academic rigor and provide a practical roadmap for optimizing operational strategies in the fabrication service industrial sector.

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