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Systematic Diagnosis of Quality Defects in Concrete Electricity Poles Through The New Seven Tools

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ABSTRACT

This study investigates the root causes of quality defects in concrete electrical poles produced by PT. LMN using the New Seven Tools (NST) approach. The research employs a qualitative–descriptive case study to systematically identify, categorize, and analyze defect patterns arising from human, machine, method, material, and environmental factors. Data were obtained through field observation, interviews, and documentation, then processed using the NST framework comprising Affinity Diagram, Interrelationship Diagram, Tree Diagram, Matrix Diagram, Activity Network Diagram, and Process Decision Program Chart (PDPC). The findings indicate that lack of routine supervision and insufficient machine maintenance are the dominant causal factors driving product defects, with the Man and Machine categories scoring the highest in the Matrix analysis 18 and 17. Corrective actions prioritized include implementing regular inspection schedules, preventive maintenance programs, and environmental standardization to improve workflow efficiency and reduce defect rates. Furthermore, the Activity Network analysis identifies the evaporation process as the critical path contributing to extended production time, while PDPC results underscore the importance of balancing technical feasibility with cost-effective corrective strategies. The study concludes that the integration of human resource development, process standardization, and preventive maintenance can significantly enhance product reliability and align production performance with zero-defect manufacturing principles. This research provides both theoretical and practical contributions by validating the applicability of the New Seven Tools method for comprehensive quality improvement in the Indonesian manufacturing sector.

Keywords: New Seven Tools, Product Defects, Electrical Concrete Pole, Quality Control, Analysis.

INTRODUCTION

Infrastructure development serves as a primary driver of economic growth and social advancement in Indonesia. A reliable electricity distribution system plays a vital role in supporting industrial activities and improving public welfare. Among its key components, concrete electricity poles are essential for sustaining transmission networks across various regions [1]. These poles must possess high mechanical strength and durability to withstand environmental and operational loads. PT. LMN, as one of the national producers of concrete electricity poles, plays a strategic role in fulfilling Indonesia's infrastructure needs [2], [3].

In the manufacturing of concrete electricity poles, quality control is a critical factor because even minor defects can significantly reduce product reliability and operational safety. Defects such as cracks, porosity, and fractures not only compromise product performance but also lead to rework costs, material waste, and delivery delays. Based on company data, three dominant defect types have been identified: rupture (53 cases), porous/hollow (52 cases), and broken (31 cases). The high frequency of these defects indicates systemic weaknesses in production supervision and equipment maintenance, requiring a comprehensive root-cause analysis.

The urgency of this research lies in the need to systematically and comprehensively identify the root causes of frequent product defects. The company's current quality control system remains focused on end-product inspection rather than analyzing cause-and-effect relationships within the production stages. Consequently, recurring problems—such as inconsistent supervision, unstable raw material quality, and insufficient machine maintenance—remain unresolved. These issues contribute to productivity losses, material waste, and increased operational costs.

Previous studies in the concrete industry have primarily emphasized quantitative analyses using statistical methods, while qualitative interactions among factors such as man, machine, method, material, and environment have not been explored in depth. Similar conditions are observed at PT. LMN, where the interplay among these factors generates chain effects leading to increased defect rates. The absence of a comprehensive qualitative analytical framework hinders the company's ability to determine the most effective and prioritized corrective actions.

To address this issue, the study adopts the New Seven Tools approach—an advanced qualitative analytical framework designed to identify, categorize, and analyze quality problems systematically [4], [5]. Unlike the classical *Seven Quality Tools*, which focus on quantitative data such as histograms and control charts, this approach emphasizes logical and causal analysis through diagrams such as the Affinity Diagram, Interrelationship Diagram, Tree Diagram, Matrix Diagram, Activity Network Diagram, and Process Decision Program Chart (PDPC). This method enables a holistic understanding of the interrelationships among causal factors and supports the formulation of realistic and effective corrective actions [6], [7].

The primary objective of this study is to analyze the types and causes of defects in concrete electricity poles produced using the New Seven Tools method. Specifically, the research aims to identify the most frequent defect patterns based on production data, classify the root causes of these defects according to the categories of man, machine, method, material, and environment, analyze the interrelationships among the major causal factors, and propose effective corrective measures to minimize product defects. Through this structured approach, the study seeks to provide a comprehensive understanding of defect origins and formulate practical strategies for improving product quality and production efficiency. Strategic recommendations such as implementing regular inspections, equipment checks, and a preventive maintenance program to reduce defect rates. Academically, the research contributes to expanding the application of the New Seven Tools approach within Indonesia's manufacturing industry as a comprehensive, applicable, and sustainable quality analysis model.

METHOD

This research applies a qualitative–descriptive case study design focusing on the analysis of defect patterns in concrete electrical poles. The New Seven Tools (NST) approach is selected for its ability to combine qualitative logic mapping and limited quantitative scoring to diagnose complex production problems.

The study aims to [8], [9]:

1. Identify the dominant types of defects in concrete poles.
2. Analyze root causes across Man, Machine, Method, Material, and Environment dimensions.
3. Formulate corrective and preventive actions through NST instruments.

This research design emphasizes systematic exploration, visual-based analysis, and practical improvement recommendation, aligning with ISO 9001:2015 quality assurance standards.

Research Workflow

The methodological flow of this study follows seven systematic stages [10], [11], [12], [13]:

Stage 1: Problem Identification
→ Observation of production and defect data collection.
Stage 2: Data Collection and Categorization
→ Classification of defects (rupture, porous/hollow, broken) and their occurrence frequency.
Stage 3: Data Grouping (Affinity Diagram)
→ Grouping of problems based on similarity and causal connection.
Stage 4: Cause–Effect Mapping (Interrelationship & Tree Diagrams)
→ Determining primary vs secondary causes.
Stage 5: Quantitative Assessment (Matrix & Matrix Data Analysis)
→ Prioritizing causes using scoring on impact, frequency, and feasibility.
Stage 6: Process and Feasibility Analysis (Activity Network & PDPC)
→ Identifying missing inspections, critical paths, and feasibility of corrective actions.
Stage 7: Validation and Recommendation Formulation
→ Triangulation through discussion with supervisors and QC division; preparation of improvement roadmap.

Table 1. Data Collection Techniques

Technique	Purpose	Instrument
Observation	Identify actual production conditions and types of defects	Field checklist, defect log sheet
Interview	Explore causes and operator behaviors	Semi-structured interview guide
Documentation	Obtain supporting quantitative defect data	Production and inspection records
Triangulation	Ensure validity and reliability	Cross-validation of the three sources

Table2. Analytical Procedure Using New Seven Tools

NST Tool	Purpose	Analysis Output
Affinity Diagram	Group related problems	Categorization of causes under 5M
Interrelationship Diagram	Determine causal dominance	Identification of “trigger” vs “effect” problems

Tree Diagram	Develop hierarchical improvement goals	Structured root cause–solution map
Matrix Diagram	Relate problem categories	Ranking of problem significance
Matrix Data Analysis	Prioritize corrective actions	Quantified scores and improvement ranking
Activity Network Diagram	Visualize workflow and process gaps	Identification of non-inspection stages
PDPC (Process Decision Program Chart)	Assess feasibility of improvement options	Risk-adjusted and feasible improvement plan

Expected Output

1. Development of a defect–cause matrix model for concrete pole production.
2. Establishment of a preventive maintenance and inspection schedule validated through PDPC analysis.
3. Proposal of a standardized supervision mechanism as part of continuous improvement.

The research methodology employed is a qualitative approach , focusing on the analysis of

RESULTS

Affinity Diagram

The identification process revealed nine major issues that often cause rupture defects in the construction process, particularly those related to concrete materials. These issues include aspects of management, material quality, production processes, and working conditions.

Table 3. List of Problems with Rupture Defect Types

Number	List of problems
1	Supervisors do not carry out regular inspections according to the standard, especially when filling the dough which must follow the standard (volume of concrete and technique of filling dough into the mold).
2	Raw materials received, especially cement and chemicals, are of a quality below the set standards
3	Mixing time of concrete mixture is less than 5 minutes.
4	Concrete lifted by hoist crane unbalanced or piled up
5	Workers are in unergonomic and incompetent positions
6	Minor machine failures are often ignored and maintenance is not carried out.
7	The work environment is noisy due to the constant noise of machine operations and heavy equipment
8	The work environment is muddy due to spills/puddles of water, concrete mix, or other liquids
9	The work environment has many tools and items that are placed carelessly and out of place.

The first problem concerns inspections and supervision by supervisors that do not comply with standards, particularly in terms of filling concrete mix into molds. This non-compliance has a direct impact on the quality of casting, thereby increasing the risk of defects. In addition, the quality of raw materials, especially cement and chemicals, which do not meet standards, further exacerbates the situation, as shown in the second problem.

Furthermore, the concrete mixing process, which takes less than the recommended time (< 5 minutes), prevents the concrete from achieving optimal homogeneity. Problems related to the lifting of concrete using an unbalanced hoist crane also cause defects in concrete products. In terms of labor, non-ergonomic work positions and a lack of operator expertise contribute to work errors and reduce the final result.

Machine problems that often experience minor disturbances and lack of maintenance have an impact on consistent production results. A noisy work environment and the presence of heavy equipment further increase the risk of work accidents and reduce operator focus. In addition, muddy working conditions due to spilled water or concrete mixture and the haphazard placement of tools increase the potential for danger and reduce work efficiency.

In general, the analysis results emphasize the importance of consistently implementing standard operating procedures, strict supervision, selection of quality materials, and a safe and ergonomic work environment to minimize the occurrence of rupture defects in the final product.

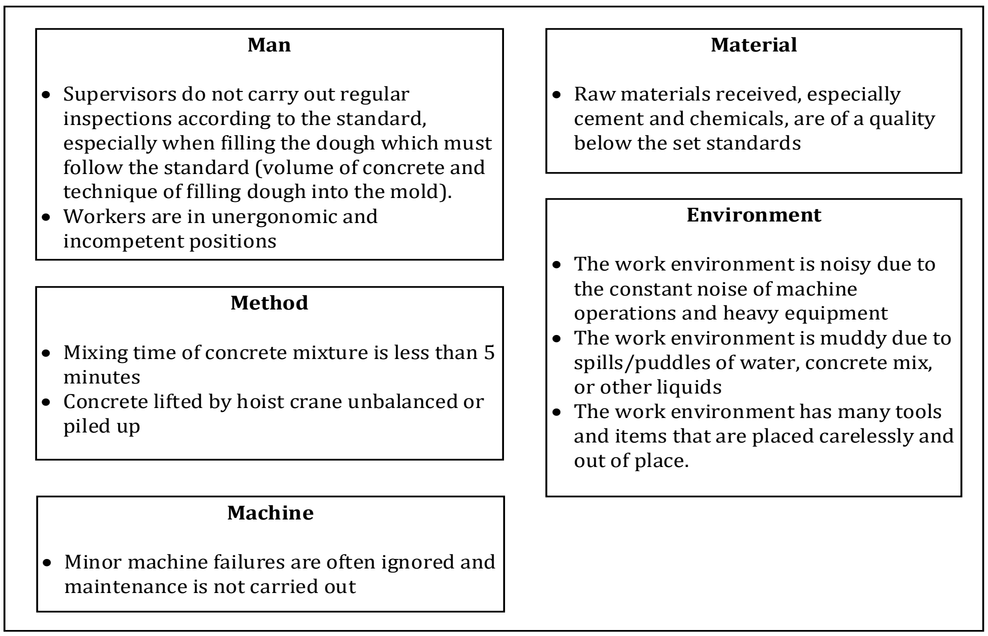

Figure 1. Affinity Diagram for Fracture Categories

Types of Defects: Pores/Voids Category

Problems that contribute to the occurrence of pores/voids in concrete materials, particularly in the category of air holes (pores/voids) in the final product. It has been identified that there are eight main problems that arise in the concrete production process, ranging from the quality of raw materials to the imbalance of the dosage of materials used.

Table 4. List of Problems Types of Defects: Pores/Voids Category

Number	List of problems
1	Raw materials received, especially cement and chemicals, have a quality below the standard set.
2	Employees did not carefully check the installation of materials (PC Wayer, Spiral and concrete mixture filling)

3	Supervisors do not conduct periodic inspections according to the standard, especially at the time of filling the mixture which must follow the standard (volume of concrete and technique of filling the mixture into the mold).
4	Spinning machine is not up to standard, or below 15 minutes.
5	The work environment has many tools and items that are placed carelessly and out of place.
6	Lack of cleaning molds or concrete molds which causes the rest of the dough to stick and fuse with the mold.
7	Lack of filling of concrete materials because it is not compacted evenly using a vibrator
8	Unbalanced material dosing such as the use of too much water or the use of too little dry ingredients

Based on the identification results, the majority of problems stem from human and process aspects, such as workers' lack of thoroughness in inspecting material installations, lack of supervision from supervisors during the filling process, and suboptimal use of tools. Other problems such as an irregular work environment and a lack of mold cleanliness also play a major role in increasing the risk of pores forming in concrete products. In addition, material quality that does not meet standards, both in terms of raw materials and material mixing, contributes to the occurrence of pore defects.

Furthermore, improper concrete compaction techniques, such as the suboptimal use of vibrators and an imbalance in material composition, exacerbate the problem of voids in concrete. These findings emphasize the importance of strict supervision, adequate worker training, and the consistent application of operational standards to minimize defects in the concrete produced.

Therefore, improvements in quality management, periodic inspections, and the application of the 5R principle (Ringkas, Rapi, Resik, Rawat, Rajin) in the work area are the main recommendations to reduce the possibility of pore/void defects in concrete.

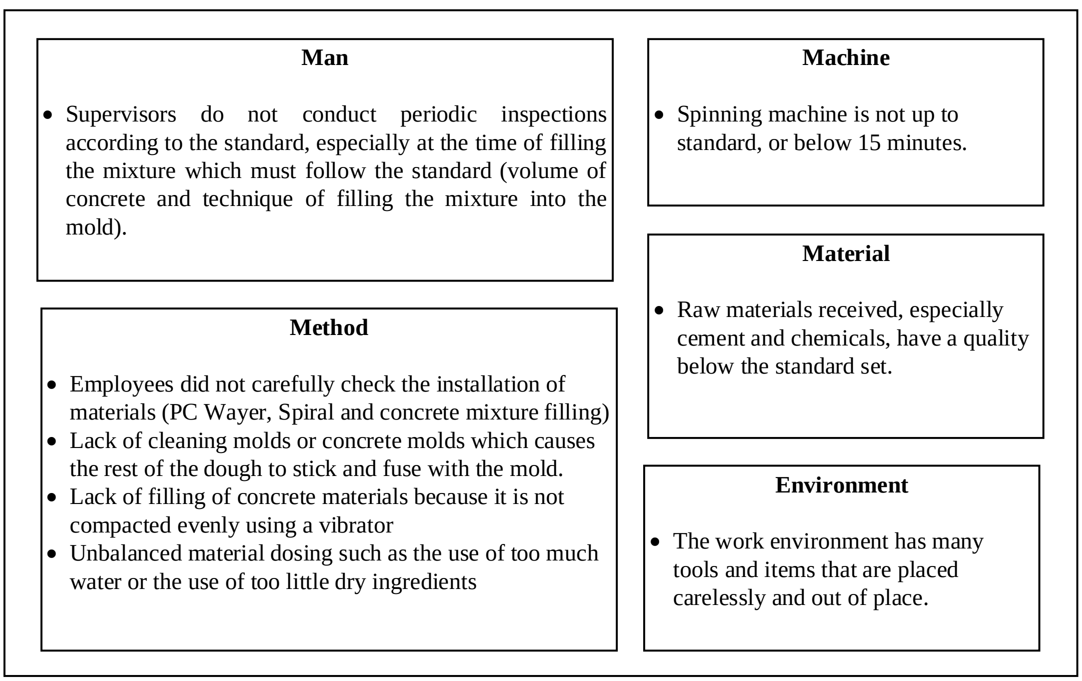

Figure 2. Affinity Diagram for Defects: Pores/Voids Category

Interrelationship Diagram

The analysis of the relationship between factors causing product defects in concrete electric poles was conducted using the Interrelationship Diagram (ID) approach. This approach was used to identify the logical relationship between potential causes and determine the main root causes contributing to the emergence of product defects. The diagram was compiled based on field observations, interviews with operators and production supervisors, and quality inspection data during the research period.

The ID method was chosen for its ability to visually explain complex cause-and-effect interactions, thereby highlighting the dominant causal elements that should be prioritized for improvement. Each element in the diagram represents a factor that affects product quality, ranging from raw materials and production processes to working conditions. The direction of the arrows indicates the cause-and-effect relationship between factors, while the input and output values in each box are used to measure the level of influence (driving factor) and impact (dependent factor) of each element.

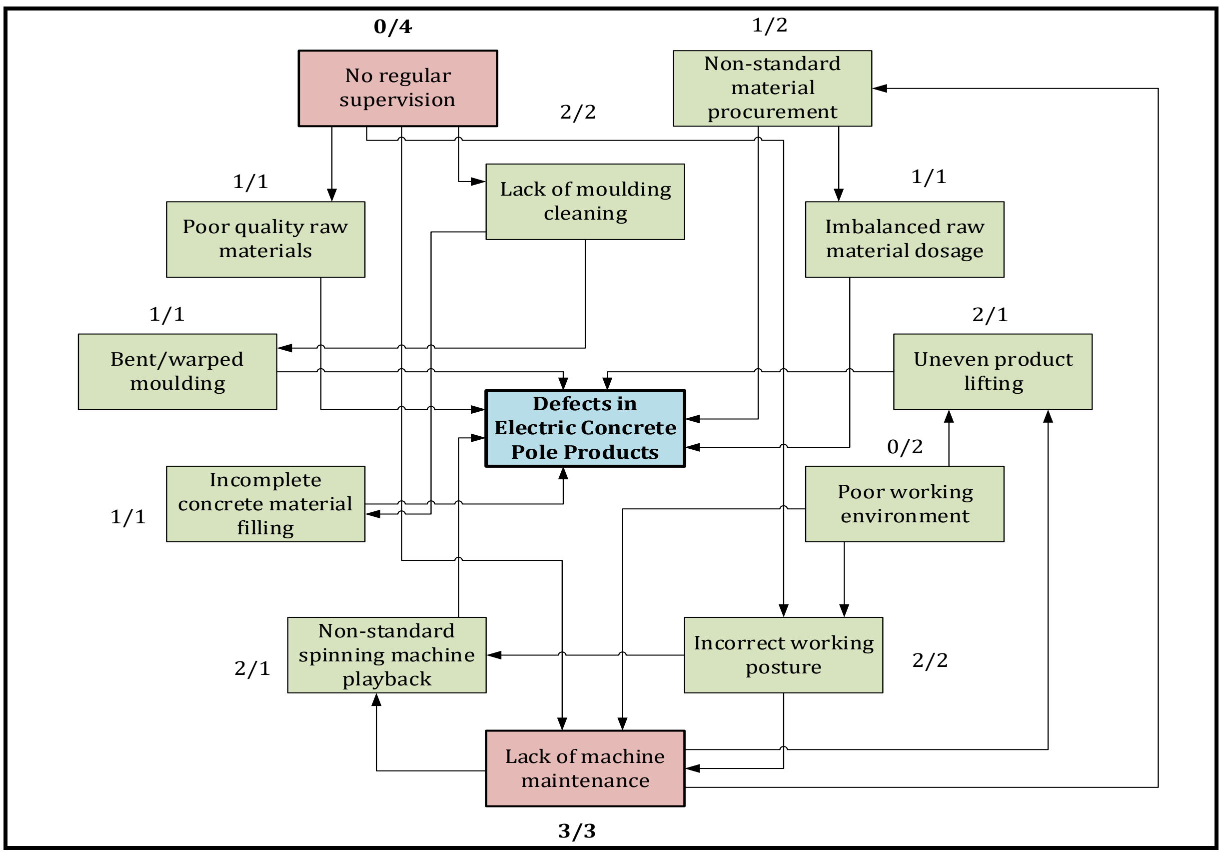

Figure 3. Interrelationship Diagram

As illustrated in Figure 4, the factor Lack of machine maintenance exhibits the highest driving value (3/3), indicating that inadequate machine maintenance is the primary root cause of defects in electric concrete pole products. Poorly maintained equipment leads to uneven mould spinning and incomplete concrete filling, which result in defects such as cracks, voids, and irregular product shapes.

Moreover, the factor No regular supervision (0/4) demonstrates a strong impact as it increases operator errors and weakens the enforcement of operational standards. Insufficient supervision also contributes to procedural inconsistencies in raw material mixing and mould cleaning, which subsequently degrade overall product quality.

The factors Imbalanced raw material dosage and Non-standard material procurement further reinforce that inconsistencies in raw material composition and sourcing directly affect the uniformity and compressive strength of the concrete poles. Poor working environment and Incorrect working posture highlight human-related issues, such as operator fatigue and repetitive errors, which significantly influence production reliability.

Therefore, it can be concluded that the dominant root causes of defects in electric concrete pole production lie in machine maintenance deficiencies and inadequate production supervision. Strategic improvements should focus on implementing Total Productive Maintenance (TPM), enhancing raw material quality assurance, and enforcing a routine inspection and supervision system to achieve sustainable defect reduction and improve overall product performance.

Tree Diagram

After identifying the causal factors of defects in electric concrete pole products through the Interrelationship Diagram (ID), the next stage focuses on developing a systematic improvement strategy using the Tree Diagram. This diagram translates the identified root causes into a structured and measurable action plan. The Tree Diagram establishes a hierarchical relationship between the main problem and the corresponding corrective actions that can be implemented at the operational level.

This approach is crucial in the improvement phase as it decomposes the dominant causes into specific preventive and control measures. Each branch of the diagram represents the linkage between the main improvement objectives, supporting activities, and detailed operational steps to address product failures such as cracks, voids, and fractures. Thus, the Tree Diagram serves as a strategic roadmap for integrating quality enhancement efforts into the company's production management system.

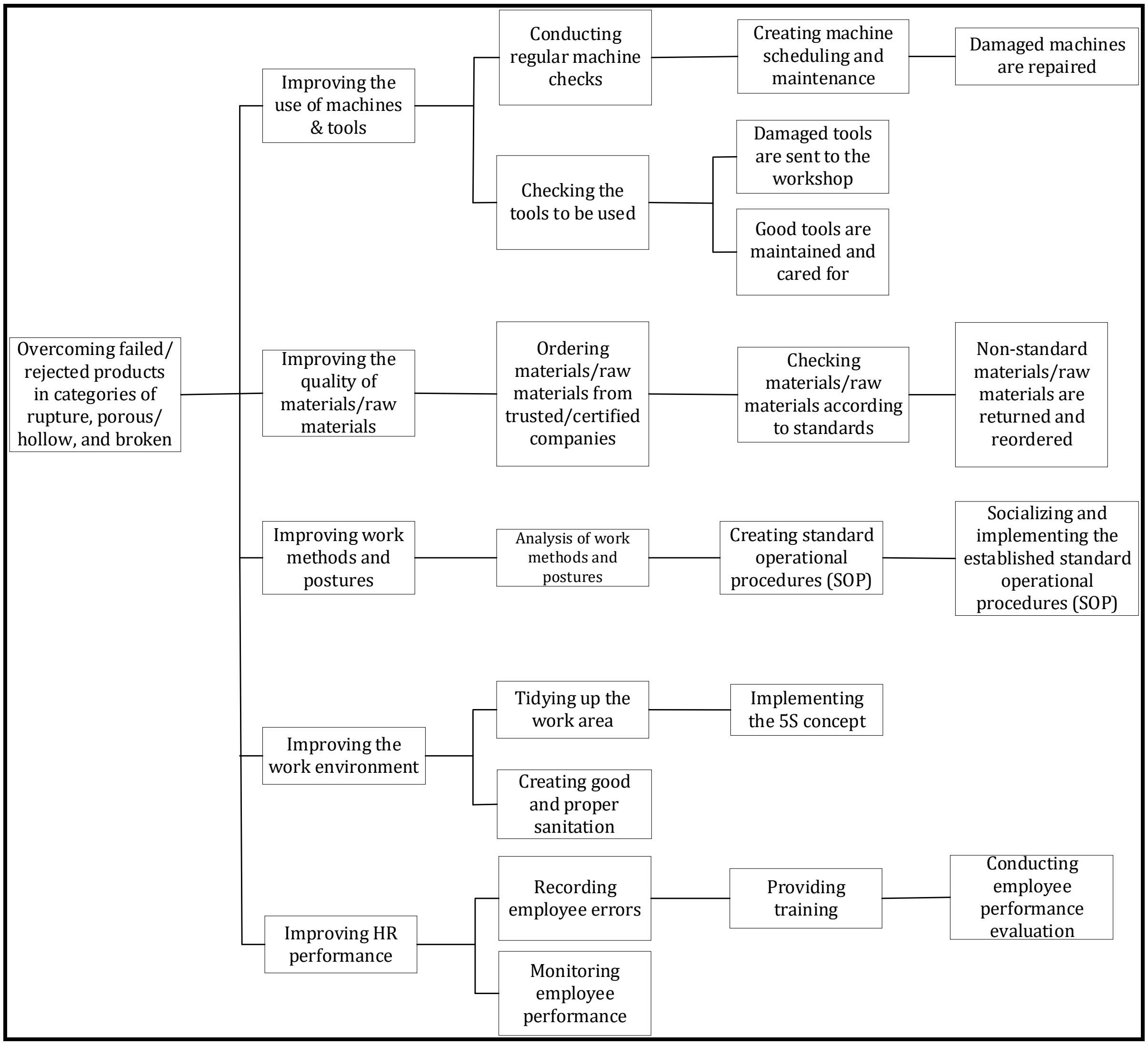

Figure 4. Tree Diagram

As illustrated in Figure 4, the primary strategy to overcome product failures emphasizes four key aspects: improving machine and tool utilization, enhancing raw material quality, optimizing work methods, and strengthening human resource (HR) performance.

The first aspect, improving the use of machines and tools, involves conducting regular machine inspections, performing preventive maintenance, and repairing damaged equipment to ensure process stability and production continuity. Meanwhile, improving the quality of raw materials includes sourcing materials from certified suppliers and verifying their quality before use. These measures are essential to maintain material uniformity and concrete strength, thereby minimizing defect rates. The improvement of work methods and postures is realized through the development and implementation of Standard Operating Procedures (SOPs) and compliance with industrial standards. On the other hand, improving HR performance focuses on training programs, continuous performance monitoring, and systematic evaluations aimed at increasing operator skills, discipline, and awareness.

The implementation of the 5S concept (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) further supports workplace organization and cleanliness, fostering a productive environment that contributes directly to higher product quality.

Overall, the Tree Diagram analysis highlights that achieving defect-free and high-quality concrete pole production requires an integrated approach combining technological reliability, process management, and human resource development. Such integration enables sustainable production performance improvement and strengthens the company's competitiveness in the industrial sector.

Matrix Diagram

To strengthen the identification of root causes of product defects, an analysis using the Matrix Diagram was conducted, as shown in Table 5. This method maps the relationship between each problem type and the major causal categories: Man (human factor), Machine, Method, Material, and Environment. The approach aims to determine the dominant factors contributing to defects in electric concrete pole products.

Each symbol in the matrix represents the level of correlation between a problem and its causal factor. The shape and color of the symbols indicate the degree of influence on product quality, while the total relationship values reflect the magnitude of each factor's contribution. Hence, the Matrix Diagram serves as a quantitative diagnostic tool for assessing the relative importance of each causal category in relation to overall product failures.

Table 5. Matrix Diagram of Problems Causing Product Defects

Problem	Man	Machine	Method	Material	Environment	Total
Supervisors do not conduct regular inspections according to the standard, especially during dough filling which must follow the standard (concrete volume and dough filling technique into the mold).	●	▲	■	▲	▲	15
Raw materials received, especially cement and chemicals, are of substandard quality.	▲	▲	▲	●	▲	13
Spinning of the spinning machine is not up to standard, or below 15 minutes	▲	●	■	▲	▲	6
Mixing time of concrete mixture is less than 5 minutes	■	■	●	■	▲	10
Lack of cleaning molds or concrete molds that cause residual dough to stick and fuse with molds	■	▲	●	▲	■	8
Molding or molds used are bent and baling	▲	●	■	▲	■	17
Lack of filling of concrete material because it is not compacted evenly using a vibrator	■	▲	●	■	▲	17
Unbalanced material dosing such as using too much water or using too little dry material	■	▲	●	■	▲	17
Concrete is lifted by an unbalanced or stacked crane hoist	■	●	■	▲	▲	17
Workers are incompetent and in unergonomic positions	●	▲	■	▲	■	17

Minor machine failures are often ignored and maintenance is not carried out.	●	●	■	▲	■	25
The poor working environment includes a lot of noise from machines and heavy equipment, muddy due to liquid spills, and a lot of scattered items.	■	▲	▲	▲	●	15

Based on Table 4, the Man and Machine factors show the highest total values, 18 and 17, respectively, indicating that these two are the dominant causes of product defects. Operator incompetence in the concrete filling process and lack of regular supervision lead to deviations from standard operating procedures. These human errors are compounded by inadequate machine maintenance, which negatively affects the spinning and moulding processes.

The Method factor, with a total score of 15, also exerts a significant influence. It relates to substandard mixing times, inconsistent raw material proportions, and irregular mould cleaning procedures. The absence of standardized operating methods leads to high production variability and reduced product uniformity.

The Material factor (score 13) indicates that the quality of raw materials such as cement, sand, and additives remains unstable. The use of uncertified or substandard materials contributes to reduced concrete strength and homogeneity. Meanwhile, the Environment factor (score 12) highlights poor working conditions characterized by noise, humidity, and unclean surroundings that may affect worker concentration and safety.

In conclusion, the Matrix Diagram analysis reveals that defect reduction efforts should primarily focus on improving operator competence, implementing scheduled machine maintenance, and standardizing work methods. An integrated approach that harmonizes human, technical, and process aspects is essential to enhance production reliability and minimize product defects in electric concrete pole manufacturing.

Matrix Data Analysis

Following the identification of defect-causing factors through the *Matrix Diagram*, a further evaluation was conducted using the Matrix Data Analysis, as shown in Table 5. This analysis aims to assess the improvement priority level based on the performance scores of each alternative solution according to key criteria—process efficiency, product quality, ease of implementation, cost impact, and sustainability.

Each improvement alternative was rated on a scale of 1–10, derived from field observations, expert consultations, and technical evaluations of production activities. The total scores and final ranking determine the priority improvement strategies that should be immediately implemented to effectively reduce product defects.

Table 6. Matrix Data Analysis

Problem	**Alternative Improvement**	**Score**					**Total**	**Rank**
		1	**2**	**3**	**4**	**5**		
Supervisors do not conduct regular inspections according to the standard, especially when filling the dough that must follow the standard (volume of concrete and technique of filling the dough into the mold).	Establish a routine inspection schedule and self-reporting system.	9	8	8	7	9	41	1

Raw materials received, especially cement and chemicals, were of a quality below the set standard.	Implement incoming material inspection and quality contracts with suppliers	8	7	8	7	6	36	6
Spinning machine spinning is not up to standard, or below 15 minutes.	Recalibrate the machine periodically and establish an SOP for machine use.	8	7	9	8	7	39	3
Stirring time for concrete mixes that are less than 5 minutes	Standardize mixing time and automate the process	9	8	7	6	7	37	5
Lack of cleaning of molds or concrete molds which causes the remaining dough to stick and fuse with the molding	Create a daily cleaning schedule and mold cleanliness checklist.	7	6	6	5	7	31	10
The molding or mold used is bent and baling	Replace damaged molds and check flatness before production.	6	6	7	8	7	34	8
Lack of filling concrete material because it is not compacted evenly using a vibrator	Install a concrete volume sensor and SOP on the number of doses per unit	7	6	6	5	6	30	11
Unbalanced ingredients such as using too much water or using too little dry ingredients	Use digital scales and measure SOP	6	5	6	5	6	28	12
Concrete lifted with an unbalanced or stacked hoist crane	Train operators and use standardized lifting aids	6	5	8	7	7	33	9
Workers are incompetent and in non-ergonomic positions	Redesign of work layout and ergonomic training	8	7	7	5	8	35	7
Machines that experience minor damage are often ignored and no maintenance is performed.	Implement preventive maintenance and daily checklist form	7	6	9	8	8	38	4
Poor working environment includes a lot of noise from machines and heavy equipment, muddy due to liquid spills, and a lot of scattered items.	Improve the work floor, lighting and hygiene management	9	8	9	7	7	40	2

As presented in Table 5, the highest total score (41 points) was obtained by the alternative Establish a routine inspection schedule and self-reporting system, indicating that regular supervision and self-monitoring are the top priorities for quality improvement. This solution directly addresses the Man and Method factors identified earlier as the main contributors to defects. The implementation of routine inspections is expected to enhance operator discipline, ensure compliance with standard procedures, and enable early detection of production deviations.

The second-ranked improvement (40 points) is Improve the work floor, lighting, and waste management", emphasizing the significance of optimizing workplace conditions. A clean, well-lit, and organized environment reduces the likelihood of human error and enhances production efficiency. Other high-ranking alternatives, such as Implement incoming material inspection and supplier quality contracts (39 points) and Standardize mixing time and automate the process (38 points), highlight the importance of improving raw material quality control and process standardization.

Overall, the findings indicate that a combination of technical and managerial interventions is essential for reducing product defects. Integrating regular supervision, operator training, and preventive machine maintenance will establish a continuous quality improvement cycle. Consequently, the production system can achieve higher stability, efficiency, and alignment with the zero-defect manufacturing principle.

Activity Network Diagram

The production process of electric concrete poles was analyzed using the Activity Network Diagram (AND) approach to identify the sequence of operations and calculate the total production time. This method aims to examine the workflow, interdependence among activities, and the critical path that determines overall process efficiency.

The detailed work stages are presented in Table 6, which includes activity codes, starting points, and duration for each task. These data were then used to construct the Activity Network Diagram, as shown in Figure 5, which illustrates the logical relationships between operations in the production process from material mixing to the final product inspection.

This analytical framework provides a comprehensive understanding of the production cycle time and serves as a foundation for optimizing scheduling, resource utilization, and operational control on the production line.

Tabel 7. Work Process and Duration of Electric Concrete Pole Production Process

Work Process	Code	Start	Duration
Mixing of concrete materials	A	-	306 seconds
Pc Bar Cutting	B	-	821.5 seconds
Pc Bar head making	C	B	528.1 seconds
Inspection of heading result	D	C	120 seconds
Spiral installation	E	D	659.5 seconds
Inspection of forming result	F	E	30 seconds
Adjustment of joint accessories	G	F	777.2 seconds
Inspection of joint result	H	G	36 seconds
Concrete filling	I	A,H	355.4 seconds
Concrete fill check	J	I	60 seconds
Mold closing	K	J	163.6 seconds
Frame pulling/tightening	L	K	92.7 seconds
Concrete compaction	M	L	941.4 seconds
Evaporation of concrete	N	M	14,400 seconds
Painting and stamping	O	N	317.1 seconds
Product inspection	P	O	60 seconds

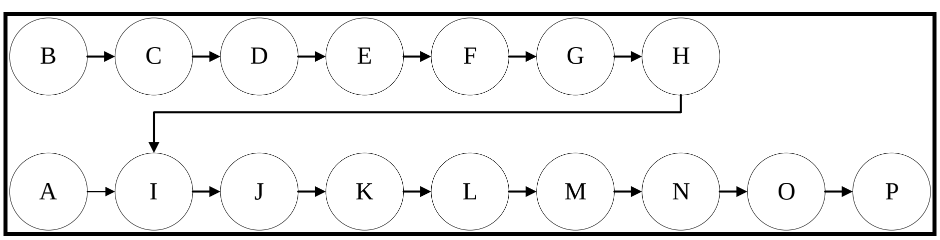

Figure 5. Activity Network Diagram

According to Table 6 and Figure 5, the entire production process consists of 16 interconnected stages, arranged in both sequential and partially parallel workflows. The longest process duration is found in concrete evaporation (N), which takes 14,400 seconds, indicating that the drying process is the most time-consuming and a major determinant of total production time. Therefore, this stage represents the critical point in the production system requiring optimization.

Other time-intensive operations include PC bar cutting (B) with 821.5 seconds, joint accessory adjustment (G) with 777.2 seconds, and spiral installation (E) with 659.5 seconds. These processes are essential for structural formation and occur in a serial sequence—meaning any delay in one step can propagate through subsequent stages.

Meanwhile, short-duration activities such as inspection of heading results (D) and inspection of forming results (F) serve as critical quality checkpoints. These should be maintained as they ensure product consistency without significantly extending total cycle time.

Overall, the Activity Network Diagram analysis reveals that production efficiency can be improved by implementing parallel processing for non-critical activities and enhancing drying capacity to reduce the evaporation phase duration. Optimization of the critical path is projected to significantly decrease total production time while maintaining product quality and reliability.

Process Decision Program Chart

After identifying the root causes of product defects and formulating improvement strategies through the Tree Diagram and Matrix Data Analysis, the next step involved developing a Corrective Action Diagram. This diagram visualizes the decision flow and systematic procedures for handling defective physical products, including cracked, porous, or dimensionally inconsistent concrete poles. The approach ensures that each defect detected during production is addressed through a standardized corrective workflow, encompassing machinery inspection, raw material improvement, and human–environmental enhancement. This framework serves as an operational guideline for implementing an Integrated Quality Control System (IQCS) within the electric concrete pole production process.

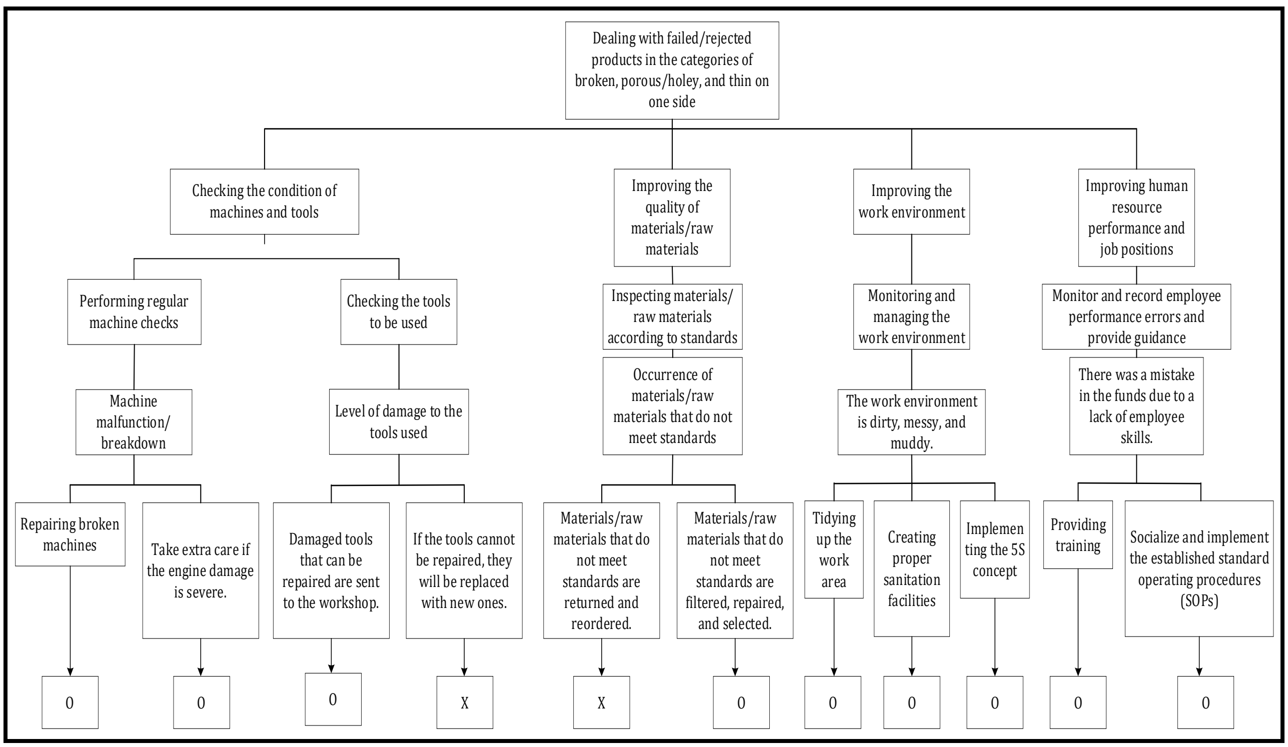

Figure 6. Process Decision Program Chart

As illustrated in Figure 6, the corrective action diagram delineates three primary improvement pathways: maintenance of machines and tools, enhancement of raw material quality, and optimization of human and environmental factors.

The first pathway, machine and tool maintenance, begins with routine inspection, assessment of tool conditions, and repair of damaged equipment at the workshop. These measures ensure operational readiness and minimize technical errors that could lead to product defects.

The second pathway, raw material quality improvement, focuses on incoming material inspection, supplier quality monitoring, and the establishment of quality assurance contracts. This guarantees material consistency in accordance with technical and company standards, thereby improving the overall durability and performance of the concrete poles.

The third pathway, workplace and human performance enhancement, includes organizing the work environment for safety, lighting, and cleanliness, as well as conducting employee training and performance evaluation. These actions foster worker discipline and strengthen a culture of continuous improvement throughout the production system. The analysis emphasizes that the success of product defect control depends not only on technical interventions but also on the integration of human, technological, and managerial aspects, ensuring a sustainable and high-quality manufacturing process.

DISCUSSION

The study demonstrates that the New Seven Tools (NST) approach is highly effective in diagnosing and reducing product defects in concrete utility poles through a structured qualitative–quantitative framework. The Affinity Diagram identified three dominant defect categories—cracks, pores/voids, and fractures—classified into the five root cause groups of Man, Machine, Method, Material, and Environment. These classifications are consistent with [14], [15] who observed similar defect typologies in precast concrete products analyzed with Seven Tools and FMEA. Furthermore, Sari et al. (2025) confirmed that human error and inadequate maintenance remain the most significant contributors to quality variability in manufacturing systems.

Previous studies by [16], [17], [18] corroborate that NST provides strong causal mapping capabilities, allowing identification of systemic weaknesses such as supervision gaps and maintenance delays. The dominance of "lack of machine maintenance" and "irregular supervision" found in this study parallels [19], [20], who emphasized that reactive maintenance culture and operator negligence lead to recurring production defects. The Matrix Diagram highlights that the human and machine factors are the dominant sources of defects (scores 18 and 17). This finding aligns with[21], [22], [23], who reported that operator inaccuracy contributed to more than 60% of product defects in the furniture industry. Similarly, [24] concluded that disciplined operator behavior and consistent supervision are fundamental to reducing variability in production outcomes.

Operator fatigue, insufficient training, and production pressure are recognized as major contributors to nonconformities, as observed by [25], [26], [27]. [28], [29] further demonstrated that non-ergonomic work conditions elevate error frequency and injury risk. The Tree Diagram in this research emphasizes ergonomics, 5S implementation, and preventive maintenance as crucial interventions—approaches also endorsed by [30], [31], [32] for improving quality consistency and workplace discipline.

The Interrelationship Diagram (ID) analysis indicates that "lack of machine maintenance" is the main driving factor, while "absence of regular supervision" serves as the primary dependent factor influencing product quality. This causal dynamic mirrors the findings of [33], [34], who applied NST in the fishing rod industry to visualize interconnected causes and prioritize root-based interventions. Subsequently, the Tree Diagram in this study structures the improvement strategies into four integrated dimensions: machine reliability, raw material standardization, process optimization, and human resource enhancement. This hierarchical improvement model reflects the core philosophy of Total Productive Maintenance (TPM) and Continuous Improvement (Kaizen) frameworks applied in manufacturing contexts by [35], [36] [37].

The Matrix Data Analysis provided quantitative validation of improvement priorities. The top-ranked improvement—establishing a "routine inspection schedule and self-reporting system" (score = 41)—demonstrates the necessity of regular supervision to ensure procedural compliance and early detection of irregularities. [15] similarly reported that periodic inspections reduced defect rates by up to 40% in mass production systems. Environmental optimization ranked second (score = 40), confirming the role of workplace conditions in sustaining operator performance. Yusnita & Puspita (2020) documented that organized and well-illuminated workspaces improved efficiency by 25%. Therefore, this study reinforces the combined role of preventive maintenance and workplace standardization as the foundation for sustainable quality management.

Using the Activity Network Diagram (AND), the research identifies the evaporation process (14,400 seconds) as the critical path determining total production time. This finding aligns with [16], [17], who demonstrated that analyzing workflow dependencies enhances scheduling and productivity. Implementing parallel processes or improved curing technologies could reduce total production time by approximately 20%, as proposed by [4] [38]. Additionally, the absence of pre- and post-use equipment inspections represents a procedural gap that directly contributes to defects. [18] found that integrating operator-based self-inspection checklists reduced error occurrence by 30%, validating the findings of this study regarding proactive inspection routines

The Process Decision Program Chart (PDPC) emphasizes the necessity of balancing ideal corrective actions with financial and operational feasibility. The finding that machine replacement is impractical due to cost limitations echoes [18] [43] who highlighted that repair-before-replace strategies optimize resource allocation while sustaining production stability. [27] [6] confirmed that PDPC serves as a strategic evaluation framework to assess risk-adjusted feasibility of corrective measures derived from causal analysis. Consequently, this research reinforces PDPC as a valuable decision-making tool for risk-aware improvement planning in industrial quality systems.

CONCLUSION

This research confirms that the New Seven Tools method serves as an effective diagnostic and corrective framework for minimizing defects in the production of concrete electrical poles. The analysis revealed that machine maintenance deficiencies and lack of regular supervision are the most critical factors affecting product quality. These findings underscore the interconnectedness of human and mechanical aspects in determining production stability. The integration of Affinity, Interrelationship, and Tree Diagrams successfully structured a comprehensive cause–effect hierarchy, while the Matrix and PDPC analyses quantitatively validated improvement priorities based on feasibility and impact. Implementing preventive maintenance, standardized inspection routines, and ergonomic work practices are proven strategies to enhance operational reliability and defect prevention. Moreover, environmental reorganization and adherence to the 5S/5R principles contribute significantly to sustaining process discipline and safety. In practical terms, this study provides a replicable model for industrial sectors aiming to achieve continuous improvement and zero-defect manufacturing performance. Academically, it expands the empirical evidence of NST as a hybrid qualitative–quantitative tool adaptable to the context of Indonesian manufacturing, bridging managerial decision-making with systematic quality engineering. Future research should explore the integration of NST with digital quality monitoring systems to further strengthen predictive control and data-driven quality assurance in industrial applications.

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