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A PROPOSED LEAN SIX SIGMA-BASED APPROACH FOR PRIORITIZING THE IMPACTFUL IMPROVEMENT AREAS: THE PACKAGING INDUSTRY

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Abstract:
This study aims to introduce and evaluate the Waste, Technical Characteristics, and Root Causes of Failure modes (WCFM) approach, a methodology grounded in Lean and Six Sigma principles, for enhancing operational efficiency and product quality in modern manufacturing systems. The purpose of this work is to develop a structured prioritization framework that focuses specifically on areas of improvement with the highest potential impact, effectively steering packaging manufacturing industry toward the most critical elements that mitigate failure modes causes, minimize waste, and elevate customer satisfaction. The WCFM approach is presented as a systematic framework comprising three core components: managing non-value adding elements (waste), optimizing technical characteristics, and analyzing root causes of failure modes. Lean methodologies and Six Sigma principles are integrated, leveraging tools such as Quality Function Deployment (QFD), identification of the eight wastes, and thorough root cause assessments. A case study at an International Company, a food packaging industry, illustrates the application and effectiveness of the WCFM approach in both product and process enhancement. The results of the case study demonstrate a significant 11.85% increase in the availability of key machinery, attributed to strategic interventions guided by the WCFM approach. This improvement indicates enhanced operational efficiency and performance. Practically, the WCFM approach offers a comprehensive strategy for addressing root causes, improving technical characteristics, and minimizing waste in manufacturing processes. By adopting this approach, organizations can enhance overall quality, fortify systems against disruptions, and drive operational efficiency. Additionally, the integration of Total Productive Maintenance (TPM) is highlighted as pivotal in ensuring consistent machinery performance. This study contributes to the field by presenting the WCFM approach as an innovative methodology that combines Lean and Six Sigma principles to address contemporary challenges in manufacturing systems. The integration of various tools and the emphasis on holistic improvement underscore the originality and value of this approach in transforming manufacturing processes.

Key words: DMAIC, Operational Improvement, Root Cause Analysis, Quality Function Deployment

INTRODUCTION

In the current competitive landscape, manufacturing organizations are pressed to consistently elevate their productivity and offerings, striving to bolster their market position. This imperative has become particularly noticeable in the post-COVID-19 landscape. Central to these endeavors is the efficient functioning of the manufacturing processes, which indirectly shapes customer satisfaction through timely and consistent product delivery.

While many manufacturing entities struggle with productivity challenges, the key underlying issue often stems from lapses in the production line, manifesting as resource wastage and consequential delays. Such pitfalls largely arise when production decisions do not optimally align with areas that yield maximum productivity impact.

Lean Manufacturing and Six Sigma are widely used in companies for continuous improvement [1]. In light of this [2], introduced a framework employing Multi-Criteria Decision-Making (MCDM) and Fuzzy Analytic Network Process in tandem with Quality Management Practices specifically tailored for Micro, Small, and Medium Enterprises (MSMEs). This framework is envisioned as a decision-support tool to refine manufacturing line performance.

Although the typical Define, Measure, Analyze, Improve, and Control (DMAIC) approach coupled with lean principles has been a go-to for diagnosing production line challenges, it falls short in holistically encapsulating the intricate interplay of Waste, Technical Characteristics, and Root Causes of Failure Modes (WCFM) – the three core tenets of our proposed approach. Notably, a deliberate and nuanced understanding of the relationships amongst these components can empower planners to prioritize improvement initiatives more astutely, guided by technical specifications and overarching system implications. While prioritization techniques have been employed individually on lean waste, root causes [3], and customer needs [4], their collective integration remains uncharted – a gap this research aspires to bridge.

To this end, our study unfolds a novel methodology that underscores the interconnectedness of the three components, aiming to uplift the quality of manufacturing processes and the resultant products. Each component is critical in the overall quality of manufacturing processes and products. The effective management of non-value-adding elements leads to more efficient and cost-effective operations, optimization of technical characteristics ensures the production of high-quality and consistent products, and a thorough analysis of failure modes' root causes helps prevent defects and enhance product reliability. Collectively, these elements contribute to a comprehensive approach to quality, covering aspects of efficiency, effectiveness, and reliability, which are essential in a competitive manufacturing environment. Hence, the above aim was established.

The focal point of this study is a case study on a food-container cardboard production line, which has encountered challenges in resource allocation, scheduling, and customer satisfaction.

Accordingly, this work attempts to answer the following question: *what are the procedural stages for packaging manufacturing sector to meet and exceed customer satisfaction levels and deliver consistently reliable products despite the ever-present hurdles of limited resources, including time and cost?*

This study embarks on a journey to innovate and refine a new approach to answer the research question. Our objective is to develop a structured prioritization framework that focuses specifically on areas of improvement with the highest potential impact, effectively steering food packaging manufacturing sector toward the most critical elements that mitigate failure modes causes, minimize waste, and elevate customer satisfaction. This approach promises solutions and a transformative roadmap for success in today's competitive market.

While our methodology gleans insights from pre-existing tools, its distinct contributions to lean management and manufacturing applications are:

1. It unveils a unique methodology linking three pivotal components (Waste, Technical Characteristics, and Root Causes of Failure Modes) for a holistic quality enhancement approach.
2. A fresh categorization model that ascertains the depth of relationships between the components, facilitating the ranking and subsequent prioritization of solutions tailored to customer prerequisites.
3. Practical implications offer managers a refined lens to classify and sequence improvement endeavors for optimal outcomes.

LITERATURE REVIEW

This section delves into four distinct yet interconnected domains of quality management and process improvement methodologies: DMAIC, Lean, Six Sigma, and Theory of Constraints (TOC). Each area represents a unique approach to enhancing operational efficiency, reducing defects, and optimizing processes within various industries. By exploring the existing body of knowledge in these four domains, this review seeks to identify gaps related to the quality aspects of these improvements.

Applications of DMAIC in Quality Management and Process Improvement

DMAIC (Define, Measure, Analyse, Improve, Control) has been successfully applied in different contexts to address issues such as waste, technical characteristics, failure, and root causes. For instance [5], investigated the problem of rejection in the fuel filters of the automobile filter manufacturing industry to improve processes to reduce the rejection level and process variation by removing waste [6] implemented the DMAIC cycle as an element of continuous improvement in practice to increase the effectiveness of the production process. [7] used the DMAIC methodology to improve the performance of manufacturing processes and determine root causes. Lean manufacturing has also been used, adding an extra dimension to the productivity improvement approach. [8] used the DMAIC approach to identify and eliminate various process wastes limiting the performance and efficiency of a supply chain system used in an electronic product manufacturing company. [9] applied DMAIC combines Lean, visual management, and standardized work to increase production and decrease delivery time and waste. [10] contributed to new knowledge-based DMAIC on the root causes of poor productivity and process performance within manual finishing operations in a laminated timber panel production cell. [11] introduced the step-by-step application of the DMAIC methodology for identifying and reducing bag production line downtime and examined the present operations management. [12] used Six Sigma DMAIC to reduce the time-wasting of line supervisors in Aluminium car parts manufacturers. Statistical tools and techniques were also used to find the root cause of variation, reduce the time-wasting, and provide a solution. [13] applied the SS DMAIC methodology to reduce the rejections experienced in manufacturing the doors of a telecommunication cabinet. [14] implemented the SS DMAIC in household appliance manufacturing to analyze door-panel alignment defects in built-in ovens. [15] achieved cost reduction and quality improvement in SMEs by implementing the DMAIC stages of Six Sigma. [16] demonstrated the effectiveness of DMAIC in improving product reliability, resulting in a twofold increase in Mean Time to Failure (MTTF). Similarly [17], emphasized using DMAIC to continuously improve process quality by analyzing waste data, identifying root causes, and implementing improvements. Furthermore [18], utilized DMAIC and lean approaches to improve service quality by analyzing the waste of customers' waiting time. In addition to these applications, DMAIC has been instrumental in addressing technical issues. For example [19], employed the DMAIC approach for process capability improvement in aluminum alloy wheel machining, highlighting its effectiveness in quality enhancement.

Moreover [20], focused on improving the sigma level of the screening process through the DMAIC approach, showcasing its relevance in addressing technical challenges. Furthermore, DMAIC has been utilized to identify and address failures and root causes [21], highlighting DMAIC as a structured methodology for reducing process variances and defects, aligning with the goal of quality improvement. Additionally [22], integrated DMAIC with other techniques, such as Failure Mode and Effect Analysis (FMEA) and Root Cause Analysis, to develop a quality improvement matrix, emphasizing the role of DMAIC in addressing root causes. These references collectively demonstrate the versatility and effectiveness of DMAIC in addressing waste, technical characteristics, failure, and root causes across various domains, including manufacturing, service, and product reliability improvement.

Applications of Lean, Six Sigma, and Lean Six Sigma in Quality Management and Process Improvement

To improve quality and reduce waste, organizations can adopt Lean thinking, which aims to eliminate non-value-adding activities and standardize work practices [23]. Lean thinking involves value stream mapping, root cause analysis, and team charters to identify and address waste and inefficiencies [24]. By implementing Lean principles, organizations can enhance productivity, quality, and satisfaction [25]. Furthermore, Lean Six Sigma has improved quality while reducing costs, indicating no trade-off between quality and expenses [26]. Additionally, Lean healthcare is designed to create continuous improvement by eliminating waste and improving processes [27]. The application of Lean in healthcare is expected to increase steadily in the coming years [28]. Lean is commonly adopted in healthcare using value stream mapping, improvement events, and standardization [29]. Moreover, Lean has been associated with improved clinical outcomes and quality of care for patients with heart failure [30]. However, it is essential to ensure that Lean implementation is comprehensive and not superficial to achieve long-term improvements in healthcare [31]. Reducing patient discharge time using Six Sigma was illustrated by [32] and reducing patient waiting time by [33].

The Six Sigma methodology has been widely applied in various industries. Six Sigma aims to achieve nearly perfect quality levels by minimizing defects and waste [34]. It incorporates the DMAIC (Define-Measure-Analyze-Improve-Control) approach to identify and eliminate the root causes of defects [35]. Integrating lean tools within the DMAIC approach facilitates waste elimination and defect reduction [36]. Additionally, Six Sigma is a statistical concept that can minimize failure variations, achieve high sigma values, and develop industrial system performance [37]. The methodology also involves using tools such as Cause and Effect diagrams and Failure Mode and Effect Analysis to discover and prioritize action on root causes, incorporating cost-effective solutions [38]. Six Sigma has been found to improve profitability, reduce defects, and enhance the quality of processes, leading to increased organizational profits [39]. For example [40], implemented the Six Sigma methodology to improve the quality and efficiency of furniture production. It has also been integrated with other decision support systems and risk analysis methods to analyze product defect levels and assess the root causes of defects [41]. The implementation of the conjunction of LSS and Industry 4.0 was demonstrated by [42]. Authors [43, 44] implemented the SS DMAIC to improve the performance of the tableting process.

Moreover, Six Sigma has improved process capability and enhanced product quality by eliminating waste and non-value-adding activities [45]. The methodology has been reported to be more comprehensive than prior quality initiatives such as Total Quality Management and Continuous Quality Improvement [46]. In conclusion, Six Sigma has effectively minimized defects, reduced waste, and enhanced process quality across various industries. Its structured approach, integration with lean tools, and focus on root cause analysis have contributed to its success in improving organizational competitiveness and profitability.

The integration of Lean and Six Sigma (LSS) in the Lean Six Sigma methodology has been recognized for its effectiveness in improving quality and operational performance in various systems [47]. It is also acknowledged for its potential to enhance the efficiency of administrative procedures and the overall quality of education in academic institutions [48]. The LSS approach was used to improve the railcar bogie assembly process, reduce the lead time, increase the value-added time, and reduce the non-value-added time [49]. [50] presented a maturity model to deliver a culture of continuous improvement through Lean Six Sigma, focusing on case studies and a structured approach, which could provide insights into analyzing relationships and their strengths within a Lean Six Sigma framework. [51] presented an integrative conceptual framework of Lean Six Sigma as a project and an organizational change process, identifying success factors and their impact [52]. The systematic literature review highlights Six Sigma projects' methods to identify and eliminate waste. [53] on the prioritization and ranking of lean practices within an automotive component manufacturing organization provides insights into how technical characteristics are evaluated and optimized for improved performance.

While the studies above provide valuable insights into quality improvements in the manufacturing industry using different approaches, including lean, Six Sigma, DMAIC, and the theory of constraints, it is crucial to note a significant gap in the literature. The impact of waste, technical characteristics, and root causes of failure modes have not been adequately addressed. This omission highlights the need for further research to comprehensively understand how these three pivotal components interact and contribute to effective quality improvement of products. Addressing this gap can significantly enhance our understanding of the complexities involved in quality improvement in the manufacturing industry, especially product quality, and inform more comprehensive and targeted approaches; hence, this work was established.

THE PROPOSED WCFM APPROACH

In the spirit of advancing manufacturing operations, the proposed WCFM approach suggests a multi-dimensional methodology, weaving together the discrete yet interrelated components of waste elimination, technical characteristics optimization, and root cause analysis of failure modes. The WCFM approach emerges as a holistic response to the intricate dynamics that define and influence product quality and operational efficiency, embracing the complexity of modern manufacturing systems and the elevated focus on resource optimization post-COVID-19. See Fig. 1 for the proposed WCFM approach framework.

The approach is methodically constructed through a six-stage framework. By carrying these structured stages, the WCFM approach provides a novel lens through which managers can discern, prioritize, and execute improvement initiatives. The proposed methodology is an extension of established Lean and Six Sigma tools and an example of a deep-seated commitment to Manufacturing performance.

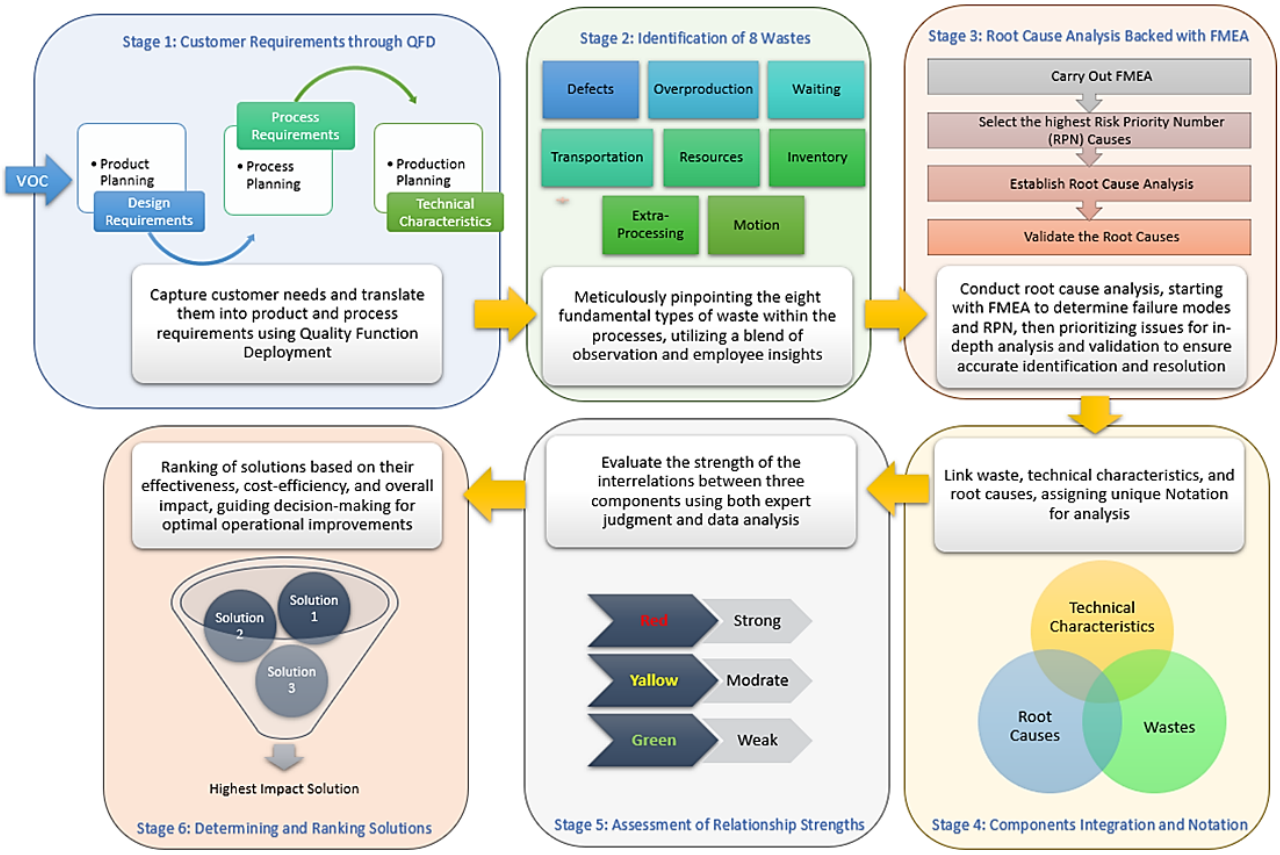


Fig. 1 WCFM Approach Framework

Stage 1: Customer Requirements Through Quality Function Deployment (QFD)

This Stage initiates a profound understanding of customer requirements, employing QFD to ensure that these needs are accurately reflected in product and process designs. In the QFD methodology, customer requirements are systematically translated into design requirements. This process is initiated by identifying what customers value in a product, called 'Customer Requirements.' These are then ranked by importance, guiding the prioritization of design efforts.

The first step of this stage is to implement the first House of Quality (HoQ) using Voice of the Customer (VoC) as input in the product planning step to derive customer requirements from customer feedback and translate it into design requirements. Design Requirements are established, specifying how the product will meet the customer's needs. The VoC could be conducted through surveys, meetings, and other related techniques to determine where the customer sees the value.

The second step, Process Planning, translates the output from the first step, represented by designed requirements, into process requirements. This translation is carried out by identifying the relationships between process steps and product characteristics.

The third step is to derive technical characteristics from the process requirements obtained from step 2 HoQ. By thoroughly planning these characteristics, the production phase aims to eliminate waste, minimize defects, and ensure the final product aligns with customer requirements and design intentions. This comprehensive planning is critical to delivering a product that meets quality standards and performs reliably in the market.

The QFD matrix helps to visualize and assess the strength of the relationships between customer desires and design specifications. Each relationship is weighted, and a correlation is established, typically using symbols to denote the strength of the correlation. The culmination of this phase is the 'Absolute Importance' score for each design requirement, a numerical value that quantifies its overall significance based on customer input. This score informs decision-making in the subsequent 'Process Planning' and 'Production Planning' phases, where process steps are aligned with the necessary technical characteristics to fulfill the design requirements, ensuring the final product meets customer expectations.

Stage 2: Identification of the 8 Wastes

This Stage Focuses on identifying and categorizing the eight wastes within the production process, laying the groundwork for targeted waste reduction and efficiency enhancement. The eight wastes is a concept central to Lean methodology, rooted in the principles of the Toyota Production System (TPS) and augmented by insights gained from direct observation or 'Gemba walks.' The eight wastes encompass Defects, Overproduction, Waiting, Transportation, Inventory, Motion, Extra-Processing, and the non-utilization of talent or 'Resources.' This systematic recording of waste aligns with the established frameworks in Lean manufacturing, as documented by [54], who emphasize the importance of waste identification as a precursor to process improvement.

Stage 3: Root Causes Analysis Backed with FMEA

This Stage explores and identifies root causes of failure modes using FMEA, pinpointing their root causes to prevent future occurrences and enhance process reliability. Failure Mode and Effects Analysis (FMEA) is thoroughly executed in this critical Stage to identify and evaluate potential failure modes and their underlying causes within the production process [55]. This Stage unfolds through a series of systematic steps:

1. **Initial Brainstorming and Listing:** the purpose is to generate an exhaustive list of possible failure modes, their effects, and causes, laying the groundwork for a comprehensive FMEA. This is done through, in addition to the analysts, a team of quality and technical professionals who are in direct contact with the process.
2. **Risk Prioritization:** Utilizing the risk priority number (RPN), each potential failure cause should be assessed for its severity, occurrence, and detectability based on Table 1 [56]. This assessment enables the prioritization of risks, directing focus toward the most significant concerns.

Table 1
Severity, Occurrence, and Detection Ranking Selection

The severity of Effect:	Occurrence Rating	Detection:
1. None	1. Remote < .01/1000	1. Almost Certain
2. Very Minor	2. Low – 0.1/1000	2. Very High
3. Minor	3. Low – 0.5/1000	3. High
4. Very Low	4. Moderate – 1/1000	4. Moderately High
5. Low	5. Moderate – 2/1000	5.Moderate
6. Moderate	6. Moderate – 5/1000	6. Low
7. High	7. High – 10/1000	7. Very Low
8. Very High	8. High – 20/1000	8. Remote
9. Hazardous with warning	9. Very High 50/1000	9. Very Remote
10. Hazardous without warning	10. Very High > 100/1000	10. Almost Impossible

Source: [56].

3. **Root Cause Analysis (RCA):** RCA is applied to investigate and ascertain the foundational reasons for each failure cause. This step is done through the 5-Whys and fishbone diagram. This in-depth analysis is pivotal to preventing recurring issues and is a fundamental component of continuous improvement within Lean Six Sigma practices.
4. **Validation of Causes:** The validation ensures that all the identified causes are eligible and valid. By integrating these steps, the FMEA and RCA within the WCFM framework embody the Lean Six Sigma commitment to detailed, data-driven analysis. The team mentioned in point 1 is responsible of this step. This approach ensures a robust foundation for

developing strategic interventions to rectify and enhance manufacturing processes.

Stage 4: Components Integration and Notation

In Stage 4, the critical task is to interconnect the key elements of Waste, Technical Characteristics, and Root Causes, establishing a comprehensive understanding of their interrelationships within the production system. This is done by the team who has been previously formed. This Stage involves interlinking the foundational components of the Waste, Technical Characteristics, and Root Causes of Failure Modes (WCFM) framework. To facilitate this, we have established a systematic notation for each component.

Moving forward, we closely examine the interrelationships between Root Causes (designated as ri) and Technical Characteristics (denoted as tj). These relationships are depicted using a binary matrix, where a "1" signifies a direct relationship and a "0" indicates no relationship. Following this notation, the next step involves incorporating the third component, 'Wastes' (wk), into the relationship analysis. We extend the binary association to encompass the triad of components, creating a three-dimensional matrix that maps the interactions between Root Causes, Technical Characteristics, and Wastes.

These relationships are pivotal as they offer a comprehensive view of the system's interactions and are instrumental in guiding the subsequent prioritization of solutions.

In summary, Stage 4 of our study explains the connections between the components of the WCFM framework but also establishes a robust foundation for the strategic alignment of solutions. This alignment is essential for targeted improvements and underscores the efficacy of the Lean Six Sigma approach in our operational enhancement endeavors.

Stage 5: Assessment of Relationship Strengths

This Stage assesses the strength of the relationships between the WCFM components, providing insights into the most impactful areas for intervention and improvement. This Stage thoroughly assesses the strengths of the relationships identified within the Waste, Technical Characteristics, and Root Causes of Failure Modes (WCFM) framework. This assessment is pivotal in distinguishing between the varying degrees of influence that each relationship exerts on the operational efficiency and effectiveness within the system. By employing a detailed and nuanced evaluation process, we categorize each relationship into strengths such as "Strong," "Moderate," and "Weak."

Stage 6: Determining and Ranking Solutions

The final Stage focuses on evaluating and prioritizing potential solutions based on their effectiveness, cost, and impact, guiding strategic decision-making for operational enhancements. In the Lean Six Sigma methodology, prioritizing solutions is critical, ensuring that selected improvements are both impactful and financially sustainable. Based on this concept, in this Stage of our WCFM approach, we embark on a comprehensive process to determine and rank solutions, seamlessly merging the processes of identification, categorization, and prioritization within the WCFM approach.

To provide a robust academic foundation for our approach and provide insights into ranking and prioritization processes, which could inspire and support the proposed approach, we reviewed very related work, including but not limited to [57], who identified, prioritized, and ranked lean practices in an automotive component manufacturing organization using interpretive ranking process (IRP) and interpretive structural modeling (ISM). These methodologies could be adapted to categorize and prioritize solutions within the WCFM framework.

Initially, we outline recommended solutions and assign them with their root causes. This foundational step is critical in establishing a clear connection between root causes and potential remedies. Building upon this foundation, we assign a solution to each relationship, encompassing root causes. Subsequently, we group relationships that share a common solution into distinct segments, This segmentation allows us to organize our solutions into manageable categories, each targeting a specific set of interrelated issues.

Moving into evaluating and ranking potential solutions, a systematic prioritization procedure is followed based on the following measures that will be employed in this final Stage:

Components Weighted Average:

The initial step involves analyzing each segment's components – Technical Characteristics, Root Causes, and Wastes – to calculate their respective achievements. For instance, if one root cause within a segment is addressed out of five possible causes, the achievement for that component is quantified at 20%. This analytical step is performed for each element, providing a nuanced perspective of the solution's scope and potential impact.

Segment Aggregated Average:

After computing each component's weighted averages, we calculate the segment aggregated average. This represents the average effectiveness of the solution across all three elements and is essential for assessing the overall potential of a solution to improve the segment it targets. It provides a single, composite measure that reflects the multifaceted nature of the solution's expected benefits.

Annual Cost Projection:

We then project the annual cost for each solution's implementation, estimating expenses based on market research, historical implementation data, and vendor quotes. This projection is vital for budget planning and resource allocation.

Cost Acceptance Percentage:

The cost acceptance percentage reflects the packaging manufacturing organization's readiness to incur the projected costs of each solution. This percentage decreases as the solution cost increases, indicating a strategic preference for more cost-effective solutions within the financial boundaries set by the organization.

Impact Percentage:

Impact determination is a crucial measure of the strength of each relationship within a segment. A robust relationship equates to a higher impact percentage, signaling a solution's potency. For instance, each relationship has an impact percent, where Strong is 100%, Moderate is 50%, and Weak is 25%. Sum all weights of all relationships in the one segment based on the scale mentioned and divide by the total number of relationships. For example, if there is a segment that contains three relationships, the first one is “moderate,” the second one is “weak,” and the third one is “weak,” the percentage is” (0.5+0.25+0.25)/3 = 33.33%.

Preference Percentage:

Finally, the preference percentage results from multiplying the segment aggregated average, the cost acceptance percentage, and the impact percentage. This calculation concludes in a prioritized ranking of solutions, with higher percentages signaling a greater preference for implementation. It synthesizes the multi-dimensional analysis into a single, actionable metric that guides decision-making towards the most beneficial and cost-effective improvements. Each measure in this Stage is defined to provide researchers and practitioners with a transparent and replicable methodology for solution prioritization within the WCFM framework. It is crafted to ensure that decisions are data-driven, financially sound, and strategically aligned, facilitating the pursuit of continuous improvement in manufacturing operations.

The subsequent sections will elaborate on applying this methodology through a detailed case study within Jordan's leading food packaging enterprise. This empirical exploration will underscore the efficacy of the WCFM approach in addressing specific challenges encountered in resource allocation, scheduling, and customer satisfaction, thereby validating the theoretical framework proposed in this study. Following the case study, we will discuss our findings' implications and suggest future research directions, ultimately asserting the WCFM approach as a pioneering model for amplifying manufacturing productivity and quality.

RESULTS ANALYSIS AND DISCUSSION

Case Study Background: Regional Food Packaging Materials Factory

This case study examines the application of the WCFM approach in a leading food packaging materials factory. The International Company is known for its extensive cardboard production line, and it has a substantial market presence locally and in over 22 countries. Their portfolio includes eco-friendly product solutions such as paper cups, bags, food trays, boxes, and sandwich wrapping papers. The Company is a primary provider of food packaging services, specializing in producing cardboard food containers. Despite its global reach and commitment to sustainability, the company faces challenges in resource utilization, production efficiency, and customer satisfaction. This study investigates these issues, particularly in the cardboard food-container production line, to provide insights and recommendations for improving operational performance.

After examining the cardboard production, the processes of concern are as follows:

- Printing: Once the order is received along with the design specifications, the operator inputs the data into the printing machine. The machine is set up according to the design, ensuring that the print aligns with the required specifications. This manual setup customization for each unique order.
- Forming: The second process is forming, which involves shaping the printed cardboard into its final form. This stage utilizes two distinct machines, with the choice of machine depending on the specific design requirements. During this process, the machine bends the cardboard and applies glue to make it into the final shape. This ensures that the cartons meet the desired structural standards.

This study aims to explore the implementation and impact of the WCFM approach across various stages of production, highlighting its role in enhancing efficiency, resource optimization, and product quality in the food packaging industry.

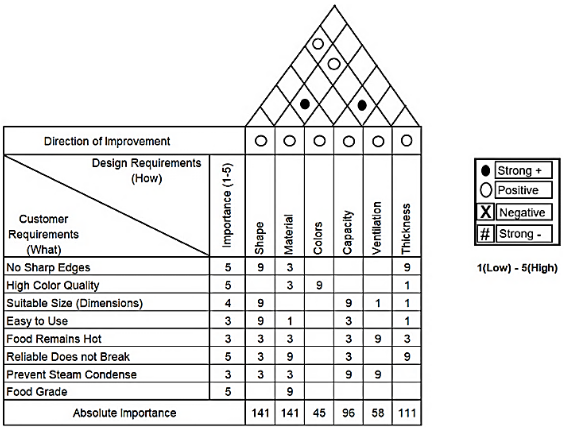
Stages Implementation

Stage 1: Customer Requirements Through QFD

For this particular case study, our subject company – a prominent food packaging materials manufacturer – caters to a diverse clientele, producing a range of items for over 200 customers. Its product portfolio is distinguished by five unique types, categorized based on the number of gluing points required in forming. These product types range from straight lines to more complex designs with 2, 3, 4, and 6-point gluing edges. Specifically, the 6-point products are intricately designed with six edges that require gluing, culminating in a finished food packaging item. For this study, we selected a representative sample encompassing 12 customers, each providing 25 units across all five product types, totaling 50 items per type, to assess the diversity and range of our manufacturing capabilities comprehensively.

The "Product Planning" phase in the QFD matrix, Fig. 2, displays the relationship between customer requirements (what the customer wants) and design requirements (how the product will meet those wants). Importance ratings are assigned to customer requirements on a scale from 1 (low) to 5 (high). The matrix then correlates the customer requirements (No Sharp Edges, High Color Quality, Suitable Size (Dimensions), Easy to Use, Food Remains Hot, Reliable Does Not Break, Prevent Steam Condense, and Food Grade) with design characteristics (Shape, Material, Colors, Capacity, Ventilation, and Thickness).

The correlation is signified by symbols: solid circles (●) denote a strong positive relationship, hollow circles (○) denote a weak positive relationship, cross (×) denotes a strong negative relationship, and a hashtag (#) denotes a weak negative relationship.



Customer Requirements (What) / Design Requirements (How)	Importance (1-5)	Shape	Material	Colors	Capacity	Ventilation	Thickness
Direction of Improvement		○	○	○	○	○	○
No Sharp Edges	5	9	3				9
High Color Quality	5		3	9			1
Suitable Size (Dimensions)	4	9			9	1	1
Easy to Use	3	9	1		3		1
Food Remains Hot	3	3	3		3	9	3
Reliable Does not Break	5	3	9		3		9
Prevent Steam Condense	3	3	3		9	9	
Food Grade	5		9				
Absolute Importance		141	141	45	96	58	111

Fig. 2 Product Planning Phase

After that, the relationship between the customer requirements and design requirements is signified as 9 for high importance, 3 for medium, and 1 for low. As a result, the "Absolute Importance" row at the bottom is calculated by multiplying each relationship by the importance of the corresponding customer requirement. This quantifies the overall significance of each design requirement based on customer needs.

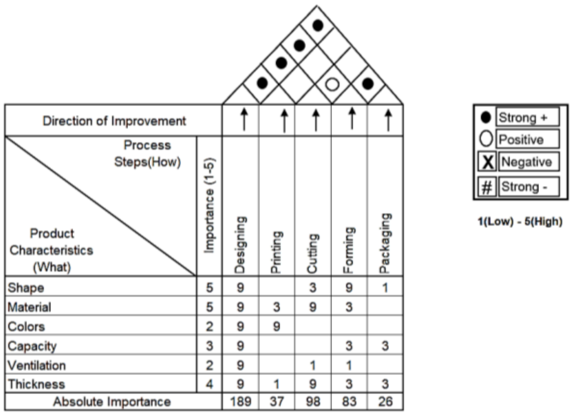
This matrix is essential in ensuring that product development focuses on attributes that are most significant to the customer, thereby improving the direction of product improvement efforts.

In the next phase, the part deployment is not applicable since food containers do not have subcomponents. The "Process Planning" phase in QFD, Fig. 3, aims to connect product characteristics directly to the various steps involved in the manufacturing process. This phase takes the insights from product planning and translates tchem into actionable steps to produce a product that meets customer requirements.

In this phase, the same product characteristics (Shape, Material, Colors, Capacity, Ventilation, and Thickness) are analyzed against the process steps (Designing, Printing, Cutting, Forming, and Packaging). Each characteristic is assigned an importance level and then evaluated on how much it is affected by each process step.

For instance, if "Shape" has a strong relationship with "Designing," the design phase significantly impacts the shape of the final product. Thus, careful attention needs to be paid during this step to meet the customer's shape requirement.

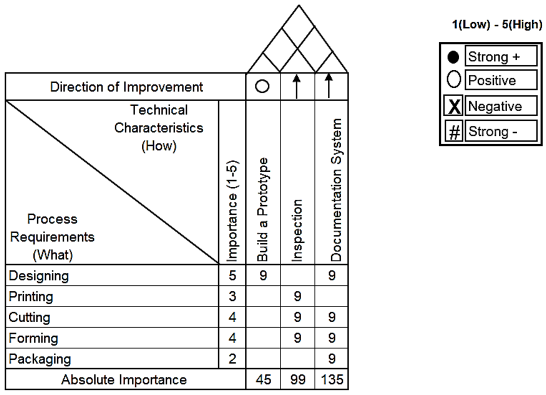
The "Absolute Importance" row at the bottom aggregates these relationships, providing a quantified overview of each process step's overall impact on meeting the product characteristics. This helps prioritize which process steps need more focus and improvement to align with customer values and expectations.



Product Characteristics (What) / Process Steps(How)	Importance (1-5)	Designing	Printing	Cutting	Forming	Packaging
Direction of Improvement		↑	↑	↑	↑	↑
Shape	5	9		3	9	1
Material	5	9	3	9	3	
Colors	2	9	9			
Capacity	3	9			3	3
Ventilation	2	9		1	1	
Thickness	4	9	1	9	3	3
Absolute Importance		189	37	98	83	26

Fig. 3 Process Planning Phase

In the "Production Planning" phase of QFD, Fig. 4, the emphasis shifts from design and process requirements to how these can be translated into concrete, executable actions within the production environment.



Process Requirements (What) / Technical Characteristics (How)	Importance (1-5)	Build a Prototype	Inspection	Documentation System
Direction of Improvement		○	↑	↑
Designing	5	9		9
Printing	3		9	
Cutting	4		9	9
Forming	4		9	9
Packaging	2			9
Absolute Importance		45	99	135

Fig. 4 Production Planning Phase

This phase aligns process requirements (Designing, Printing, Cutting, Forming, and Packaging) with specific technical characteristics (Building a Prototype, Inspection, and Documentation System) critical to production quality and efficiency.

For each process step, such as Designing or Printing, the team identifies the necessary technical characteristics that must be achieved to meet the established process requirements. This might include the development of prototypes during the Design phase to ensure the product meets customer expectations or a rigorous Inspection process to maintain quality during Printing.

The technical characteristics serve as a roadmap for setting up the production system. For instance, a robust documentation system is essential for maintaining consistency and traceability when cutting through packaging.

Stage 2: Identification of the 8 Wastes

The application of Stage 2 in our study was manifested through an empirical analysis conducted on the production floor. The '8 Wastes Check Sheet' was instrumental in capturing real-time data, providing a vivid snapshot of inefficiencies, which were cataloged in detail in Table 2, providing a foundational understanding of the areas where efficiency gains could be pursued.

Table 2
"8 Wastes Check Sheet"

	Waste Type	Observed Wastes	Description of Issues
D	Defects	Defective Products	Defectives are observed, and quality is an issue
O	Overproduction	Stockpiling finished products	Seize work area
W	Waiting	Communication problems	Machine waiting
		Waiting for material	
N	Non-Utilized Talent	Workers not fully trained	Unsupportive environment
		Untapped skilled Workers	
T	Transportation	Backtracking	Excess Movements
		Moving among departments	
I	Inventory	Excess storage	Making too much stock
M	Motion	Repetitive strokes	Employees frequently walk between departments
E	Extra-Processing	Forming Process 100% inspection	Increase production time
		Extra design details	

Observations such as excessive stockpiling of finished products and machine downtime due to waiting highlighted critical areas for intervention. By correlating these observed wastes with specific production activities, we could prioritize areas with the most substantial impact on operational efficiency, reflecting the practical implications of our findings in pursuing Lean transformation in the food packaging industry.

Stage 3: Root Causes Analysis Backed with FMEA

Failure Mode and Effects Analysis (FMEA) is executed to identify and evaluate potential failure modes and their underlying causes within the production process. This Stage unfolds through a series of systematic steps:

1. **Initial Brainstorming and Listing:** A collaborative brainstorming session, inclusive of pivotal production stakeholders, is conducted to generate a list of possible failure modes, their effects, and causes, as illustrated in Table 3.

The brainstorming team included the quality manager and his assistant, and three technicians of the production process, and the researchers/analyst team who are six. However, the failure modes and effect analysis shown in Table 3 is based on the rubric of the ranking selection as shown in Table 1. Table 1, according to [56], illustrates the guide for determining the severity of the potential effect of failure, occurrence rating, and detection rank. For example, if there is no effect for a specific failure, then the severity is assigned 1. If a specific failure is hazardous and no warning is given, then this effect is assigned a severity number of 10. For the occurrence, if the mechanism of a failure happens rarely (0.01 occurrence in 1000 times or in other words 1 time per 100,000), then the occurrence is remote which is assigned an occurrence rating of 1.

Table 3
Failure Mode and Effects Analysis

Process Function	Potential Failure Modes	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occ	Current Process Controls	Detect	RPN
Printing	Dense Colors Light Colors Miscoloring	Unwanted Color Printing	4	Machine Startup	6	Getting rid of the first ten items at each startup/ one item is sampled every 1000 items	1	24
				Miscommunication (Design)	10		4	160
				Parameters' Variation	10		8	320
Forming	Wrong Gluing Position	Break (8) Undesired Shape (4)	8	Miscommunication (Planning and Design)	10	Clean the gluing gun when it clogs/ 100% inspection	4	320
				Wrong Dimensions Measuring	3		5	120
	Glue Amount Variation	Inadequate Gluing (6)	10	Glue Gun Clogging	9		3	270
		Food Contact (10)		Improper Machine Setup	3		4	120

For those mechanisms that happens very frequently, for example 100 times per 1000 times, then the failure is assigned a mechanism rating very high of 10. Lastly, the detection rating is assigned 1 if the failure will be definitely detected, and 10 if it is impossible to detect it.

The next step identifies potential failure modes within the production process, a meticulous exercise encapsulated in the FMEA Table, shown in Table 3. Each process function is investigated, with potential failure modes systematically recorded alongside their possible effects and severity. The rigor of FMEA is evident in quantifying each potential cause of failure, with occurrences and current process controls mapped to provide a detailed view of risks, as signified by the Risk Priority Number (RPN). For example, in the printing process, dense colors might be an unwanted outcome attributed to machine startup procedures, with a relatively low RPN of 24, indicating a less critical risk. Conversely, miscommunication during the design phase presents a more significant risk, as reflected by a higher RPN of 160. Based on common practice, the acceptable RPN threshold value ranges between 100 to 200. In our work, we will consider 200 as the threshold value, and any risk above 200 is not acceptable and needs action. This table records the current state of process risks. It sets the stage for targeted improvements, with the controls and detection mechanisms hinting at areas where intervention can yield the most significant impact.

2. **Risk Prioritization:** This assessment has shown the identified causes with the highest Risk Priority Numbers (RPN) – Parameters' Variation, Miscommunication (Planning and Design), and Glue Gun Clogging – which will be subjected to an intensive root cause analysis in the next step. These areas were highlighted for their potential to impact the production process's integrity and efficiency significantly.

3. **Root Cause Analysis (RCA):** Delving deeper into the intricacies of identified highest RPN causes, we have employed both the '5 Whys' methodology and the Ishikawa diagram, which identifies the many potential causes of an effect of a problem. Professor Kaoru Ishikawa is the father of the CE diagram [56]. Here, it is used to find the root causes for failure mode causes that are not obvious.

The team conducted a brainstorming session involving all concerned personnel in the process.

There were six stakeholders included in the meeting session, in addition to the research team. This team consisted of the forming process supervisor, printing supervisor, quality manager, supervisor and technician of the design process, and plant manager. Employing the '5 Whys' in Fig. 5, the glue-gun clogging problem results from choosing an under-rated supplier.

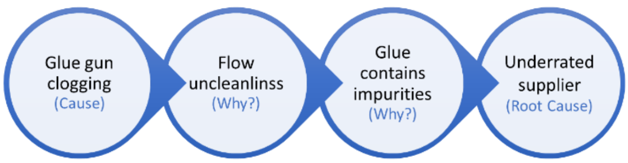


Fig. 5 5-Whys for Glue Gun Clogging

Fig. 6 shows the miscommunication problem results from poor coordination between the planning and designing departments.

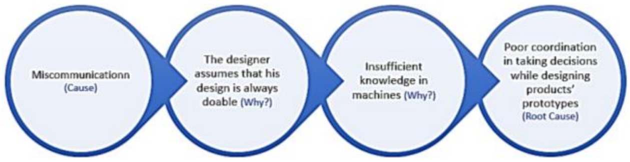


Fig. 6 5-Whys for Miscommunication

As shown in Fig. 7, a list of possible causes for parameter variation was generated, categorized into (materials, management, people, and machine); each has a break-down of potential causes.

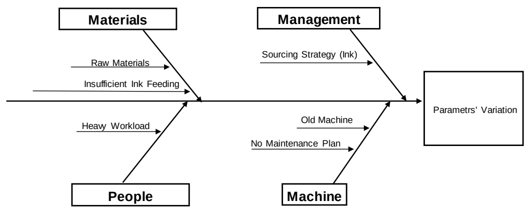


Fig. 7 Ishikawa Diagram for Parameters' Variation

4. **Validation of Causes:** In the root causes validation, each potential cause (resulted from "RCA" step) was illustrated and validated, as shown in Table 4. This step involves a detailed review of observations against desired standards or specifications. Each potential cause is assessed to determine if it genuinely influences the failure mode. For example, 'Heavy Workload' may be validated as a root cause if it violates labor laws by exceeding allowable working hours, impacting employee well-being and productivity. Conversely, while observed, a machine's age might not be a root cause if it still operates within expected performance parameters. The plan ensures that each identified root cause, such as 'Insufficient ink feeding' or 'Glue Gun Clogging,' is not just an observed issue but correlates with a specific shortfall from the desired operational standard, necessitating corrective measures for process improvement. Each cause is thoroughly vetted to differentiate between genuine root causes and mere observations, enabling targeted and practical solutions.

Stage 4: Components Integration and Notation

In the fourth Stage of our approach, we operationalize the integration of critical components within the Waste, Technical Characteristics, and Root Causes (WCFM) framework through a comprehensive binary notation system.

Table 5 establishes the groundwork by defining the technical characteristics, root causes, and wastes relevant to our study, such as "Build a prototype (t_1)" and "Heavy Workload (r_1)."

Table 6 highlights the judgmental analysis used to identify significant relationships between root causes and technical characteristics, for example, illustrating how "Heavy Workload (r_1)" is directly related to "Inspection (t_2)" and "Documentation system (t_3)."

Table 4
Cause Validation Plan

Potential Causes of Failure	Causes	Observation	Desired Status/ Specification	Specification Reference	Remarks
Parameters Variation	Heavy Workload	Intensive Working Hours (Up to 12 hours a day, seven days a week)	No more than 48 hours of duty per week, with a weekly holiday	Jordanian labor law	Root cause
	Old Machine	In the useful life (19 years)	Less than 20 years	Machine manual	Not a root cause
	No Maintenance Plan	The inspection scanner has malfunctioned/ unscheduled maintenance or repair.	Have a defect detection/ Schedule preventive maintenance plan	-	Root cause
	Sourcing Strategy (Ink)	Quality-oriented	Quality-oriented	-	Not a root cause
	Raw Material	Satisfactory level of quality	Fulfill requirements	Based on customer desire	Not a root cause
	Insufficient ink feeding	No ink refeeding indicator	Maintain a level of ink/ prevent ink from getting below a specific limit	-	Root Cause
Glue Gun Clogging	Choosing under-rated suppliers	Inadequate adhesion in the corners	Consistent glue flow and uniform adhesion at corners	-	Root Cause
Miscommunication	Poor coordination between the planning and designing departments	Missing information	Clear the Communication channel	-	Root Cause

Table 5
Notation for Each Component

Technical Characteristics	Notation	Root Causes	Notation	Wastes	Notation
Build a prototype	t_1	Heavy Workload	r_1	Defective Products	w1
Inspection	t_2	No Maintenance Plan	r_2	Stockpiling finished products	w2
Documentation system	t_3	Insufficient ink feeding	r_3	Communication problems	w3
		Choosing under-rated suppliers	r_4	Waiting for material	w4
		Poor coordination between the planning and designing departments	r_5	Workers not fully trained	w5
				Untapped skilled Workers	w6
				Backtracking	w7
				Moving among departments	w8
				Excess storage	w9
				Repetitive strokes	w10
				100% forming inspection	w11
				Extra design details	w12

Table 6
Root Causes and Technical Characteristics Binary Relationship Matrix

Technical Characteristics/Root Causes	Build a prototype (t_1)	Inspection (t_2)	Documentation system (t_3)
Heavy Workload (r_1)	0	1	1
No maintenance plan (r_2)	0	1	1
Insufficient ink feeding (r_3)	0	1	0
Choosing under-rated suppliers (r_4)	0	1	0
Poor coordination between the planning and designing departments (r_5)	1	0	1

Building upon this, Table 7 showcases a three-dimensional analysis that further incorporates wastes, revealing complex relationships such as the interaction between "Heavy Workload (r_1)," "Inspection (t_2)," and "Defective Products (w1)."

Table 7
Tripartite Relationship Matrix of WCFM Components

Wastes	(r_1, t_2)	(r_1, t_3)	(r_2, t_2)	(r_2, t_3)	(r_3, t_2)	(r_4, t_2)	(r_5, t_1)	(r_5, t_3)
Defective Products (w1)	1	1	1	1	1	1	0	0
Stockpiling finished products (w2)	0	1	0	0	0	0	0	0
Communication problems (w3)	0	1	0	0	0	0	1	0
Waiting for material (w4)	0	1	0	0	0	0	0	0
Workers not fully trained (w5)	0	0	0	0	0	0	0	0
Untapped skilled Workers (w6)	0	0	0	0	0	0	0	0
Backtracking (w7)	0	0	0	0	0	0	0	0
Moving among departments (w8)	0	0	0	0	0	0	0	0
Excess storage (w9)	0	0	0	0	0	0	0	0
Repetitive strokes (w10)	0	0	0	0	0	0	0	0
100% forming inspection (w11)	0	0	1	0	0	0	0	0
Extra design details (w12)	0	0	0	0	0	0	1	0

This case study exemplifies the practical application of our framework, demonstrating how the methodology can be used to systematically identify and analyze the multifaceted relationships within an organization, thereby enabling targeted interventions for operational enhancement.

Stage 5: Assessment of Relationship Strengths

In Stage 5 of our approach, we analyze the strengths of the previously identified relationships within our WCFM framework. Each relationship's strength is evaluated through a reasonable process firmly rooted in a deep understanding of the case, as outlined in Table 8.

Take, for instance, the relationship denoted as R(r_1, t_2, w1). This relationship represents the interaction between a Heavy Workload (root cause), Inspection (technical characteristic), and Defective Products (waste). This particular triad is identified to have a strong relationship due to observable patterns within the printing department. Under heavy workload conditions, it was noted that workers often expedited tasks to meet high demand. This rush resulted in inadequate inspection of the machine parameters, leading to a higher rate of product defects.

The rectification of the root cause – Heavy Workload – in this scenario is expected to significantly positively influence the other two components, reducing waste and enhancing adherence to technical specifications. Therefore, we categorize this as a strong relationship, indicating that solutions targeting this relationship will likely profoundly impact the system’s overall efficiency and quality.

Table 8
Evaluation of WCFM Relationships' Strength

Relationship Notation	Relationship	Relationship Strength
R (r_1, t_3, w2)	Heavy Workload – Documentation system – Stockpiling finished products	Strong
R (r_1, t_3, w1)	Heavy Workload – Documentation system – Defective Products	Weak
R (r_1, t_2, w1)	Heavy Workload – Inspection – Defective Products	Strong
R (r_2, t_2, w1)	No Maintenance Plan – Inspection – Defective Products	Strong
R (r_2, t_3, w1)	No Maintenance Plan – Documentation system – Defective Products	Moderate
R (r_4, t_2, w1)	Choosing under-rated suppliers – Inspection – Defective Products	Moderate
R (r_3, t_2, w1)	Insufficient Ink Feeding – Inspection – Defective Products	Moderate
R (r_1, t_3, w3)	Heavy Workload – Documentation system communication problems	Strong
R (r_5, t_1, w3)	Poor coordination between the planning and designing departments – Build a prototype – Communication problems.	Strong
R (r_1, t_3, w4)	Heavy Workload – Documentation system – Waiting for Material	Strong
R (r_2, t_2, w11)	No Maintenance Plan – Inspection –Forming 100% inspection	Strong
R (r_5, t_1, w12)	Poor coordination between the planning and designing departments – Build a prototype – Extra design details.	Strong

In essence, this Stage of our study is not merely an assessment of interactions but also a strategic determinant of where to focus our improvement efforts. It solidifies our approach towards prioritizing solutions that will most effectively reduce waste and bolster technical compliance, ultimately leading to heightened operational performance in line with Lean Six Sigma principles.

Stage 6: Determining and Ranking Solutions

In this Stage of our WCFM approach, we embark on a comprehensive process to determine and rank solutions, seamlessly merging the processes of identification, categorization, and prioritization within the WCFM approach. Table 9 directly links identified root causes and the recommended solutions. This foundational step ensures a targeted approach to problem-solving, emphasizing the critical link between problems (like heavy workload, lack of maintenance plans, and insufficient ink feeding) and their potential remedies (such as flexible workforce strategies and total productive maintenance).

Table 9
Recommended Solutions for Root Causes

Root Cause	Recommended solution
Heavy Workload (r_1)	**Flexible Workforce Strategies:** Introduce flexible workforce strategies, such as cross-training employees to enable them to work on multiple tasks and rotate between different roles to manage peak demand periods more effectively.
No maintenance plan (r_2)	**Total Productive Maintenance (TPM):** Develop a comprehensive preventive maintenance schedule based on Total Productive Maintenance (TPM) principles. This schedule should be integrated into the daily workflow and include regular inspections, standardized work for maintenance tasks, and involve operators in routine maintenance to foster a sense of ownership and proactive care for machinery.
Choosing under-rated suppliers (r_4)	**Revise the supplier selection criteria:** Revise the supplier selection criteria to include stringent quality standards and performance metrics. Employ a Supplier Relationship Management (SRM) system to evaluate supplier performance continuously and establish long-term partnerships with suppliers that align with the company's quality objectives.
Insufficient ink feeding (r_3)	**Automatic Ink-level Monitoring System:** Introduce an automatic ink-level monitoring system with alerts for refills to maintain consistent ink levels. Apply the poka-yoke (mistake-proofing) concept to the ink feeding system to prevent the issue from occurring, ensuring that ink levels cannot fall below a critical threshold.
Poor coordination between the planning and designing departments (r_5)	**Interdepartmental Collaboration:** Facilitate interdepartmental collaboration by establishing a concurrent engineering approach, where cross-functional teams work together throughout the product development cycle. Implement regular design review meetings and utilize collaborative project management tools to ensure alignment and real-time communication between departments.

Table 10 details the relationships between root causes, technical characteristics, and wastes, with each relationship assigned a specific solution. This methodological step aligns with the Lean Six Sigma philosophy of addressing issues in a manner that is both systematic and root-cause-focused.

Table 11 groups relationships by standard solutions into segments, allowing for a structured approach to tackle interrelated issues. This packaging manufacturing organization aids in understanding how multiple problems can be addressed through a single, comprehensive solution.

Table 10
The Selected Solution for Each Related Relationship

Relationship Notation	Relationship	Selected solution
R (r_1, t_3, w2)	Heavy Workload – Documentation system – Stockpiling finished products	Flexible Workforce Strategies
R (r_1, t_3, w1)	Heavy Workload – Documentation system-Defective Products	Flexible Workforce Strategies
R (r_1, t_2, w1)	Heavy Workload – Inspection – Defective Products	Flexible Workforce Strategies
R (r_2, t_2, w1)	No Maintenance Plan – Inspection – Defective Products	TPM
R (r_2, t_3, w1)	No Maintenance Plans – Documentation system-Defective Products	TPM
R (r_4, t_2, w1)	Choosing under-rated suppliers – Inspection-Defective Products	Revise the supplier selection criteria
R (r_3, t_2, w1)	Insufficient Ink Feeding – nspection – Defective Products	Automatic Ink-level Monitoring System
R (r_1, t_3, w3)	Heavy Workload – Documentation system communication problems	Flexible Workforce Strategies
R (r_5, t_1, w3)	Poor coordination between the planning and designing departments – Build a prototype – Communication problems	Interdepartmental Collaboration
R (r_1, t_3, w4)	Heavy Workload – Documen-tation system-Waiting for Material	Flexible Workforce Strategies
R (r_2, t_2, w11)	No Maintenance Plan – Inspection – Forming 100% inspection	TPM
R (r_5, t_1, w12)	Poor coordination between the planning and designing departments – Build a prototype – Extra design details.	Interdepartmental Collaboration

Table 11
Segment-Based Solutions

Segment	Suggested Solution	Relationship Notation
Segment 1	Flexible Workforce Strategies	R (r_1, t_2, w1)
		R (r_1, t_3, w1)
		R (r_1, t_3, w2)
		R (r_1, t_3, w4)
		R (r_1, t_3, w3)
Segment 2	TPM	R (r_2, t_2, w1)
		R (r_2, t_2, w11)
		R (r_2, t_3, w1)
Segment 3	Interdepartmental Collaboration	R (r_5, t_1, w12)
		R (r_5, t_1, w3)
Segment 4	Automatic Ink-level Monitoring System	R (r_3, t_2, w1)
Segment 5	Revise the supplier selection criteria	R (r_4, t_2, w1)

Table 12 illustrates the packaging manufacturing organization's readiness to accept the financial implications of proposed solutions, setting a strategic preference for cost-effectiveness. The decreasing acceptance percentage with rising costs underscores the importance of budget considerations in the decision-making process.

Table 12
Cost Acceptance Percentage Ranges

Range	Cost Acceptance Percentage
0-1,000 $	100%
1,000-5,000 $	75%
5,000-10,000 $	50%
10,000 and above $	25%

Finally, Table 13 outlines the prioritization process, combining weighted averages, cost acceptance, and impact percentages to calculate a preference percentage for each solution. This complex yet systematic approach enables the ranking of solutions based on their potential impact, cost-efficiency, and overall benefit to the organization.

Table 13
Strategic Solutions Cost-Benefit Analysis

Solution	Segment	Components Weighted Average	Segment Aggregated Average	Annual Cost Projection	Cost Acceptance Percentage	Impact Percentage	Preference %
Flexible Workforce Strategies	segment 1	Technical Characteristics = 67%	51.1%	Include costs for additional training, cross-training, and development of flexible job descriptions Estimated cost: \$2,000-\$3,750	75%	85%	32.6%
		Root Causes = 20%					
		Wastes = 67%					
Total Productive Maintenance (TPM)	segment 2	Technical Characteristics = 67%	40.0%	This can involve training costs, setup for preventive maintenance schedules, and potential initial maintenance work to bring machinery up to standard. Estimated Cost: \$5,000-\$10,000	50%	88%	18%
		Root Causes = 20%					
		Wastes = 33%					
Interdepartmental Collaboration	segment 3	Technical Characteristics = 33%	28.9%	This may involve the costs of implementing new communication tools or software, training, and potential consultancy fees if external help is sought. Estimated Cost: \$2,000-\$3,000	75%	100%	22%
		Root Causes = 20%					
		Wastes = 33%					
Automatic Ink-level Monitoring	segment 4	Technical Characteristics = 33%	23.3%	The cost for electronic monitoring systems plus potential software and installation costs. Estimated Cost: \$3,000-\$5,000	75%	50%	9%
		Root Causes = 20%					
		Wastes = 17%					
Revise the supplier selection	segment 5	Technical Characteristics = 33%	23.3%	This can include the costs associated with market research, potential consultancy fees, and the administrative costs of changing suppliers. Estimated Cost: \$1,000-\$2,000	75%	50%	9%
		Root Causes = 20%					
		Wastes = 17%					

The implementation of the WCFM approach, as illustrated through these tables, reveals a comprehensive, data-driven approach to problem-solving within manufacturing operations. The detailed analysis above demonstrates a commitment to operational excellence and continuous improvement. The methodology's strength lies in its rigorous, step-by-step process that ensures each solution is thoroughly evaluated against multiple criteria, including technical feasibility, cost implications, and expected impact.

Challenges in this approach may include the complexity of data analysis, potential resistance to change within the organization, and the necessity for accurate, up-to-date information for effective decision-making. However, as outlined in the tables, the structured prioritization and categorization process provides a clear pathway through these challenges, ensuring that decisions are made on a solid empirical foundation.

Moreover, using segment aggregated averages and impact percentages introduces an accurate understanding of each solution's potential, encouraging strategic decision-making that balances cost with benefits. As a culmination of this analysis, the preference percentage is a powerful tool for guiding implementation efforts toward the most impactful, cost-effective solutions.

In conclusion, the WCFM approach, supported by the detailed methodologies described, offers a robust framework for enhancing operational efficiency and driving continuous improvement in manufacturing environments. Integrating Lean Six Sigma principles with a structured prioritization and categorization process ensures that solutions are strategically selected and aligned with the organization's financial and operational objectives.

CONCLUSION AND FUTURE WORK

This study examined a food-container cardboard production line, addressing challenges in resource allocation, scheduling, and customer satisfaction. It introduced the Waste, Technical Characteristics, and Root Causes of Failure Modes (WCFM) approach to enhance operational efficiency and product quality in modern manufacturing systems. The primary objective was to develop a structured prioritization framework targeting high-impact improvement areas to guide the packaging manufacturing industry toward mitigating failure mode causes, minimizing waste, and elevating customer satisfaction.

The WCFM approach integrates Lean methodologies and Six Sigma principles, comprising three core components: managing non-value-adding elements (waste), optimizing technical characteristics, and analyzing root causes of failure modes. Tools such as Quality Function Deployment (QFD), identification of the eight wastes, and thorough root cause assessments are leveraged. A case study at an international food packaging company demonstrated the approach's effectiveness, showing an 11.85% increase in key machinery availability, indicating enhanced operational efficiency and performance.

This structured prioritization framework guides manufacturers towards critical elements that mitigate failure modes, minimize waste, and improve customer satisfaction, offering solutions and a transformative roadmap in today's competitive market. Distinct contributions include a unique methodology linking the three pivotal components for a holistic quality enhancement approach, a categorization model clarifying component relationships to facilitate prioritization, and practical implications to help managers classify and sequence improvement endeavors.

The study robustly affirms the WCFM approach as an innovative and transformative strategy for manufacturing productivity. By embracing Lean and Six Sigma principles, the framework demonstrated its capacity to dissect and address complex manufacturing challenges. Critical interventions, such as Total Productive Maintenance (TPM), revising supplier selection criteria, integrating an Automatic Ink-Level Monitoring System, and advancing Interdepartmental Collaboration, drove significant operational efficiency improvements, reflected in the increased machinery availability.

The WCFM approach sets a new precedent for manufacturing enhancements, serving as a scalable and versatile blueprint for operational excellence across various contexts. The introduction of Flexible Workforce Strategies underscores its adaptability, ensuring resilience and efficiency in human resource management. This synergy of strategic solutions, underpinned by a meticulous prioritization process within the Lean Six Sigma framework, has resolved prevailing challenges and paved the way for sustainable, continuous improvement.

In summary, the WCFM approach aligns closely with critical performance criteria such as efficiency, quality, reliability, customer satisfaction, and adaptability. By addressing waste, optimizing technical characteristics, and analyzing failure modes, this approach enables packaging manufacturing organizations to meet and exceed performance standards essential for operational excellence and competitive advantage.

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