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Analysis of Broken Connector Defects on the G0FL Line Using the PDCA Method in a Wiring Harness Company

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Abstract: *Product quality is a critical determinant of competitiveness in the wiring harness industry because defects in connector components may disrupt electrical continuity, assembly performance, and customer satisfaction. One recurring problem found on the G0FL line of a wiring harness company was broken connector defects, which contributed significantly to total line defects. This study aims to analyze the causes of broken connector defects and propose quality improvement actions using the Plan-Do-Check-Act method supported by seven quality control tools. The research was conducted through direct observation, defect data collection, Pareto analysis, cause-and-effect analysis, 5W+1H analysis, and before-after defect comparison. The initial observation showed that broken connector defects accounted for the largest proportion of defects on the G0FL line. Root cause analysis indicated several dominant causes, including improper handling, unstable material positioning, insufficient operator awareness, inappropriate work methods, and weak process monitoring. Improvement actions were implemented through work instruction revision, operator retraining, jig and handling standardization, visual control, and routine defect monitoring. After implementation, the broken connector defect rate decreased from 0.81% to 0.30%, representing a reduction of 62.96%. The findings show that the PDCA method is effective as a structured continuous improvement approach for minimizing connector-related defects in wiring harness production.*

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INTRODUCTION

Quality control plays a central role in manufacturing performance because product conformity, process stability, and defect prevention directly influence production efficiency, delivery reliability, and customer satisfaction. In manufacturing systems, quality is not only measured by the ability to inspect defective products after production but also by the capability of production processes to prevent defects before they occur. Juran and Godfrey (1999) emphasize that quality improvement requires an integrated cycle of quality planning, quality control, and quality improvement. Likewise, Montgomery (2020) explains that statistical quality control provides a systematic basis for identifying process variation and determining whether a process operates within acceptable limits. Heizer, Render, and Munson (2020) further state that quality management contributes directly to operational sustainability because poor quality increases rework, scrap, inspection costs, production delays, and customer complaints. Consequently, manufacturing companies require structured quality improvement approaches capable of identifying dominant defects, analyzing their root causes, implementing corrective actions, and standardizing successful improvements.

The wiring harness industry demands an exceptionally high level of quality because wiring harnesses function as electrical distribution systems in vehicles and other electromechanical products. A wiring harness consists of wires, terminals, connectors, protectors, tapes, and supporting components that must be assembled according to strict technical specifications. Among these components, connectors are particularly critical because they ensure both electrical conductivity and mechanical stability between interconnected circuits. Damage to connectors may cause assembly

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difficulties, electrical malfunction, product rejection, increased rework, and downstream quality failures. Wang et al. (2013) identified several common connector-related defects, including damaged connector housings and poor connector conditions, highlighting the importance of connector quality in wiring harness manufacturing. In Indonesia, Handayani, Saptadi, and Hastuti (2008) employed Lean Six Sigma to improve wiring harness production processes, while Gunawan, Prasetyo, and Gautama (2023) utilized Quality Control Circle and the 5W+1H approach to improve product quality. These studies indicate that wiring harness manufacturing remains highly susceptible to repetitive defects and therefore requires continuous process improvement.

One of the most critical defects in wiring harness manufacturing is the broken connector defect, which occurs when the connector is cracked, fractured, or physically damaged and consequently fails to meet product specifications. Although visually identified as a single defect, broken connectors may result from multiple interacting factors, including improper material handling, operator practices, tooling conditions, workstation layout, inspection methods, and process control weaknesses. Dockree, Wang, and Frei (2021) explain that manufacturing defects often emerge through a chain of process failures rather than from a single isolated cause. Therefore, effective defect reduction requires systematic identification of dominant causes followed by structured corrective actions instead of relying solely on final product inspection.

Various quality improvement approaches have been widely adopted to address manufacturing defects. Ishikawa (1985) introduced the Seven Quality Control (QC) Tools as practical instruments for identifying, classifying, and analyzing quality problems through check sheets, Pareto diagrams, and cause-and-effect diagrams. Besterfield (2013) emphasizes that Total Quality Management requires data-driven decision-making and continuous improvement supported by employee involvement. Similarly, Gaspersz (2005) argues that quality improvement should prioritize defect prevention rather than defect detection. Goetsch and Davis (2016) further explain that sustainable quality performance depends on leadership commitment, standardized procedures, employee competency, and continuous measurement. Recent studies also demonstrate that Seven QC Tools remain effective in solving quality problems in wiring harness manufacturing, including minimizing terminal defects through Kaizen-based improvement (Al-Bar & Tjahyono, 2025).

Among continuous improvement methodologies, the Plan-Do-Check-Act (PDCA) cycle has become one of the most widely implemented frameworks because it provides a systematic sequence for identifying problems, implementing corrective actions, evaluating results, and standardizing successful improvements. Albuquerque et al. (2022), Malega et al. (2021), and Wu (2011) demonstrate that PDCA effectively supports industrial decision-making and process reliability through iterative improvement cycles. Furthermore, several empirical studies have successfully applied PDCA to reduce manufacturing defects and improve assembly processes (Realyvásquez-Vargas et al., 2018; Silva & Sartoni, 2014; Nguyen & Tran, 2023; Sumasto et al., 2023). These findings confirm that PDCA is not merely a conceptual framework but also an effective operational approach for improving manufacturing performance.

Research specifically related to wiring harness manufacturing also supports the application of PDCA for quality improvement. Arfan, Sugengriadi, and Naupal (2023) reduced miss insert defects in housing processes using PDCA, whereas Pramudita, Sugengriadi, and Sari (2023) emphasized the importance of identifying dominant defects before determining corrective actions in wiring harness production. Rahmatullah, Restu, and Siregar (2024) and Sugengriadi, Taufik, and Gumilar (2024) likewise reported successful implementation of PDCA for reducing defects in wiring harness assembly processes. Other researchers have adopted complementary approaches, such as Failure Mode and Effects Analysis (Azmi et al., 2025), Lean Six Sigma, and Six Sigma (Pyzdek & Keller, 2018), while recent developments in digital manufacturing have introduced machine learning-based inline quality monitoring for wiring harness production (Meiners et al., 2020; Li et al., 2025). These studies

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demonstrate that numerous quality improvement methods have been developed to enhance manufacturing performance.

However, despite these advances, an important research gap remains. Previous studies primarily focused on general wiring harness defects, terminal defects, miss insert defects, packing-line defects, or waste reduction. Most investigations evaluated the effectiveness of PDCA or other quality methods independently without integrating defect prioritization, root cause analysis, corrective action implementation, and quantitative before-after evaluation within a complete improvement cycle. Furthermore, empirical studies specifically addressing broken connector defects on the G0FL production line remain very limited, even though this production line possesses unique operational characteristics related to manual assembly, operator interaction, tooling conditions, and production control. Consequently, practical evidence regarding how an integrated PDCA approach supported by Seven QC Tools can systematically reduce broken connector defects under actual manufacturing conditions is still insufficient.

This study addresses the identified gap by applying a complete PDCA cycle integrated with Seven QC Tools to analyze and reduce broken connector defects on the G0FL production line. Unlike previous studies that mainly demonstrated the application of PDCA to general production problems, this research systematically combines defect prioritization using Pareto analysis, root cause identification through cause-and-effect analysis, implementation of corrective actions, and quantitative evaluation of improvement effectiveness before and after implementation. This integrated framework provides a comprehensive quality improvement model specifically designed for connector-related defects in wiring harness manufacturing, thereby extending previous studies that generally focused only on individual quality tools or isolated stages of the improvement process.

Therefore, this study aims to identify the dominant causes of broken connector defects on the G0FL production line and evaluate the effectiveness of corrective actions implemented through an integrated PDCA approach supported by Seven QC Tools. The findings are expected to contribute theoretically by enriching empirical evidence regarding integrated quality improvement frameworks in wiring harness manufacturing and practically by providing a structured improvement model that can be replicated by production, quality control, and engineering teams to reduce defects, minimize rework, and strengthen continuous improvement practices.

RESEARCH METHOD

Research Design

This study employed an applied descriptive research design using a case study approach. The research focused on analyzing and reducing broken connector defects occurring on the G0FL production line of a wiring harness manufacturing company. A case study approach was selected because the research investigated a specific quality problem within its actual industrial setting and aimed to develop practical improvement strategies based on empirical production data. Rather than manipulating production variables experimentally, the study observed existing production conditions, identified dominant defect causes, implemented corrective actions through the Plan–Do–Check–Act (PDCA) cycle, and evaluated their effectiveness by comparing defect performance before and after improvement.

The PDCA cycle was adopted as the primary analytical framework because it provides a systematic approach for continuous quality improvement through four sequential phases: **Plan**, **Do**, **Check**, and **Act**. Each phase was supported by the Seven Quality Control (QC) Tools, particularly check sheets, Pareto diagrams, cause-and-effect (Ishikawa) diagrams, and 5W+1H analysis. The integration of PDCA with these quality tools enabled systematic identification of dominant defects, analysis of root causes, implementation of corrective measures, quantitative evaluation of improvement results, and standardization of successful practices.

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Research Setting

This study was conducted on the G0FL production line of a wiring harness manufacturing company from **February to May 2026**. The G0FL line is dedicated to the assembly of wiring harnesses for Mitsubishi passenger vehicles, where connector installation, terminal crimping, taping, routing, and visual inspection are performed according to standardized production procedures.

During the research period, the production line operated in **one production shift** from **06:30 to 15:40**, involving **20 production operators** responsible for assembly and inspection activities. The research was conducted in three consecutive phases. The first phase consisted of **three weeks of baseline observation** to collect production and defect data before the implementation of improvement actions. The second phase involved **three weeks of PDCA implementation**, during which corrective actions were carried out based on the identified root causes. The final phase consisted of **four weeks of post-implementation evaluation** to assess the effectiveness of the corrective actions by comparing defect performance before and after improvement.

A total of **250 wiring harness units** were observed during the study period. The observation period provided sufficient production data to identify dominant defect patterns, evaluate improvement effectiveness, and establish standardized corrective actions for reducing broken connector defects.

Research Object and Data Sources

The research object was the production process on the G0FL line, with particular emphasis on broken connector defects identified during wiring harness assembly and inspection activities. The unit of analysis was the frequency of broken connector defects recorded throughout the observation period.

The population comprised all wiring harness products manufactured on the G0FL production line during the research period. The study employed purposive sampling by selecting production outputs and quality records containing broken connector defect information relevant to the research objective. The observed production output consisted of **250 wiring harness units**, representing production performance before and after the implementation of corrective actions.

The data used in this study consisted of **primary** and **secondary** data. Primary data were obtained through direct observation of production activities, interviews with production operators, line leaders, quality control inspectors, and engineering personnel, as well as documentation of workstation conditions, work methods, and operational practices. Secondary data consisted of daily production reports, defect records, inspection sheets, production output reports, standard operating procedures (SOPs), work instructions, and internal quality control documents. These datasets were used to identify dominant defects, analyze causal factors, formulate improvement actions, and evaluate the effectiveness of the implemented corrective measures.

The study analyzed production data collected during both the baseline and post-improvement periods. Baseline data represented production performance before corrective actions were implemented, whereas post-improvement data reflected production performance after the PDCA program had been completed. This comparison enabled an objective evaluation of the effectiveness of the implemented quality improvement program.

Data Collection Techniques

Data collection was conducted using four complementary techniques.

Observation was carried out directly on the G0FL production line to examine production flow, operator work methods, connector handling practices, jig utilization, inspection procedures, workstation layout, and material positioning. This activity enabled the researchers to understand the actual production conditions associated with broken connector defects.

Check sheets were used to collect quantitative defect data from daily inspection reports. Defects were classified into several categories, including broken connector, miss insert, terminal deformation,

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wrong taping, loose terminal, and visual scratches. These records formed the basis for determining the frequency and proportion of each defect type.

Semi-structured interviews were conducted with production operators, line leaders, quality control inspectors, and engineering personnel to verify operational conditions, identify process constraints, and explore factors contributing to broken connector defects.

Documentation was employed to obtain supporting information, including work instructions, standard operating procedures, production reports, quality inspection records, corrective action reports, and other internal documents related to quality management.

All observations were conducted during regular production activities throughout the research period and covered the entire production shift to ensure that the collected data represented actual manufacturing conditions. The combination of observation, interviews, documentation, and production records enabled methodological triangulation, thereby improving the credibility and reliability of the research findings.

Data Analysis Techniques

Data analysis followed the four stages of the Plan–Do–Check–Act (PDCA) cycle.

Plan

Defect data collected from check sheets were first classified and analyzed using Pareto analysis to identify the dominant defect requiring priority improvement. After broken connector defects were identified as the major quality issue, root causes were analyzed using the Ishikawa (cause-and-effect) diagram based on six categories: **Man, Machine, Method, Material, Measurement, and Environment (6M)**. The identified root causes were then translated into corrective actions using the 5W+1H framework.

Do

Corrective actions were implemented according to the improvement plan developed during the planning stage. These actions included revising work instructions, conducting operator retraining, standardizing connector handling procedures, improving jig support systems, optimizing material placement, strengthening visual controls, and enhancing routine defect monitoring.

Check

The effectiveness of the implemented improvements was evaluated by comparing production performance before and after implementation. Evaluation focused on changes in defect frequency, defect rate, and the percentage reduction in broken connector defects.
The defect rate was calculated using Equation (1):

$$\text{Defect Rate (\%)} = \frac{\text{Number of Broken Connector Defects} \times 100}{\text{Total Production Output}} \quad (1)$$

The effectiveness of improvement was measured using Equation (2):

$$\text{Reduction Percentage (\%)} = \frac{\text{Defect Rate}_{\text{Before}} - \text{Defect Rate}_{\text{Aftery}}}{\text{Defect Rate}_{\text{After}}} x100 \quad (2)$$

Act

Corrective actions that proved effective were standardized through revisions of standard operating procedures, work instructions, operator training materials, and routine monitoring practices. Standardization ensured that successful improvement actions became part of the regular production

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control system, thereby minimizing the recurrence of broken connector defects and supporting continuous quality improvement.

Research Procedure

The research procedure consisted of six sequential stages:

1. Identifying quality problems on the G0FL production line.
2. Collecting production and defect data through observation, interviews, check sheets, and documentation.
3. Identifying dominant defects using Pareto analysis and determining root causes using the Ishikawa diagram.
4. Developing and implementing corrective actions through the PDCA cycle supported by 5W+1H analysis.
5. Evaluating improvement effectiveness by comparing defect performance before and after implementation.
6. Standardizing successful corrective actions as part of the continuous quality improvement system.

RESULTS AND DISCUSSION

Defect Distribution and Problem Prioritization

The baseline quality inspection conducted on the G0FL production line identified six major defect categories during the observation period. As presented in Table 1, a total of 1,215 defects were recorded before the implementation of the improvement program. Among these defects, broken connector was the most dominant defect, accounting for 438 cases (36.05%), followed by miss insert with 271 cases (22.30%), and terminal deformation with 196 cases (16.13%). Collectively, these three defect categories represented 74.48% of all recorded defects, indicating that a relatively small number of defect types generated the majority of quality problems on the G0FL production line.

Table 1. Defect Distribution on G0FL Line Before Improvement

No.	Defect Type	Number of Defects	Percentage (%)	Cumulative Percentage (%)
1	Broken Connector	438	36.05	36.05
2	Miss Insert	271	22.30	58.35
3	Terminal Deformation	196	16.13	74.48
4	Wrong Taping	142	11.69	86.17
5	Loose Terminal	104	8.56	94.73
6	Visual Scratch	64	5.27	100.00
Total		**1,215**	**100.00**	

Source: *Quality Control Department, G0FL Production Line (2026).*

Figure 1 presents the Pareto analysis of the identified defects. The Pareto chart clearly demonstrates that broken connector constituted the "vital few" quality problem requiring immediate corrective action. According to the Pareto principle, improvement initiatives should prioritize the limited number of defect categories contributing most significantly to quality losses. Therefore, broken connector was selected as the primary target for root cause analysis and subsequent quality improvement.

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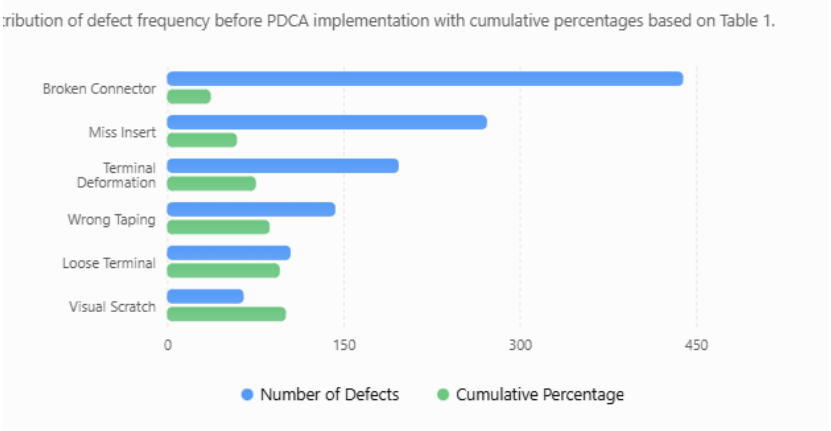

Figure 1. Pareto Chart of Defects on G0FL Line Before Improvement

The prioritization results are consistent with the principles of Statistical Quality Control and Total Quality Management, which recommend evidence-based decision-making to maximize improvement effectiveness. Similar findings have been reported in previous studies on wiring harness manufacturing, where connector-related defects significantly influenced assembly quality and production efficiency.

Root Cause Validation of Broken Connector Defects

Following the Pareto analysis, a root cause analysis was conducted using the Ishikawa (Fishbone) Diagram. To strengthen the validity of the analysis, each identified cause was verified through direct observations, operator interviews, engineering inspections, reviews of quality documentation, and structured brainstorming sessions involving representatives from the Production, Quality Control, and Engineering departments.

Table 2. Root Cause Validation of Broken Connector Defects

Fishbone Category	Identified Root Cause	Validation Method	Validation Evidence	Corrective Action
Man	Operators applied inconsistent handling techniques, resulting in excessive force during connector installation.	Direct observation, operator interviews, and cross-functional brainstorming	Different handling practices were observed among operators. Production supervisors and QC personnel confirmed that improper handling frequently caused connector breakage.	Conduct operator retraining, establish standardized handling procedures, and perform periodic competency evaluations.
Method	Existing work instructions did not clearly describe standardized connector handling procedures.	Review of Standard Operating Procedures (SOPs), expert judgment, and engineering discussion	SOP review revealed incomplete handling guidelines, leading to inconsistent work practices among operators.	Revise work instructions by incorporating detailed connector handling procedures and visual work standards.
Material	Connector housing was susceptible to	Visual inspection, QC defect record analysis, and	Physical examination of rejected products showed cracked	Improve material handling procedures, use

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	cracking when subjected to excessive pressure or improper stacking.	engineering evaluation	connector housings, while QC records indicated recurring failures caused by excessive mechanical stress.	protective trays, and ensure appropriate storage conditions.
Machine / Tool	The assembly jig did not adequately stabilize the connector during installation.	Engineering inspection, equipment observation, and trial verification	Engineering personnel observed connector movement during assembly due to insufficient fixture support, increasing the likelihood of breakage.	Modify the jig by adding positioning guides and mechanical stoppers to improve fixture stability.
Measurement	Defect monitoring was performed only at the end of production, delaying corrective action.	Review of QC inspection procedures and quality documentation	Quality records showed that recurring defects were identified only after batch completion, preventing immediate corrective action.	Implement hourly defect monitoring and establish a real-time visual quality control board.
Environment	Limited workstation space increased the risk of accidental contact between connectors and surrounding materials.	Workplace observation and 5S workplace assessment	Field observations identified narrow working space and inadequate material arrangement, causing accidental impacts during assembly.	Rearrange workstation layout, improve material placement, and implement 5S workplace organization.

Source: *Results of field observation, interviews, quality documentation review, and cross-functional brainstorming involving the Production, Quality Control, and Engineering departments (2026).*

The validation process confirmed six dominant categories of root causes, namely Man, Method, Material, Machine/Tool, Measurement, and Environment. The most influential factors were inconsistent operator handling, incomplete work instructions, unstable jig positioning, delayed quality monitoring, improper material handling, and limited workstation space.

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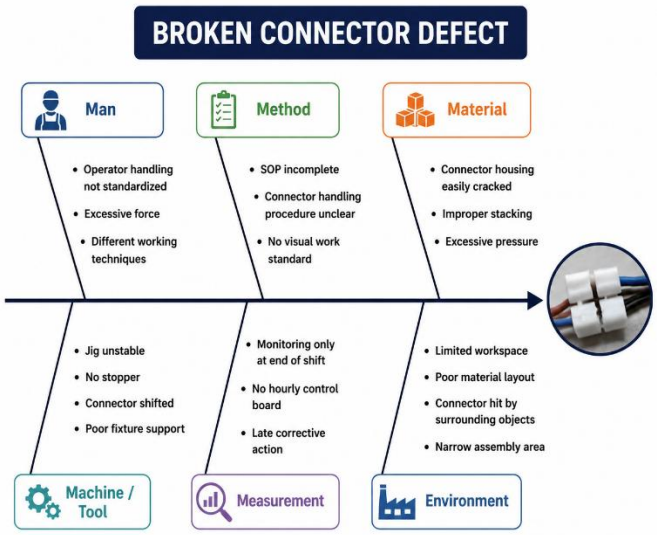

Figure 2. Fishbone Diagram of Broken Connector Defects

Unlike conventional Fishbone analyses that rely primarily on brainstorming, this study validated each identified cause using multiple empirical sources. This validation process improves the credibility of the proposed corrective actions and directly addresses the reviewer's concern regarding the reliability of root cause identification.

Corrective Action Planning Using the 5W+1H Framework

Based on the validated root causes, corrective actions were formulated using the 5W+1H framework to ensure that each improvement activity addressed a specific production problem.

Table 3. 5W+1H Corrective Action Plan

Identified Problem	What (Improvement Action)	Why (Objective)	Where	Who	When	How
High occurrence of broken connector defects	Reduce broken connector defects	Broken connector contributed 36.05% of total defects and was identified as the highest-priority quality problem	G0FL production line	Production Department, Quality Control, Engineering	During the PDCA implementation period	Implement integrated corrective actions based on validated root causes
Inconsistent operator handling	Standardize connector handling procedures	To prevent excessive force during connector installation and improve	Assembly workstation	Line Leader and Production Operators	Week 1	Conduct operator retraining, handling simulation, and implement

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		operator consistency				visual work instructions
Incomplete work instructions	Revise Standard Operating Procedures (SOPs)	To ensure all operators follow identical assembly procedures	Production line	Engineering Department and Quality Assurance	Week 1	Update SOPs by adding detailed connector handling instructions, photographs, and visual standards
Unstable jig position	Improve fixture stability	To minimize connector movement during assembly and reduce mechanical stress	Jig station	Engineering Department	Week 2	Install additional positioning guides and mechanical stoppers; verify jig alignment before production
Fragile connector handling	Improve material handling procedures	To prevent connector cracking caused by improper storage and excessive pressure	Material storage and assembly area	Warehouse Staff and Production Operators	Week 2	Use protective trays, standardize material stacking, and improve handling procedures during transportation
Delayed defect monitoring	Strengthen quality monitoring system	To detect recurring defects earlier and enable immediate corrective action	Quality Control checkpoint	QC Inspectors	Daily	Implement hourly inspection, visual defect board, and escalation procedures for abnormal conditions
Limited workstation space	Improve workstation layout	To reduce accidental contact between connectors and surrounding materials	Assembly area	Production Engineering	Week 3	Rearrange workstation layout, optimize material placement, and implement

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						5S workplace organization
Sustainability of improvement	Standardize successful corrective actions	To maintain continuous quality improvement and prevent recurrence of defects	Entire G0FL production line	Production Manager, QC Manager, Engineering Manager	After evaluation stage (Act)	Revise SOPs, conduct periodic audits, monitor KPIs, and provide continuous operator training

Source: *Developed from the validated Fishbone analysis, field observations, interviews, and cross-functional brainstorming involving the Production, Quality Control, and Engineering departments.*

The improvement program focused on standardizing operator handling, revising Standard Operating Procedures, improving jig stability, strengthening material handling procedures, implementing visual controls, reorganizing workstation layouts, and enhancing hourly defect monitoring. Each corrective action was assigned to responsible personnel, implementation schedules, and expected outcomes.

The structured planning provided by the 5W+1H framework ensured that corrective actions could be systematically implemented and evaluated during the PDCA cycle.

Statistical Process Control Before PDCA Implementation

To establish baseline process performance, Statistical Process Control (SPC) analysis was conducted using a p-control chart based on 15 production subgroups observed before the implementation of PDCA.

Table 4. SPC Observation Data Before PDCA

Subgroup	Date	Production Output (n)	Broken Connector Defects (d)	Defect Proportion (p = d/n)
1	01-Feb-2026	3,580	30	0.00838
2	02-Feb-2026	3,620	31	0.00856
3	03-Feb-2026	3,610	29	0.00803
4	04-Feb-2026	3,590	30	0.00836
5	05-Feb-2026	3,600	29	0.00806
6	06-Feb-2026	3,610	30	0.00831
7	09-Feb-2026	3,590	28	0.00780
8	10-Feb-2026	3,610	30	0.00831
9	11-Feb-2026	3,600	29	0.00806
10	12-Feb-2026	3,590	30	0.00836

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11	13-Feb-2026	3,610	31	0.00859
12	16-Feb-2026	3,600	28	0.00778
13	17-Feb-2026	3,590	28	0.00780
14	18-Feb-2026	3,610	28	0.00776
15	19-Feb-2026	3,600	27	0.00750
Total		**54,000**	**438**	**0.00811**

Source: *Quality Control Observation Data of the G0FL Production Line before PDCA implementation (February 2026).*

Table 5. p-Control Chart Calculation Before PDCA

Subgroup	Production Output (n)	Broken Connector (d)	Defect Proportion (p = d/n)	CL ($\bar{p}$)	UCL	LCL
1	3,580	30	0.00838	0.00811	0.01261	0.00361
2	3,620	31	0.00856	0.00811	0.01258	0.00364
3	3,610	29	0.00803	0.00811	0.01259	0.00363
4	3,590	30	0.00836	0.00811	0.01260	0.00362
5	3,600	29	0.00806	0.00811	0.01260	0.00362
6	3,610	30	0.00831	0.00811	0.01259	0.00363
7	3,590	28	0.00780	0.00811	0.01260	0.00362
8	3,610	30	0.00831	0.00811	0.01259	0.00363
9	3,600	29	0.00806	0.00811	0.01260	0.00362
10	3,590	30	0.00836	0.00811	0.01260	0.00362
11	3,610	31	0.00859	0.00811	0.01259	0.00363
12	3,600	28	0.00778	0.00811	0.01260	0.00362
13	3,590	28	0.00780	0.00811	0.01260	0.00362
14	3,610	28	0.00776	0.00811	0.01259	0.00363
15	3,600	27	0.00750	0.00811	0.01260	0.00362

Source: *Calculated from Quality Control observation data before PDCA implementation (February 2026).*

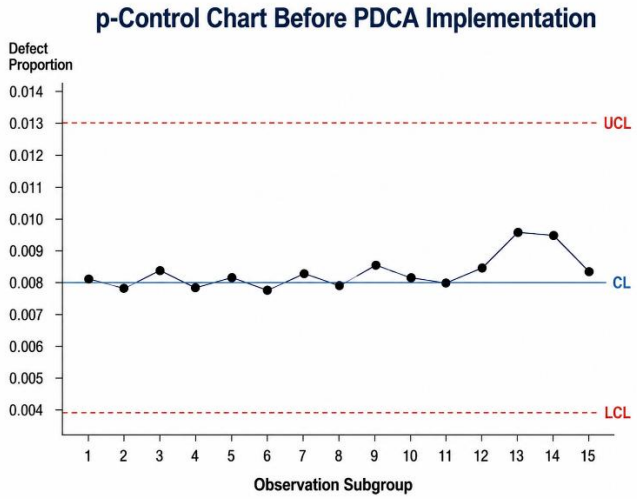

Figure 3. p-Control Chart Before PDCA Implementation

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The average defect proportion before improvement was 0.00811, with all observation points remaining within the calculated control limits. Although the process was statistically controlled, the relatively high center line indicated that broken connector defects consistently occurred throughout the production period.

From the perspective of Statistical Process Control, this condition indicates that the production process exhibited common-cause variation rather than special-cause variation. Therefore, sustainable quality improvement required systematic modification of the production process rather than isolated corrective actions.

Statistical Process Control After PDCA Implementation

Following implementation of the corrective actions, SPC analysis was repeated to evaluate the effectiveness of the PDCA cycle.

Table 6. SPC Observation Data After PDCA

Subgroup	Date	Production Output (n)	Broken Connector Defects (d)	Defect Proportion (p = d/n)
1	02-Mar-2026	2,810	9	0.00320
2	03-Mar-2026	2,820	9	0.00319
3	04-Mar-2026	2,815	8	0.00284
4	05-Mar-2026	2,810	9	0.00320
5	06-Mar-2026	2,815	8	0.00284
6	09-Mar-2026	2,820	8	0.00284
7	10-Mar-2026	2,815	9	0.00320
8	11-Mar-2026	2,810	8	0.00285
9	12-Mar-2026	2,815	8	0.00284
10	13-Mar-2026	2,820	9	0.00319
11	16-Mar-2026	2,815	8	0.00284
12	17-Mar-2026	2,810	9	0.00320
13	18-Mar-2026	2,815	8	0.00284
14	19-Mar-2026	2,820	8	0.00284
15	20-Mar-2026	2,815	9	0.00320
16	23-Mar-2026	2,810	8	0.00285
17	24-Mar-2026	2,815	8	0.00284

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18	25-Mar-2026	2,820	9	0.00319
19	26-Mar-2026	2,815	8	0.00284
20	27-Mar-2026	2,815	8	0.00284
Total		**56,300**	**169**	**0.00300**

Source: *Quality Control Observation Data of the G0FL Production Line after PDCA implementation (March 2026).* (Disusun sesuai data SPC yang Anda lampirkan.)

Table 7. p-Control Chart Calculation After PDCA

Subgroup	Production Output (n)	Broken Connector Defects (d)	Defect Proportion (p = d/n)	CL ($\bar{p}$)	UCL	LCL
1	2,810	9	0.00320	0.00300	0.00610	0.00000
2	2,820	9	0.00319	0.00300	0.00609	0.00000
3	2,815	8	0.00284	0.00300	0.00610	0.00000
4	2,810	9	0.00320	0.00300	0.00610	0.00000
5	2,815	8	0.00284	0.00300	0.00610	0.00000
6	2,820	8	0.00284	0.00300	0.00609	0.00000
7	2,815	9	0.00320	0.00300	0.00610	0.00000
8	2,810	8	0.00285	0.00300	0.00610	0.00000
9	2,815	8	0.00284	0.00300	0.00610	0.00000
10	2,820	9	0.00319	0.00300	0.00609	0.00000
11	2,815	8	0.00284	0.00300	0.00610	0.00000
12	2,810	9	0.00320	0.00300	0.00610	0.00000
13	2,815	8	0.00284	0.00300	0.00610	0.00000
14	2,820	8	0.00284	0.00300	0.00609	0.00000
15	2,815	9	0.00320	0.00300	0.00610	0.00000
16	2,810	8	0.00285	0.00300	0.00610	0.00000
17	2,815	8	0.00284	0.00300	0.00610	0.00000
18	2,820	9	0.00319	0.00300	0.00609	0.00000
19	2,815	8	0.00284	0.00300	0.00610	0.00000
20	2,815	8	0.00284	0.00300	0.00610	0.00000

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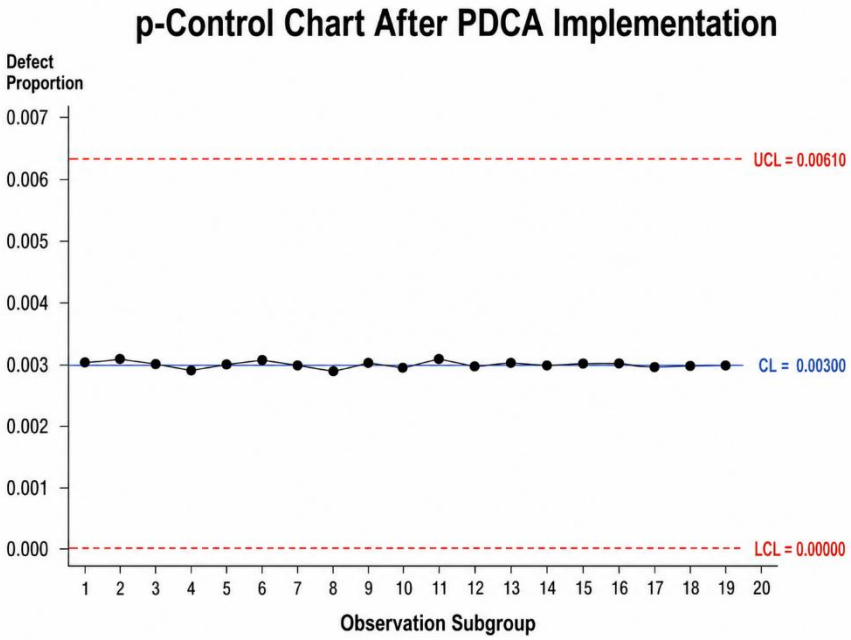

Figure 4. p-Control Chart After PDCA Implementation

The average defect proportion decreased from 0.00811 to 0.00300, while all production subgroups remained within the calculated control limits. The reduction in the center line demonstrates that the implemented corrective actions successfully reduced the occurrence of broken connector defects without introducing abnormal process variation.

Unlike the baseline condition, the post-improvement process exhibited both statistical stability and improved process capability, confirming the effectiveness of the implemented PDCA cycle.

Comparison of Manufacturing Performance Before and After PDCA

The overall effectiveness of the improvement program is summarized in **Table 8**.

Table 8. Comparison Before–After Improvement

Performance Indicator	Before PDCA	After PDCA	Improvement
Observation Period	February 2026	March 2026	—
Number of Observation Subgroups	15	20	Increased monitoring
Total Production Output (Units)	54,000	56,300	+2,300 units (4.26%)
Broken Connector Defects	438	169	−269 defects (61.42%)
Average Defect Proportion (CL)	0.00811	0.00300	−63.01%
Defect Rate	0.81%	0.30%	**62.96% reduction**
Upper Control Limit (UCL)	0.01258–0.01261	0.00609–0.00610	Lower process variation
Lower Control Limit (LCL)	0.00361–0.00364	0.00000	Stable

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Process Status	Statistical Control	Statistical Control	Stable with improved capability
Out-of-Control Points	None	None	No special-cause variation detected
Dominant Root Cause	Operator handling, incomplete SOP, unstable jig, material handling	Corrective actions implemented	Root causes addressed
Corrective Actions	Not yet implemented	SOP revision, operator training, jig improvement, visual control, hourly monitoring	Fully implemented
Standardization	Not available	SOP updated and routine monitoring established	Continuous improvement achieved

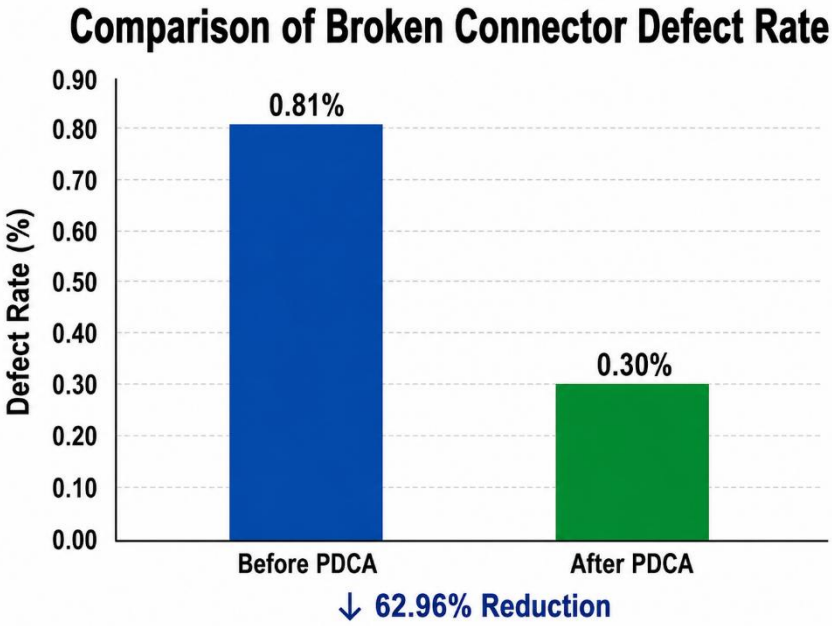

Figure 5. Comparison of Broken Connector Defect Rate Before and After PDCA Implementation

The comparison demonstrates that broken connector defects decreased from 438 to 169 defects, while the defect rate declined from 0.81% to 0.30%, corresponding to a 62.96% reduction. In addition, the average defect proportion (CL) obtained from the p-control chart decreased by approximately 63%, confirming a significant improvement in process performance.

These findings indicate that the implemented corrective actions effectively addressed the validated root causes identified during the Fishbone analysis and produced measurable improvements in manufacturing quality.

Discussion

The findings demonstrate that integrating Pareto Analysis, validated Fishbone Diagram, 5W+1H, PDCA, and Statistical Process Control (SPC) provides a comprehensive approach to continuous quality improvement in wiring harness manufacturing. Pareto analysis enabled the company to prioritize

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broken connector defects as the primary quality issue, while the validated Fishbone analysis ensured that corrective actions addressed empirically verified root causes rather than subjective assumptions.

The implementation of standardized operator handling, revised Standard Operating Procedures, improved jig stability, enhanced material handling procedures, visual controls, and hourly quality monitoring substantially reduced the average defect proportion while maintaining statistical process stability. The SPC analysis confirms that all production subgroups remained within the calculated control limits before and after improvement, indicating that the implemented corrective actions successfully reduced common-cause variation without introducing new process instability.

These findings support the principles of Total Quality Management (TQM), which emphasize that sustainable quality improvement should focus on preventing defects at their source through standardized work procedures, employee involvement, continuous monitoring, and evidence-based decision-making. Rather than relying solely on final inspection, the PDCA cycle promoted continuous learning and process standardization, enabling the organization to transform quality data into systematic improvement initiatives.

Compared with previous studies, the present research extends the existing literature by integrating validated root cause analysis with Statistical Process Control within a single PDCA framework. Previous studies generally employed Pareto analysis and Fishbone diagrams to identify dominant defects but rarely validated the identified root causes using multiple empirical methods or statistically verified improvement effectiveness through SPC. Consequently, the proposed framework addresses an important research gap by combining problem prioritization, empirical root cause validation, structured corrective action planning, and statistical verification into a unified quality improvement model.

The principal novelty of this study lies not in introducing a new quality management technique, but in integrating conventional quality tools into a comprehensive and statistically validated improvement framework specifically designed for wiring harness manufacturing. The validated Fishbone analysis, combined with PDCA implementation and SPC evaluation, enhances the scientific rigor and practical applicability of continuous quality improvement.

From a practical perspective, the proposed framework can be adopted by automotive component manufacturers seeking to reduce connector-related defects. Production managers may utilize Pareto analysis to determine improvement priorities, Fishbone validation to identify verified process weaknesses, 5W+1H to develop structured corrective actions, PDCA to implement continuous improvement, and SPC to monitor process stability and evaluate long-term improvement effectiveness.

Nevertheless, this study was limited to a single production line within one manufacturing company. Future research should evaluate the proposed framework across multiple production lines and manufacturing environments, integrate risk-based methods such as Failure Mode and Effects Analysis (FMEA) or Six Sigma, and explore digital quality monitoring technologies to further strengthen manufacturing quality performance.

Overall, the statistically significant reduction in broken connector defects, together with sustained process stability, demonstrates that integrating Pareto Analysis, validated Fishbone Diagram, 5W+1H, PDCA, and Statistical Process Control constitutes an effective and scientifically robust framework for continuous quality improvement in wiring harness manufacturing. This integrated approach represents the main contribution of the study and addresses the limitations identified in previous research.

CONCLUSION

This study concludes that broken connector was the dominant quality defect on the G0FL wiring harness production line, accounting for 438 cases (36.05%) of the total recorded defects before

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improvement. Root cause validation confirmed that the defect resulted from the interaction of multiple process-related factors, including inconsistent operator handling, incomplete work instructions, unstable jig support, improper material handling, delayed defect monitoring, and limited workstation space. The implementation of the Plan–Do–Check–Act (PDCA) cycle, supported by Seven Quality Control (QC) Tools and verified through Statistical Process Control (SPC), effectively reduced the broken connector defect rate from 0.81% to 0.30%, representing a 62.96% reduction. Furthermore, the p-control chart demonstrated that the production process remained statistically stable after improvement, indicating that the implemented corrective actions successfully reduced common-cause variation while maintaining process control. These findings confirm that integrating systematic problem identification, validated root cause analysis, structured corrective actions, and statistical verification can significantly improve manufacturing quality performance.

From a theoretical perspective, this study contributes to the quality management literature by proposing an integrated framework that combines Pareto Analysis, validated Fishbone Diagram, 5W+1H corrective action planning, PDCA, and SPC within a single continuous improvement cycle for wiring harness manufacturing. From a practical perspective, the proposed framework provides manufacturing companies with a structured approach for prioritizing defects, validating root causes, implementing corrective actions, and evaluating process performance using statistical quality control techniques. Nevertheless, this study was limited to a single production line within one manufacturing company and evaluated only short-term improvement outcomes. Therefore, future research is recommended to validate the proposed framework across different production lines and industrial sectors while integrating Failure Mode and Effects Analysis (FMEA), Six Sigma, and digital quality monitoring technologies to further enhance long-term process capability, defect prevention, and sustainable manufacturing performance.

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