Effectiveness of Single Piece Flow Implementation in Assembly Line Operations

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ABSTRACT: This project focuses on the implementation and effectiveness of Single-Piece Flow (SPF) in the A-Line Assembly operations at Roots Industries India Private Limited, a leading manufacturer of automotive horns. The company initially followed a batch production system, which led to operational challenges such as high rejection rates, increased rework, excessive work-in-progress (WIP) inventory, inefficient storage utilization, and long cycle and lead times. These inefficiencies contributed to delays in production, inconsistent daily output, and higher operational costs. To address these issues, the project introduced Single-Piece Flow (SPF) as a lean manufacturing approach aimed at streamlining the assembly process. A quantitative research design was adopted, with pre-implementation data collected over a span of six months, and postimplementation data gathered for 50 days after introducing Single-Piece Flow (SPF). The performance metrics analyzed include daily production output, cycle time (seconds), lead time (minutes), rejection rate (%), rework (%), work-in-progress (WIP) inventory, storage utilization (%), and machine idle time (minutes). Statistical tools such as descriptive statistics, paired sample t-tests, correlation, and regression analysis were used to evaluate improvements across the key parameters. The study's objectives were to assess enhancements in production performance, quality control, and inventory management efficiency after implementing Single-Piece Flow (SPF). The results indicated a significant improvement in overall efficiency, with reductions in lead time, cycle time, rejection and rework rates, and better inventory and space utilization. The study concludes that Single-Piece Flow (SPF) positively impacts production operations, making it a highly effective lean strategy for Roots Industries India Private Limited to achieve consistent quality, timely output, and reduced waste in horn manufacturing.
KEYWORDS: Single-Piece Flow, Lean Manufacturing, Production Efficiency, Inventory Management, Quality Improvement

I. INTRODUCTION

Single-Piece Flow (SPF) is a lean manufacturing method where products move one unit at a time through each production stage, rather than in batches. This approach reduces waiting time, work-in-progress inventory, and enhances quality by allowing quick detection of defects. Rooted in Lean and Just-in-Time (JIT) principles, SPF emphasizes continuous flow, pull-based production, waste elimination, and built-in quality (jidoka). It improves equipment efficiency, shortens lead times, boosts productivity, and supports continuous improvement. When implemented well, SPF leads to lower costs, better resource use, and higher customer satisfaction.

Batch Production involves making products in groups, allowing flexibility and cost-effectiveness for low volumes or varied products. However, it often results in high WIP inventory, longer lead times, and delayed defect detection. Machine changeovers between batches also cause inefficiencies. In contrast, **Single-Piece Flow (SPF)** moves one item at a time through each stage, reducing lead time, improving quality control, and enhancing workflow efficiency. While batch production suits varied, low-volume runs, SPF is ideal for high-volume, standardized operations focused on speed and consistency. Transitioning to SPF requires process changes but offers long-term gains in productivity, quality, and customer satisfaction.

STAGES OF A LINE ASSEMBLY

1. **Spool assembly locking** - The process begins by securely fitting and locking the spool component into its designated place. The spool is vital for the horn's electromagnetic mechanism, and proper assembly ensures that the electromagnetic coil functions effectively during operation.
2. **Point holder and tuning screw assembly** - At this stage, the point holder and tuning screw are attached. The point holder accommodates the electrical contact, while the tuning screw is adjusted to regulate the sound frequency. Accurate placement is necessary to maintain consistency in the horn's tone.
3. **Terminal base riveting and continuity check** - The terminal base, which connects the electrical wiring, is riveted firmly to the horn body. Once fixed, a continuity test is conducted to confirm the electrical path is uninterrupted, ensuring reliable flow of current through the circuit.
4. **Pre-crimping and final crimping** - Wires or terminals are first lightly crimped to hold them in place, followed by a final crimp to lock them securely. This ensures firm electrical connections that can withstand vibrations and usage over time, preventing loose or faulty contact points.

5. **Diaphragm Assembly and Riveting** - The diaphragm, a thin metal disc that vibrates to produce sound, is placed and riveted into the horn body. Accurate positioning is essential for optimal sound production and to avoid issues like distortion or reduced volume.
6. **Air gap measurement and adjustment** - The air gap—the distance between the diaphragm and magnetic core—is measured and finely adjusted. Correct air gap ensures efficient vibration, which affects both sound clarity and horn durability. Too large or too small a gap can impact horn performance.
7. **Pre-tuning and mounting bracket assembly -** In this stage, the horn undergoes an initial sound check (pre-tuning) to detect major issues. Simultaneously, mounting brackets are assembled to facilitate easy installation in vehicles. The horn is now structurally and acoustically ready for final tuning.
8. **Horn tuning and testing -** Final tuning involves adjusting the horn to produce the required pitch and volume. The horn is tested under actual operating conditions to verify that it meets performance standards for sound frequency and amplitude.
9. **Tuning range verification and batch coding** - Once tuned, the horn's sound range is verified to ensure it falls within the specified limits. After approval, batch codes are marked on the unit to aid in identification, traceability, and quality control tracking.
10. **Sealant application** - A protective adhesive or sealant is applied to critical areas to prevent ingress of dust, moisture, or other contaminants. This enhances the horn's durability and long-term reliability, especially in challenging environmental conditions.
11. **Final quality inspection** - The completed horn undergoes a thorough quality check. This includes visual inspection, functionality testing, sound verification, and occasionally sample testing for durability. Only units that meet all required standards proceed to packaging and dispatch.

PROBLEM STATEMENT

The current batch production system in the A-Line Assembly of the horn manufacturing company is causing significant inefficiencies, including high rejection rates, delayed quality issue identification, production delays, and poor inventory management. Due to the lack of real-time defect detection, defective products proceed through multiple stages before being identified, leading to increased rework, material wastage, and production losses. Additionally, excessive work-in-progress (WIP) results in inefficient resource utilization and longer lead times, preventing the company from achieving its daily target of 1600 pieces. To address these challenges, the company aims to implement a Single-Piece Flow (SPF) system, which ensures that each unit moves through the assembly line one at a time, allowing for real-time defect detection, reduced WIP, improved production speed, and better inventory control. This project focuses on designing and implementing SPF to enhance quality, reduce rejection rates, eliminate delays, and optimize production efficiency, ultimately improving the company's overall competitiveness in the automotive horn industry.

OBJECTIVES

- To analyze production performance by comparing cycle time, lead time, and daily output before and after implementing Single-Piece Flow.
- To evaluate quality improvements by measuring rejection rates and rework percentage, ensuring better defect detection and reduction.
- To assess inventory management efficiency by analyzing work-in-progress (WIP) inventory levels and storage utilization before and after implementing Single-Piece Flow.
- To evaluate the effectiveness of single piece flow in minimizing workflow interruptions and enhancing production consistency, based on operator feedback.

II. REVIEW OF LITERATURE

The literature reviewed for this study highlights the increasing relevance of Single-Piece Flow (SPF) in modern manufacturing as a lean strategy to enhance productivity, reduce waste, and improve quality. Multiple case studies and research papers demonstrate how transitioning from batch production to a continuous, one-piece flow leads to measurable operational improvements across industries.

Miltenburg (2001) provided a comprehensive tutorial on U-shaped lines for one-piece flow. The design allowed for cross-trained operators and minimal travel time. Key benefits included enhanced communication, reduced WIP, and faster changeovers. The tutorial emphasized system design considerations and control logic. One-piece flow was shown to enhance flexibility and efficiency. Practical guidelines supported implementation in varied factory environments.

Liker (2004) explored Toyota's one-piece flow as a pillar of Lean manufacturing. Emphasizing just-in-time production, the work outlines how reduced batch sizes improve quality and minimize waste. One-piece flow was linked to faster defect detection and enhanced team coordination. The 14 principles reinforce continuous improvement (Kaizen) and respect for people. Key insights suggest one-piece flow demands cultural transformation for long-term success. The Toyota Production System serves as the foundation for global Lean practices.

Scharf and Kissing (2007) discussed one-piece flow as a flexible concept for serial production. The article emphasized simplicity and operator autonomy in line design. Shorter feedback loops enhanced quality control. Implementation led to improved delivery reliability and reduced space requirements. The study highlighted modular workstations as enablers of flexibility. One-piece flow was shown to support varied product ranges in small-batch production.

Paneru (2011) implemented lean tools, including one-piece flow, in a garment manufacturing unit. The focus was on the sewing section of men's shirts, where output increased by 22%. Line reconfiguration and takt time alignment enabled real- time defect correction. WIP levels 24 decreased significantly due to continuous flow. Operator training and 5S ensured stability of lean gains. One-piece flow was effective in integrating quality and efficiency in apparel production.

Chowdary and George (2011) applied lean tools, including one-piece flow, to restructure manufacturing operations. Their case study reported significant reductions in cycle time and work-in-progress inventory. By aligning process layout with lean principles, productivity improved by 25%. Key tools used included cellular manufacturing and 5S. The findings underscore the practical feasibility of flexible lean tool integration. One-piece flow was a central enabler of operational efficiency and responsiveness.

Alarcón and González (2023) discussed one-piece flow in the context of lean construction. They emphasized minimizing batch work to improve on-site coordination and material flow. One-piece techniques helped reduce delays and rework. The guide outlined tools like pull planning and crew balancing. A core takeaway was that continuous flow principles apply beyond manufacturing. One-piece flow was adapted to improve construction efficiency and project control.

Candea and Candea (2023) examined one-piece flow adoption in garment enterprises. Their research highlighted time savings and quality improvements in sewing operations. Lean layouts and visual tools enhanced workflow transparency. One-piece flow facilitated early defect detection and better process discipline. Cultural change and workforce training were 28 emphasized as prerequisites. Findings supported lean applicability in labor-intensive industries.

III. RESEARCH METHODOLOGY

Research Methodology is the structured approach used to carry out a research project. It involves choosing an appropriate research design, determining methods for collecting data, selecting tools for analysis, and applying suitable sampling techniques. This methodology guides the entire research process, ensuring that information is collected, examined, and interpreted in a logical and meaningful way. A strong research methodology helps ensure the study's outcomes are trustworthy, consistent, and can be reproduced in future research.

RESEARCH DESIGN:

The research adopts a quantitative approach with a comparative design framework to assess the effectiveness of Single Piece Flow (SPF) in the horn assembly line. This design enables the analysis of production efficiency by comparing key performance metrics before and after SPF implementation. Parameters such as cycle time, lead time, WIP inventory, storage utilization, and machine idle time are closely examined to evaluate the overall impact of the new production system.

Type of Research: Descriptive and Applied

Purpose To evaluate the effectiveness of Single Piece Flow on operational performance Methodology:

Time study, WIP observation, and data analysis

Approach: Comparative study of performance metrics before and after implementation.

DATA COLLECTION AND CLEANING:

Data was collected from secondary sources within Roots Industries India Pvt. Ltd., specifically from production logs, quality reports, and inventory records. Pre implementation data was gathered from the six months prior to SPF introduction, while post-implementation data covers a 50-day period. The collected data underwent a thorough cleaning process to eliminate inconsistencies, missing values, and outliers to ensure the accuracy and reliability of the analysis.

TOOLS USED SPSS (Statistical Package for the Social Sciences)

SPSS was utilized to carry out statistical analysis on the collected data. In particular, a Paired t-test was employed to evaluate critical parameters—such as rejection rates, work in-progress levels, and cycle times—before and after the implementation of improvements in the A-Line Assembly. This test was instrumental in assessing whether the changes observed in production performance following the adoption of Total Productive Maintenance (TPM) practices were statistically significant.

DESCRIPTIVE ANALYSIS

Descriptive analysis is a method used to summarize and organize data in a meaningful way. It involves calculating measures such as mean, median, standard deviation, minimum, and maximum to describe the basic features of a dataset without making predictions or drawing conclusions beyond the data.

PAIRED T-TEST

A paired t-test is a statistical method used to compare the means of two related groups, typically before-and-after measurements on the same subjects. It helps determine whether the observed difference in means is statistically significant.

CORRELATION

Correlation is a statistical technique used to measure the strength and direction of a linear relationship between two variables. It is expressed as a correlation coefficient (r), which ranges from -1 to +1, indicating negative or positive relationships, respectively.

DATA VISUALIZATION

To enhance interpretability, visual tools such as bar charts, line graphs were used. These visuals depict trends, patterns, and variations across the pre- and post-implementation periods, helping stakeholders quickly grasp the improvements achieved through the SPF approach.

ONE SAMPLE T TEST

A one-sample t-test is a statistical method used to determine whether the mean of a single sample differs significantly from a known or hypothesized population mean. It is typically applied when the population standard deviation is unknown, and the sample size is relatively small. The test evaluates if the sample data provides enough evidence to reject the null hypothesis, which states that there is no difference between the sample mean and the population mean. This method assumes that the data is approximately normally distributed. It is widely used in research to validate assumptions about a population based on sample data.

IV. ANALYSIS AND INTERPRETATION

ANALYSIS OF PRODUCTION PERFORMANCE

- To analyze production performance by comparing cycle time, lead time, and daily output before and after implementing Single-Piece Flow.

This objective is focused on examining the effectiveness of implementing Single-Piece Flow (SPF) by comparing critical production indicators such as cycle time, lead time, and daily output — before and after the implementation of Single-Piece Flow (SPF). The comparison aims to highlight any improvements in production efficiency resulting from the adoption of SPF. Through this analysis, the study seeks to gain insights into how the new system influences operational performance and whether it leads to more consistent and streamlined manufacturing outcomes. The goal is to determine if SPF provides measurable advantages over traditional batch production in a real-world assembly environment.

Available factor:

i. Cycle time

Cycle time refers to the total time taken to complete one unit of production from start to finish within a specific process or workstation. It includes processing time and any minor delays but excludes major downtimes.

Formula:

$$\text{Cycle Time} = \frac{\text{Total Production Time}}{\text{Number of Units Produced}}$$

ii. Lead Time

Lead time is the total time it takes for a product to move through the entire production system—from the receipt of raw materials to the final delivery of the product. It includes processing time, waiting time, transportation, and inspection time.

iii. Daily Output

Daily output represents the number of units produced by a process or production line in a single working day. It serves as a direct measure of productivity and helps evaluate how efficiently the process meets daily demand.

4.1.1 DESCRIPTIVE ANALYSIS OF PRODUCTION PERFORMANCE

Parameter	Period	N	Minimum	Maximum	Mean	Standard Deviation
Daily Production	Pre- Implementation	180	504	999	761.01	143.858
	Post- Implementation	50	906	1196	1060.30	89.323
Cycle Time (sec)	Pre- Implementation	180	30	90	60.36	17.773
	Post- Implementation	50	15	39	25.26	7.250
Lead Time (min)	Pre- Implementation	180	61	180	120.24	34.784
	Post- Implementation	50	33	90	60.02	16.022
Rejection Rate (%)	Pre- Implementation	180	1.51	4.99	3.295	1.00295
	Post- Implementation	50	0.52	2.00	1.2230	0.48686

Rework (%)	Pre- Implementation	180	2.04	5.99	3.9636	1.15667
	Post- Implementation	50	1.05	2.98	1.9688	0.56576
WIP Inventory (units)	Pre- Implementation	180	200	499	340.00	88.236
	Post- Implementation	50	51	149	95.18	28.330
Storage Utilization (%)	Pre- Implementation	180	50.39	84.69	67.9154	9.8119
	Post- Implementation	50	30.09	59.97	43.885	9.3439
Machine Idle Time (min)	Pre- Implementation	180	30	120	74.81	27.325
	Post- Implementation	50	10	40	26.50	8.728

INTERPRETATION

The comparative analysis of pre- and post-implementation data reveals significant enhancements in manufacturing performance metrics, indicating the effectiveness of the implemented process improvements.

Production Efficiency: The average daily production increased from 761.01 units to 1060.30 units, reflecting a substantial boost in output. This improvement suggests that the implemented changes have optimized production processes, leading to higher efficiency.

Operational Timelines: The cycle time decreased from 60.36 seconds to 25.26 seconds, and the lead time reduced from 120.24 minutes to 60.02 minutes. These reductions indicate streamlined operations and faster processing, contributing to quicker turnaround times.

Quality Metrics: The rejection rate dropped from 3.295% to 1.223%, and the rework percentage decreased from 3.9636% to 1.9688%. These declines point to improved quality control measures, resulting in fewer defects and less need for rework.

Inventory and Resource Utilization: Work-in-progress (WIP) inventory levels fell from 340 units to 95.18 units, and storage utilization decreased from 67.9154% to 43.885%. Additionally, machine idle time was reduced from 74.81 minutes to 26.50 minutes. These changes suggest more efficient use of resources and better inventory management.

The post-implementation data demonstrates substantial improvements in production efficiency, quality, and resource utilization. The increases in daily production, coupled with reductions in cycle time, lead time, rejection and rework rates, WIP inventory, storage utilization, and machine idle time, collectively indicate that the implemented changes have positively impacted the manufacturing process

PAIRED SAMPLE T TEST OF PRODUCTION PERFORMANCE

Paired Samples	Mean Difference	Std. Deviation	Std. Error Mean	t-value	df	Sig. (2-tailed)
Pair 1: Daily Production	-313.000	162.900	23.038	-13.587	49	0.000
Pair 2: Cycle Time (sec)	35.360	18.754	2.652	13.332	49	0.000
Pair 3: Lead Time (min)	60.300	35.274	4.988	12.088	49	0.000

INTERPRETATION

The paired samples t-test results indicate significant changes across all three measured parameters: Daily Production, Cycle Time (seconds), and Lead Time (minutes).

For Daily Production, the mean difference is -313.000 units, with a standard deviation of 162.900 and a standard error of 23.038. The t-value is -13.587 with 49 degrees of freedom, and the p-value is 0.000. This negative mean difference suggests a decrease in daily production post-implementation, and the p-value indicates that this change is statistically significant.

Cycle Time, the mean difference is 35.360 seconds, with a standard deviation of 18.754 and a standard error of 2.652. The t-value is 13.332 with 49 degrees of freedom, and the p-value is

0.000. This positive mean difference indicates an increase in cycle time, and the statistical significance suggests that this change is not due to random variation.

Lead Time, the mean difference is 60.300 minutes, with a standard deviation of 35.274 and a standard error of 4.988. The t-value is 12.088 with 49 degrees of freedom, and the p-value is

0.000. This positive mean difference reflects an increase in lead time, and the statistical significance confirms that this change is meaningful.

EVALUATION OF QUALITY PERFORMANCE

➢ To evaluate quality improvements by measuring rejection rates and rework percentage, ensuring better defect detection and reduction.

This objective focuses on evaluating the quality performance of the production process by analysing rejection rates and rework percentages before and after the implementation of Single-Piece Flow (SPF). The intention is to determine whether SPF contributes to better defect detection and reduced quality issues within the assembly line. By comparing these quality indicators, the objective aims to assess if the production system has become more effective at minimizing errors, reducing waste, and improving overall product consistency. This analysis provides insight into the role of SPF in enhancing product quality and achieving a more stable and reliable manufacturing process.

Available factor:

i. Rejection Rate

Rejection rate refers to the percentage of products that fail to meet quality standards and are discarded during or after production. A high rejection rate indicates poor process control or quality issues.

Formula

$$\text{Rejection Rate (\%)} = \frac{\text{Number of Rejected Units}}{\text{Total Units Produced}} \times 100$$

ii. Rework Percentage

Rework percentage indicates the proportion of units that did not meet initial quality requirements but can be corrected and reused. It reflects process inefficiencies and impacts production time and cost.

Formula

$$\text{Rework Percentage} = \frac{\text{Number of Reworked Units}}{\text{Total Units Produced}} \times 100$$

4.1.2 PAIRED T TEST OF QUALITY PERFORMANCE

Pair Comparison	Mean Difference	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Rejection Rate	2.11540	1.21520	0.17186	12.309	49	0.000
Rework	1.84700	1.15768	0.16372	11.281	49	0.000

INTERPRETATION

The paired samples test compares the mean differences between two related groups. In this case, we are analysing the difference in rejection rate and rework percentage before and after an intervention.

1. **Rejection Rate (%)**: The mean difference in rejection rates between the two time points is 2.11540. The standard deviation is 1.21520, with a standard error mean of 0.17186. The t-statistic is 12.309, with 49 degrees of freedom, and the p-value is less than 0.001, indicating that the difference in rejection rates before and after the intervention is statistically significant.

2. **Rework (%)**: The mean difference in rework percentages is 1.84700, with a standard deviation of 1.15768 and a standard error mean of 0.16372. The t-statistic is 11.281, and the p-value is also less than 0.001, suggesting a statistically significant difference in rework percentages before and after the intervention

EVALUATION OF INVENTORY MANAGEMENT EFFICIENCY THROUGH WIP AND STORAGE UTILIZATION ANALYSIS

➢ To assess inventory management efficiency by analyzing work-in-progress (WIP) inventory levels and storage utilization before and after implementing Single-Piece Flow.

The aim is to evaluate how effectively inventory is managed by examining the levels of work-in-progress (WIP) inventory and the usage of storage space. This assessment involves comparing data collected before and after the implementation of the Single-Piece Flow system. The focus is on determining whether the new approach leads to a reduction in excess WIP and improves the utilization of available storage areas, indicating more streamlined and efficient inventory handling.

Available factor:

i. Work-in-Progress (WIP) Inventory

WIP inventory refers to the number of partially completed products that are still within the production process. It includes raw materials, sub-assemblies, and components that are not yet finished goods. High WIP often indicates production bottlenecks or inefficiencies.

ii. Storage Utilization

Storage utilization measures how effectively available storage space is used in a production or warehouse area. It helps assess space planning and inventory control efficiency.

Formula

$$\text{Storage Utilization (\%)} = \frac{\text{Used Storage Space}}{\text{Total Available Storage Space}} \times 100$$

CORRELATION MATRIX: WIP INVENTORY AND STORAGE UTILIZATION (PRE AND POST IMPLEMENTATION)

	Pre-WIP Inventory	**Post-WIP Inventory**	**Pre-Storage Utilization**	**Post-Storage Utilization**
Pre-WIP Inventory	1.000	0.051 (p = 0.727)	0.104 (p = 0.167)	0.148 (p = 0.305)
Pre-Storage Utilization	0.104 (p = 0.167)	-0.149 (p = 0.302)	1.000	0.123 (p = 0.395)
Post-WIP Inventory	0.051 (p = 0.727)	1.000	-0.149 (p = 0.302)	0.331 (p = 0.019)

Post-Storage Utilization	0.148 (p = 0.305)	0.331 (p = 0.019)	0.123 (p = 0.395)	1.000

Table 4.4: Correlation Matrix: WIP Inventory and Storage Utilization (Pre and Post implementation

INTERPRETATION

The correlation analysis examines the relationship between WIP inventory and storage utilization before and after the implementation of the Single-Piece Flow system.

- **Pre-Implementation Phase:**
  - There is a very weak positive correlation between WIP inventory and storage utilization (**r = 0.104**, *p = 0.167*), which is not statistically significant. This suggests that, prior to implementation, changes in WIP inventory levels had minimal and insignificant influence on how storage space was utilized.
- **Post-Implementation Phase:**
  - A moderate positive correlation is observed between WIP inventory and storage utilization (**r = 0.331**, *p = 0.019*), and this result is statistically significant. This indicates that after implementing Single-Piece Flow, an increase in WIP inventory is more closely associated with increased storage usage, reflecting a stronger and more structured relationship between inventory movement and space utilization.

The implementation of Single-Piece Flow appears to have improved the alignment between WIP inventory levels and storage utilization. The stronger and significant post- implementation correlation suggests that inventory handling and space usage became more synchronized, contributing to better inventory management efficiency.

OPERATOR-BASED EVALUATION OF WORKFLOW STABILITY IN SINGLE- PIECE FLOW IMPLEMENTATION

➢ To evaluate the effectiveness of single piece flow in minimizing workflow interruptions and enhancing production consistency, based on operator feedback.

The purpose of this objective is to assess how well the Single-Piece Flow system performs in reducing disruptions in the production process and promoting consistent workflow. This evaluation is based on feedback gathered directly from operators, who are closely involved in day-to-day operations. By analysing their observations and experiences, the study aims to understand whether the new system has led to smoother production flow, fewer delays, and improved operational stability.

Available factor:

- Daily production
- Cycle time
- Rejection Rate
- Work in Progress

4.1.3 DESCRIPTIVE ANALYSIS OF EVALUATION OF WORKFLOW STABILITY

	N	Range	Minimum	Maximum	Sum	Mean	Std. Deviation	Variance
Daily production	20	1.2	1.4	2.6	38.4	1.920	.2628	.069
Cycle time	20	1.2	1.4	2.6	37.4	1.870	.3197	.102
Rejection rate	20	1.4	1.0	2.4	36.2	1.810	.3582	.128
Work in progress	20	1.0	1.4	2.4	37.4	1.870	.2697	.073
Valid N (listwise)	20							

Table 4.5: Descriptive analysis of Evaluation of Workflow Stability

INTERPRETATION

The table summarizes the descriptive statistics for four key production parameters—daily production, cycle time, rejection rate, and work-in-progress (WIP)—based on a sample of 20 observations.

Daily Production

- The production output ranges from 1.4 to 2.6 units, with a mean of 1.920.
- The standard deviation is 0.2628, indicating moderate variability in daily production levels.
- The relatively low variance (0.069) suggests consistent output across the observed days.

Cycle Time

- The cycle time varies between 1.4 and 2.6 units, with an average of 1.870.
- A higher standard deviation of 0.3197 and variance of 0.102 compared to daily production indicate slightly greater inconsistency in the time taken to complete production cycles.

Rejection Rate

- Rejection rates show the widest range (1.0 to 2.4), with a mean value of 1.810.
- This parameter has the highest variability, as shown by a standard deviation of 0.3582 and variance of 0.128, indicating frequent fluctuations in quality or process stability.

Work-in-Progress (WIP)

- WIP levels range from 1.4 to 2.4, with an average of 1.870, matching the mean of cycle time.
- The standard deviation is 0.2697, and variance is 0.073, reflecting relatively stable WIP levels across the production period.

Among the four variables, rejection rate shows the highest variability, pointing to potential inconsistencies in quality or process issues. Daily production and WIP inventory are more stable, as evidenced by their lower standard deviations and variances. The consistency in these parameters may indicate that the production environment is generally controlled, but further efforts may be required to reduce fluctuations in cycle time and rejection rates to improve overall efficiency and product quality.

ONE SAMPLE T TEST OF EVALUATION OF WORKFLOW STABILITY

Variable	t-value	df	Sig. (2-tailed)	Mean Difference
Daily Production	32.676	19	0.000	1.9200
Cycle Time	26.158	19	0.000	1.8700
Rejection Rate	22.597	19	0.000	1.8100
Work in Progress	31.008	19	0.000	1.8700

Table 4.6: One Sample T Test of Evaluation of Workflow Stability

INTERPRETATION

The one-sample t-test was conducted to determine whether the mean values of key production parameters—daily production, cycle time, rejection rate, and work-in-progress (WIP)—differ significantly from a test value of zero. The results for all variables are statistically significant at the 0.05 level.

Daily Production

- The mean daily production is 1.920, with a t-value of 32.676 and a p-value of 0.000.
- This indicates a highly significant deviation from the test value, confirming a consistent production output in the process.

Cycle Time

- The average cycle time is 1.870, with a t-value of 26.158 and a p-value of 0.000.
- The result shows a significant difference from the test value, reflecting a steady and controlled process time across observations.

Rejection Rate

- The mean rejection rate stands at 1.810, with a t-value of 22.597 and a p-value of 0.000.
- This suggests a consistent pattern in quality levels, though further improvement may be needed to reduce defects.

Work-in-Progress (WIP)

- The average WIP inventory is 1.870, with a t-value of 31.008 and a p-value of 0.000.
- This confirms a stable flow of material within the production system.

The results of the one-sample t-test indicate that all key production parameters—daily production, cycle time, rejection rate, and work-in-progress—show statistically significant mean values when compared to the reference point. This suggests that the production process is functioning with a high degree of consistency and control.

The consistently high t-values and low p-values across all variables confirm that the observed means are not due to random variation but reflect a stable and repeatable process performance. The findings imply that the current production system, likely influenced by the implementation of Single-Piece Flow, supports improved workflow reliability, predictable output, and systematic inventory handling.

Moreover, the significance of the rejection rate highlights that although defects are present, they follow a consistent pattern, providing a solid foundation for targeted quality improvement efforts.

V. FINDINGS AND CONCLUSION

FINDINGS

The study highlights the positive outcomes following the implementation of Single-Piece Flow in the horn assembly line at Roots Industries India Private Limited. Notable improvements were observed in several key areas of production. There was a clear increase in daily output, along with a significant reduction in both cycle time and lead time, indicating a more streamlined and efficient workflow. Quality performance also improved, as seen through the reduction in both rejection rates and rework percentages. Inventory levels, particularly work in-progress (WIP), were effectively minimized, leading to better flow of materials and reduced congestion. In addition, the utilization of storage space became more efficient, and machine idle time decreased, reflecting better coordination and reduced downtime. Furthermore, the post-implementation data showed a stronger and statistically significant relationship between WIP inventory and storage utilization, suggesting improved alignment between production and space management. Overall, these findings confirm that Single-Piece Flow contributed to enhanced productivity, quality, and operational control.

SEVALUATION OF PRODUCTION PERFORMANCE

- The implementation of Single-Piece Flow led to significant improvements in key production metrics.
- Daily production output increased from 761.01 units to 1060.30 units, showing enhanced productivity.
- Cycle time was reduced from 60.36 seconds to 25.26 seconds, and lead time dropped from 120.24 minutes to 60.02 minutes, indicating faster processing and improved operational efficiency.
- The paired t-test confirmed these improvements to be statistically significant, reflecting the effectiveness of the new system in streamlining production flow and reducing process delays.

EVALUATION OF QUALITY PERFORMANCE

- After implementing Single-Piece Flow, both rejection rate and rework percentage saw notable reductions.
- The average rejection rate decreased from 3.295% to 1.223%, and the rework percentage dropped from 3.9636% to 1.9688%.
- The paired samples t-test results showed statistically significant differences in both metrics ($p < 0.001$), confirming that the process changes contributed to better defect detection and reduced quality-related waste.

EVALUATION OF INVENTORY MANAGEMENT EFFICIENCY

- A clear improvement in inventory control and space utilization was observed post implementation.
- WIP inventory decreased significantly from 340 units to 95.18 units, while storage utilization dropped from 67.92% to 43.88%, indicating more streamlined inventory handling.
- The correlation analysis showed a moderate and statistically significant positive relationship between WIP and storage utilization in the post-implementation phase ($r = 0.331$, $p = 0.019$), suggesting better synchronization between production flow and space usage.

OPERATOR-BASED EVALUATION OF WORKFLOW STABILITY

- Operator feedback showed consistency in production parameters post-implementation.
- Daily production, cycle time, rejection rate, and WIP inventory had stable averages with low variance, indicating a controlled workflow environment.
- The one-sample t-test showed statistically significant mean values across all four parameters, confirming that the production system maintained reliable performance.
- While rejection rate had the highest variability, its consistent pattern offers an opportunity for continuous quality improvement.

CONCLUSION

The implementation of Single-Piece Flow (SPF) in the horn assembly line at Roots Industries India Private Limited has yielded clear and measurable improvements in operational efficiency, quality, and inventory management. The shift from traditional batch production to a continuous flow system has significantly enhanced daily output while simultaneously reducing cycle time and lead time, indicating streamlined and faster production processes.

Quality performance also showed marked progress, with a substantial decrease in rejection rates and rework percentages, reflecting better defect detection and control. Inventory management became more efficient, as demonstrated by the reduction in work-in-progress (WIP) inventory and improved utilization of storage space. Moreover, machine idle time decreased, further contributing to higher equipment efficiency.

Statistical analyses, including paired sample t-tests and correlation studies, validated the significance of these improvements. Operator feedback supported these findings, indicating a more stable and predictable production workflow. Overall, the successful adoption of SPF confirms its effectiveness as a lean manufacturing strategy that not only boosts productivity and quality but also supports sustainable operational practices.

Continued focus on lean tools, workforce training, and data-driven process improvement will be essential to sustain these gains and extend the benefits across other production lines within the organization.

REFERENCES

1. Miltenburg, J. (2001). *U-shaped production lines: A review of theory and practice*. Springer.

2. Liker, J. K. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw-Hill Education.

3. Scharf, R., & Kissing, D. (2007). *One-piece flow in flexible serial production*. Journal of Manufacturing Systems.

4. Paneru, S. (2011). *Implementation of lean manufacturing tools in garment manufacturing process focusing sewing section of men's shirt*. Master's Thesis, University of Borås.

5. Chowdary, B. V., & George, D. (2011). *Improvement of manufacturing operations through lean: A case study*. International Journal of Lean Six Sigma.

6. Sun, X., Ni, J., & Djurdjanovic, D. (2011). *Multi-objective optimization for flow shop scheduling*. International Journal of Production Research.

7. Che Ani, A. I. (2012). *Impacts of lean manufacturing and one-piece flow*. Procedia Engineering.

8. Li, X., Wang, Y., & Rajamani, D. (2012). *Timed process flow diagrams for one-piece flow systems*. Computers & Industrial Engineering.

9. Sastry, V. A. R., Kumar, P. M., & Venkateswara Rao, P. (2013). *Simulation-based analysis of one-piece flow*. Procedia Engineering.

10. He, W., Song, X., & Zhang, J. (2013). *Design of one-piece flow for electronics production*. Applied Mechanics and Materials.

11. Rane, S. B., & Sunnapwar, V. K. (2017). *Simulation of one-piece flow manufacturing system*. International Journal of Industrial Engineering.

12. Nguyen, T. D., & Do, D. Q. (2016). *Lean manufacturing in assembly lines*. International Journal of Advanced Science and Technology.

13. Klimecka-Tatar, D., & Ingaldi, M. (2019). *Efficiency improvement in assembly lines using lean tools*. Management and Production Engineering Review.

14. Komaki, H., Yoshimoto, K., & Hiraishi, K. (2019). *Review on flow shop scheduling with lean perspectives*. Journal of Manufacturing Systems.

15. Apafaian, M., Bologa, R., & Mican, D. (2020). *Application of one-piece flow in automotive sector*. Procedia Manufacturing.

16. Patel, A., & Desai, T. (2020). *Lean manufacturing in SMEs using one-piece flow*. Materials Today: Proceedings.

17. Zhang, Y., & Luo, X. (2018). *Digital lean implementation in mobile phone assembly*. Procedia CIRP.

18. Kumar, S., Jain, P., & Shukla, S. (2021). *Lean implementation in precision machining*. Materials Today: Proceedings.

19. Soliman, M. (2022). *Creating one-piece flow cells for JIT*. Procedia CIRP.

20. Ramadan, M. Z. (2022). *Simulation-based lean training for one-piece flow*. Simulation Modelling Practice and Theory.

21. Thomas, A., & Roy, R. (2022). *Impact of one-piece flow in packaging industry*. International Journal of Production Economics.

22. Ezzeldin, M., Habib, M., & Abdelwahab, O. (2022). *Improving productivity using simulation and lean*. Alexandria Engineering Journal.

23. Mehta, A., Sharma, A., & Gupta, R. (2019). *Lean practices in medical devices manufacturing*. Journal of Manufacturing Technology Management.