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Achieving Manufacturing Excellence Using Lean DMAIC †

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Abstract: This paper explores the role of business process optimization in achieving manufacturing excellence in railway manufacturing through Lean principles and Quality Function Deployment (QFD). It identifies key inefficiencies, such as waiting times, overproduction, and document errors, using the DMAIC method, along with Root Cause Analysis (RCA) and Failure Mode and Effect Analysis (FMEA), to prioritize waste reduction. A significant 42.86% of activities were classified as non-value added, pointing to substantial opportunities for improvement. This study proposes key solutions, including the development of a shared database, streamlined procedures, and the alignment of targets with the Master Production Schedule to reduce waste and improve operational efficiency. These recommendations aim to foster manufacturing excellence by enhancing communication, process integration, and employee training.

Keywords: lean; railway manufacturing; critical waste; quality function deployment

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1. Introduction

Efficiency in business processes is achieved by maintaining lean flows, with Lean principles playing a central role in achieving manufacturing excellence through waste elimination and streamlined operations. In order to address manufacturing inefficiencies and related challenges, the adoption of Lean manufacturing is essential within the industry. Lean manufacturing facilitates the achievement of these goals by optimizing process mapping and distinguishing between value-adding and non-value-adding activities. Besides that, Six Sigma represents a systematic, statistical approach that enhances product quality, fosters innovation, and elevates customer satisfaction [1–3]. The framework that is usually used for Six Sigma methodology is DMAIC (Define, Measure, Analyze, Improve, Control) [4,5]. The Six Sigma methodology is widely adopted in industry as a tool for business improvement, employing a product-centric management approach aimed at minimizing defects across goods, services, and processes [6]. It is a methodically organized strategy for enhancing operational quality and product standards [7]. By fully implementing a project-driven approach, Six Sigma supports organizations in reaching their strategic objectives [8]. The DMAIC framework initiative could be implemented as the roadmap for an improvement process [3,6].

Many companies continuously strive to enhance their efficiency and effectiveness using various methodologies such as Lean, Kaizen, Six Sigma, and others, aiming particularly at reducing costs and improving ongoing production processes. Research from [9] conducted a study aimed at devising a new method for suggesting Six Sigma projects

and prioritizing them. The research employed an event study technique to investigate the impact of adopting Six Sigma programs. Financial information from 200 organizations that implemented Six Sigma was compared with data from similar companies that served as control groups in the studies. Another research conducted by [10] investigated the automobile manufacturing sector with a focus on engine muffler production. This study found that implementing Six Sigma reduced the rejection rate of mufflers from 8.21% to 4.81%. Moreover, the industry's Sigma level improved from 2.89 to 3.16, and process capability increased from 91.73% to 95.19%. This introduction should briefly place this study in a broad context and define the purpose of this work and its significance.

This paper focuses on a case study involving a railway manufacturer headquartered in East Java, which aims to offer comprehensive solutions for sustainable ground transportation systems in Asia. To fulfill this vision, the company has developed strategies to enhance its operational efficiency, particularly in its manufacturing processes, while integrating its affiliates strategically. Railway manufacturing serves as both a system integrator and a function for managing and evaluating operations, ensuring the effective implementation of the company's strategic goals. Effective performance management, measured using Key Performance Indicators (KPIs), such as zero defects, on-time delivery, and precise material scheduling, is crucial to the company's success. Recent KPI reports reveal inconsistencies in achieving these goals, particularly in the production and supply chain departments. This performance shortfall underscores the impact of business inefficiencies and waste, not only in manufacturing but also across business processes as a whole.

Addressing these inefficiencies requires a structured approach to business process improvement. This study proposes the use of Lean and Quality Function Deployment (QFD) methodologies to support railway manufacturing excellence. Manufacturing excellence is a strategic framework focused on enhancing business growth and operational effectiveness, enabling companies to outperform competitors through the reduction in operational risks, costs, and the enhancement of revenue. It emphasizes continuous improvement embedded within an organization's culture, involving all levels of the workforce, not just those on the factory floor [11]. The key principles of manufacturing excellence include safety, good housekeeping, preventive maintenance, process capability, product quality, and delivery performance, among others. Lean Six Sigma combines speed and process quality to drive continuous innovation and meet customer needs, focusing on data-driven improvements through the DMAIC (Define, Measure, Analyze, Improve, Control) cycle. This framework helps identify areas of waste and implement corrective actions, promoting a culture of improvement within the organization. Implementing Lean Six Sigma allows the company to minimize non-value-added activities at each stage of production and reduce variability in the manufacturing process, leading to more streamlined and effective product production processes [12]. Meanwhile, QFD translates customer requirements into actionable technical specifications, further aligning improvements with customer expectations [13].

Previous research has shown the effectiveness of Lean Six Sigma in improving operational efficiency and driving growth across various industries. For example, Ref. [14] found that LSS enhanced efficiency and profitability in small- and medium-sized enterprises in Pakistan during the COVID-19 pandemic, though their study did not address the link between sustainability and performance. Similarly, [15] explored Lean Six Sigma in digital technology sectors, while [16] applied DMAIC in higher education, both of which are less relevant to manufacturing contexts. Ravindra Ojha and Umashankar Venkatesh (2021) [17] focused on Lean in automotive manufacturing, emphasizing leadership and continuous improvement, factors also critical for the railway sector, which require adherence to stringent safety standards. The success factors for Lean Six Sigma in the food industry were outlined in [18], although their findings are not directly applicable to the capital-intensive railway

manufacturing sector. By applying Lean and QFD to optimize business processes, this research aims to foster manufacturing excellence in railway production, ultimately achieving efficient, high-quality operations that contribute to the company's competitive advantage.

2. Methodology

In this study, the methodology consisted of two primary phases, the data collection process and data processing using the DMAIC framework. The data collection process was carefully structured across multiple stages to ensure comprehensive and reliable results.

2.1. Data Collection

Data collection is conducted through the following:

1. Interviews with structural employees (manager-level, senior manager, and general manager) or those with over 10 years of experience in railway manufacturing production environments. Interviews involve personnel involved in decision-making regarding production business processes and experienced staff. Questions cover company information such as the production processes, duration of work, sequence of production business processes, supporting documents, etc.
2. Historical data or archival data, such as Key Performance Indicators (KPIs), Performance Assessment Reports (LPKs), Master Schedule, Production Schedule, Bill of Materials (BoM), etc.
3. Questionnaire completion by structural employees (manager-level, senior manager, and general manager) and experienced staff with over 10 years of experience in railway manufacturing production environments. The questionnaire focuses on identifying railway manufacturing business processes.

2.2. Data Processing Using DMAIC Framework

A. Define and Measure

The Define phase involves mapping the railway manufacturing business processes to pinpoint inefficiencies and establish research boundaries. Interviews and questionnaires with key personnel provide insights into production operations. Flowcharting these processes aids in identifying high-waste activities, creating a baseline for waste-reduction efforts.

In the Measure phase, after identifying the issues, quantitative data collection and evaluation of the current process state are conducted. Questionnaire data processing includes satisfaction and expectation surveys among personnel assessing alignment with operational needs. Data testing which evaluates sufficiency, validity, and reliability, ensures robust insights, and gap assessments quantify discrepancies between satisfaction levels and expectations. Additionally, critical waste factors are identified, focusing on high-waste activities that significantly impact production efficiency.

B. Analysis and Improvement

The Analyze and Improve phases deploy advanced analytical tools to identify root causes and prioritize improvements. In Analyze phase, Root Cause Analysis (RCA) and Failure Mode and Effect Analysis (FMEA) are used to assess critical waste factors. RCA employs the "5 Whys" technique to trace each issue to its origin, while FMEA evaluates severity, occurrence, and detection ratings for each high-waste activity:

- Severity: Assesses the impact of wasteful activities on production goals.
- Occurrence: Estimates the frequency of these wasteful activities.
- Detection: Measures the likelihood of identifying wasteful activities before they cause negative effects.

In the Improve phase, improvement actions are formulated based on the findings from the Analyze phase. This process integrates Quality Function Deployment (QFD) and the House of Quality (HOQ). QFD translates customer requirements into technical process specifications, with HOQ providing a matrix of customer needs, competitive data, and technical details. This ensures that prioritized improvements meet customer expectations and technical standards.

C. Control

The Control phase focuses on sustaining process improvements through standardized procedures and continuous monitoring. Standard Operating Procedures (SOPs) are developed through discussions with experienced personnel, ensuring consistent application across railway manufacturing processes. Control mechanisms emphasize variation management, establishing monitoring strategies to maintain process stability. Although not implemented in this study, future improvements may apply the Plan–Do–Check–Act (PDCA) cycle to reinforce continuous process improvement.

3. Results and Discussion

This chapter provides a detailed breakdown of each DMAIC stage's outcomes, illustrating how Lean principles can drive impactful improvements within a complex manufacturing environment.

3.1. Define Stage

The Define stage serves as the initial step in identifying issues within the railway manufacturing business processes. Through an examination of the company's history, mission, organizational structure, and key workflows, this stage provides a comprehensive view of the manufacturing environment and identifies potential areas for improvement.

An in-depth interview with long-term employees and senior managers provided insights into the company's business processes. The mapping process has a clear structure for each major step in the production and procurement workflow, from the issuance of the Master Production Schedule (MPS) and Bill of Materials (BoM) to the final production report (Kurva-S). This mapping clarifies roles across departments and affiliates, highlighting areas where delays or redundancies occur, such as in BoM updates and document approvals.

Survey data collected through questionnaires revealed the impact of business processes on the company's Key Performance Indicators (KPIs). Specifically, processes like the Master Production Schedule (MPS), subcontractor planning, and Purchase Requisition issuance significantly influenced KPIs related to on-time delivery (50.27%) and Material Arrival Accuracy (35.22%). Additional insights indicate that 85% of employees agreed with the processes, although some considered certain workflows misaligned with manufacturing needs. The Define stage laid the groundwork for identifying key inefficiencies, setting the stage for subsequent analysis and improvements in waste reduction and process optimization.

3.2. Measure Stage

At this stage, the processing of questionnaire data was carried out, identifying waste and measuring the waste that occurred in the railroad manufacturing business process as well as identifying gaps in satisfaction and expectations in the railroad manufacturing business process. The identification and measurement of waste are carried out to obtain critical waste which will then be analyzed for this waste.

3.2.1. Data Adequacy Test

This data adequacy test was conducted to find out whether the number of questionnaires distributed was sufficient to proceed to the next stage. The data adequacy test can be calculated by the following Equation (1):

$$N' \geq \frac{\left(\frac{Z^{\alpha}}{2}\right)^2 .p.q}{e^2} \quad (1)$$

The results of the data adequacy test calculation yield a value of N', which is 12.16. Therefore, $N \geq N'$ is $20 \geq 12.16$, indicating that the questionnaire distribution data are adequate and could be used as the basis for observation.

3.2.2. Validity Test

A validity test was conducted to find out whether the activity on the questionnaire is valid or not. The validity test was carried out on the satisfaction and expectation questionnaire data distributed. In this test, a comparison of t_{count} and t_{table} values was carried out for each activity in the railroad manufacturing business process. And it was found that all activities of expectation and satisfaction t_{count} were greater than t_{table} (1.729). This shows that the activity questionnaire is valid and can be used as an object of observation.

3.2.3. Reliability Test

A reliability test was conducted to determine whether the activity on the questionnaire can be trusted and relied upon. The reliability test was carried out by using the Cronbach Alpha test on the distributed and valid questionnaire data of satisfaction and expectations. And the obtained R_{count} is greater than R_{table} (0.444); this shows that satisfaction activity data can be trusted and relied upon and can be used as an object of observation.

3.2.4. Activity Classification and Waste Identification

The principle of Lean manufacturing is to create more value using less work and waste. Therefore, efficiency is needed for activities in railroad manufacturing that generate waste, which are categorized into 2 (two) types, value added (VA) and non-value added (NVA). By classifying activities, it becomes possible to identify those that cause waste. Non-value-added activities are considered waste, and they contribute to inefficiencies. These wastes are as follows:

- Errors in documents (Defect)
- Performing work not requested (Overproduction)
- Waiting for the next step (Waiting)
- Transport of documents (Transportation)
- Backlog in work (Inventory)
- Unnecessary motions (Motion)
- Process Steps and Approvals (Processing)

3.2.5. Determination of Critical Waste

After identifying the waste in the railroad manufacturing business process, which is a non-value-added activity, the next step is to determine the critical waste. The questionnaire method used in this observation is the Borda weighting method, where this method is carried out by giving a rating to each waste that was previously multiplied by the appropriate weight. The highest weight is obtained from $n - 1$ (n = number of waste groups) to the lowest weight, which is 0. Then, the multiplication results are ranked according to these results. Table 1 shows the results of critical waste processing.

Table 1. Results of critical waste processing.

Waste	Score	Weight After Normalization	Ranking
Errors in documents (Defect)	67	0.160	3
Performing work not requested (Overproduction)	109	0.260	2
Waiting for the next step (Waiting)	111	0.264	1
Transport of documents (Transportation)	47	0.112	5
Backlog in work (Inventory)	11	0.026	6
Unnecessary motions (Motion)	9	0.021	7
Process Steps and Approvals (Processing)	66	0.157	4

3.3. Analyze Stage

In the analysis phase, an investigation is conducted to identify the root causes of critical waste in manufacturing business processes. Once the causes are identified, the root cause that can be addressed is selected, and a technical response is determined to prioritize improvements in the railroad manufacturing business process.

3.3.1. Root Cause Analysis (RCA)

Based on the critical waste identified earlier, the root causes of the issues arising from non-value-added activities that impact the railroad manufacturing business processes were examined. The critical wastes identified as root causes include waiting for the next step (Waiting), performing unrequested work (Overproduction), and errors in documents (Defects).

A. Root Cause Analysis (RCA) of Waiting for the Next Step (Waiting)

Using the 5 Whys method, the root cause of the waiting-for-the-next-step waste (Waiting) was identified. Subcategories of waste related to waiting for the next step (Waiting) are divided into 5 (five) types:

- Issuance of a Bill of Materials (BoM) that is not yet clear, which affects the next process.
- Delayed document distribution processes.
- The process of waiting for the activation of the material code because the material code in the Bill of Materials (BoM) is not yet active in the SAP application (Systems, Applications, and Products).
- The process of waiting for answers on the proposed substitution of materials or components.
- The process of waiting for the approval of the documents made, such as the Master Production Schedule, Undertaking Agreement, Purchase Request (PR), Price Offer Letter (SPH), Purchase Order (PO), and Production Progress Report (S-Curve).

B. Root Cause Analysis (RCA) of Performing Work Not Requested (Overproduction)

Using the 5 Whys method, the root cause of the overproduction waste, where work is performed that is not requested, was identified. Subcategories of waste related to performing unrequested work (Overproduction) are divided into 2 (two) types:

- Excessive use of paper for document distribution.
- Preparation of documents that cannot be used as a reference for further work processes.

C. Root Cause Analysis (RCA) of Errors in Documents (Defects)

Using the 5 Whys method, the root cause of the document errors waste (Defects) was identified. Subcategories of waste related to errors in documents (Defects) are divided into 4 (four) types:

- There are errors in the data entry activities, both the existing data for submissions and answers from material or component substitution.
- There is a shortage of data input in the preparation of the Master Production Schedule, Bill of Materials (BoM), Undertaking Agreement, Subcontractor Planning Documents, Production Progress Reports, and Production Progress Reports (S-Curve).
- There is an error in data entry in the Bill of Materials (BoM), for example, an error in coding the component material or the amount needed.
- There is an error in data entry when making a Purchase Request (PR); for example, the number of needs and the Work Breakdown Structure (WBS) of the project in the SAP application (Systems, Applications, and Products).

3.3.2. Failure Mode and Effect Analysis (FMEA)

After identifying the root causes for each of the wastes, the next step involves selecting specific root causes for corrective action. The Failure Mode and Effect Analysis (FMEA) method is used to assign a Risk Priority Number (RPN) to each root cause. Each root cause is evaluated in terms of severity (S), occurrence (O), and detection (D). The RPN is then calculated by multiplying these three values. This calculation is performed for each identified waste type, and the resulting RPN values guide the prioritization of improvement actions. The RPN values for each waste are shown in Table 2.

Table 2. Risk Priority Number (RPN).

Waste	Potential Failure	Potential Effect	S	Potential Cause	O	D	Control	RPN	Recommended Action	Actions Taken
Waiting for the Next Step (Waiting)	Issuance of a Bill of Materials (BoM) that is not yet clear which affects the next process	Need additional time to adjust the Bill of Materials (BoM)	8	Adjustment of work completion targets from customers	8	3	Making work completion targets	192	Make completion targets by the Master Production Schedule	Break down targets according to the Master Production Schedule
Performing Work Not Requested (Overproduction)	Making documents that cannot be used as a reference for further work processes	Unused documents issued	8	The output issued between railroad manufacturers and affiliates is the same	7	2	Simplify procedures between rail manufacturers and affiliates	112	Creation of clear procedures to eliminate the same output	Planned discussion of procedures between rail manufacturers and affiliates
Errors in Documents (Defect)	There is a shortage of data input in the preparation of documents	Revision of work issued, and additional time required for re-checking	5	There is a change in technical specifications due to a detailed design that has not been 100% complete	6	3	Making work completion targets	90	Make completion targets by the Master Production Schedule	Break down targets according to the Master Production Schedule

3.4. Improvement Stage

The Improvement stage focuses on implementing corrective actions for the key issues identified in the railway manufacturing process. Based on the Failure Mode and Effect Analysis (FMEA), the root causes of inefficiencies—particularly data input deficiencies in the Master Production Schedule, Bill of Materials (BoM), and other critical documents—were prioritized for action. After identifying the priority areas for business process improvements, Quality Function Deployment (QFD) and House of Quality (HOQ) were developed in several steps. First, customer requirements and customer priority were identified, highlighting activity categories with high waste levels based on satisfaction and expectation gaps in the railroad manufacturing process. Customer priority further

classified these activities by importance to determine which required immediate attention. Next, technical requirements were set, focusing on high-waste activities that were prioritized according to Risk Priority Number (RPN) rankings and aligned with manufacturing excellence principles. Following this, relationships between customer requirements and technical requirements were mapped to illustrate the impact of each technical criterion on customer priorities. A Planning Matrix was then created to define the goals and objectives for the manufacturing process that are shown in Tables 3 and 4.

Table 3. Customer priority Planning Matrix between customer requirements and each technical requirement.

Customer Requirements	Customer Importance	Maximum Relationship	Relative Weight
Creation of Bill of Material (BoM)	5	10	5%
Creation of Master Production Schedule	7	7	8%
Creation of Work Documents including Production Flow Process and Production Takt System	4	7	4%
Creation of Subcontractor Planning Documents	11	7	12%
Creation of Undertaking Agreement	8	7	9%
Issuance of Purchase Requisition (PR)	13	7	14%
Submission of Material Substitution Request	2	4	2%
Issuance of Purchase Order (PO)	3	7	3%
Creation of Production Schedule	6	10	7%
Execution of Production Process and Inspection	1	10	1%
Creation of Production Progress Report (S-Curve)	10	4	11%
Monitoring Production Progress	12	7	13%
Creation of Production Progress Report	9	7	10%

Table 4. Planning Matrix of customer priority between technical requirements and each customer requirement.

Technical Requirements	Importance Rating	Maximum Relationship	Relative Weight
Creating a database for material or component codes	41.76	4	4%
Breaking down targets according to the Master Production Schedule	165.93	10	16%
Developing a shared database for collaborative use	365.93	7	35%
Conducting SAP (Systems, Applications, and Products) application training	128.,57	7	12%
Performing system analysis before system integration	14.29	4	1%
Discussing procedures between railway manufacturing and affiliates	332.97	10	32%

Based on Table 3, the highest priority is Purchase Requisition (PR) issuance (14%), which plays a crucial role in initiating the supply chain. Production Monitoring (13%) follows closely, emphasizing the need for continuous oversight to keep projects on track. Subcontractor Planning Document creation (12%) and Production Progress Reporting (Kurva-S) (11%) are also critical, ensuring detailed planning and progress tracking. Other important activities include Production Progress Report creation (10%), Undertaking Agreement drafting (9%), and Master Production Schedule development (8%), which align

production targets and ensure clear agreements. Lower-priority tasks, such as BoM preparation (5%) and Production Flow Process documentation (4%), are necessary but have less impact on overall efficiency, indicating that they are foundational activities that support more critical functions.

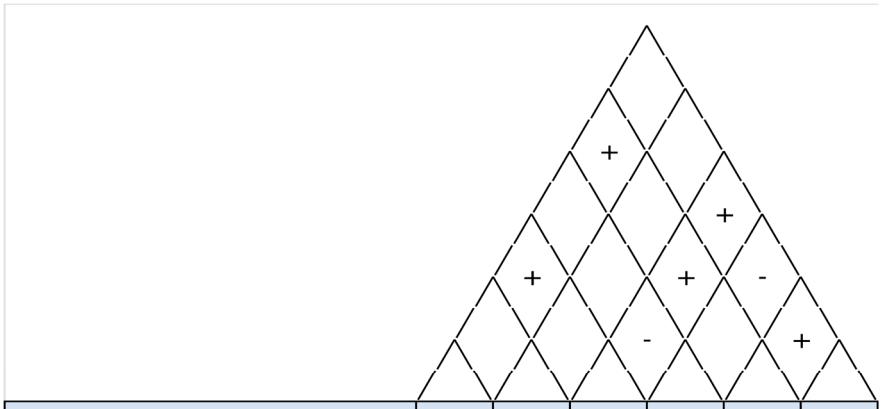
The Importance Rating that is shown in Table 4 is the calculated value resulting from the multiplication of customer priority by the relationship value between each technical requirement and customer priority. The maximum relationship is the value obtained from the strongest relationship between the technical requirement and each customer priority. Meanwhile, the relative weight shows the ranking of technical requirements from the most important to the least important, derived from the normalization of the Importance Rating values.

Additionally, technical correlation established links among technical criteria, helping to determine if improvements were on target, needed enhancement, or should be minimized. This included creating shared databases, setting completion targets according to the Master Production Schedule, and aligning procedures with affiliates. Finally, the Matrix House of Quality provided an integrated overview, summarizing all matrix elements to clarify the requirements for enhancing the railroad manufacturing business process shown in Figure 1.

The selection of critical technical requirements based on the House of Quality Matrix identifies four key priorities that will serve as the foundation for improvements in the railroad manufacturing process. These critical technical requirements are as follows: creating a shared database, discussing procedures between the railroad manufacturer and affiliates, breaking down targets according to the Master Production Schedule, and conducting SAP (Systems, Applications, and Products) application training. The selected technical requirements were chosen due to their high Importance Rating, with the shared database (365.93, 35%) ranking the highest, followed by procedure discussions (332.97, 32%), target breakdowns (165.93, 16%), and SAP training (128.57, 12%). These activities are expected to address the root causes of inefficiencies in the manufacturing process, contributing to greater effectiveness and efficiency.

As part of the improvement phase, alternative solutions are developed based on the critical technical requirements, with a focus on eliminating the root causes identified through Root Cause Analysis (RCA) and Failure Mode and Effect Analysis (FMEA). Each alternative is designed to address specific wastes, such as waiting times, document errors, and overproduction. The process improvements proposed include creating a unified database to reduce document errors and time spent on data conversion, simplifying and integrating procedures between the manufacturer and affiliates to eliminate redundant tasks, and breaking down the Master Production Schedule to better manage workload distribution across units. Additionally, SAP training aims to improve the workforce's soft skills and system knowledge, thereby enhancing overall productivity.

A weighted evaluation of the proposed alternatives was conducted using the Analytical Hierarchy Process (AHP) to prioritize the improvements based on three criteria: timely completion, document and database creation, and system integration. Based on the results, the highest-ranking improvement alternative is a combination of alternatives 1, 2, and 3, which focuses on creating a shared database, simplifying procedures, and aligning production targets with the Master Production Schedule. This combination received the highest matrix value of 0.150, indicating its potential for the greatest impact on improving the railroad manufacturing process.



Column #	1	2	3	4	5	6
Direction of Improvement	◇	▲	◇	▼	◇	▲
Technical Requirements	Create a database of material or component codes	Break down targets according to the Master Production	Create a database that can be used together	Conduct SAP application training (Systems, Applications	Perform system analysis prior to system integration	Conduct procedural discussions between railroad
Preparation of Bill of Materials (BoM)	⊙	●●	●	O	O	
Making master production schedule			●			
Preparation of work documents consisting of Production Flow Process and Production System Takt			●			
Preparation of subcontractor planning documents			●			
Making Undertaking Agreement						●
Issuance of Purchase Requisition (PR)		●	⊙	●		
Material Substitution Submission	⊙		⊙		⊙	
Issuance of Purchase Order (PO)				●		
Making Production Schedule						●●
Production Process Implementation and Inspection		●●				
Production Progress Report Creation (S-Curve)	O					⊙
Production Progress Monitoring			⊙			●
Making Production Progress Reports			⊙			●
Max Relationship	4	10	7	7	4	10
Importance Rating	41.76	165.9	365.9	128.6	14.29	333
Relative Weight	4%	16%	35%	12%	1%	32%
Weight Chart						

Figure 1. Matrix House of Quality. (+: Positive, -: Negative, ◇: Target, ▲: Maximize, ▼: Minimize, ⊙: Equal, ●●: Very Strong, ●: Strong, and O: Weak).

The chosen improvement alternative (combination 1, 2, and 3) promises significant benefits, such as streamlined operations, reduced administrative overhead, and minimized delivery delays. However, potential challenges include differing priorities between the manufacturer and affiliates, which may complicate the integration of systems and procedures. Nonetheless, with disciplined implementation, this alternative is expected to enhance overall efficiency and achieve manufacturing excellence.

3.5. Control Stage

At this stage, to achieve the principles of manufacturing excellence, focusing on product quality, the related manufacturing units are trying to make integrated business process SOPs that are mutually beneficial for railroad manufacturers and affiliates. The rail manufacturing unit controls the SOPs for the rail manufacturing business processes and affiliates to comply with ISO and company objectives.

4. Conclusions

In conclusion, this study identifies seven types of waste within the railroad manufacturing process, including document errors (Defect), overproduction (performing work not requested), waiting times (Waiting), transport of documents (Transportation), inventory backlog (Inventory), unnecessary motions (Motion), and excessive process steps and approvals (Processing). The critical wastes identified were waiting for the next step, performing work not requested, and errors in documents. Specific activities contributing to these wastes include delays in material code activation, pending document approvals, the excessive use of paper, and errors in data entry for critical documents like the Master Production Schedule and Purchase Orders. Additionally, non-value-added activities account for 42.86% of the total process, significantly reducing efficiency. To achieve manufacturing excellence, this study recommends improvements such as creating a shared database between the manufacturer and affiliates, simplifying and integrating procedures, and aligning targets with the Master Production Schedule. These improvements are expected to enhance communication, streamline workflows, and reduce unnecessary activities, ultimately improving the overall efficiency of the railroad manufacturing process. Furthermore, these solutions have the potential for scalability in other manufacturing sectors, as the principles of waste reduction, process integration, and data-driven decision-making are universally applicable.

For future research, it would be valuable to conduct a longitudinal study to assess the long-term impact of these proposed improvements on productivity, cost reduction, and overall manufacturing efficiency. Future research could extend the findings to other industries, particularly those with similar manufacturing processes, to evaluate the transferability and scalability of the recommended solutions across different sectors. Finally, a deeper exploration of employee training programs and their role in achieving continuous improvement and fostering a culture of manufacturing excellence would provide further insights into the human element of process optimization.

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