Production Improvement through Fixture Design: A Case Study of an Agricultural Machinery Parts Manufacturer

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Abstract

This case study focuses on a manufacturing company producing agricultural machinery parts. The company faced a significant challenge: it could not meet customer demand due to inefficiencies in the production process. The primary objective of this study was to enhance the production process by implementing a new Jig Fixture and leveraging the principles of karakuri kaizen. Through a thorough analysis of the production process, the Customer revealed that the daily demand was 350 units, while the company could only produce 280 units per day. The researchers employed engineering principles to address this issue, including 7 QC Tools and Failure Mode and Effects Analysis (FMEA). By identifying the root causes of the production bottlenecks, the team developed and implemented solutions involving a new workpiece holding device and Karakuri Kaizen automation. The results of these improvements were substantial. The cycle time per unit decreased from 96.22 seconds to 75.52 seconds, enabling the company to produce 362 daily units. The total production distance was reduced from 30.2 meters to 27.7 meters.

Keywords: Karakuri Kaizen, Jig Fixture, Failure Mode and Effects Analysis, 7 QC Tools

1. Introduction

The automotive parts industry is vital in driving a country's economy. Thailand's automotive industry is the largest in Southeast Asia and the 10th largest globally, with an annual production exceeding 1.5 million units, encompassing passenger cars, pickup trucks, motorcycles, and engine-powered vehicles. The country exports automotive parts worth more than $5 billion, surpassing the combined value of all Southeast Asian members in the same year. Additionally, 80% of automotive parts are produced domestically [1]

Thailand has over 2,000 parts manufacturing plants dispersed across industrial zones [2]. Procurement is categorized into 1) engine parts and components, 2) transmission parts, 3) suspension and brake parts, 4) electrical system parts, 5) body parts, and 6) other parts and accessories. Collaborative agreements among automotive parts manufacturers in all sectors have been developed to establish common goals, joint work plans, shared resource agreements, and long-term relationships among companies in the same industry, such as risk, benefits, planning, and technology sharing [3].

The case study company manufactures and distributes automotive and agricultural machinery parts to industrial operators, such as agricultural machinery. The company also exports agricultural machinery parts to domestic customers. Currently, the company aims to produce 350 units per day, but with the existing production system, it can only produce 280 units per day. To meet this target, overtime work is required, as customers prioritize quality and timely delivery. This places an additional burden on the company in terms of labor costs. Researchers have studied related research to solve production process problems [4] by analyzing process failures using Failure Mode and Effects Analysis (FMEA) and 7 QC Tools. These tools effectively assess the risk of failure modes in systems, processes, designs, or services, enabling accurate assessment of failure risks, identification of critical failures, and application to complex systems [5-7].

This study focuses on analyzing the production process of a factory to implement appropriate engineering management techniques. By examining relevant research and theories, the aim is to improve the production process through the application of Jig fixtures. These fixtures will secure and precisely position workpieces during production, mitigating the risk of human error and increasing overall output. The fixtures will be designed for versatility and adaptability [8-13]. The ECRS principles of Eliminate, Combine, Rearrange, and Simplify will be employed to reduce unnecessary costs, conserve resources, minimize waste, and enhance organizational efficiency [14]. Production balancing will be implemented to reduce variability within the production line, minimize waiting times, and lower costs [15]. Karakuri Kaizen will be utilized to reduce energy consumption, transportation time, and physical strain. Its basic mechanisms include: 1. levers, 2. winches, 3. pulleys, 4. springs, 5. inclines, 6. direction changes, 7. power transmission through rotation, 8. fluids, and 9. magnets. The development of workpiece fixtures will also be a key component [16-18]. These improvements aim to enhance production efficiency by minimizing machine downtime, reducing overtime expenses, and enabling more effective and efficient operations. Additionally, simple tools and fixtures will be developed to improve torque control and reduce excessive force exertion, thereby preventing musculoskeletal disorders (MSDs). The objective of this project is to reduce the actual working cycle time from 96.22 seconds per piece to less than 78 seconds per piece.

2. Study and Method

2.1 Study Production Process

The case study company produces 7,280 parts per month, operating 26 days a month. This means that 280 parts are produced daily, with a daily working time of 7.6 hours. However, the demand for parts is 350 units per day, resulting in a Takt time of 78.17 seconds per unit. Conversely, the actual cycle time is 96.22 seconds per unit, which is a problem due to the nature of agricultural machinery parts as shown in Figure 1, and the workspace as shown in Figure 2.

a) Model 120 b) Model 90

Figure 1 Agricultural machinery part

2.2 Study the work procedures

Collect operational data using a workpiece flow chart to create a Flow Process Chart [19], which presents information on raw materials, employees, production processes, workpieces, and space. Standard time is established for the production process of agricultural machinery spare parts, as shown in Figure 3 and an example of collecting time data of Step 5 as shown in Table 1.

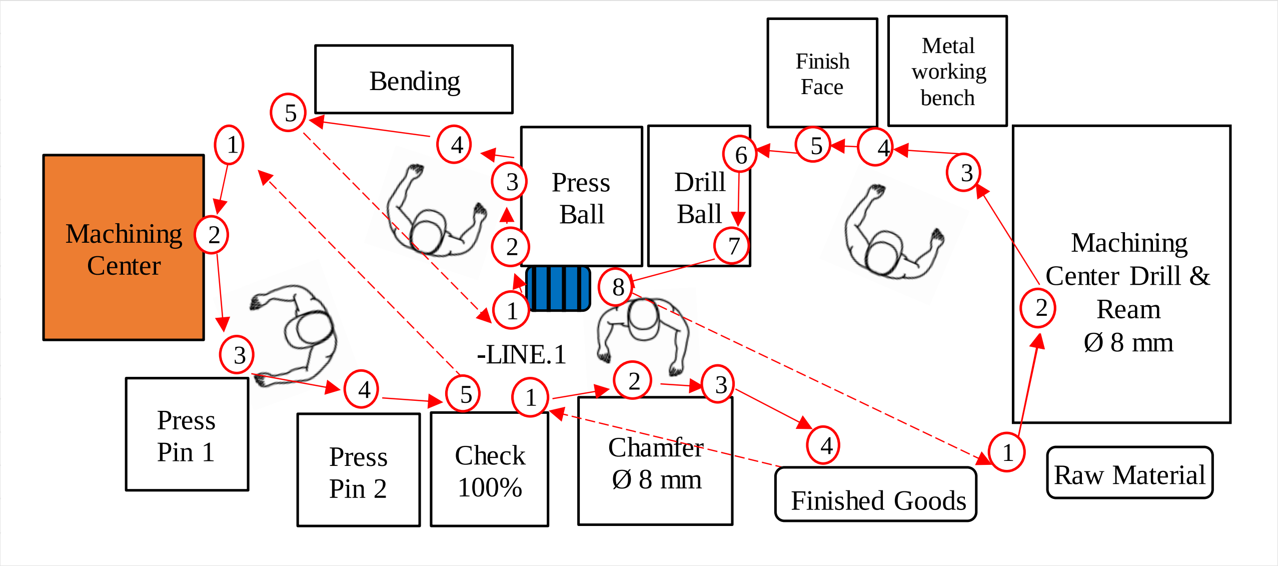


Figure 2 Process line agricultural machinery parts

Figure 2 shows the following machinery

1. R/M: Parts in Storage box
2. Drill & Ream: The process involves drilling and reaming the workpiece.
3. Metalworking bench
4. Finish Face: A machine used for shaping workpieces.
5. Drill Ball: A machine capable of drilling circular holes.
6. Press Ball: A hydraulic press.
7. Bending: A table used for bending or hammering workpieces.
8. Machining Center: An automatic machine (CNC).
9. Press Pin 1: A hydraulic press.
10. Press Pin 2: A hydraulic press.
11. Check 100 percent: A table for placing measuring tools to inspect workpieces.
12. Chamfer Ø 8 mm: A table for checking holes with a diameter of 8 millimeters.
13. F/G: A box for good-quality workpieces.

Table 1 Example of collecting time data for Step 5 (Forming workpiece bottom)

No.	Time (sec)	No.	Time (sec)
1	24.63	16	23.50
2	24.27	17	24.61
3	22.57	18	24.63
4	26.21	19	25.18
5	25.56	20	24.87
6	21.18	21	23.96
7	24.56	22	24.71
8	24.51	23	24.16
9	26.10	24	26.73
10	24.61	25	24.31
11	23.47	26	25.22
12	22.54	27	24.87
13	24.76	28	23.64
14	21.15	29	26.24
15	26.66	30	24.88
		Average	24.48
		Max	26.73
		Min	21.15
		Standard Deviation	1.36

FLOW PROCESS CHART					APPROVER	INSPECTOR	ORGANIZER
LINE NAME	Process	OPERATOR: A	BEFORE	REV.	A	B	C
PART NO:	Door	PART NAME: XX		0			
CHART NO: XX		SHEET NO. X	SUMMARY				
ACTIVITY :			ACTIVITY	PRESENT	Operater		C.T (Sec.)
METHOD:			OPERATION ○	12	Operater 1 (OP1)		94.57
LOCATION: OPERATOR (S):			TRANSPORT ⇨	13	Operater 2 (OP2)		90.56
			DELAY D	3	Operater 3 (OP3)		96.22
OPERATOR (S):			INSPECTION □	8	Operater 4 (OP4)		71.56
CHECK BY: X APPROVED BY: X		DATE: XX/XX/XX DATE: XX/XX/XX	STORAGE ▽	5	The Sum of Process		96.22
			DISTANCE (m)	30.2			
			TIME (Sec)	352.91			

DESCRIPTION	TIME (Sec)	DIST(m)	SYMBOL	REM
1. Incoming Part		25	● ➡ □ D ▽	
2. Check tiny hole and dent	120	0.3	○ ➡ ■ D ▽	Not taken into account
3. Load and Unload Ream Dia 8 mm	10.74+65		● ➡ ■ D ▽	Machine time
4. Strike ball and check	19.94	0.3	● ➡ ■ D ▽	
5. Forming workpiece (bottom)	24.48	0.3	● ⇨ □ ◗ ▽	OP 1
6. Forming workpiece (top)	18.09		● ➡ □ ◗ ▽	
7. Drill ball and check	21.32	2	○ ➡ ■ ◗ ▼	
8. Insert workpiece into ball	8.22		● ⇨ □ D ▽	
9. Press ball	8.48	0.4	● ➡ □ D ▽	OP 2
10. Bring workpiece to bend by striking	73.86		● ➡ ■ D ▼	
11. Load, unload, and machine at the center	25.22+71		● ➡ □ D ▽	Machine time
12. Bring workpiece for grinding	44.63	0.2	● ➡ □ D ▽	
13. Press pin 1	8.52		● ⇨ ■ D ▽	OP 3
14. Press pin 2	14.84	1	○ ➡ □ D ▼	
15. Inspect workpiece in jig	47.85	0.2	○ ⇨ ■ D ▽	
16. Check plug and appearance	16.95		○ ➡ ■ D ▼	OP 4
17. Check diameter 8mm	6.76	0.5	● ➡ □ D ▼	
รวม	352.91	30.2		

Figure 3 Flowchart of the workpiece before improvement

Figure 3 shows a total cycle time of 352.91 seconds. The analysis reveals that machine idle time contributes significantly to the overall cycle time. This imbalance in process times leads to reduced efficiency, resulting in a cycle time of 96.22 seconds per piece, or an output of 37 pieces per hour. The total travel distance recorded is 30.2 meters.

2.3 Analysis Cause

An analysis of production inefficiencies in the manufacturing process of non-conforming products was conducted, including a root cause analysis. A fishbone diagram, categorized by the 4M factors (Man, Machine, Materials, and Method) [20-22], was used to identify potential causes in Figure 4. These identified problems were then subjected to a Failure Mode and Effects Analysis (FMEA) to assess their severity. Severity, occurrence, and detection scores were evaluated and recorded in Table 2, as per reference [23]. Finally, these problems were prioritized using a Pareto chart in Figure 5

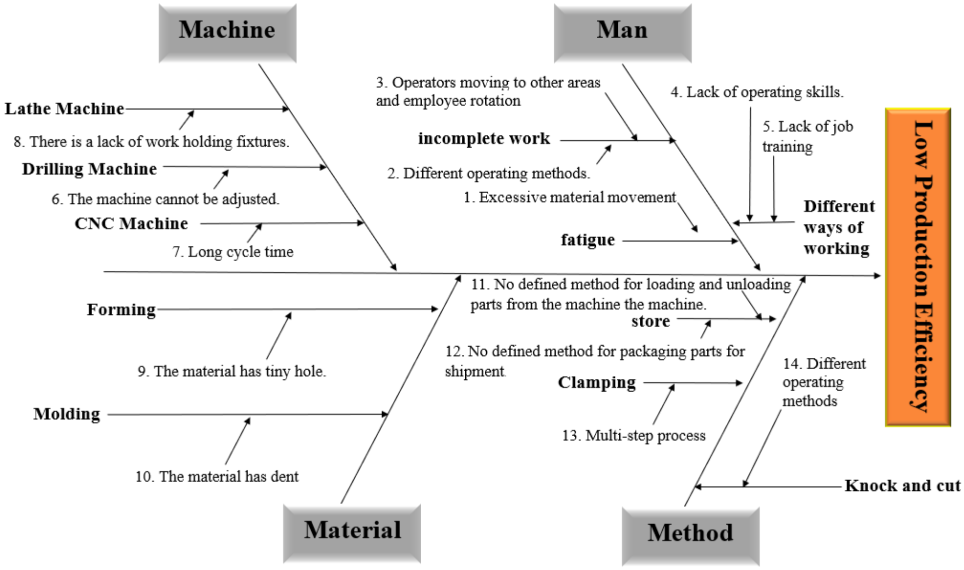


Figure 4 Fishbone diagram

Table 2 FMEA before improvement.

Cause	Problem	S	O	D	RPN
1	Excessive material movement	7	6	4	168
2	Different operating methods	6	3	3	54
3	Operators moving to other areas and employee rotation	2	4	4	32
4	Lack of operating skills	7	4	3	84
5	Lack of job training	7	5	2	70
6	The machine can't adjust	7	10	2	140
7	Long cycle time	2	8	2	32
8	There is a lack of work holding fixtures.	10	3	3	90
9	The material has a tiny hole	2	3	8	48
10	The material has Dents	2	9	2	36
11	No defined method for loading and unloading parts from the machine	3	10	2	60
12	No defined method for packaging parts for shipment	5	8	2	80
13	Multi-step process	5	10	2	100
14	Different operating methods	5	3	2	30

Severity (S) = Severity assessment criteria
Occurrence (O) = Likelihood assessment criteria
Detection (D) = Detection assessment criteria
Risk Priority Number (RPN) = S x O x D

Based on Table 1, the problems with the highest RPN scores were prioritized and visualized using a Pareto chart. The company has decided to focus on issues with an RPN greater than 80 [24] as these have the most significant impact on operations and lead to delays, as illustrated in Figure 5.

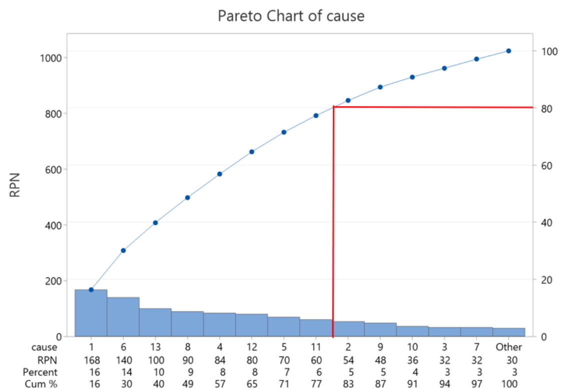


Figure 5 Pareto chart

As shown in Figure 5, a Pareto chart was used to identify and prioritize problems for resolution using the 80:20 rule [25,26]. Problems 1, 6, 13, 8, 4, 12, 5, and 11 collectively account for a significant 80% of the overall issues. These problems will be addressed first.

2.4 Proposed Solutions

Following the process analysis in Figure 5, a detailed examination of the root causes was carried out. To mitigate these issues, engineering management techniques were employed. Table 3 outlines the proposed solutions and their anticipated benefits.

Table 3 Root Causes, Solutions, and Expected Benefits

Case	Solutions	Expected Benefits
1. Excessive material movement	Line balance	Reduced travel distance
6. The machine can't adjust	ECRS	Significant increase in work speed
13. Multi-step process	Design Jig Fixture	Streamlined work processes
8. Work holding fixtures	ECRS	Increased production speed
4. Lack of operating skills	Workforce training	Reduced error rate leads to increased work speed
12. No defined method for packaging parts for shipment	Karakuri	Reduced work time and movement
5. Lack of job training	Training	Employees can learn more about the work process.
11. No defined method for loading and unloading parts from the machine	Work Instructions	Able to work faster

3. Results

3.1 Results of Karakuri Kaizen Implementation

Before the improvements, workpieces were transported via manual labor. By applying the Karakuri Kaizen concept and utilizing the principles of inclined planes and gravity, we have streamlined the process [27]. The modifications have led to a 4 second reduction in task duration, a 2.5 meter decrease in travel distance, and a substantial reduction in the physical exertion required for lifting workpieces. Visual representations of the before and after states are provided in Figures 6 and 7.

Figure 6 Design Karakuri Kaizen

Before After

Figure 7 Before and after Karakuri Kaizen implementation

3.2 Results of ECRS implementation

The redesigned fixture and ECRS implementation aimed to simplify the workflow and enhance workpiece locking speed. By replacing the bolt with a spring mechanism, the improved process involves inserting the workpiece while compressing the spring. Upon release, the workpiece is driven against a stopper. Subsequently, a cam is activated to further secure the workpiece. Additionally, the orange lock has been replaced with a cam lock for streamlined operation. As a result, the third worker's task time has been reduced from 96.22 seconds to 74.51 seconds, as depicted in Figures 8 and 9.

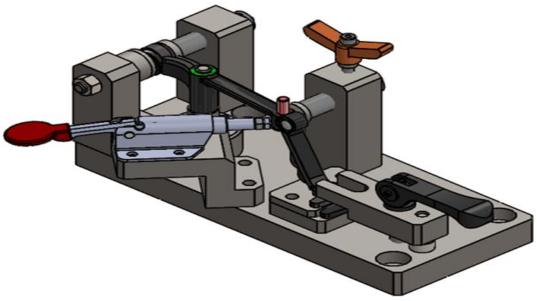


Figure 8 Design Jig Fixture

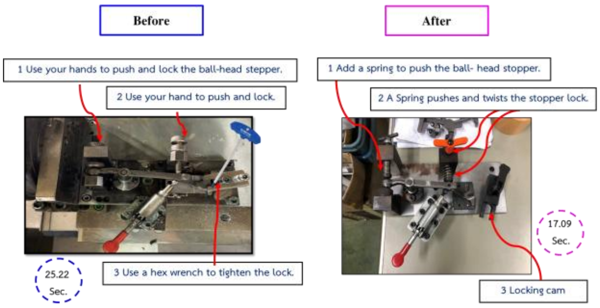


Figure 9 Before and after Jig Fixture implementation

3.3 Results of Jig Fixture Implementation

The original process required the workpiece to be pressed and clamped. The new fixture design, with its added attachment, enables the simultaneous clamping of two workpieces, streamlining the process and reducing task time from 42.57 seconds to 17.09 seconds. The process flow is depicted in Figures 10 and 11.

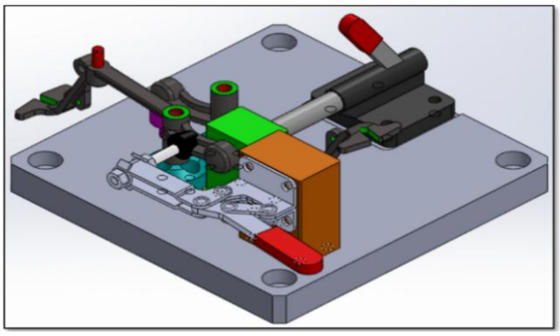


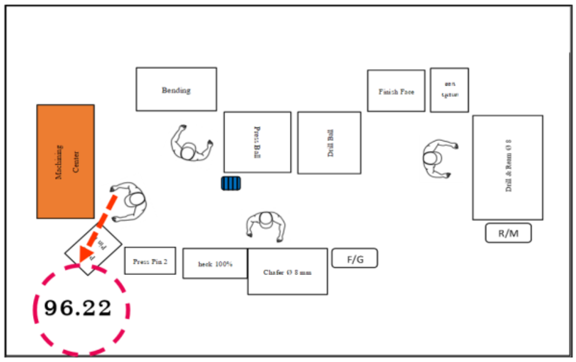
Figure 10 Design Jig Fixture

Before After

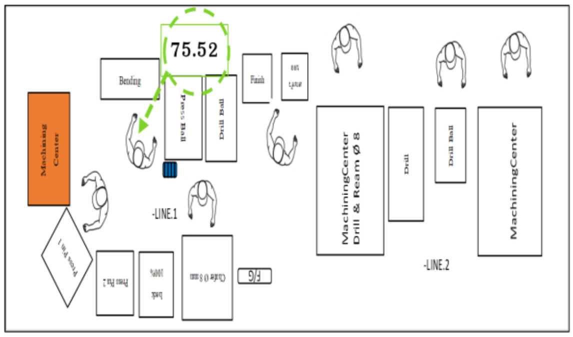
Figure 11 Before and after Jig Fixture implementation

3.4 Results of Line Balance Implementation

The rigid setup of the previous machine led to production bottlenecks. To enhance flexibility and streamline operations, a CNC machine has been installed and integrated with the following production stage. This integration ensures a seamless workpiece flow and prevents idle time for operators on the B line. Furthermore, the second workstation has undergone a workforce adjustment due to the integration. These improvements have resulted in a cycle time reduction from 96.22 seconds to 75.22 seconds.



Before



After

Figure 12 Before and after line balance implementation

3.5 Results of Flow Process Implementation

Following the improvements, a post-implementation study was carried out to measure the actual cycle time. Data was collected from each workstation in the modified production line. The results showed a reduction in the number of sub-processes to 13 steps, as depicted in Figure 12, indicating a potential decrease in cycle time.

FLOW PROCESS CHART					APPROVER	INSPECTOR	ORGANIZER
LINE NAME	Process	OPERATOR: A	AFTER	REV.	A	B	C
PART NO:	Door	PART NAME: XX		0			
CHART NO: XX		SHEET NO. X	SUMMARY				
ACTIVITY :			ACTIVITY	PRESENT	Operater		C.T (Sec.)
METHOD:			OPERATION ○	12	Operater 1 (OP1)		54.35
LOCATION:			TRANSPORT ⇨	13	Operater 2 (OP2)		75.52
OPERATOR (S):			DELAY D	3	Operater 3 (OP3)		75.07
OPERATOR (S):			INSPECTION □	8	Operater 4 (OP4)		70.47
CHECK BY: X		DATE: XX/XX/XX	STORAGE ▽	5	The Sum of Process		75.52
APPROVED BY: X		DATE: XX/XX/XX	DISTANCE (m)	27.7			
			TIME (Sec)	275.41			

DESCRIPTION	TIME (Sec)	DIST(m)	SYMBOL					REM
1. Incoming Part		25	●	➡	□	D	▽	
2. Check tiny hole and dent	120	0.3	○	➡	■	D	▽	Not taken into account
3. Load and Unload Ream Dia 8 mm	75		●	➡	■	D	▽	Combine Line
4. *Strike ball*	17.94		●	➡	■	D	▽	
5. *Forming workpiece (bottom and top)*	17.09		●	⇨	□	◗	▽	OP 1
6. Drill ball and check	19.32	0.1	○	➡	■	◗	▼	
7. Insert workpiece into ball	7.22		●	⇨	□	D	▽	
8. Press ball	8.44	0.4	●	➡	□	D	▽	OP 2
9. Bring workpiece to bend by striking	59.86		●	➡	■	D	▼	
10. Load, unload, and machine at the center	17.07+58		●	➡	□	D	▽	Machine time
11. Bring workpiece for grinding	31.85	0.2	●	➡	□	D	▽	
12. Press pin 1	6.94		●	⇨	■	D	▽	OP 3
13. Press pin 2	17.65	1	○	➡	□	D	▼	
14. Inspect workpiece in jig	46.85	0.2	○	⇨	■	D	▽	
15. Check plug and appearance	16.95		○	➡	■	D	▼	OP 4
16. Check diameter 8mm	6.67	0.5	●	➡	□	D	▼	
รวม	275.41	27.7						

Figure 13 Flowchart of the workpiece after

The implementation of a new workpiece jig fixture, ECRS, and karakuri kaizen in processes 3 to 6 and 9 to 13, as shown in Figure 13, has significantly reduced task times and distances. The first operator's time was reduced by 40.22 seconds, the second by 15 seconds, the third by 21.15 seconds, and the fourth by 1.09 seconds. This resulted in a cycle time of 75.52 seconds per piece, increasing production to 47.54 pieces per hour, and a total daily output of 362 pieces for a 7.6 hour workday.

3.6 Results of Statistical

The post-improvement data was analyzed using a one-sample t-test to test the hypothesis. The null hypothesis (H_0) was rejected if the p-value was less than 0.05, indicating that the alternative hypothesis (H_1) was more likely to be true. Conversely, if the p-value was greater than 0.05, the null hypothesis (H_0) was accepted. This analysis was conducted to determine if the data supported the proposed hypothesis, $H_0 : \mu \leq 78$ $H_1 : \mu > 78$ as shown in Table 4.

Table 4 Results of the one-sample t-test after the improvement

N	Mean	StDev	SE Mean	P-Value
30	75.520	0.840	0.153	1.000

Table 4 presents the results of a one-sample t-test conducted using statistical software on the post-improvement cycle time data. The calculated p-value is 1.000, which is greater than the significance level of 0.05. Therefore, we fail to reject the null hypothesis (H_0). It can be concluded that the mean post-improvement cycle time is less than or equal to 78.17 seconds per unit.

3.7 Results of FMEA implementation

From Table 2, the causes of defects in the production process were identified through collaborative discussions with production staff and inspectors. It was found that after implementing corrective actions, the Risk Priority Number (RPN) decreased, indicating that the solutions effectively reduced the occurrence of defects, as shown in Table 5 and Figure 15.

Table 5 FMEA After improvement.

Cause	Problem	S	O	D	RPN Before	RPN After
1	Excessive material movement	7	3	4	168	84
2	Different operating methods	6	3	3	54	54
3	Operators moving to other areas and employee rotation	2	4	4	32	32
4	Lack of operating skills	7	4	2	84	56
5	Lack of job training	7	3	2	70	42
6	The machine can't adjust	7	1	2	140	14
7	Long cycle time	2	8	2	32	32
8	There is a lack of work holding fixtures.	7	3	3	90	63
9	The material has a tiny hole	2	3	8	48	48
10	The material has Dents	2	9	2	36	36
11	No defined method for loading and unloading parts from the machine	3	10	1	60	30
12	No defined method for packaging parts for shipment	5	4	2	80	40
13	Multi-step process	4	10	2	100	80
14	Different operating methods	5	3	2	30	30

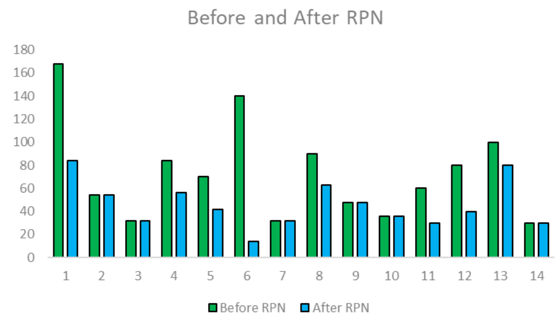


Figure 15 Compare RPN scores before and after

3.8 Analyze the improvement results

After implementing engineering improvements to the production process, the cycle time was significantly reduced from 352.91 seconds to 275.45 seconds, representing a 21.95% decrease. This improvement resulted in an increased daily production from 280 units to 362 units, exceeding the target of 350 units per day. Additionally, the working distance was reduced by 2.5 meters, as illustrated in Table 6 and Figures 16 and Figures 17 for detailed data.

Table 6 Improvement results analysis

Improvement	Cycle Time (sec/piece)	Production Quantity (pieces)	Distance (m)
Before	96.22	282	30.2
After	75.52	362	27.7

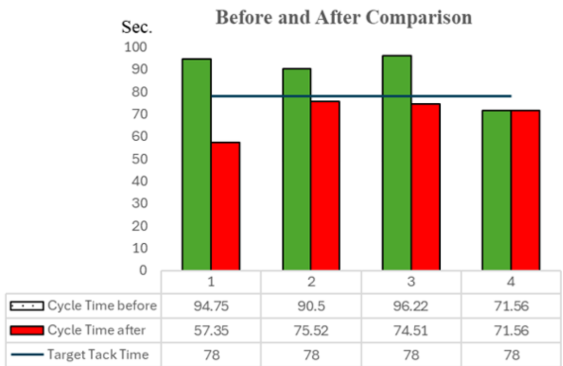


Figure 16 Cycle time before and after improvement

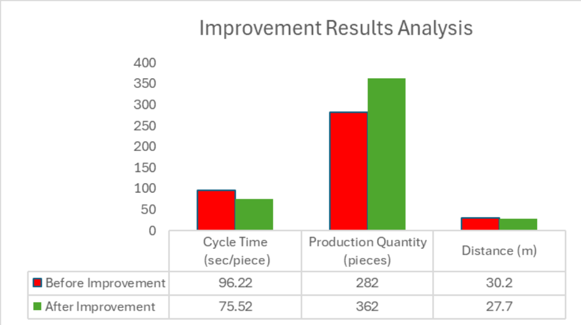


Figure 17 Improvement Results

4. Discussion

A case study of an agricultural parts manufacturing company revealed a production bottleneck due to an inability to meet demand. Researchers employed engineering principles, quality control tools, and Failure Mode and Effects Analysis (FMEA) to identify and mitigate risks associated with the production process. FMEA proved to be an effective tool in pinpointing potential problems and their associated impacts.

The majority of improvements involved equipment replacement, sharing of machinery among production lines, and the addition of work-holding fixtures to reduce process steps. A redesigned fixture was developed to enhance the efficiency of agricultural machinery parts production. Techniques such as ECRS, Jig fixture design, karakuri, and production balancing were employed to identify targeted improvement areas [28-30].

Data collection revealed a significant reduction in cycle time from 96.22 seconds to 75.52 seconds, representing a 21.74% decrease. Similarly, the total working distance decreased from 30.2 meters to 27.7 meters, a reduction of 8.28%. Overall line efficiency increased from 66.24% to 97.23%, a 30.99% improvement. The production cycle time was consistently maintained below 78 seconds per unit.

5. Conclusions

This research highlights the novel application of Karakuri Kaizen and Jig Fixture Design to address production bottlenecks in the manufacturing process of agricultural machinery parts. the root causes of the problem were identified. To address the issues, the researchers applied the karakuri kaizen principle, leveraging gravity, weight, and inclination, as well as implementing workpiece holding fixtures to reduce operator fatigue and cycle time. Additionally, the balancing of shared machinery streamlined the production process and minimized operational steps. As a result, the cycle time was significantly reduced from 352.91 seconds to 275.45 seconds, representing a 21.95% decrease. This improvement led to a daily production of 362 units, surpassing the previous output of 280 units. The primary limitation of this study lies in its focus on a single case, which restricts the generalizability of the findings to other industries or operational contexts. Additionally, the initial investment required for the design and implementation of Jig Fixtures may present financial challenges, particularly for small or resource-constrained organizations. Future research should explore the application of these methodologies-specifically Karakuri Kaizen and Jig Fixture implementation, across a wider range of manufacturing sectors to validate the results. Further studies should also address the long-term sustainability and cost-effectiveness of these approaches to support broader industrial adoption.

6. Acknowledgment

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