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Integration of Lean Six Sigma and Theory of Inventive Problem Solving for Minimizing Waste in Shuttlecock Industry

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Abstract. *In today's competitive business world, organizations are striving to improve their operations and stay ahead. Lean Six Sigma is a popular approach that helps optimize processes and reduce waste. This research focuses on using Lean Six Sigma and TRIZ together to reduce waste in the shuttlecock industry. The study uses a structured process and tools like Value Stream Mapping and Fault Tree Analysis to find and solve waste issues. The results show problems like unnecessary activities, delays, and defects in the production process. Using TRIZ, suggestions for improvements are made based on the analysis. This study shows that combining Lean Six Sigma and TRIZ can effectively reduce waste and improve processes. The findings add to our understanding of using these methods in the shuttlecock industry and offer insights for future research and improvements.*

Keywords: *Shuttlecock industry, Defect, Lean Six Sigma, TRIZ*

I. INTRODUCTION

In today's intensely competitive business environment, organizations seek operational excellence and continuous refinement to maintain a competitive advantage. Lean Six Sigma has emerged as a powerful methodology in this pursuit, offering a structured and data-driven approach to process optimization and waste reduction (Dutt, 2013). Combining Lean with Six Sigma has resulted in the development of a successful and disciplined organizational transformation strategy and a problem-solving tool known as Lean Six Sigma (Shokri, 2019). Several organizations worldwide have adopted Lean Six Sigma methods and are increasingly using them to improve their operations and quality (Chugani, Kumar, Garza-Reyes, Rocha-Lona, & Upadhyay, 2017). This approach offers an excellent way to improve company processes by identifying problems (Sojka & Lepšík, 2020).

Many manufacturing companies has begun implementing Lean Six Sigma (Ruben, Vinodh, & Asokan, 2018). Compared to the service sector, the implementation level of Lean Six Sigma in manufacturing is relatively low (Singh & Rathi, 2019). Previous studies investigated the implementation of Lean Six Sigma in various manufacturing industries, including pharmaceutical (Alkunsol, Sharabati, AlSalhi, & El-Tamimi, 2019), automotive (Ben Ruben, Vinodh, & Asokan, 2017), mould (Pereira, Silva, Domingues, & Sá, 2019), wood furniture (Guerrero, Leavengood, Gutiérrez-Pulido, Fuentes-Talavera, & Silva-Guzmán, 2017), and other industries. Based on previous studies, Lean Six Sigma has been implemented in a variety of industries to help businesses in achieving great financial success and increasing customer satisfaction (Adikorley, Rothenberg, & Guillory, 2017; Elyoussoufi, Mazouzi, & Cherrafi, 2022). However, to confront rising consumption and intensifying competition, organizations require a strategic vision and innovative tools (Antony, Snee, & Hoerl, 2017). The Theory of Inventive Problem Solving (TRIZ) can provide solutions to these flaws (Soti, Shankar, & Kaushal, 2012).

Developed by Genrich Altshuller in the middle of the 20th century, TRIZ offers a structured way to solve complex problems using inventive ideas and patterns. This theory is based on the idea that creativity means breaking old patterns and making new ones, using methods

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like brainstorming and reverse engineering (Ekmekci & Nebati, 2019). Simultaneously, TRIZ has earned recognition for its ability to stimulate innovative thinking and surmount complex challenges through a structured, inventive-principles-based approach.

Based on the literature reviews that have been conducted, the TRIZ method is mostly applied to minimize defective products (Boangmanalu, Abigail, Sembiring, & Tampubolon, 2020) and in product development (Donnici, Frizziero, Liverani, & Leon-Cardenas, 2022; Noronha, Bhat, & Bhat, 2020; Purushothaman & Ahmad, 2022; Wang, Yeh, & Chu, 2016). However, to the best of our knowledge, only two papers have discussed the integration of Lean Six Sigma and TRIZ for waste minimization (Nurcahyo & Apdillah, 2017; Purnomo & Lukman, 2020). In Nurcahyo and Apdillah (2017) research, the proposed improvements are not given to each detailed waste. To address the gaps in previous research, this study will offer improvement suggestions for each detailed waste. Furthermore, their research integrated these methods in the motorcycle industry and the wood industry. To date, no research has been conducted on waste reduction in the shuttlecock industry. However, some waste is still found in the shuttlecock production process, resulting in low process efficiency. This study proposed using Lean Six Sigma and TRIZ as an alternative strategy to reduce waste in Shuttlecock production. The TRIZ method is applied in the improvement phase in the DMAIC process (Purnomo & Lukman, 2020; Sojka & Lepšík, 2020). Although TRIZ was initially designed for product innovation, it should be an excellent tool for process improvement (Sojka & Lepšík, 2020).

Table 1 presents a list of previous researches on Lean, Six Sigma, and Lean Six Sigma with TRIZ in various applications. It demonstrates that most publications address a variety of issues related to performance improvement and product

Table 1. Summary of Lean, Six Sigma, and Lean Six Sigma with TRIZ studies

Author (Year)	Research Purpose (To)	Type of Industry	Research Technique (s)	Tools
Wang and Chen (2010)	improve performance in banking services	Banking Service	Lean Six Sigma and TRIZ	SIPOC, FMEA, TRIZ
Muruganantham, Navaneetha Krishnan, and Arun (2013)	improve performance and cost minimization	Manufacturing	Lean and TRIZ	Seven MUDA, TRIZ
Cabrera and Li (2014)	improve the efficiency of resources	Construction Industry	Lean and TRIZ	VSM, TRIZ
Muruganantham, Navaneetha Krishnan, and Arun (2014)	improve productivity	Manufacturing	Lean and TRIZ	Kaizen, SMAIC, TRIZ
Nurcahyo, Apdillah, and Yadrifil (2017)	reduce waste and improve the quality	Automotive Industry	Lean Six Sigma and TRIZ	VSM, FMEA, TRIZ
Noronha et al. (2020)	product development	Manufacturing	Lean Six Sigma and TRIZ	DOE, TRIZ
Indrawati, 'Azzam, Adrianto, Miranda, and Prabaswari (2020)	improve the service system	Fast Food Industry	Lean Six Sigma and TRIZ	VSM, TRIZ
Purnomo and Lukman (2020)	reduce waste	Wood Industry	Lean Six Sigma and TRIZ	VSM, FTA, TRIZ
Demirkesen and Zhang (2021)	solve safety problems	Construction Industry	Lean and TRIZ	Andon, TRIZ
Purushothaman and Ahmad (2022)	develop an automated inspection system.	Manufacturing	DMADV and TRIZ	QFD, DFMEA, TRIZ
Donnici et al. (2022)	product development	Cigarette Industry	DFSS and TRIZ	QFD, TRIZ
This Research	minimize waste	Shuttlecock Industry	Lean Six Sigma and TRIZ	VSM, FTA, TRIZ

development, but there is scarce research regarding the identification of significant factors that contribute to waste in the production process. In addition, Fault Tree Analysis (FTA) is rarely utilized as a tool in the Lean Six Sigma methodology. Furthermore, integrating quality techniques with TRIZ is commonly implemented across manufacturing, service, and construction industries. However, the application of integrating Lean Six Sigma and TRIZ in the shuttlecock industry remains unexplored. Therefore, to address this gap, this study employs a Defect-Measure-Analyze-Improve (DMAI) process, involving VSM in the define phase, FTA in the analyze phase, and TRIZ in the improve phase.

II. RESEARCH METHOD

This section describes the proposed DMAI framework for this research, which is shown in Figure 1. The framework's general structure consists of four phases.

Define

The first phase of the DMAIC methodology is to define the problem to be addressed using a value flow diagram and process quality analysis. This project begins with the development of a current state VSM (CSVSM). The model incorporates the VSM tool as a strategic project selection instrument. This tool makes it easy to identify problems that occur during production, clarify the production process flow, find out production activities that do not have added value, and find out the time needed from one line to another (Saha & Mahmud, 2022).

Measure

During the measure phase, there are 3 steps that will be carried out.

Step I: Identify the dominant waste

This step involves identifying waste by distributing questionnaires to company owners and workstation operators who possess a thorough understanding of the production process. The questionnaire responses are then analyzed using the BORDA method to assign weights to each identified waste. Subsequently, the waste categories and their corresponding weights are depicted in a Pareto diagram. The dominant waste is determined based on the waste categories that contribute to over 80% of the cumulative percentage on the Pareto diagram.

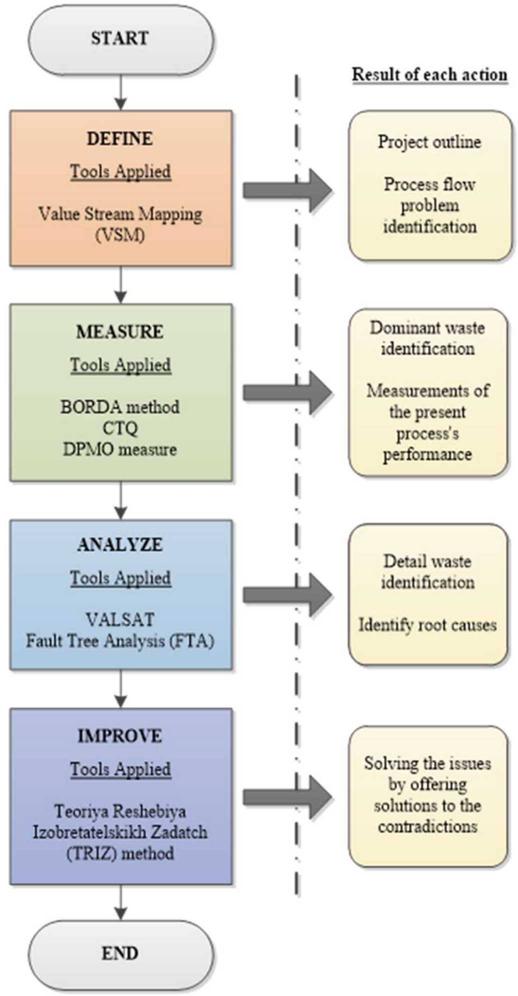

Figure 1. Proposed DMAI framework for implementation in the shuttlecock industry

Step II: Identify CTQs

The purpose of identifying Critical to Quality (CTQ) factors for each dominant waste is to determine more specific criteria that have a significant impact on the quality of the shuttlecock. The identification of CTQ factors was achieved through interviews conducted with the company owner.

Step III: Calculates DPMO and Sigma value

The sigma value is calculated using the Defect per million opportunities (DPMO) value.

DPMO calculation measures the level of defect problems in the case study company. The following equation is used (Harry & Schroeder, 2000):

$$\mathrm{DPMO} = \frac{\varepsilon}{h} * 1{,}000{,}000 = \frac{d}{N*h} * 1{,}000{,}000 \tag{1}$$

Where,

ε = defect rate
h = amount of CTQs
d = amount of defects
N = amount of outputs

The DPMO measurement is concluded with Sigma-level calculation using the NORMSINV function in Microsoft Excel. The following formula for calculating the sigma value is used (Gaspersz, 2002):

$$Sigma = Normsinv\left(\frac{1000000 - DPMO}{1000000}\right) + 1.5 \tag{2}$$

Analyze

The analyze phase aims to analyze the root causes of each detailed waste. This phase consists of 2 steps.

Step I: Selection of tools and identification of detailed waste using VALSAT

VALSAT is employed to choose the appropriate tools for analyzing and identifying the detailed waste associated with each dominant waste. The seven Stream Mapping Tools are used to analyze the essential elements in VSM. The tool selection is determined by calculating a score using equation 3. Subsequently, the stream mapping tool with the highest score is chosen to identify the detailed waste for each dominant waste.

$$Score\ mapping\ tool = weight\ of\ the\ dominant\ waste \times correlation\ scores\ on\ the\ matrix \tag{3}$$

Step II: Identify the causes of detailed waste

The Fault Tree Analysis (FTA) procedure is utilized to identify the root causes of detailed waste based on the results of value stream analysis tools (VALSAT). At this phase, the FTA serves as an illustration of the problems and conditions that lead to waste. Quantitative and qualitative analyses were conducted based on the FTA analysis results.

Improve

In the improve phase, improvements are made by providing recommendations to the root causes with the highest occurrence. Proposed improvements are made using the TRIZ methodology, by analyzing contradictions between 39 parameters to find solutions based on 40 innovative principles (Sibalija & Majstorovic, 2009).

III. RESULT AND DISCUSSION

This section provides a detailed explanation of the results and in-depth analysis obtained from implementing the proposed DMAI framework.

Define Phase

During the define phase, specific information regarding the current condition of a process is gathered. The production process is identified at this stage using Value Stream Mapping (VSM), shown in Figure 2. Creating a VSM is done by first observing the flow of the shuttlecock production process. The data needed in making the VSM is the sequence of the production process, namely, drying the feathers in the oven, cutting the feathers, selecting the feathers, and packing. Other data include the number of machines used during the production process, the number of production operators, cycle time, the number of work shifts applied in each process, and the distance between workstations.

Based on the results of VSM, the total value time is 19,657 seconds and the total value added (VA) activity accounts for 2,252 seconds. Non-value added (NVA) and non-necessary value added (NNVA) activities both have significantly high values, indicating that actions are required to minimise them.

Measure Phase

Referring to the studies conducted by Suhardi, Hastuti, Jauhari, and Laksono (2021) , the BORDA method is utilized to determine the dominant waste. Figure 3 shows the Pareto diagram, which illustrates the weight of waste. The most significant waste, as indicated by the Pareto chart, is waiting, with a weight value of

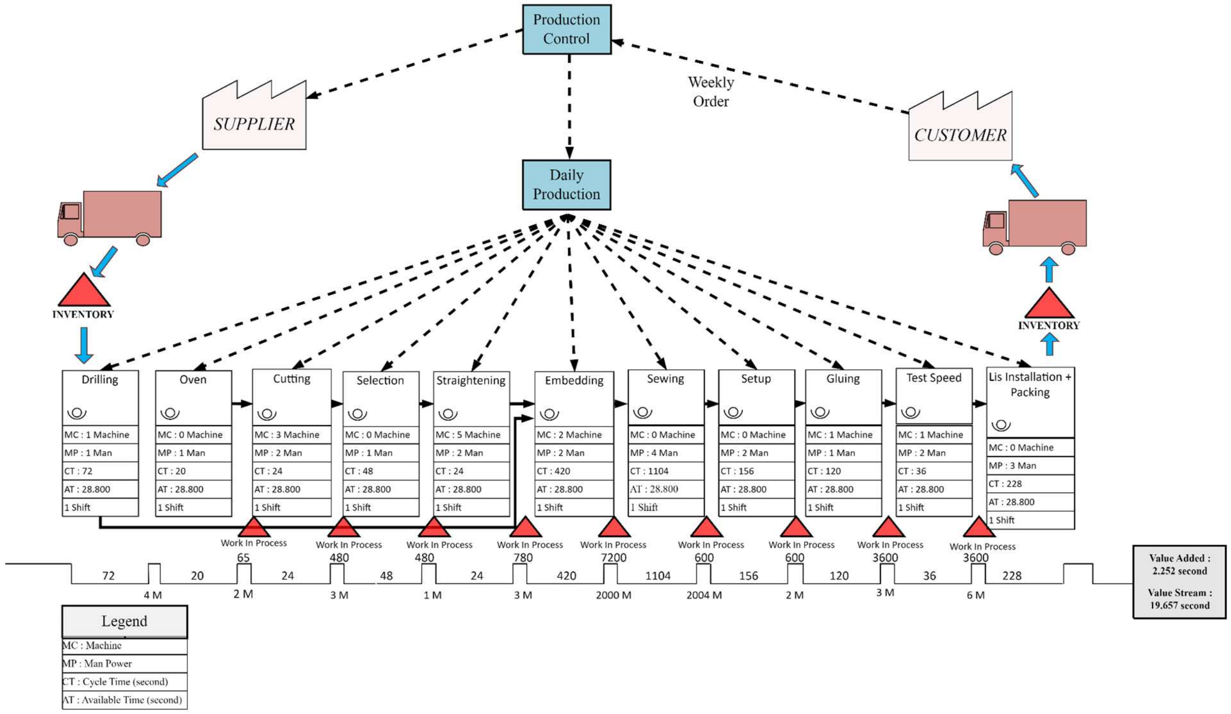

Figure 2. Current State VSM of the Shuttlecock Production

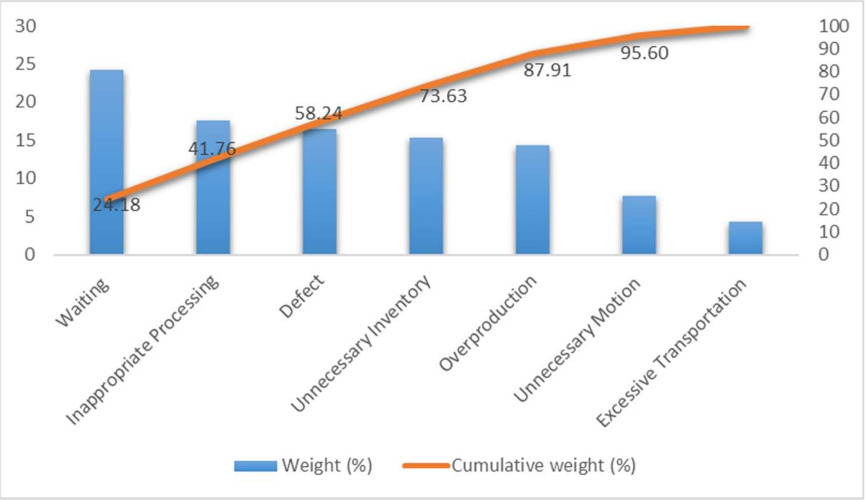

Figure 3. Pareto diagram

24.18%. Moreover, inappropriate processing accounts for 17.58% of the total waste. This is followed by defects and inventory, contributing 16.48% and 15.38% respectively.

The dominant waste is identified by examining the cumulative weight that exceeds 80%. Based on Figure 3, the cumulative weight of waste categories such as waiting, inappropriate processing, defects, unnecessary inventory, and overproduction reaches 87.91%. Therefore, these five waste categories are considered as the dominant waste. The next step involves determining the Critical to Quality (CTQ) factors for each dominant waste, which serve as the foundation for calculating the sigma value.

Through interviews conducted with company owners, it was determined that there are six CTQs associated with waste defects. These include hole

Table 2. Critical to Quality Shuttlecock and Sigma Values

Dominant Waste	Critical to Quality	Number of Criteria	Sigma value
Defect	Hole feathers Broken stick The shuttlecock head is oval Yellow color Feather off Feather weight is different	6	3.489
Waiting	There is a long wait for material because the number of machines is limited Machine downtime Operators work slowly in processing feathering and gluing Waiting time for raw materials	4	2.758
Unnecessary Inventory	Inventory work in process Finished product inventory	2	3.419
Inappropriate Processing	Setup process error Repetitive work because it does not comply with the SOP	2	3.339
Overproduction	Total production of finished products exceeded the production target	1	3.632

feathers, broken stick, the shuttlecock head is oval, yellow color, feather off, and feather weight is different. Table 3 presents the CTQs and corresponding sigma values for all dominant waste categories.

The number of CTQ is 6 for the defect, with a sigma value of 3.49. The number of CTQ for unnecessary inventory and inappropriate processing is 2, with sigma values of 3.42 and 3.34. While the number of CTQ for overproduction is 1, with sigma values of 3.63. With a value range between 3 to 4-sigma, the company's average defect per million opportunity (DPMO) is currently 6,210-66,807 and still needs to be increased to 6-sigma.

Analyze Phase

The analyze phase is conducted to determine the detailed waste of each dominant waste using Value Stream Analysis Tools (VALSAT)). The value stream mapping tool with highest scores are Process Activity Mapping (PAM), Supply Chain Response Matrix (SCRM), Demand Amplification Mapping (DAM), and Quality Filter Mapping (QFM).

Table 4 shows the results of Process Activity Mapping (PAM), revealing that the shuttlecock production process consists of 31 activities, including 12 operation activities, 11 transportation activities, 3 inspection activities, 4 delay activities, and 1 storage activity. The total time obtained is 5,710 seconds. Based on the types of activities that have been categorized, namely, value added (VA), non-value added (NVA), and necessary non-value added (NNVA), it can be concluded that the production process consists of 4.1% value added (VA), 73.7% non-value added (NVA), and 22.2% necessary non-value added (NNVA).

Table 3. Summary of Total PAM Activity Time

Activity	Total Activity	Total time (seconds)
Operation	12	217
Transportation	11	1,264
Inspection	3	15
Delay	5	4,210
Storage	1	4
Total	**31**	**5,710**

The results indicate the presence of significant non-valueadded activities, particularly delays, throughout the production process.

Therefore, it is crucial to develop solutions to address these issues, which will be discussed in detail during the improvement phase.

As illustrated in Figure 4, the supply Chain Response Matrix (SCRM) for the shuttlecock manufacturing process will be divided into three areas: the raw material warehouse, the production floor area, and the finished product warehouse.

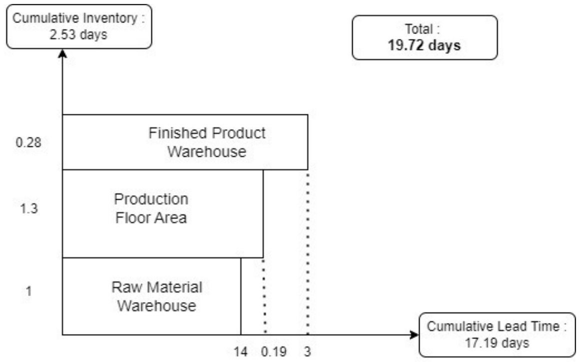

Figure 4. Supply Chain Response Matrix

The graph's horizontal axis represents the cumulative lead time, which amounts to 17.19 days, while the vertical axis represents the physical stock days, which is 2.53 days. As a result, the total time for the order process to reach the storage warehouse is calculated as 19.72 days.

Moreover, the highest physical stock days contribute to a buildup of raw materials in the production floor area, lasting for 1.3 days. Consequently, the accumulated raw materials in the production floor area are identified as a detailed waste within the context of inventory.

Based on the findings presented in Figure 5, it is clear that the actual demand exhibits weekly fluctuations, necessitating frequent adjustments to forecasts. For instance, in the first week of June, the forecast demand was projected to be 225 slops, whereas the actual demand turned out to be 220 slops. Similarly, in the third week of July, the forecast demand was estimated at 250 slops, but the actual demand was lower, at 205 slops. The diagram indicates a discrepancy between the actual demand and the forecasted demand. Therefore, demand forecasting errors are identified as a detailed waste within the waste of overproduction.

Figure 6 shows the results of Quality Filter Mapping (QFM) indicate that broken stick has the highest defect rate, with a total of 624. Therefore, broken stick become a detailed waste. The causes of broken stick will further be discussed in the fault tree analysis step and suggestions for enhancements will be made in the improvement phase.

Based on the PAM, SCRM, DAM, and QFM, detailed waste has been obtained for each dominant waste: delay, raw materials accumulation in the production area, demand forecasting errors, and broken stick. The next step is to determine the causal factors using Fault Tree Analysis (FTA).

Figure 7 depicts the waiting process in the feather sticking and product speed test, which contributes to delays. In feather sticking, delays are caused by product stacking (15 to 30 slaps on average) due to manual process and a shortage of skilled workers. In product speed test, delays

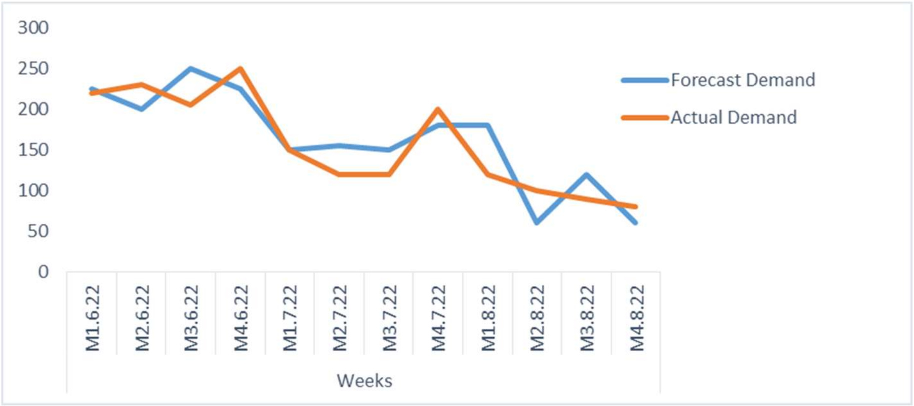

Figure 5. Demand Amplification Mapping Graph

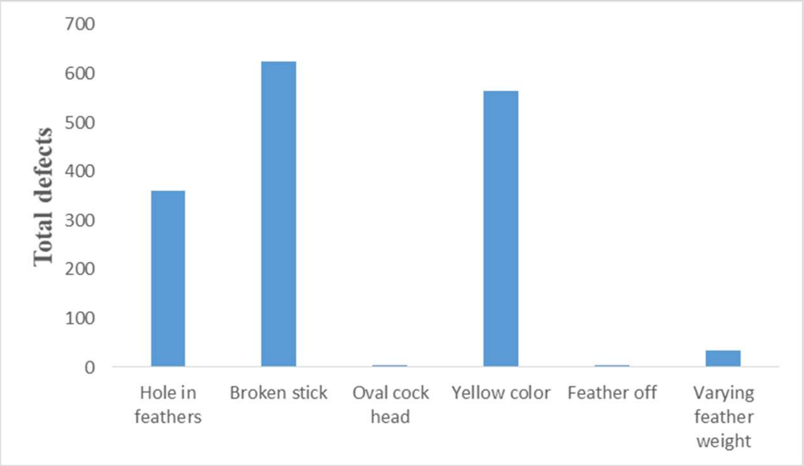

Figure 6. Quality Filter Mapping

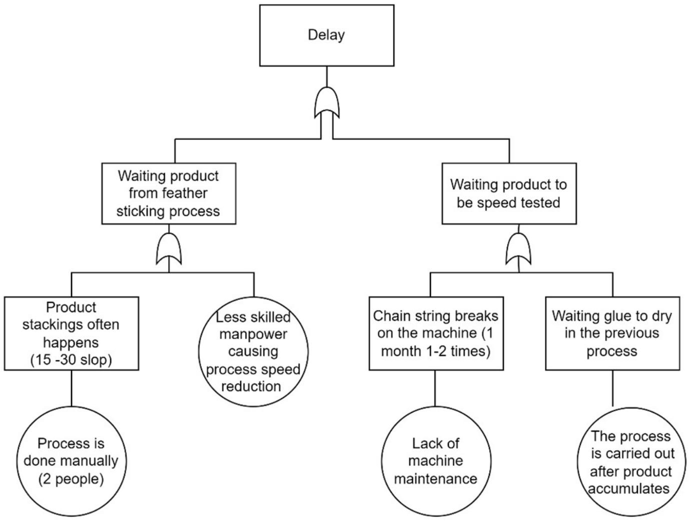

Figure 7. Fault tree analysis on the causes of delay

arise from occasional chain string breaks (1 to 2 times per month) due to poor machine maintenance and waiting for glue to dry from the previous step.

Several root causes of delay have been identified through the Fault Tree Analysis (FTA), and one root cause will be selected for further attention. Based on interviews conducted with company owners, the manual feather sticking process emerges as the most critical root cause requiring immediate resolution in the improvement phase.

There are 3 factors that causes of raw materials accumulation in the production area: the absorption of raw materials is less than optimal, long production process in some manual processes, and machine shortages for production due to breakdowns. Following interviews with company owners, it was determined that the root cause of the raw materials accumulation in the production area is inadequate line balancing. This can be observed by the accumulation of products at specific workstations, particularly during the sticking and sewing processes.

Two fundamental causes contribute to demand forecasting errors. According to interviews with company owners, the primary issue is the lack of accurate weekly demand data. On the other hand, the results of the Quality Function Mapping (QFM) analysis identify four factors that impact defects: the setup process, the gluing process, the raw materials storage, and the suboptimal goose feather drying process. Additionally, from the interviews with company owners, it is revealed that the setup process not aligning with the company's standard operating procedures is a common cause of broken sticks.

Improve Phase

The TRIZ principle is utilized to identify improvement recommendations. This involves analyzing potential contradictions across 39 parameters in order to propose solutions or recommendations for resolving the problem. These suggestions are based on 40 inventive principles. The specific problem to be addressed for each detailed waste is derived from the root cause identified in the Fault Tree Analysis (FTA).

The issue at hand is the manual execution of the feather sticking process, which affects both the yield and speed of assembling feathers to cork. Table 6 displays the identified contradictions resulting from this problem, focusing on the delay-related conflict parameters selected from the 39 TRIZ technical parameters. The objective of this improvement initiative is to enhance the material layout, making the work more effective and efficient by ensuring easy accessibility (ease of manufacture). To address these challenges, the emerging contradictions call for the implementation of an automated system to enhance the speed of sticking feathers to cork (extent of automation).

After conducting a contradiction analysis, the suggested inventive principles are anti-weight (8), mechanics substitution (28), and segmentation (1). The most suitable improvement recommendation based on the company's condition is mechanics substitution (28). The key points within the mechanics substitution for formulating a solution are as follows:

a. Replacing mechanical methods with sensory methods.
b. Utilizing electric fields, magnets, and

Table 4. The "improve" recommendation for delay

Problems	Delays are caused by the process being carried out manually, causing accumulation of goods
Contradictions	(32) Ease of manufacture >< (38) Extent of automation
Principle suggestion	Anti weight (8), Mechanics substitution (28), Segmentation (1)
Solution	The following solution is proposed after analyzing the factory's current state and the Fault Tree Analysis's findings. • Mechanics substitution (28) The addition of an automatic machine for feather sticking process in the shuttlecock, with a sensor to adhere the feathers precisely and firmly into the cork. This aims to reduce processing time and can minimize the occurrence of product accumulation so that the product can be transferred to the next process.

Table 5. The "improve" recommendation for raw materials accumulation in the production area

Problems	Raw materials accumulation in the production area
Contradictions	(32) Ease of manufacture >< (12) Organizational hierarchy/level
Principle suggestion	Segmentation (1), Mechanics substitution (28), The other way round (13), Cheap short-living objects (27)
Solution	The following solution is proposed after analyzing the factory's current state and the Fault Tree Analysis's findings. • Mechanics substitution (28) By grouping work according to the order of the production process and utilizing a movable conveyor or a similar device, sending goods to the next workstation will become simpler. This will maximize production results, thereby reducing inventory and maximizing material processing.

Table 6. The "improve" recommendation for overproduction

Problems	Overproduction in the Production Process
Contradictions	(28) Actual compared to plan >< (27) Reliability
Principle suggestion	Merging or combining (5), Beforehand cushioning (11), Segmentation (1), Feedback (23)
Solution	The following solution is proposed after analyzing the factory's current state and the Fault Tree Analysis's findings. • Segmentation (1) Companies can target the number of consumers willing to purchase in significant quantities by offering different unit prices to increase the number of purchasers.

Table 7. The "improve" recommendation for broken stick

Problems	Broken stick
Contradictions	(29) Precision/consistency >< (27) Reliability
Principle suggestion	Beforehand cushioning (11), Colour changes (32), Segmentation (1)
Solution	The following solution is proposed after analyzing the factory's current state and the Fault Tree Analysis's findings. • Beforehand cushioning (11) Work procedures must adhere to the company's standards; companies can employ a few strategies to prevent product defects, including the training of all workstation process operators and the placement of operators based on their skills and experience.

electromagnetic fields to interact with objects.

c. Transforming from static to movable surfaces, from surfaces without structure to surfaces with structure.
d. Employing surfaces in connection with activated surface particles (e.g., ferromagnetic).

Tables 6 to 9 explain in detail regarding improvement recommendation for delay, raw materials accumulation in the production area, demand forecasting errors, and broken sticks.

IV. CONCLUSION

This study focuses on the application of Lean Six Sigma and TRIZ in the shuttlecock industry with the aim of waste minimization. The research successfully identifies the dominant waste generated in the shuttlecock production process. Fault tree analysis is employed to identify the factors that contribute to detailed waste. Subsequently, improvements are implemented based on the TRIZ methodology to minimize detailed waste. For future research, it is recommended to further develop the Lean Six Sigma and TRIZ framework by conducting multiple case studies. This will help validate the effectiveness of the framework in different contexts and industries.

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