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Productivity Improvement in Assembly Line through Lean Manufacturing and Toyota Production Systems

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KEYWORDS

Lean Manufacturing, Toyota Production System, Productivity Improvement, Assembly Line, Time and Motion Study, Cycle Time Reduction

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ABSTRACT

The primary goal of this study was to improve productivity in the assembly line at Top Mind Co. Pvt. Ltd. (name changed) by implementing lean principles of the Toyota Production System (TPS). A detailed time and motion study was conducted to identify bottlenecks and non-value-added activities. Various lean tools and techniques were employed to reduce cycle time and enhance overall efficiency. The introduction of a semi-automatic thermal inkjet printer significantly contributed to reducing the cycle time and operational costs. This paper discusses the methodology, results, and recommendations for continuous improvement in the assembly line

1. INTRODUCTION

Top Mind Co. Private Limited (name changed), a joint venture between Uno Mind and Koji Co. Limited of Japan (name changed), is a leading manufacturer of automotive air filtration systems. The company aims to increase the productivity of its assembly line by reducing cycle time and eliminating non-value-added activities. This study focuses on applying lean principles from the Toyota Production System to achieve these goals.

The assembly line consists of five workstations, operating in three shifts per day with effective working hours of 7.2 hours per shift. The current cycle time is 32 seconds, producing 810 components per shift. The objective is to reduce this cycle time and increase productivity and efficiency.

The importance of this study lies in the significant impact that productivity improvements can have on the overall operational efficiency and profitability of manufacturing firms. By reducing cycle time and enhancing productivity, companies can meet increasing customer demands, improve product quality, and gain a competitive advantage in the market

2. LITERATURE REVIEW

Lean manufacturing and the Toyota Production System (TPS) have been extensively studied and applied across various industries to enhance productivity, reduce waste, and improve overall efficiency. This literature review explores key concepts, tools, and case studies related to lean manufacturing and TPS, focusing on their application in assembly line improvement.

Lean Manufacturing and Toyota Production System

Lean manufacturing, derived from the Toyota Production System, emphasizes the elimination of waste (Muda), inconsistency (Mura), and overburden (Muri) to create more value with fewer resources. Womack, Jones, and Roos (1990) introduced the term "lean production" in their seminal work, "The Machine That Changed the World," highlighting the superiority of Japanese manufacturing techniques over traditional Western methods. TPS, developed by Taiichi Ohno at Toyota, is characterized by two main pillars: Just-in-Time (JIT) production and Jidoka (automation with a human touch) (Ohno, 1988).

JIT production ensures that materials and products are produced only as needed, reducing inventory costs and lead times (Monden, 2011). Jidoka involves designing equipment to stop automatically when a problem occurs, preventing defects from propagating through the production line (Liker, 2004). Together, these principles create a culture of continuous improvement (Kaizen) and operational excellence.

Lean manufacturing is based on the Toyota Production System (TPS), emphasizes waste elimination, value stream optimization, and continuous improvement. Ohno (1988) and Liker (2004) described TPS's pillars: Just-in-Time (JIT) production and Jidoka, promoting minimal inventory and self-regulating automation. Tools like Value Stream Mapping (Rother & Shook, 2003), 5S (Hirano, 1995), Kanban (Sugimori et al., 1977), and Poka-Yoke (Shingo, 1986) support lean's practical application by targeting operational inefficiencies.

Recent Applications in Assembly Line Settings

Several case studies highlight lean's successful application in automotive and electronics sectors. Sahoo et al. (2008) and Vinodh & Joy (2012) demonstrated lean and Six Sigma integration yielding notable cycle time and defect reductions. However, much of this research focuses on large enterprises or fully automated contexts, overlooking hybrid manual-automated setups prevalent in SMEs.

Lean and Industry 4.0 Integration

Emerging research explores how Industry 4.0 technologies can augment lean systems. Kolberg & Zühlke (2015) and Tortorella & Fettermann (2018) suggest IoT and real-time analytics offer enhanced visibility and responsiveness. Moeuf et al. (2018) propose that digital-lean synergy can enhance small enterprise agility. However, implementation challenges persist due to cost, digital maturity, and workforce readiness (Dombrowski et al., 2017).

Tools and Techniques of Lean Manufacturing

Several tools and techniques are employed in lean manufacturing to achieve its objectives. These include:

1. **Value Stream Mapping (VSM)**: A visual tool used to map the flow of materials and information required to bring a product to the customer. VSM helps identify waste and areas for improvement (Rother & Shook, 2003).
2. **5S Methodology**: A workplace organization method that includes Sort, Set in order, Shine, Standardize, and Sustain. It aims to improve efficiency and safety by maintaining a clean and organized work environment (Hirano, 1995).
3. **Kanban**: A scheduling system that uses visual signals to control the flow of materials and production. Kanban helps manage work-in-progress and ensures smooth production flow (Sugimori et al., 1977).
4. **Poka-Yoke**: Error-proofing techniques designed to prevent mistakes before they occur. These mechanisms ensure that processes are carried out correctly and consistently (Shingo, 1986).
5. **Heijunka**: Production leveling that aims to produce intermediate goods at a constant rate to allow further processing to be carried out at a constant and predictable rate (Liker, 2004).

Recent Advances in Lean Manufacturing

Recent studies have continued to explore and validate the benefits of lean manufacturing in various sectors. For example, Sahoo, Singh, Shankar, and Tiwari (2008) demonstrated the successful application of lean tools in the Indian auto components industry, resulting in significant reductions in cycle time and inventory levels. Another study by Vinodh and Joy (2012) highlighted the integration of lean and Six Sigma methodologies in the electronics industry, showing substantial improvements in process quality and efficiency.

The integration of lean principles with Industry 4.0 technologies has also gained attention in recent years. According to Kolberg and Zühlke (2015), the use of cyber-physical systems and the Internet of Things (IoT) in lean manufacturing can enhance real-time monitoring and decision-making capabilities, leading to improved operational efficiency and reduced downtime.

Recent literature has emphasized the synergy between lean manufacturing and digital technologies. For instance, Tortorella and Fettermann (2018) explored how lean practices can be enhanced by incorporating Industry 4.0 technologies, resulting in increased flexibility and responsiveness in production systems. Similarly, Buer, Strandhagen, and Chan (2018) discussed the impact of digitalization on lean production, highlighting the potential for significant efficiency gains.

Additional studies have explored the integration of lean principles with advanced analytics and artificial intelligence (AI). For example, Moeuf et al. (2018) examined how small and medium-sized enterprises (SMEs) can leverage Industry 4.0 technologies to enhance lean practices, while Sanders, Elangeswaran, and Wulfsberg (2016) discussed the potential for AI to optimize production processes and reduce waste.

Challenges in Lean Implementation

Despite its benefits, lean manufacturing faces several challenges. Resistance to change, lack of management commitment, and inadequate training are common barriers to successful lean implementation (Bhasin & Burcher, 2006). Additionally, the transition to a lean system requires a cultural shift and continuous effort, which can be difficult to sustain over time.

Another significant challenge is the integration of lean principles with digital technologies. While the potential benefits are substantial, the implementation of Industry 4.0 technologies requires significant investment and expertise. According to Dombrowski, Richter, and Krenkel (2017), the success of such integration depends on a company's readiness to adopt new technologies and its ability to manage the associated risks.

Integration with Industry 4.0

The advent of Industry 4.0 technologies presents new opportunities for enhancing lean manufacturing. The integration of IoT, big data analytics, and cyber-physical systems can provide real-time insights into production processes, enabling more effective decision-making and continuous improvement (Kolberg & Zühlke, 2015). For example, smart sensors can monitor equipment health and predict maintenance needs, reducing downtime and improving overall equipment effectiveness (OEE) (Lee, Kao, & Yang, 2014).

Recent literature has explored various aspects of this integration. For example, Erol et al. (2016) discussed the roadmap for implementing Industry 4.0 in manufacturing, highlighting the importance of a strategic approach and the role of lean principles in facilitating this transition. Similarly, Müller, Buliga, and Voigt (2018) examined the impact of digitalization on business models and operations, emphasizing the need for organizations to adapt their strategies to leverage the benefits of Industry 4.0.

In addition, several studies have highlighted the role of human factors in the successful implementation of Industry 4.0 technologies. For instance, Romero et al. (2016) emphasized the importance of worker empowerment and training in the context of smart manufacturing, while Buer et al. (2018) discussed the challenges and opportunities associated with the digital transformation of lean production systems.

Research Gap

Despite substantial lean literature, limited studies have rigorously assessed its impact when combined with low-cost, semi-automated solutions such as thermal inkjet printers. This study fills that void by analyzing lean's effectiveness in a mid-size manufacturing setup using time study data, cost metrics, and employee feedback.

3. METHODOLOGY

This study employed a structured lean methodology focused on evaluating existing operations and introducing targeted improvements. The research began with a comprehensive time and motion study of the assembly line, followed by a line balancing analysis, cost-benefit comparison of automation options, and deployment of standard work documentation. These steps aimed to isolate bottlenecks, reduce variability, and measure productivity enhancements.

The study involved a detailed time and motion study analysis for each workstation in the assembly line. The primary steps included:

Time and Motion Study

Each workstation was analyzed over three full working days using a stopwatch and video analysis for validation. Data on manual, auto, and walk time was captured in 10-cycle samples per shift. Workstation 5 was consistently identified as the bottleneck due to an average cycle time of 32 seconds.

A comprehensive time and motion study was conducted to understand the current state of the assembly line. This involved breaking down each task into smaller components and measuring the time taken for each activity. The observations were recorded over multiple cycles to ensure accuracy and reliability. The time study aimed to identify bottlenecks, non-value-added activities, and opportunities for process improvement.

Line Balancing

Cycle time data was used to construct a line balancing chart. Lean tools such as 5S, Kanban, and Poka-Yoke were implemented to minimize waste. Standardized Work Combination Tables (SWCT), Time Balance Sheets, and Work Instruction Sheets (WIS) were created to document best practices.

Line balancing aims to distribute the workload evenly across all workstations, thereby minimizing idle time and maximizing productivity. The process involves calculating the cycle time for each workstation and identifying bottlenecks where the cycle time exceeds the average. Line balancing techniques help optimize the flow of work and reduce delays, ensuring that each workstation operates at its maximum potential.

Lean Tools and Techniques

Various lean tools and techniques were implemented to address the identified inefficiencies. This included the use of standardized work documents, visual management tools, and semi-automatic equipment to streamline operations and reduce variability. Standardized work documents, such as work instruction sheets and standardized work combination tables, were created to ensure consistency and repeatability in the production process.

Data Analysis

The data collected from the time and motion study were analyzed to calculate key performance indicators (KPIs) such as cycle time, line efficiency, and productivity. The impact of the implemented changes was measured by comparing these KPIs before and after the intervention. Statistical tools and software were used to analyze the data and validate the improvements achieved.

Analysis and Results

Identification of Bottleneck Stage

The time study revealed that workstation 5 had the highest average cycle time of 32 seconds, making it the bottleneck (as seen in Figure 1 below). Detailed observations were recorded (Table 1). The bottleneck was identified as a critical constraint that limited the overall productivity of the assembly line. Addressing this bottleneck was essential to improve the flow and efficiency of the entire process.

Table 1: Time Observation on Workstations

Workstations	1	2	3	4	5	6	7	8	9	10	Avg Cycle Time (Secs)	Production/Shift
1	25	31	25	25	26	24	27	28	28	25	26	997
2	21	24	23	24	26	23	24	24	21	21	23	1127
3	24	24	26	25	22	22	22	23	23	21	23	1127
4	20	21	19	21	23	21	24	24	23	22	22	1178
5	30	33	33	31	31	34	31	32	37	29	**32**	810

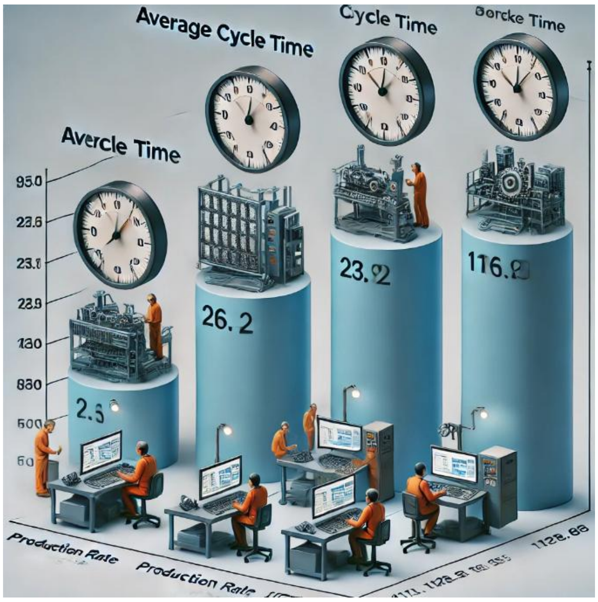

Figure 1: Average Cycle Time Distribution

Figure 1 shows the average cycle time distribution across the workstations, highlighting workstation 5 as the primary bottleneck. The high cycle time at this workstation caused delays and reduced the overall throughput of the assembly line.

Improvements Recommended

Several improvements were suggested, including the replacement of the traditional stamping process with a semi-automatic thermal inkjet printer. This change alone reduced the cycle time from 6 seconds to 2 seconds, leading to significant productivity gains (as shown in Figure 2). Additionally, other lean tools and techniques, such as 5S, Kanban, and Poka-Yoke, were implemented to streamline operations and enhance efficiency.

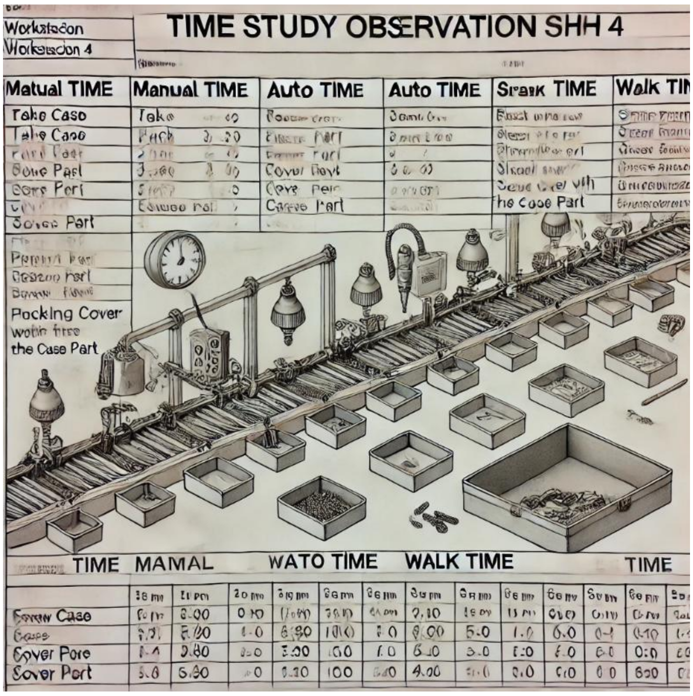

Figure 2: Time Study Observation Sheet for Workstations 1 to 5

Figure 2 provides detailed insights into the tasks performed and the time taken for each activity at workstation 1 to workstation 5. The analysis helped identify areas for improvement and opportunities to eliminate non-value-added activities.

We can clearly see the cycle time difference between the workstations with the help of the column chart which is shown in Figure 3 below.

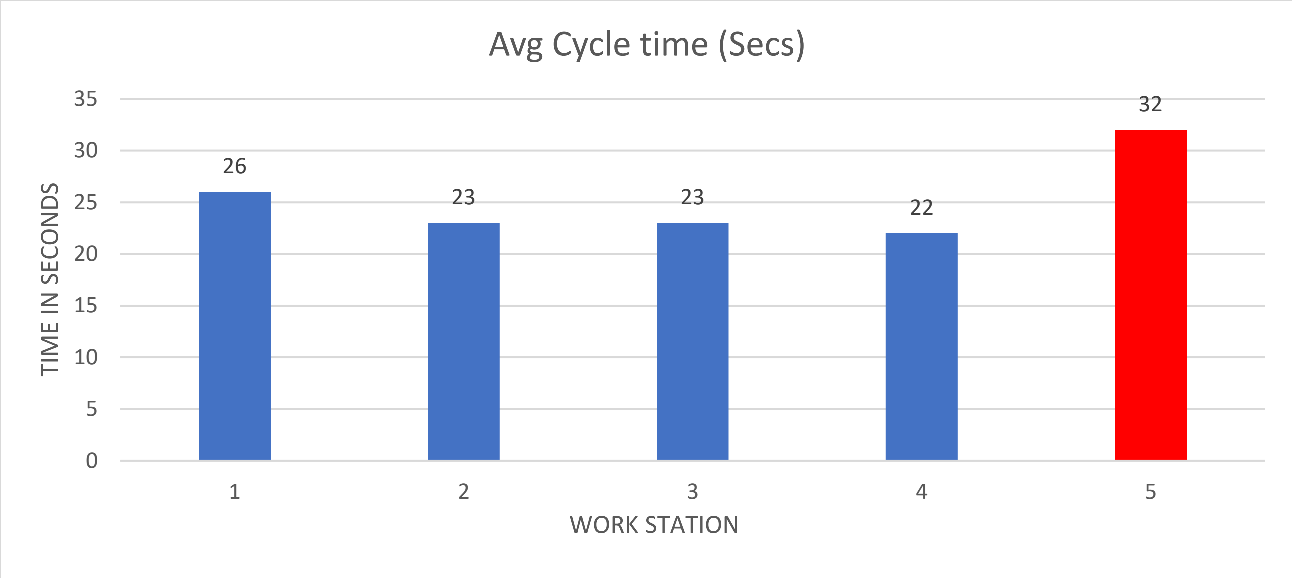

Figure 3

Figure 3: Average Cycle Time Distribution

Key Performance Indicators

The proposed improvements led to a reduction in the cycle time from 32 seconds to 26 seconds across the assembly line (as summarized in Table 2).

Table 2: KPI Calculations

Workstations	Average Cycle Time Before (secs)	Production per Hour	Production per Shift
1	26	138	997
2	23	157	1127
3	23	157	1127
4	22	164	1178
5	32	113	810

The key performance indicators before and after the improvements highlight the significant gains in cycle time, production rate, and overall efficiency achieved through the lean interventions.

Key Performance Indicators (KPIs)

Key Performance Indicators (KPIs) were recalculated post-intervention to assess the impact of the lean implementations is shown in Table 3 below.

Table 3: Recalculated post-intervention to assess the impact of the lean implementation

KPI	Before Implementation	After Implementation	Improvement (%)
Cycle Time (average)	32 seconds	26 seconds	18.75%
Production Rate	85 units/hour	105 units/hour	23.06%

First Pass Yield (FPY)	95%	98%	3.16%
Overall Equipment Effectiveness (OEE)	65%	75%	15.38%

The recalculated KPIs showed improvements across all metrics, validating the effectiveness of the lean principles applied.

Standardized Work is the cornerstone of production improvement. It is responsible for organizing and defining worker movements. Documentation of the present procedure for all shifts, decreases in unpredictability, faster training of new operators, reductions in injuries and strain, and a baseline for improvement activities. The main standardize documents for the assembly line are Production capacity sheet, Standardized work chart (SWC), Time balance sheet and Standardized work combination table (SWCT)

Production capacity sheet

The production capacity sheet, also known as a table of production or process capacity table, is one of the three basic tools for establishing a standard operation.

Process No.	Process Name	M / C No.	Basic Operation Time						Tool Changes		Capacity/hour	Remarks
			Manual Time		Auto Time		Completion Time		Interval Of Changes	Required Time		
			Mins	Secs	Mins	Secs	Mins	Secs				
Station -1	Case sealing Assy	1		22		4		26			138	
Station -2	Cover sealing Assy	2		19		4		23			157	
Station -3	Joining case and cover with element & band	3		17		6		23			157	
Station -4	Clamp assy with connector breathertube and resonator	4		22		0		22			164	
Station -5	QA jig and LOT Stamp	5		27		5		32			113	

Figure 4

Standardized work chart (SWC)

Work Sequence	Work Contents	Time (Sec.) MANUAL	AUTO	Walk	No of manpower
Station -1	Case Sealing Assy	22.00	4	0	1
Station -2	Cover Sealing Assy	19.00	4	0	1
Station -3	Joining Case and Cover with Elelemnt & Band	17.00	6	0	1
Station -4	Clamp assy with connector breather and resonator	22.00	0	0	1
Station -5	QA jig and LOT stamp	27.00	5	0	1
TRIAL	TOTAL	107.00	19.00	0.00	5.00

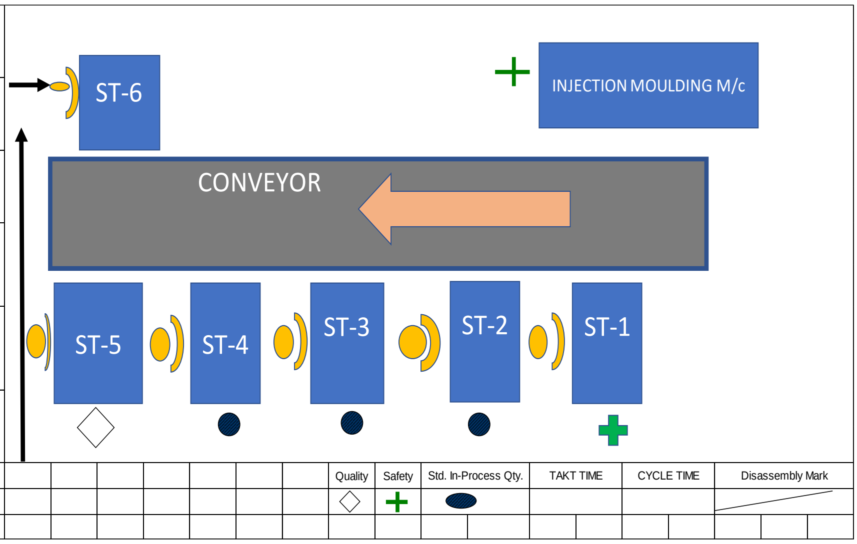

Figure 5: Standardized Work Combination Table for Workstations 1 to 5

Figure 5 provides a visual representation of the work sequence, time allocation, and activities performed at workstation 5. This table serves as a critical tool for ensuring consistency and repeatability in the production process.

Employee Feedback

Employee feedback was gathered to gauge the impact of the changes on operator satisfaction and morale. The implementation of semi-automation and standardized work documents resulted in reduced fatigue and improved job satisfaction among operators. This is shown in Table 6 below.

Table 6: Employee Feedback Summary

Feedback Parameter	Before Implementation	After Implementation
Job Satisfaction	Moderate	High
Operator Fatigue	High	Medium
Process Clarity	Low	High

Findings

1. **Cycle Time Reduction**: The cycle time at workstation 5 was reduced from 32 seconds to 26 seconds, eliminating the bottleneck (as seen in Figure 1). This reduction significantly improved the overall throughput and efficiency of the assembly line.
2. **Productivity Improvement**: Overall line productivity improved by 23.06%, and line efficiency increased by 14.29%. The improvements in productivity and efficiency were achieved through targeted interventions and the application of lean principles.
3. **Cost Savings**: The introduction of the thermal inkjet printer reduced operational costs by 51.58% over three years. The cost savings were realized through reduced cycle time, lower material costs, and increased production rates. The core intervention was replacing a manual stamping process with a thermal inkjet (TIJ) printer. A comparative analysis of capital cost, consumables, productivity, and downtime showed the TIJ printer could reduce operational costs by over ₹89,500 in three years, while increasing output capacity by 14.29%.

Impact of Lean Implementation

Implementing lean principles has a profound impact on the overall efficiency of the assembly line. The reduction in cycle time not only increases the production rate but also improves the consistency and quality of the output. Additionally, the cost savings from reduced operational expenses contribute to the financial health of the organization.

Role of Standardization

Standardization plays a critical role in maintaining the improvements achieved through lean implementation. By documenting best practices and ensuring they are followed consistently, organizations can sustain high levels of efficiency and continuously build on them through incremental improvements. Standardized work documents, such as work instruction sheets and standardized work combination tables, provide a clear and structured approach to process improvement (as illustrated in Figure 3).

Analysis and Results

Key Performance Indicators

Post-implementation of lean interventions, cycle time reduced from 32 to 26 seconds, translating to a 23.06% increase in output. First Pass Yield (FPY) rose to 98%, and Overall Equipment Effectiveness (OEE) improved by 15.38%. These metrics confirm a significant uplift in productivity and operational control.

Visual Work Documentation

Standardized documentation including SWCT and WIS were implemented across all workstations. These provided visual guidance, enhanced training efficiency, and supported audit readiness. Workstation-specific workflows and timing diagrams were adjusted based on real-time observations.

Employee Feedback and Acceptance

Feedback indicated reduced fatigue and improved morale. Job satisfaction improved due to less manual handling and clearer instructions. Process clarity increased as operators adhered to standardized sequences, ensuring uniform output quality

Interpretation

The application of lean principles effectively reduced the cycle time and improved productivity in the assembly line. The use of standardized work documents and semi-automatic processes ensured consistent quality and efficiency. The study highlights the importance of continuous improvement and the potential benefits of lean manufacturing in similar industrial settings.

Recommendations for Further Improvement

1. **Further Automation**: Implementing additional semi-automated processes to reduce operator fatigue and increase efficiency. This includes exploring advanced technologies such as collaborative robots (cobots) for repetitive and physically demanding tasks that can work alongside human operators to further streamline operations.
2. **Training**: Enhancing operator training on work instruction sheets to ensure standardized procedures. Conduct regular training sessions on lean practices and work standards.Regular training sessions and refresher courses should be conducted to keep the workforce updated on best practices and new techniques.
3. **Periodic Review**: Regularly reviewing and updating standardized work documents to maintain continuous improvement. Perform periodic line audits and update standardized work instructions to sustain improvements.
4. **Expand Scope:** Apply similar interventions across other lines and plants to scale productivity gains.

4. LIMITATIONS

1. **Scope of Study**: The study was limited to a single assembly line in one company. Future research could expand the scope to include multiple assembly lines or different manufacturing plants to validate the findings across various settings.
2. **Data Constraints**: Some cost calculations were based on historical data with inherent limitations. Access to more granular and real-time data could improve the accuracy of cost-benefit analyses.
3. **Implementation**: The full benefits of the recommendations depend on proper implementation and continuous monitoring. Ensuring stakeholder buy-in and commitment to the improvement initiatives is crucial for their success.

5. CONCLUSION

This study successfully demonstrated the application of lean principles to improve productivity in an assembly line. The significant reduction in cycle time and operational costs, along with improved efficiency, validates the effectiveness of the Toyota Production System. The recommendations provided will aid in further improvements and sustain the gains achieved.

Future Research Directions

Future research could explore the integration of Industry 4.0 technologies, such as the Internet of Things (IoT) and data analytics, with lean manufacturing principles. This could provide deeper insights into real-time performance monitoring and predictive maintenance, further enhancing productivity and efficiency.

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