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(Research/Review) Article

Optimization and Efficiency of Spot Welding Process: Waste Reduction Through the Value Stream Mapping Approaches

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Abstract: A four-wheeled vehicle bracket component manufacturing company experienced a surge in demand for a hook transport product. However, the production process was found to be inefficient due to the presence of non-value-added activities and barriers. The objective of the research was to identify and minimize waste in the production of spot welding, as well as to determine the takt time for hook transport production. To this end, a Value Stream Mapping (VSM) analysis was conducted, leveraging the existing VSM framework to assess the production process's efficiency for identify and eliminate non-value-added activities. The analysis revealed that the cycle process efficiency prior to the implementation of improvements stood at 74%, characterized by various forms of waste, including defects, over-processing, waiting, and motion. The subsequent improvement, as depicted in the anticipated future state value stream mapping, resulted in a 94% enhancement in cycle process efficiency, representing a 20% increase. Beyond the efficiency cycle process outcome, the takt time calculation for spot welding production set yielded a value of 52.85 seconds per product. This indicates that the takt time required for hook transport cycle production to meet consumer demand is 52.85 seconds. The implementation of the VSM method is expected to facilitate the identification and reduction of production waste, enhance efficiency, and optimize the fulfillment of demand targets.

Keywords: Production Efficiency; Spot Welding; Takt Time; Value Stream Mapping; Waste Reduction.

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1. Introduction

In the contemporary business landscape, characterized by intensified competition, enhancing production efficiency has become a pivotal strategy for maintaining competitive advantage [1]. However, the manufacturing process frequently exhibits inefficiencies, often attributable to the presence of non-value-added activities, which are often referred to as "waste" [2]. This phenomenon can result in increased costs, diminished worker productivity, and delayed delivery of goods to customers, potentially eroding public trust in manufactured goods [3]. Spot welding, a process characterized by its abundance of free resources, exemplifies this challenge. This metal-joining technique has a wide range of applications, including in the automotive industry and parts manufacturing [4]. However, it is essential to analyze the various wastes associated with spot welding, such as defects, waiting time, and motion, to enhance efficiency and optimize products. Furthermore, a number of earlier studies have sought to address the issue of waste in manufacturing processes by employing the Value Stream Mapping (VSM) approaches.

Komariah's (2022) endeavor in the aluminum processing industry involved the utilization of VSM, a method that identifies production waste and pinpoints the most significant problem in terms of inventory [5]. Concurrently, Fitriadi and Muzakir's (2019) research sought to implement lean concepts in conventional cake production, leading to the identification of the primary forms of waste, namely waiting time and transportation. These inefficiencies could be mitigated through mechanized tools [6]. Dhiwangkara and Lukmandono (2021) employed VSM and Failure Mode and Effect Analysis approaches to minimize production lead time, but encountered challenges in eliminating non-value-added activities [7]. The studies have contributed to the enrichment of lean manufacturing practices, they do not offer a definitive methodology for investigation in the spot welding process.

For this reason, a more focused approach is offered in this study by using VSM as a method to not only visualize wastes, but also find the degree of interrelationship between wastes in the production process. At this stage, not only the types of wastes are likely to be identified, but also the relationships between wastes. Therefore, the elimination strategy has already been determined. Furthermore, this research calculates the takt time to ensure that the products produced match market demand and eliminate any imbalance between production and demand that may occur. The research focuses on the spot welding process in passenger vehicles produced under contract. The procedures include collecting production data, visualizing the process using VSM, analyzing the waste categorization relationship, and transforming the results with Takt Time. The study's findings will propose actionable recommendations for the authorities to enhance production flow, minimize unproductive activities, and bolster competitiveness.

The tested data was then processed using the Value Stream Mapping (VSM) method.The initial step in data processing was to create a Current State VSM to map the current production conditions. Subsequent to this initial phase, value-added and non-value-added activities were subjected to rigorous analysis.

2. Methodology

The present study was conducted in the production process of transport hooks in the spot welding department of a manufacturing company. The research flow includes preliminary stages, data collection, data processing, and analysis of observations. This research is of an applied nature, with the objective of analyzing potential improvements to the production line with respect to the spot welding process. The technique employed is descriptive analysis, informed by the principles of Lean Manufacturing, particularly through the utilization of Value Stream Mapping (VSM) and Takt Time calculation. The collected data is characterized as quantitative and is subsequently described in a way that elucidates its inherent properties. The research procedure commences with field research and literature research. Field research involves direct observation of the production process, conducting interviews with relevant parties, and documenting issues that emerge during the process.

The data collection process involved two distinct sources: primary data and secondary data. Primary data was obtained through direct observation of the production process, interviews with operators and production managers, and recording of production cycle time. Meanwhile, secondary data was obtained from the company's historical records, including customer demand data and previous production results. Following the collection of data, a rigorous data testing stage was conducted to ensure its validity and reliability, calculate using equation 1. The sufficiency test was conducted to ascertain the adequacy of the collected data to support the analysis. The validity test was executed using the bivariate Pearson correlation method to ascertain the relationship between the measured variables, while the reliability test was conducted using the Cronbach's Alpha method.

$$\boldsymbol{r} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \qquad (1)$$

with r is correlation coefficient, while x and y are respectively independen and dependen variable that used in this work.

3. Results and Discussion

The manufacturing industry faces significant challenges in improving production efficiency. Efficiency is crucial to meeting consumer demand in the right quantity, at the right time, and at minimal cost [8]. An inefficient production process can lead to delays, resource wastage, and increased operational costs. Therefore, the Lean Manufacturing approach is applied to identify and eliminate waste occurring along the production flow [9]. In this study, the primary focus is on the spot welding process, particularly the production of hook transport, which has seen increased demand but still encounters various operational obstacles [10]. To address these challenges, the Value Stream Mapping (VSM) method is used to map the production flow and identify areas needing improvement. Lean Manufacturing focuses on waste elimination, defined as activities that do not add value to the product. Based on observations, several types of waste occur in the spot welding process, including defects, which result from machine parameter mismatches or operator errors [11]; over-processing, which involves excessive production steps that do not adhere to standards, leading to longer production times than necessary [12]; waiting, caused by delays in receiving materials from the previous process [13]; and motion, where excessive movement occurs due to poor workstation layout, causing inefficiencies [14]. Waste identification is performed using the Waste Relationship Matrix (WRM) analysis tool, which maps the relationships between different types of waste and their impact on production efficiency, as shown in Figure 1 below:

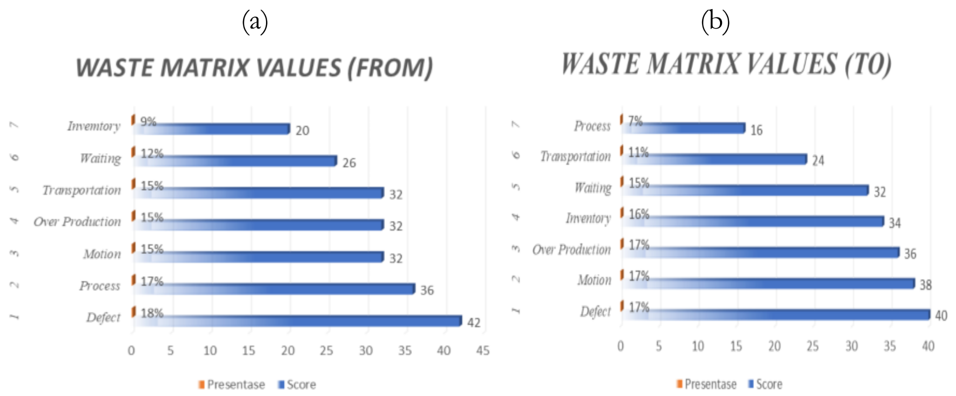

Figure 1. (a) WRM from (b) WRM to.

Value Stream Mapping (VSM) is a key tool used in this study to analyze production efficiency. This method classifies production activities into two main categories: Value-Added Activities, which directly contribute to the product, such as proper spot welding processes, and Non-Value-Added Activities, such as waiting times and reinspection due to defective products [15]. Using VSM, researchers successfully identified the current production state (Current State Map) and designed an improved future production state (Future State Map) [16]. At this stage, it was found that the production cycle efficiency (Process Cycle Efficiency, PCE) before improvement was 74%.

Takt Time is used to determine the ideal production time to meet customer demand without causing waste. The formula for calculating Takt Time is shown in Equation 2.

$$\textbf{Takt Time} = \frac{\textbf{Available Work Time}}{\textbf{Customer Demand}} \qquad (2)$$

Based on the analysis, the calculated Takt Time in this study is 52.85 seconds per product, meaning each unit must be completed within this time to meet production targets [17]. If production time exceeds this value, inefficiencies arise, potentially causing delivery delays.

Based on the analysis results, several improvement recommendations were proposed to enhance production efficiency. These include reducing defects by training operators to ensure proper machine parameter settings, thereby minimizing production errors [18]; improving workstation layouts to position materials and tools more efficiently, reducing unnecessary movements [19]; enhancing production planning using a more accurate scheduling system to minimize material waiting times [20] and eliminating unnecessary production steps that do not add value [21]. After implementing these improvement recommendations, production efficiency was reassessed using VSM. The results showed that production cycle efficiency (PCE) increased to 94%, reflecting a 20% improvement.

This study demonstrates that the Lean Manufacturing method, particularly Value Stream Mapping, is highly effective in identifying and reducing waste in the production line. By improving production efficiency, companies can better meet customer demand while reducing operational costs. The key implications of this study include increased productivity, where production becomes faster and better planned; reduced waste, where various forms of inefficiency are minimized or eliminated; and improved customer satisfaction, as faster and defect-free production enhances consumer trust. Overall, this study provides strong evidence that the Lean Manufacturing approach can be effectively applied in the manufacturing industry to improve efficiency and competitiveness.

4. Conclusions

In summary, the results of the VSM analysis revealed that wasteful activities include defect activity, waiting time, motion, and over-processing, which contribute to waste, inefficiency, and lengthen the production cycle. The current state VSM analysis reveals that the production cycle efficiency is only 74% before implementing improvements. The primary factors contributing to waste include defective products due to the less precise nature of the spot welding process, prolonged waiting times due to material supply imbalances, inefficient operator movement due to poor work area layout, and welding tool change procedures that are not in accordance with established standards, resulting in high cycle time and inefficiency. The implementation of an enhanced VSM approach, as outlined in the subsequent research results, has led to a substantial enhancement in production cycle efficiency, with a 20% increase from the initial 74% to a noteworthy 94%. This enhancement has been achieved through a meticulous optimization of material flow, a substantial improvement in operator work standards, and the elimination of unproductive activities within the spot welding process. The calculation of takt time, defined as 52.85 seconds per product, underscores the significance of a well-designed produce system in ensuring optimal customer demand is met without the occurrence of over- or under-production. The findings substantiate the efficacy of value stream mapping in identifying waste and enhancing production efficiency. The application of the VSM method enables the company to minimize non-productive activities, enhance operator productivity, and substantially reduce waste. This, in turn, paves the way for the potential implementation of the Lean Manufacturing concept in the future. It is recommended that the company undertake periodic evaluations of the production process using VSM to ensure that any modifications implemented contribute to enhancing efficiency. Furthermore, the company should prioritize the enhancement of operator training to ensure the consistent delivery of high-quality products and to equip operators with the necessary knowledge of work standards and maintenance techniques for spot welding tools. By implementing these recommendations, the company can maintain its competitive edge and ensure the seamless operation of its processes.

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