Evaluate the Yield Rate of Multi-Process Products Using the Six Sigma DMAIC Method

Sung-Chang Lin and Shui-Chuan Chen

July 18, 2024

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Sung-Chang Lin
National Changhua University of Education
Department of Industrial Education and Technology
Changhua,Taiwan
dragon998829@gmail.com

Shui-Chuan Chen
National Chin-Yi University of Technology
Industrial Engineering & Management
Taichung,Taiwan
Scchen@ncut.edu.tw

Abstract - With the rising consumer awareness, the emphasis on quality management and risk control has significantly increased. Without an effective quality assurance system, manufacturing costs can rise due to yield issues, and inconsistent quality may lead to market backlash. This study applies the Six Sigma DMAIC methodology to wheelchair accessory parts, focusing on the critical stages of Define, Measure, Analyze, Improve, and Control.

Initially, during the sampling stage, the production process is planned, incorporating inspection points into the key processes using a production flowchart. Failure Modes and Effects Analysis (FMEA) is used to identify potential failures, assess their severity, frequency, and detectability to implement preventive measures. Simultaneously, the control plan outlines quality characteristics from mechanical equipment and inspection methods to process parameters, evaluation methods, inspection ratios, frequencies, and analysis methods, and proposes improvement recommendations when anomalies are detected.

Finally, the process capability index is used to evaluate the quality stability of the product in continuous production, aiming to control defects within three standard deviations, reduce complaints, transportation, and technical maintenance carbon emissions, promote sustainable development, reduce production costs, and improve customer loyalty.

***Keywords*:** Six Sigma、Process Capability Index、Quality Function Deployment、FMEA

I. INTRODUCTION

With the increasing standards of global market supply chains, this study aims to utilize the Six Sigma DMAIC methodology to review potential defect risks in multi-process product manufacturing. The potential failures of each process are evaluated, and the severity of undetected risks is analyzed and classified for planning. Corresponding preventive measures are implemented to ensure source management, enhance product quality in multi-process products, and reduce production costs.

Based on the definition of the Six Sigma DMAIC methodology in [1], the following is a list of tools used in this study:

TABLE I. DMAIC OBJECTIVES AND QUALITY TOOLS CORRESPONDENCE TABLE

	Stage objectives	Quality tools
Definition	Define the problem, customer requirements,and project objectives.	QFD
Measure mente	Understand the current process performance and collect relevant data.	Process Flow Diagram
Analysis	Identify and validate the relationships between causes and effects.	FMEA
Improve	Enhance process performance by implementing solutions	Control Plan
Control	Sustain improvements and ensure process stability.	Process Capability Index；Cpk

II. Literature Review

Six Sigma is an optimization strategy used to enhance a company's profitability by avoiding waste, scrap, and losses . [2]

Quality Function Deployment (QFD) translates customer requirements into design specifications during the product's conceptual design stage, with the House of Quality being a key component . [3][6]

FMEA is primarily used for product reliability and safety analysis.[4] Control Plans document the systems used to control and minimize product and process variation . [8]

Process Capability Indices (PCA) assess a process's ability to meet specified limits set by customers, engineers, or designers .[5]

III. EXPERIMENTS & APPLICATIONS

3.1 Definition

According to [1], the key point of the Definition phase in the DMAIC framework is "Define the problem, customer requirements, and project objectives". This study integrates Quality Function Deployment (QFD) with Product Engineering Diagrams to achieve the objectives of the Definition phase. The research uses wheelchair components as a case study, and upon execution, establishes project goals and foundational framework as follows:

TABLE II. QUALITY HOUSE TABLE

number	1	2	3	4	5	6	7	8	9	10	needs assessment: Products of this research	Market competitor products	1	2	3	4	5
Technical requirements / Customer quality needs	Geometry - Bearing bore dimensions and tolerances	Geometry-The flower drum is the mostlarge diameter	Geometry - Bearing to Bearing Distance	Material Properties - Weight	Material Properties-Strength	Material Properties-Aluminum Alloy	Design Features-Gravity casting combines body and brak	Design Features - Product Appearance	Design Features - Spoke Hole Specifications	Design Features - Brake Drum Turning Dimensions							
1. Brake drum rigidity	△	△	△	○	◎	◎	◎	△	△	◎	5	4					
2.Aluminum alloy composite material	△	△	△	◎	◎	◎	◎	△	△	○	4	4					
3. There is no risk of the brake drum and hub falling off	△	◎	△	△	△	◎	◎	◎	△	◎	5	3					
4. Equipped with quick release function	◎	△	◎	△	△	△	△	○	△	△	5	5					
5. Adapt to existing peripheral parts	◎	◎	◎	△	△	△	△	◎	◎	◎	5	1					
6.Surface gloss	△	△	△	△	△	○	△	○	△	△	5	3					
7. Lightweight	△	△	△	◎	◎	◎	△	○	△	△	4	2					
8. Product reliability	◎	△	△	○	◎	◎	◎	○	△	◎	5	3					
technical goals	Hole diameter Ø28mm-0.02/-0.03	Maximum outer diameter Ø 100mm	The distance between bearings is 37.6mm$^{+0.0}/_{-0.30}$	Weight 600Below a gram	Aluminum alloy body hardness HRB > 48°	A356aluminum alloy	gravity casting production	Product height 69.9mm	Number of drum holes: 36hole	DiameterØ70mm							
technologyGoal importance	32	24	24	26	40	50	40	32	16	42							
our products	4	4	3	4	4	4	4	4	3	4							
Market competitor products	3	3	3	2	3	2	2	2	3	3							
5																	
4																	
3																	
2																	
1																	
0																	

Products of this research
competitor products
△ weak positive correlation = 1
○ medium positive correlation = 3
◎ Strong positive correlation = 3

3.2 Measuremente

According to [1], the key point of the Measurement phase in the DMAIC framework is to "Understand the current process performance and collect relevant data." This study uses a Process Flow Diagram (PFD) to assess the current production process of wheelchair components.

Based on the product characteristics defined in the House of Quality and Engineering Diagrams from the Define phase, the production stages are integrated into four processing blocks in the PFD:

Receiving and Shipping

Outsourcing

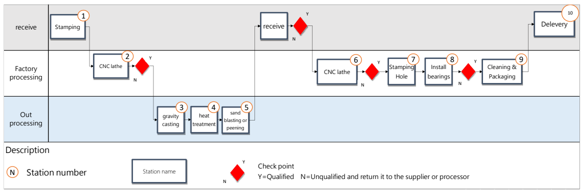
In-house Production Processing

Quality Issue Handling

Due to the multiple production processes required for wheelchair components defined in the Definition phase, the PFD includes plans for outsourcing and in-house production processing. To minimize quality variations, quality issue handling methods and inspection points are incorporated into the PFD. These inspection points are marked with red diamonds, with "Y" indicating pass and "N" indicating fail. Details and specifications for these inspections will be discussed in the Improve phase.

To integrate the FMEA tool from the Analyze phase and the Control Plan from the Design phase, each production process is defined with a workstation number, marked with an orange circle in the upper right corner of the workstation name for easy identification.

FIGURE I . PROCESS FLOW DIAGRAM



3.3 Analysis

According to [1], the key point of the Analyze phase in the DMAIC methodology is to "Identify and validate the relationships between causes and effects." This phase will use the Failure Modes and Effects Analysis (FMEA) method to assess the severity, occurrence frequency, and detection probability of potential defects.

TABLE III. FMEA ASSESSMENT FORM

FMEA number	Work process	Potential anomalies or failure modes	Potential impacts caused by anomalies or failures	severity	Potential causes of exceptions/failures	Existing process: Preventive control at this stage	occurrence frequency	Detectable control methods	probability of being discovered	RPN	solution	Responsibilities & Targets & Completion Dates	Improve results: action plan	severity	occurrence frequency	probability of being discovered	RPN
1	Brake drum stamping forming	Using wrong steel	speed up wear and tear	3	Using the wrong steel for processing	When receiving materials, the supplier is required to provide material certification and a label card will be made to indicate the material name after receiving the materials.	2	Check whether the incoming materials and labels are correct	2	12							0
2	Brake drum CNC turning	Wrong part size	Product main functions reduced	8	Too small clamping area causes deformation of parts	Set checkpoints in the process	7	Vernier caliper measurement 2.5D projection measurement	5	280							0
3	gravity casting	Part body has air holes	Reduced strength of parts	3	The air is not completely exhausted during casting	Set up inspection station	3	Visual inspection	6	54							0
4	gravity casting	Hub deformation	Reduced strength of parts	2	The operator opened the mold and took it out before cooling and setting.	Set up standard operating procedures	6	Visual inspection	5	60							0
5	Aluminum alloy heat treatment	Hardness does not meet requirements	Reduced strength of parts	7	Hardness after heat treatment does not meet production specifications	Require suppliers to provide test reports when receiving materials	2	Visual inspection	5	70							0
6	sandblasting	Uneven spraying	Part appearance defects	5	Sandblasting time is too short	Increase and fix sandblasting machine operation time	2	Visual inspection	7	70							0
7	Hub CNC turning	Wrong part size	The function of the part is reduced or the appearance is abnormal	3	Tool loss and abnormal machine parameters	Tool life management	3	Vernier caliper measurement height gauge combined with fixture measurement	6	54							0
8	Hub drum hole stamping	Wrong part size	The function of the part is reduced or the appearance is abnormal	5	Operator negligence	Set up sampling inspection station	3	Visual inspection	7	105							0
9	Press-in bearing	Wrong part size	The function of the part is reduced or the appearance is abnormal	5	Operator negligence	Set checkpoints in the process	2	Vernier caliper measurement height gauge combined with fixture measurement	3	30							0
10	clean	Residual chemicals and burrs	The parts are dirty and have sharp angles	2	Operator negligence	Correct standard work manual	3	Visual inspection	7	42							0
11	Package	Wrong packing quantity	Customer received insufficient product	3	Negligence on the part of the packing staff	Correct packaging manual	4	Weighing inspection	5	60							0

After FMEA evaluation, two significant issues were identified:

1.During CNC lathe clamping, deformation easily occurs, preventing proper alignment with the mold during gravity casting. This results in molten aluminum alloy leaking into the workpiece, potentially leading to brake malfunction.

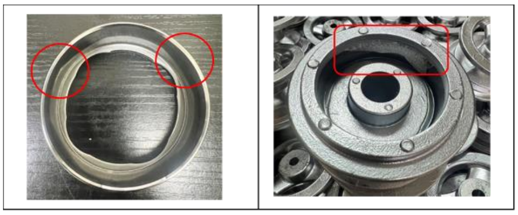


FIGURE II .SIGNIFICANT ISSUES 1

2.During the stamping process, if leftover materials are not effectively cleared by personnel, it may result in workpiece damage.

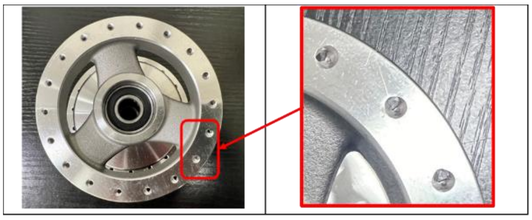


FIGURE III .SIGNIFICANT ISSUES 2

The improvement method is as follows:

1. CNC lathe

FIGURE IV . CNC LATHE IMPROVEMENT

2. Stamping

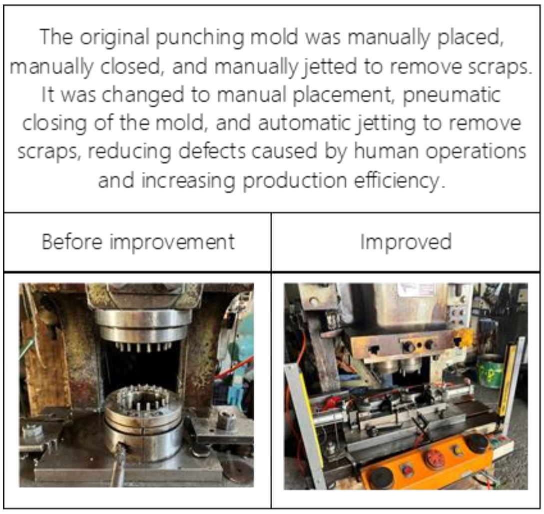


FIGURE V . STAMPING IMPROVEMENT

After improvement, the reassessment of the two improvement points for FMEA is as follows:

TABLE IV. IMPROVED FMEA ASSESSMENT FORM

FMEA number	Work process	Potential anomalies or failure modes	Potential impacts caused by anomalies or failures	severity	Potential causes of exceptions/failures	Existing process: Preventive control at this stage	Existing process: occurrence frequency	Existing process: Detectable control methods	Existing process: probability of being discovered	RPN	solution	Responsibilities & Targets & Completion Dates	Improve results: action plan	Improve results: severity	Improve results: occurrence frequency	Improve results: probability of being discovered	Improve results: RPN
1	Brake drum stamping forming	Using wrong steel	speed up wear and tear	3	Using the wrong steel for processing	When receiving materials, the supplier is required to provide material certification and a label card will be made to indicate the material name after receiving the materials.	2	Check whether the incoming materials and labels are correct	2	12							0
2	Brake drum CNC turning	Wrong part size	Product main functions reduced	8	Too small clamping area causes deformation of parts	Set checkpoints in the process	7	Vernier caliper measurement 2.5D projection measurement	5	280	Redesign the CNC chuck to increase the clamping area	Management	Design and build turnkey collets	3	3	7	63
3	gravity casting	Part body has air holes	Reduced strength of parts	3	The air is not completely exhausted during casting	Set up inspection station	3	Visual inspection	6	54							0
4	gravity casting	Hub deformation	Reduced strength of parts	2	The operator opened the mold and took it out before cooling and setting.	Set up standard operating procedures	6	Visual inspection	5	60							0
5	Aluminum alloy heat treatment	Hardness does not meet requirements	Reduced strength of parts	7	Hardness after heat treatment does not meet production specifications	Require suppliers to provide test reports when receiving materials	2	Visual inspection	5	70							0
6	sandblasting	Uneven spraying	Part appearance defects	5	Sandblasting time is too short	Increase and fix sandblasting machine operation time	2	Visual inspection	7	70							0
7	Hub CNC turning	Wrong part size	The function of the part is reduced or the appearance is abnormal	3	Tool loss and abnormal machine parameters	Tool life management	3	Vernier caliper measurement height gauge combined with fixture measurement	6	54							0
8	Hub drum hole stamping	Wrong part size	The function of the part is reduced or the appearance is abnormal	5	Operator negligence	Set up sampling inspection station	3	Visual inspection	7	105	Change the manufacturing process from manual to semi-automatic	Production Department	Changed to manual placement, pneumatic mold closing and automatic air jet removal to reduce defects caused by	4	2	7	56
9	Press-in bearing	Wrong part size	The function of the part is reduced or the appearance is abnormal	5	Operator negligence	Set checkpoints in the process	2	Vernier caliper measurement height gauge combined with fixture measurement	3	30							0
10	clean	Residual chemicals and burrs	The parts are dirty and have sharp angles	2	Operator negligence	Correct standard work manual	3	Visual inspection	7	42							0
11	Package	Wrong packing quantity	Customer received insufficient product	3	Negligence on the part of the packing staff	Correct packaging manual	4	Weighing inspection	5	60							0

3.4 Improve

According to [1], the key point of the Improve phase in the DMAIC methodology is to "Enhance process performance by implementing solutions." This study will use a Control Plan to finalize the production processes, machinery, locations, quality characteristics, specification tolerances, measurement conditions, analysis methods, and improvement measures. This will optimize customer requirements and finalize production conditions, inspection standards, and limitations.

After evaluation, the list is as follows:

TABLE V. CONTROL PLAN TABLE

manufacturing process			Tools or locations used for machines and equipment fixtures	product properties			Standardization and testing				Analytical method	Improvement measures after abnormality is discovered
FMEA number	Station number	Process name process description		Effect Size Balloon Number	Quality characteristics	Process parameters	Product process specification tolerances	Measurement tools	Measurement conditions: Measurement percentage	Measurement conditions: Detection frequency		
1	1	Iron ring stamping forming	Direct punch press		Material correctness	Make sure you use the right materials	SPHC steel plate	Factory material certificate	N/A	per order	testing report	Return to supplier
2	2	Brake drum CNC turning	CNC lathe	15	Inner diameter size Height size	Make sure the size is correct	Ø 68.7mm ± 0.1 Height 23mm ± 0.1	Vernier caliper	5%	per order	Measuring tools	Stop production/separate abnormal products/notify management/load
3	3	gravity casting	Gravity casting related machines	2, 3	Cosmetic defects	Make sure there are no pores during casting	Blank casting mold production	Visually	100%	per order	Visual inspection	Return to supplier
4	4	Aluminum alloy heat treatment	Heat treatment stove		Aluminum alloy hardness	Make sure the material hardness is correct	HRB 48~55	Hardness tester	1%	per order	Hardness measurement	Return to supplier for rework
5	5	sandblasting	Ring belt sandblasting machine		Remove carbonized layer	Ensure the carbonized layer is removed	#100~150 steel balls	Visually	5%	per order	Visual inspection	Return to supplier for rework
6	6	Hub CNC turning	CNC lathe	1~15	Outer diameter dimensions Inner diameter dimensions Height dimensions	Make sure the size is correct	Ø 100mm ± 0.15 Ø 67.9mm ± 0.15 Ø 59.82mm ± 0.15 Ø 3.35mm ± 0.05 Ø 38.1mm ± 0.15 Ø 82.1mm ± 0.15 Ø 28.6mm ± 0.10 Ø 28.0mm $^{-0.02}/_{-0.03}$ Ø 8.0mm ± 0.10 Ø 37.6mm ± 0.15 Ø 32.96mm ± 0.15 Ø 23.75mm ± 0.10 Ø 70mm $^{+0.15}/_{-0.00}$	Vernier caliper height gauge + inspection fixture three-point inner diameter micrometer	5%	per order	Measuring tools	Stop production/separate abnormal products/notify management/load improvement plan
7	7	Hub drum hole stamping	Direct punch press		Inner diameter size	Make sure the size is correct	2.8mm±0.1mm	Vernier caliper	5%	per order	Measuring tools	Return to supplier for rework
8	8	Push in bearing	4Ton hydraulic press		Confirm bearing specifications	Ensure the bearing is bonded to the workpiece	6001 specification bearings	Visually	100%	per order	Visual inspection	Stop production/separate abnormal products/notify management/load
9	9	clean	cotton		Parts quality control	Make sure the surface of the part is clean and	Cotton cloth wipe	Visually	100%	per order	Visual inspection	Stop production/separate abnormal products/notify management/load
10	10	Package	carton		Correct parts, quantities, packaging and	Ensure correct parts, quantities, packaging and	60pcs/carton	electronic scale	100%	per order	Visual inspection	Stop production/separate abnormal products/notify management/load

3.5 Control

According to [1], the key point of the Improve phase in the DMAIC methodology is to "Sustain improvements and ensure process stability." In this study, we will implement the Process Capability Index (Cpk) to achieve this. The Process Capability Index is used to measure the manufacturing capability of a product and to quantify process yield, evaluating whether it meets the requirements. The calculation of the Process Capability Index is based on the mean and standard deviation of the product characteristics of the process, and it is compared to the upper and lower design specification limits.

The process capability index will be assessed following the methodology outlined by Chen et al[7]. in their paper on "Capability performance analysis for processes with multiple characteristics using accuracy and precision." This method will be applied to evaluate the process capability index of products with multiple quality characteristics. Methods as below:

$$C_{p(u,v)}(\delta,\gamma) = \frac{1-u|\delta|}{3\sqrt{\gamma^2+v\delta^2}} \quad (1)$$

δ represents the index of accuracy, measuring the centrality of the process.

γ is defined as the index of precision, measuring the dispersion of the process.

$u = 0$ or 1

$v = 0$ or 1

$Cp(0,0)\ (\mu,\sigma) = Cp$

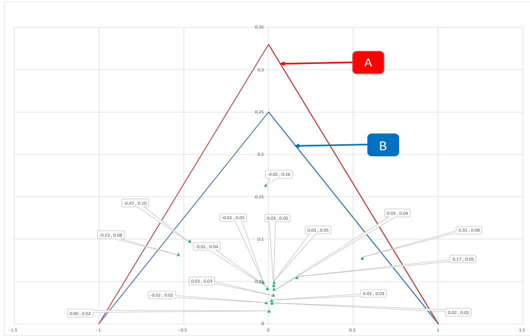
$Cp(1,0)\ (\mu,\sigma) = Cpk$

$Cp(0,1)\ (\mu,\sigma) = Cpm$

$Cp(1,1)\ (\mu,\sigma) = Cpmk$

After analysis, the list is as follows:

TABLE VI. PROCESS CAPABILITY INDEX EVALUATION FORM



When the value falls within Zone A, it indicates 1.33 < Cpk > 1; when it falls within Zone B, it indicates Cpk > 1.33. When Cpk > 1.33, the coordinates (1, 0.25) and (-1, -0.25) define the accepted region. When Cpk = 1, the coordinates (1, 0.33) and (-1, -0.33) define the accepted region.

IV. CONCLUSIONS

This study aims to investigate the production part approval process by integrating methods such as Six Sigma, Quality Function Deployment (QFD), manufacturing flowcharts, control plans, Process Capability Index (Cpk), and Failure Modes and Effects Analysis (FMEA). The goal is to improve manufacturing processes, enhance product quality, and reduce risks. By utilizing various risk planning and quality tools, the study hopes to avoid learning from accidents or failures and to prevent costly losses. Additionally, the application of these quality tools is expected to increase customer satisfaction and enhance product competitiveness.

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