Line Balancing Study Using Value Stream Mapping Tool on Lean Manufacturing: A Case Study in an Electronic Industry

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ABSTRACT

XY Electronics, a leading international company in electronic components manufacturing, is confronting significant production constraints that adversely affect output, lead times, and operational expenses. This study examines the manufacturing line for product A using Value Stream Mapping to analyze process times and identify bottlenecks where takt times are exceeded. It focuses on areas surpassing production cycle times and aims to enhance line utilization through better line balancing and waste reduction. The results reveal that the header assembly, along with coplanarity and pre-testing 3, are major bottlenecks, which significantly impact productivity. By optimizing task allocation, refining workforce distribution, and employing cross-training, the production line efficiency improved significantly. In addition, strategic workforce reallocation and station optimization were crucial in addressing resource underutilization and enhancing overall operational efficiency.

Keywords: *Value Stream Mapping, Bottlenecks, Utilization, Line Balancing*

ABSTRAK

XY Electronics yang merupakan perusahaan internasional terkemuka dalam pembuatan komponen elektronik, saat ini sedang menghadapi kendala produksi yang signifikan yang berdampak negatif terhadap output, waktu timbal, dan biaya operasional. Studi ini meneliti lini produksi untuk produk A menggunakan Value Stream Mapping (VSM) (Pemetaan Aliran Nilai) untuk menganalisis waktu proses dan mengidentifikasi titik-titik bottleneck di mana waktu takt terlampaui. Fokus penelitian ini adalah area yang melebihi waktu siklus produksi dan bertujuan untuk meningkatkan pemanfaatan lini melalui keseimbangan lini yang lebih baik dan pengurangan limbah. Hasil penelitian menunjukkan bahwa perakitan header, bersama dengan coplanarity dan pra-uji 3, merupakan titik penyumbatan utama, yang secara signifikan mempengaruhi produktivitas. Dengan mengoptimalkan alokasi tugas, menyempurnakan distribusi tenaga kerja, dan menerapkan pelatihan silang, efisiensi lini produksi meningkat secara signifikan. Selain itu, realokasi tenaga kerja strategis dan optimasi stasiun sangat penting dalam mengatasi pemanfaatan sumber daya yang kurang dan meningkatkan efisiensi operasional secara keseluruhan.

Kata kunci: Value Stream Mapping, Bottlenecks, Utilitas, Keseimbangan Lini

1. Introduction

The main challenge for manufacturers is to deliver their products or services efficiently, economically, and with exceptional quality despite numerous obstacles. Various methodologies, such as computer simulation, statistical analysis, and lean manufacturing, have been employed to improve the productivity and efficiency of production lines (Hatami et al., 2014; Kłos & Patalas-Maliszewska, 2015; Ünal & Bilget, 2021). Among these, lean manufacturing has become a particularly effective approach widely adopted across various manufacturing sectors globally (Andrade et al., 2016; Rathod et al., 2016; Sangwa & Sangwan, 2023). The popularity of lean manufacturing is on the rise as industries seek to maintain competitiveness in an expanding global market.

Lean manufacturing focuses on cost reduction by eliminating waste and non-value-added operations, enabling industrial systems to achieve their full potential. Lean manufacturing identifies and eliminates non-value-added activities, which consume resources but do not contribute to customer satisfaction or product quality. These non-value-added activities are classified into seven types: overproduction, waiting, transportation, inventory, motion, overprocessing, and defects. Lean manufacturing has proven to be effective in enhancing workplace efficiency, reducing costs, and increasing customer satisfaction. An efficient workplace, typically a physical location where tasks are performed and coordinated, is critical. In today's competitive environment, nearly all industrial sectors strive to boost productivity by reducing production lead-times and waste (Jayswal, 2017).

Value Stream Mapping (VSM) is an important tool within the framework of lean manufacturing, specifically tailored to meet the challenges faced by manufacturers who strive to deliver products efficiently and economically while maintaining high quality. Lean manufacturing emphasizes the reduction of waste and optimization of value-added operations to enhance overall productivity. In this context, VSM acts as a strategic methodology for visualizing and analyzing every step of the production process, from raw material acquisition to the final delivery of the product. It helps in identifying and eliminating non-value-added activities, which are categorized into seven types: overproduction, waiting, transportation, inventory, motion, overprocessing, and defects. By providing a clear and detailed layout of how processes interconnect and where inefficiencies lie, VSM enables manufacturers to make informed decisions to streamline operations, thus supporting the lean manufacturing goal of improving workplace efficiency, cutting costs, and increasing customer satisfaction. Through the use of VSM, industries are better equipped to address inefficiencies in their production lines, aligning with global competitiveness by continuously enhancing their operational workflows.

1.1 Company Background

XY Electronics has been one of the leading producers and suppliers of electronic components and manufacturing services for more than a century. The company's roots were traced back to the Industrial Revolution, specifically to 1868 when Tyzack Turner—a Birmingham-based firm specializing in wire ropes and cables—was established. As electricity began to revolutionize industries, Tyzack Turner shifted its focus to resistor production under the name crystalate. This strategic move positioned the company at the heart of the rapidly expanding electronic sector.

Over the following decades, consistent growth through acquisitions and expansions led to the formation of the XY Group, which later became known as XY Electronics. The company absorbed entities such as AB Electronic Products and BI Technologies, expanding its offerings to include sensors, magnetics, and semiconductors alongside its established resistor business. In the early 2000s, XY Electronics was officially launched and organized into three core divisions: Sensors and Specialist Components, Power Electronics, and Global Manufacturing Solutions. Today, it operates globally, employing over 4,000 people across 20 countries, with its products powering everything from industrial automation to medical equipment and even contributing to space exploration.

XY products are not the sole characteristics of XY Electronics. It survives a culture of innovation that continually tests the limits of technology. Engineers have developed advanced power modules and designed tiny sensors that are capable of detecting even the smallest vibration and fashion custom manufacturing solutions for high-mix, low-volume requirements. These operations are woven with sustainability. XY Electronics maintain its impact on the environment through energy-efficient designs and responsible sourcing. The future of electronics relates to harmony with the planet, and this philosophy is reflected in current green initiatives.

Despite its historical and ongoing growth, XY Electronics faces challenges such as production inefficiencies caused by bottlenecks, particularly in Malaysian operations. These bottlenecks limit the capacity and disrupt the flow of production, leading to decreased productivity. Accordingly, this study aims to identify and analyze the processes in the production of product "A" that exceed the specified takt time, with the goal of enhancing manufacturing line utilization and addressing these critical inefficiencies.

2. Literature Review

2.1 Fish Bone Analysis

Fishbone analysis, also known as the Ishikawa diagram, is a structured tool that helps to identify the underlying causes of a problem (Wong et al., 2016). It is envisioned as a fish lying on its stomach with the main problem positioned at the head, the diagram's spine branches out into major categories such as “people” and “machines.” Each category leads to smaller branches that represent individual contributing factors. This visual structure facilitates comprehensive brainstorming, allowing organizational teams to explore a wide array of potential causes beyond the obvious ones. The systematic approach of examining each branch aids in identifying root causes and supports focused problem-solving and corrective actions. This method is versatile and applicable across various fields including manufacturing, healthcare, software development, and business management (Chan & Wu, 2005)

2.2 Value Stream Mapping

Value Stream Mapping (VSM), developed by Toyota as part of the Toyota Production System, is a key tool in lean manufacturing. It maps out the material and information flows from start to finish, focusing on eliminating "waste"—processes that consume resources without adding value from the customer's perspective (Womack & Jones, 1997). VSM differentiates between value-adding and non-value-adding activities, such as welding a bicycle frame and waiting for parts. It assesses inefficiencies by analyzing lead times, inventory levels, and processing times, offering a detailed view of potential improvements.

VSM's strength of VSM lies in its collaborative approach, enhancing communication and understanding, which leads to effective interventions. Whether it involves streamlining inventory management, implementing pull-based production, or automating repetitive tasks, VSM guides efforts to streamline processes and enhance their value. More than just a mapping tool, VSM embodies the philosophy of continuous improvement, driving organizational change, increasing productivity, reducing costs, and securing competitive advantage (Shou et al., 2017).

2.3 Takt Time

Takt time is a critical concept in lean manufacturing that acts as the system's "heartbeat" by aligning production rhythms with customer demand. This term was derived from the German word for "beat" or "pulse.” This represents the maximum time allowed to complete a unit of production to perfectly meet customer needs without overproduction or shortages. It serves as a guiding principle for optimizing processes, calculated by dividing the available production time by customer demand. As described by Womack and Jones (1997), takt time sets the rhythm for all related activities, similar to how each instrument in an ensemble contributes to harmonious performance.

In a lean environment, production steps are closely aligned with takt time, minimizing waste, and ensuring smooth operations. Takt time is not simply about maintaining the production pace; it is also a powerful tool for identifying and eliminating inefficiencies and imbalances within production lines. By comparing takt time to actual cycle times—the duration it takes to complete one unit—manufacturers can easily identify bottlenecks and areas of improvement. Addressing these issues facilitates shorter lead times, controlled inventory levels, and enhanced customer satisfaction (Soliman 2020). Finally, following the principle of takt time within the lean philosophy promotes continuous improvement and creates a flexible demand-driven production system. By consistently focusing on this critical rhythm, manufacturers can orchestrate symphony of efficiency and deliver exceptional value to customers.

2.4 Line Balancing

In lean manufacturing, line balancing is an important process that ensures smoothing out production flow and eradicating time wastage caused by wavering idle time. It entails the assignment of tasks and workloads across a production line such that each activity may operate close to the wished-for cycle time or takt. Production time availability divided by customer demand equals takt time, providing an idea of the optimal speed at which units would be completed (Russell & Taylor, 2019). Optimizing schedules involves balancing individual task durations, identifying dependencies between tasks, and considering worker-skill sets and ergonomics. Line balancing can be performed using a variety of methodologies, ranging from basic manual computations to complex software algorithms, each with its strengths and weaknesses based on the complexity level of the production line and desired detail (Tompkins, 2010). Thus, lean manufacturing revolves around successful line balancing that ensures lower lead times, shorter waiting periods, better overall labor use, and higher productivity (Jayswal, 2017).

3. Methods

3.1. Study Design

This study employed a descriptive quantitative design within a case study framework that focused on the collection and analysis of numerical data through mathematical models. Specifically, the collected data encompassed the actual cycle times for each process involved, as well as information provided by the operators. This approach allows for a detailed examination of the processes within the case study to identify the efficiencies, bottlenecks, and potential areas for improvement.

3.2. Fishbone Diagram

In the case of XY Electronics, fishbone analysis was employed to address production inefficiencies in creating product A. By visually mapping out complex problems and their interconnections, this method allowed managers and team members from various departments to collaboratively identify and prioritize root causes. This clear overview of the potential causes and their relationships enhances understanding and fosters creativity, leading to a comprehensive examination of issues. The main contributing factors were systematically targeted, streamlining problem solving, and preventing the waste of resources on fewer issues. Furthermore, fishbone analysis facilitates the tracking of corrective actions and documentation of both the process and outcomes, serving as a reference for continuous improvement in the manufacturing process.

3.3. Data Analysis

In this study, we calculated the takt time and identified bottlenecks based on the cycle time of each process. Takt time represents the rate at which products must be manufactured to meet customer demands. Essentially, as demand increases, takt time decreases and vice versa. In contrast, if the cycle time of the bottleneck process is less than the takt time, customer demand is met; otherwise, the demand is not met. Thus, takt time serves as a vital managerial tool to determine whether the production line operates ahead of or behind the schedule. It also plays a critical role in measuring current production needs in real time. The formulas used to compute takt time and identify bottlenecks are detailed below.

$$\text{Takt Time} = (\text{Net time available to work}) \,/\, (\text{Customer Demand}) \tag{1}$$

$$\text{Cycle time per Headcount (operator)} = \text{Actual cycle time}/\text{Operator provided} \tag{2}$$

4. Results and Discussion

4.1 Fishbone Diagram

Figure 1 illustrates four primary categories—machine, material, process, and management—that contribute to bottlenecks and utilization. Several specific factors were identified within these categories.

1. Machine: This category includes equipment malfunction, slow cycle times, and improper maintenance.
2. Process: Challenges in this category are attributed to complex procedures, human errors, and stringent quality-control checks.
3. Management: Problems arise from inadequate communication, insufficient training, and scheduling.
4. Material: The factors identified included material inconsistency and handling difficulties.

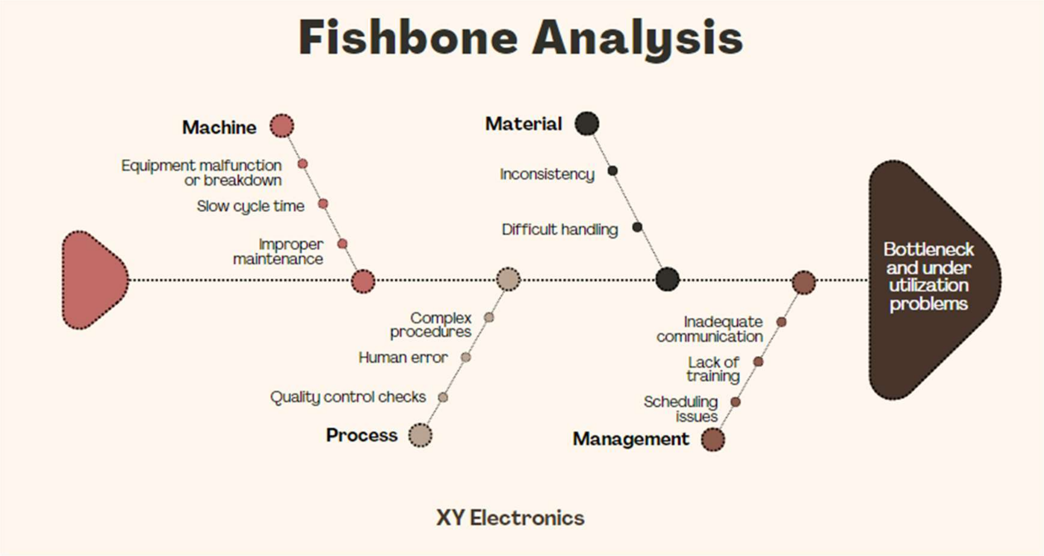

Figure 1. Fishbone analysis of XY Electronics in producing Product A.

4.2 Current Value Stream Mapping

The ultimate goal of Value Stream Mapping is to illustrate how a product flows through the value stream, from raw materials to the finished product. In this study, 24 processes are visualized in Figure 2 and detailed in Table 1.

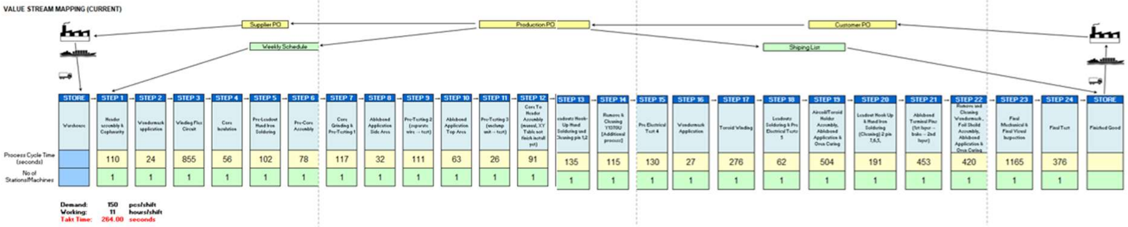

Figure 2. Current value stream mapping

Table 1. Twenty-Four (24) Identified Process of Production "A"

Process	Actual Cycle Time (Seconds)
Header assembly & Coplanarity	110
Wondermask application	24
Winding Flex Circuit	855
Core Insulation	56
Pre-Leadout Hand Iron Soldering	102
Pre-Core Assembly	78
Core Grinding & Pre-Testing 1	117
Ablebond Application Side Area	32
Pre-Testing 2 (separate wire → test)	111
Ablebond Application Top Area	63
Pre-Testing 3 (unclamp unit→ test)	26
Core To Header Assembly (manual, XY Table not finish install yet)	91
Leadouts Hook-Up Hand Soldering and Cleaning pin 1,2	135
Remove & Cleaning Y1370U [Additional process]	115
Pre-Electrical Test 4	130
Wondermask Application	27
Toroid Winding	276
Leadouts Soldering & Pre-Electrical Tests 5	62
Aircoil/Toroid Holder Assembly, Ablebond Application & Oven Curing	504
Leadout Hook Up & Hand Iron Soldering (Cleaning) 2 pin 7,6,5,	191
Ablebond Terminal Pins (1st layer→ bake→ 2nd layer)	453
Remove and Cleaning Wondermask , Foil Sheild Assembly, Ablebond Application & Oven Curing	420
Final Mechanical & Final Visual Inspection	1,165
Final Test	376

Takt Time

Takt time is calculated as a function of customer demand per day and working time. In this study, customer demand for product A was 150 per day, while the working time was 11 h or one shift per day. Therefore, takt time was computed as follows:

$$\text{Takt time} = \ (11 \text{ hours} \times 3600 \text{ seconds})/150 \text{ pcs} = 264 \text{ seconds}$$

Bottleneck

To compute the extent of the bottleneck, we create a bar chart that clearly illustrates the process that encounters the bottleneck and the process that is not fully utilized. Based on the data in Table 2, we created Figures 3 and 4, and calculated the cycle time per headcount (HC) for each process.

The bar chart highlights significant inefficiencies in the production of product A at XY Electronics, with six processes exhibiting cycle times that surpassed the takt time of 264 s. Notably, the header assembly and the three coplanarity and pre-testing 3 processes (unclamp unit → test) serve as major bottlenecks, requiring 524 s and 325 s, respectively, almost double the target time. This disparity in workload distribution requires immediate corrective measures to optimize the production line and improve efficiency. Efficient workforce distribution is essential to mitigate these bottlenecks and enhance overall productivity. Strategies such as matching employee skills to specific tasks, implementing cross-training programs, balancing workloads, and making temporary adjustments can significantly improve production line effectiveness. By addressing these issues, companies can streamline processes and boost operational efficiency.

Table 2. Cycle Time Data (in Seconds) by Process

Process	Actual Cycle Time (seconds)	Cycle Time per HC	Takt Time (seconds)	Operator provided
Header assembly & Coplanarity	110	524	264	0.21
Wondermask application	24	160	264	0.15
Winding Flex Circuit	855	214	264	4.00
Core Insulation	56	134	264	0.42
Pre-Leadout Hand Iron Soldering	102	102	264	1.00
Pre-Core Assembly	78	135	264	0.58
Core Grinding & Pre-Testing 1	117	86	264	1.37
Ablebond Application Side Area	32	27	264	1.20
Pre-Testing 2 (separate wire → test)	111	317	264	0.35
Ablebond Application Top Area	63	63	264	1.00
Pre-Testing 3 (unclamp unit→ test)	26	325	264	0.08
Core To Header Assembly (manual, XY Table not finish install yet)	91	46	264	2.00
Leadouts Hook-Up Hand Soldering and Cleaning pin 1,2	135	265	264	0.51
Remove & Cleaning Y1370U [Additional process]	115	164	264	0.70
Pre-Electrical Test 4	130	100	264	1.29
Wondermask Application	27	179	264	0.15
Toroid Winding	276	276	264	1.00
Leadouts Soldering & Pre-Electrical Tests 5	62	317	264	0.20
Aircoil/Toroid Holder Assembly, Ablebond Application & Oven Curing	504	168	264	3.00
Leadout Hook Up & Hand Iron Soldering (Cleaning) 2 pin 7,6,5,	191	191	264	1.00
Ablebond Terminal Pins (1st layer→ bake→ 2nd layer)	453	227	264	2.00
Remove and Cleaning Wondermask , Foil Sheild Assembly, Ablebond Application & Oven Curing	420	234	264	1.79
Final Mechanical & Final Visual Inspection	1,165	292	264	4.00
Final Test	376	188	264	2.00

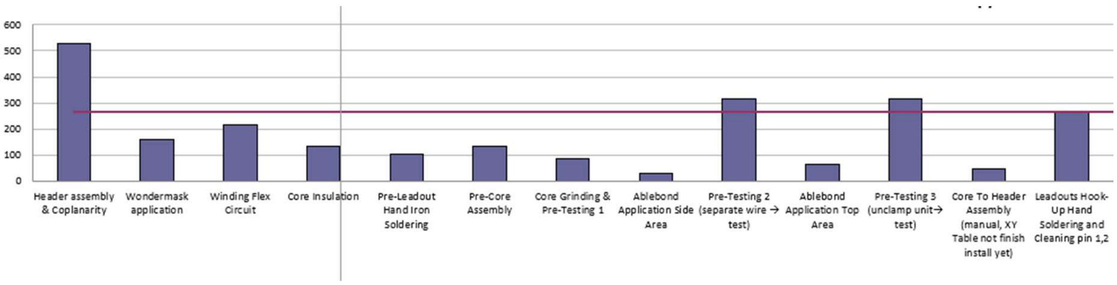

Figure 3. Bar chart for processes 1 to 13.

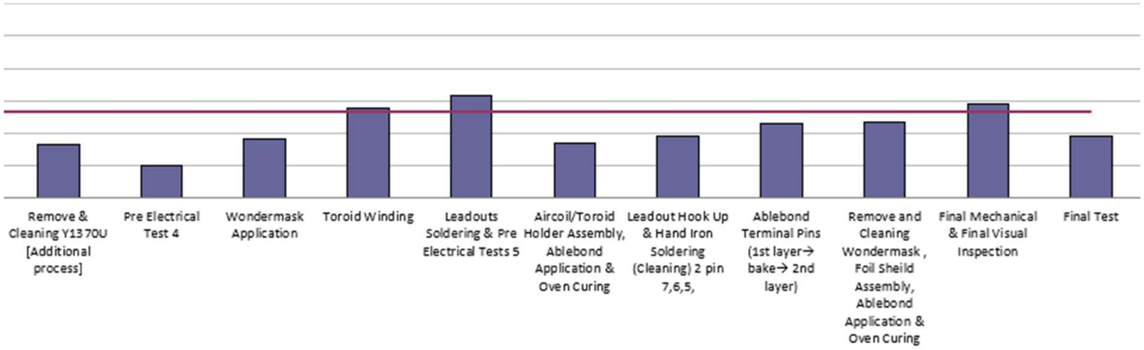

Figure 4. Bar charts for processes 14–24.

An example of the calculation of the cycle time per head count (operator) for process 1 is given below:

Cycle time per Headcount(operator) = 110 / 0.21
= 524 seconds

4.3. Strategies to Address Bottleneck Issue

Optimize Workforce Distribution and Allocation

To address the bottleneck issue and optimize productivity, it is essential to break down the tasks at each station into smaller and more manageable components. This approach enables a detailed understanding of the required skill levels and workloads for each task, thereby facilitating the identification of potential areas for improvement. Task analysis plays a vital role in efficiently allocating worker resources and analyzing the current distribution of workers across stations. This analysis helps determine whether skilled workers are optimally positioned and whether some stations are overstaffed or understaffed, allowing for targeted corrective actions to optimize workforce distribution.

Optimizing workforce allocation involves assigning tasks based on individual skill sets, which increases efficiency and minimizes errors. Placing proficient workers in roles where they excel can significantly enhance overall performance. Additionally, introducing cross-training programs can increase workforce adaptability, enabling employees to cover absent colleagues or assist at stations with temporary increases in demand. This strategy enhances staff versatility and helps mitigate the effects of personnel shortage.

To effectively manage bottlenecks, it is important to distribute the workload evenly across stations. Reassigning workers from underutilized stations to those experiencing bottlenecks or supporting roles can ensure a more efficient use of resources, reduce idle times, and maximize productivity. Adapting to fluctuations in production demand may require temporary redistribution of workers. Implementing flexible schedules or offering overtime at bottleneck stations can effectively manage peak demand and prevent production disruptions.

Implementation and Monitoring

Before adopting widespread labor distribution changes, it is recommended to conduct a pilot test. This test helps detect unforeseen issues and ensures the effectiveness of planned manpower strategies, which enables tactical refinements before full implementation. Regular monitoring of production data is essential to evaluate the success of these adjustments. Tracking key performance indicators (KPIs), such as lead time, cycle time, and work-in-progress (WIP) inventory, is important for assessing progress and making well-informed decisions. This continuous analysis highlights areas for further optimization and necessitates continuous adjustments and improvements. Furthermore, figures 3 and 4 illustrate that beyond bottleneck issues, some stations in the production of product A are underutilized. Addressing this through strategic task organization and resource management in line production enhances the overall efficiency and reduces expenses.

Optimizing Station Use

Improving station utilization involves enabling stations to perform additional tasks during idle periods such as pre-assembling components or conducting maintenance checks. This maximizes resource use and boosts productivity. In addition, batching similar tasks improves efficiency by reducing setup times and allowing workers to specialize, enhancing skill proficiency, and station utilization. Automation plays a key role in handling repetitive and demanding tasks, thereby increasing productivity and safety. Although automation requires an initial investment, the long-term benefits of increased utilization and safety are substantial.

Empowering the Team

Using visual management tools, such as production boards, to track progress, highlight bottlenecks, and celebrate achievements can significantly improve station utilization and transparency. This approach helps workers to understand their roles in production flow, fostering engagement, and ownership. Encouraging workers to identify underutilized stations and suggest improvements, such as suggestion boxes or kaizen initiatives, taps into their creativity and expertise. Motivating workers through performance-based incentives aligns their goals with company objectives, encouraging proactive efforts to optimize station utilization. Implementing these strategies creates a culture of continuous improvement and engagement, which is crucial for maximizing productivity and achieving optimal performance in line production.

5. Conclusion

In summary, XY Electronics encounters significant inefficiencies due to bottlenecks in the production of product A, notably in processes such as header assembly, coplanarity, and pre-testing 3, where cycle times exceed target times. These bottlenecks reduce the overall productivity and efficiency of the production system, leading to issues such as stalled production and localized stockpiling. To enhance efficiency, it is critical to optimize the production line by subdividing tasks, appropriately distributing workers, and employing strategies such as cross-training and staff reallocation to address underutilized stations. Additionally, implementing pilot testing and regular monitoring of production data are necessary to ensure effective manpower allocation and facilitate continuous improvement. By refining task management and workforce allocation and optimizing station usage during idle periods, companies can not only alleviate bottlenecks, but also significantly boost productivity and operational efficiency in line production.

The main limitation of this study is its case study design, which was conducted within a single organization and focused on a specific product. This may limit the generalizability of our findings to other settings. In addition, operational environments are influenced by numerous external and internal factors that are difficult to control, potentially introducing bias into the results. Future research should be extended to multiple organizations or industries to enhance the generalizability of the results. Employing more robust statistical methods to control for potential confounding variables is also essential to produce more reliable and applicable insights.

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Declaration of Conflict of Interest

The author(s) confirm that they have no affiliations or involvement with any organization or agency that has a financial interest (such as receiving honoraria, educational grants, or holding stock ownership) or non-financial interest (such as personal or professional relationships, affiliations, expertise, or beliefs) in the subject matter or materials discussed in this manuscript.

References

Andrade, P. F., Pereira, V. G., & Del Conte, E. G. (2016). Value stream mapping and lean simulation: A case study of an automotive company. *The International Journal of Advanced Manufacturing Technology*, *85*(1–4), 547–555. https://doi.org/10.1007/s00170-015-7972-7

Chan, L., & Wu, M.-L. (2005). A systematic approach to quality function deployment with a full illustrative example. *Omega*, *33*(2), 119–139. https://doi.org/10.1016/j.omega.2004.03.010

Hatami, M., Zahraee, S. M., Khademi, A., Shahpanah, A., & Rohani, J. M. (2014). Evaluating the Effect of Main Factors in Manufacturing Production Line Based on Simulation Experiment. *Applied Mechanics and Materials*, *606*, 199–203. https://doi.org/10.4028/www.scientific.net/AMM.606.199

Jayswal, A. (2017). A Literature Review on Lean Manufacturing Techniques. *International Journal of Advance Research, Ideas and Innovations in Technology*, *3*(2), 606–611.

Kłos, S., & Patalas-Maliszewska, J. (2015). Throughput Analysis of Automatic Production Lines Based on Simulation Methods. In K. Jackowski, R. Burduk, K. Walkowiak, M. Wozniak, & H. Yin (Eds.), *Intelligent Data Engineering and Automated Learning – IDEAL 2015* (Vol. 9375, pp. 181–190). Springer International Publishing. https://doi.org/10.1007/978-3-319-24834-9_22

Rathod, B., Shinde, P., Raut, D., & Waghmare, G. (2016). *Optimization of Cycle Time by Lean Manufacturing Techniques-Line Balancing Approach*. *4*.

Russell, R. S., & Taylor, B. W. (2019). *Operations and supply chain management* (Tenth edition). Wiley.

Sangwa, N. R., & Sangwan, K. S. (2023). Leanness assessment of a complex assembly line using integrated value stream mapping: A case study. *The TQM Journal*, *35*(4), 893–923. https://doi.org/10.1108/TQM-12-2021-0369

Shou, W., Wang, J., Wu, P., Wang, X., & Chong, H.-Y. (2017). A cross-sector review on the use of value stream mapping. *International Journal of Production Research*, *55*(13), 3906–3928. https://doi.org/10.1080/00207543.2017.1311031

Soliman, M. (2020). *Takt Time Takt Time: A Guide to the Very Basic Lean Calculation*.

Tompkins, J. A. (Ed.). (2010). *Facilities planning* (4th ed). J. Wiley.

Ünal, C., & Bilget, S. (2021). Examination of lean manufacturing systems by simulation technique in apparel industry. *The Journal of The Textile Institute*, *112*(3), 377–387. https://doi.org/10.1080/00405000.2020.1756104

Womack, J. P., & Jones, D. T. (1997). Lean Thinking—Banish Waste and Create Wealth in your Corporation. *Journal of the Operational Research Society*, *48*(11), 1148–1148. https://doi.org/10.1038/sj.jors.2600967

Wong, K. C., Woo, K. Z., & Woo, K. H. (2016). Ishikawa Diagram. In W. O'Donohue & A. Maragakis (Eds.), *Quality Improvement in Behavioral Health* (pp. 119–132). Springer International Publishing. https://doi.org/10.1007/978-3-319-26209-3_9