REDUCING THE DEFECTS OF A-PILLAR STAMPING PART IN AUTOMOTIVE ASSEMBLY PROCESS

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การลดข้อบกพร่องของชิ้นส่วนโลหะปั๊มขึ้นรูป A-Pillar ในกระบวนการประกอบรถยนต์

นายหัสสกรณ์ โรจน์ปิตินิธิกร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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หัสสกรณ์ โรจน์ปิตินิธิกร : การลดข้อบกพร่องของชิ้นส่วนโลหะปั๊มขึ้นรูป A-Pillar ในกระบวนการประกอบรถยนต์. (REDUCING THE DEFECTS OF A-PILLAR STAMPING PARTIN AUTOMOTIVE ASSEMBLY PROCESS) อ.ที่ปรึกษาหลัก : อ. ดร.ณัฏฐ์ ลีละวัฒน์

งานวิจัยนี้มีวัตถุประสงค์เพื่อลดของเสียในกระบวนการประกอบรถยนต์ จากการพิจารณาค่าความเสียหายที่เกิดขึ้นนั้นพบว่า ชิ้นส่วนโลหะปั๊มขึ้นรูปเสาเอ มีมูลค่าความเสียหายสูงที่สุด ดังนั้นจึงทำการวิเคราะห์การผลิตตลอดจนปัญหาที่เกิดขึ้นในกระบวนการผลิต โดยใช้เทคนิคการวิเคราะห์ข้อบกพร่องและผลกระทบ มาใช้ในการวิเคราะห์ หลังจากนั้นดำเนินการทดลองโดยใช้วิธีการออกแบบการทดลอง จากการวิเคราะห์พบว่า ปัญหาที่เกิดขึ้นเกิดจากการออกแบบแม่พิมพ์ปั๊มขึ้นรูปโลหะที่ไม่ดีพอสำหรับผลิตชิ้นงานขนาดใหญ่ซึ่งมีความเสี่ยงในการเกิดปัญหาการดีดตัวกลับของชิ้นงานได้ หลังจากการปรับปรุงกระบวนการปั๊มขึ้นรูปโดยการเพิ่มแม่พิมพ์ย้ำขึ้นมานั้น ทำให้สามารถกำจัดปริมาณของเสียจาก 492 ปัญหาได้ ซึ่งสามารถลดค่าความเสียหายที่เกิดขึ้นจำนวน 27 ล้านบาทต่อปี ลงได้ทั้งหมด และค่าความสามารถของกระบวนการ Cpk ของตำแหน่งชิ้นงานที่พบปัญหา A10 และ A11 มีค่าดีขึ้นจาก 0.05 เป็น 0.9 และ 0.03 เป็น 0.92 ตามลำดับ

สาขาวิชา	วิศวกรรมอุตสาหการ	ลายมือชื่อนิสิต ....
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KEYWORD: Automotive parts, Design of Experiment (DOE), Failure modes and effects analysis (FMEA), Metal Stamping, Quality improvement

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The goal of this research is to minimize defects in the process of automotive assembly. Regarding the one-year defect and value; the biggest defect cost come from portion of the A-Pillar stamping parts. Therefore, by using Failure Mode and Effect Analysis (FMEA) to examine it and perform experiments using the Design of Experiment (DOE), we investigated the production process as well as figuring out the cause of the problems that happen in the stamping process. The results found that the issue arose from the design of stamping die, which is the risk of springback problems of parts, is not good enough to make a huge parts. Once the stamping process has been improved by adding re-strike die; the quantity of defects from 492 cases is expected to be zero and the defect cost amount of 27 million Thai Baht per year is saved. The process capability Cpk of position A10 and A11 has improve from 0.05 to 0.90 and 0.03 to 0.92, respectively.

Field of Study:	Industrial Engineering	Student's Signature ....
Academic Year:	2019	Advisor's Signature ....

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Hassakorn Rojpitinithikorn

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Cars are vehicles that are important and essential to human life. Almost human in the world knows cars. In a word, the car is the fifth factor of the human because it can bring human from one place to another for a great variety of reasons, be comfortable and fast travel. Therefore, the automotive industry has grown rapidly in many countries.

The automotive industry is a major industry that is important to the development of Thailand in terms of economy, employment, value creation and automotive technology development. Thailand has a policy to develop this industry continuously. Beginning in 1961, the automotive factory imported parts from abroad to be assembled car in Thailand. Then in 1971, Thailand government has a policy to promote the automotive factory by use parts produce in the country instead of import (Boonyanukhroh, 1996).

Regarding Thailand has a large population of agricultural workers, medium-sized pickup trucks are very popular in the country. Furthermore, Thailand being the main production center for pickup trucks in Asia, the quantity of pickup truck (1-ton) production is greater than the passenger car. From the disclosure of the automotive production quantity from the Federation of Thai Industries (FTI) that shown in Table 1.1, found that the total production quantity of the year 2017 and 2018; the 1-ton pickup truck has total production 1,130,058 cars and 1,250,483 cars respectively, while the passenger car has total production 826,787 cars and 884,609 cars respectively (MReport, 2018). As a result, 1-ton pickup truck manufacturers in Thailand are highly competitive in terms of production quantity and good quality.

Table 1.1

Automotive production quantity for export and domestic sales.

Unit: Car

	Y2017	Y2018
Export		
Passenger Car	417,664	416,184
1-ton Pickup Truck	708,768	726,549
Domestic		
Passenger Car	409,123	468,425
1-ton Pickup Truck	421,290	523,934
Total		
Passenger Car	826,787	884,609
1-ton Pickup Truck	1,130,058	1,250,483

Note. Source: (MReport, 2018). Retrieved 3 May 2019, from www.mreport.co.th

Car assembly is a work that requires constant improvement and continuous development because cars are products that have changes and evolution over time. Moreover, cars are the product that most vulnerable to accidents and make impact to human easily. Therefore, the car assembly factory must pay attention to produce a car with good quality to ensure that customers who use the car will get the most convenience and safety.

A study company is the carmaker manufacturing pickup truck (1-ton) in Thailand and have location of the manufacturing in Rayong Province. They are global company based in the United State of America (this research is called Company X). Another study company is the first-tier automotive parts supplier that produces metal stamping parts and supplies to Company X (this research is called Company Y).

<u>Company X background</u>

Company X is the global automotive carmaker in the world. They manufacture 1-ton pickup truck in U.S.A., Brazil and Thailand.

The U.S.A. manufacturing plant produces those trucks and its supplies within the country, the Brazil manufacturing plant produces those truck and its supplies to South America, Europe and other region (focused on left hand drive countries) and the Thailand manufacturing plant is produced those truck and supplied to Asia, Australia and other region (focused on right hand drive countries).

The Thai manufacturing plant was established since 2000 with registered capital of 13,800,000 Baht. Main production was 1-ton pickup truck and SUV vehicles. 60% of vehicles was export to Australia's market, 30% was sold in Thailand and 10% was sold to other region.

1. Product

Company X in Thailand produces 2 types of vehicle: 1-ton pickup truck and SUV (Sport Utility Vehicle). The 1-ton pickup truck is divided into 3 types according to the style of passenger room (Regular cab, Double cab and Crew cab).

The Regular cab has a single row of seats and a single door set each side. The Double cab has additional extra space behind the main seat. The Crew cab has a second row of seats to carry additional crew. The SUV (Sport Utility Vehicle) has the same chassis with Crew cab but have not pickup box. The pickup box of SUV was instead of third row of seats. Products shown as Figure 1.1.

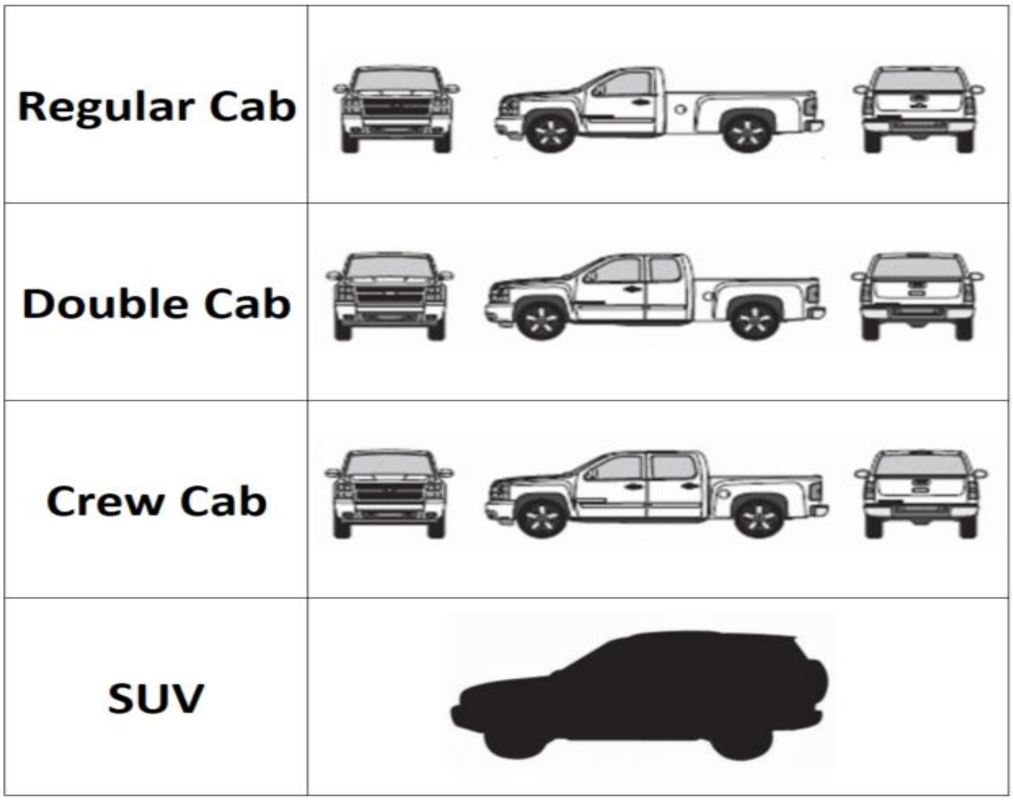

Figure 1.1. Main product of company X in Thailand.

2. Manufacturing Process (Thailand Plant)

The Thai manufacturing plant have 4 main processes to produce 1-ton pickup truck as shown in Figure 1.2.

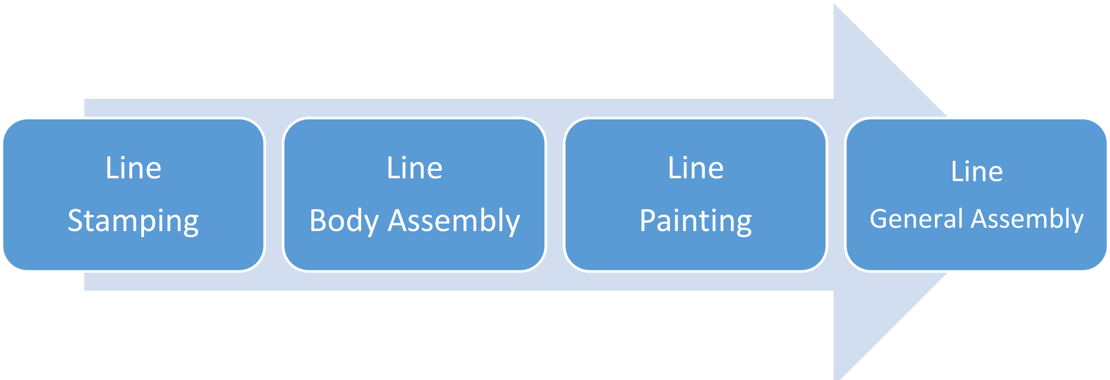

Figure 1.2. Main process of 1-ton pickup truck production of company X.

2.1 Stamping Line

This process to do stamping of big panels (i.e., Hood, Fender, Roof, Door, Body Side and Endgate). According to big panel required a huge size of stamping machine which high processing cost. So, company X decided to do stamping in-house. Figure 1.3 shown the stamping dies in the manufacturing plant.

Figure 1.3. Stamping dies in the manufacturing plant of 1-ton pickup truck.
Note. Source: Retrieved 29 May 2019, from www.victorytool.com

2.2 Body Assembly Line

As shown in Figure 1.4 this process to do assembly the body in white to be body structures of 1-ton pickup truck. Company X purchased each component from 1st tier suppliers and to do assembly in the shop floor.

Figure 1.4. Body assembly process of 1-ton pickup truck.

Note. Source: Retrieved 28 May 2019, from www.allpar.com

2.3 Painting Line

This process to do painting the body in white. The color of painting follow customer required as shown in Figure 1.5.

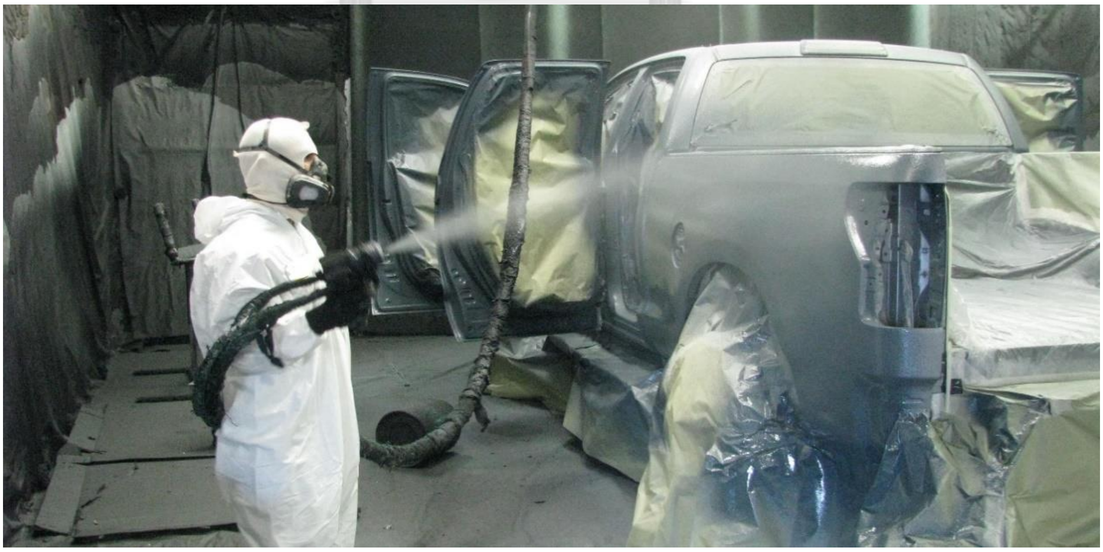

Figure 1.5. Painting process of 1-ton pickup truck.

Note. Source: Retrieved 28 May 2019, from www.usatoday.com

2.4 General Assembly Line

This process to do assembly the body in white that has been painted with other parts and become to completely 1-ton pickup truck (as shown in Figure 1.6).

Figure 1.6. General assembly process of 1-ton pickup truck.

3. Global Customer Audit (GCA) process

The Global Customer Audit “GCA” is the official audit guide. It was designed to provide customer-oriented audit criteria for Company X Corporate. The protocol specifies identical methods (audit techniques, standards, facilities, equipment and staff) desired to carry out the audit in the assembly manufacturing of Company X worldwide. There must be clear international implementation of the GCA norm and procedure. No exceptions are allowed and no "buy offs."

3.1 Purpose of process

- Support Company X's "Best in Section" corporate goal of manufacturing quality goods.
- Provide audit standardized methods for assembly manufacturing worldwide to assess the outgoing quality of the product
- Provide common measurement ratings of product quality for each vehicle assembly center / product line worldwide.
- The standard represents our discerning globally customer.
- The standard drives to keep product excited, not just to prevent defects.

3.2 Locations of audit process

Based on a standard of company X globally, they are settle location of GCA audit process with 13 stations as shown in Figure 1.7.

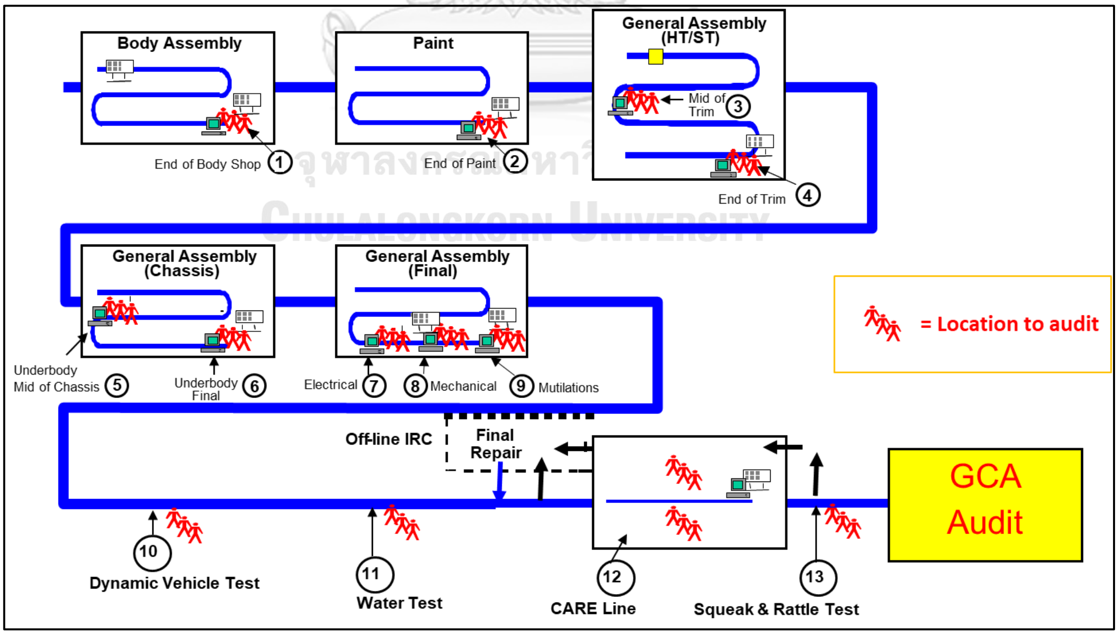

Figure 1.7. GCA audit process locations.

3.3 Audit sample size & selection

The GCA audit is perform each production day at every assembly line. Audit vehicles should be vehicles ‘OK’ for shipment, randomly selected, proportionally, from each production shift. Audits should be performed on every vehicle type the plant produces. The selection of audit vehicles should take into consideration increasing VIN / job number. In order to achieve a high level of confidence that low frequency problems will detect, the following sample sizes are required. Can see requirement as shown in Table 1.2.

Table 1.2

Audit sample size and selection

Production Volume (Vehicles/Day)	Minimum Audit Sample (Vehicles/Day)	OR	Optional Minimum Full Audit Sample (Vehicles/Day)		Optional “Boost Dynamic Sample” (Vehicles/Day)		Optional Total Audit Samples (Vehicles/Day)
≤ 250	2	OR	2	+	0	=	2
251 – 500	4	OR	3	+	2	=	5
501 – 750	6	OR	4	+	3	=	7
751 – 1000	8	OR	6	+	3	=	9
> 1000	10	OR	8	+	3	=	11

Note. Source: Global Customer Audit (G.C.A.) Worldwide Audit Procedure, p.7

3.4 Audit Reporting

The audit results were summarized and reported using a specific regional reporting system to the appropriate quality staff. The GCA results are recommended to be reported in the following categories shown as Table 1.3.

Table 1.3

Categories of GCA results

No	Category Description
1	Body Fits
2	Drivability
3	Electrical
4	Exterior Trim
5	Interior Trim
6	Metal
7	Noise
8	Paint
9	Underhood / Underbody
10	Waterleak
11	Paint / Metal Mutilation (Cracks, Peeling, Rust, Chips, Scratches, Dents

Note. Source: Global Customer Audit (G.C.A.) Worldwide Audit Procedure, p.7

Company Y background

Company Y is the Thailand automotive parts maker established since 1967. They are 100% Thai people owners. The main product is stamping parts (as shown in Figure 1.8). They are supplied the product to many automotive carmaker in Thailand included supplied those parts to company X to produce 1-ton pickup truck. Manufacturing plant location in Chachoengsao Province.

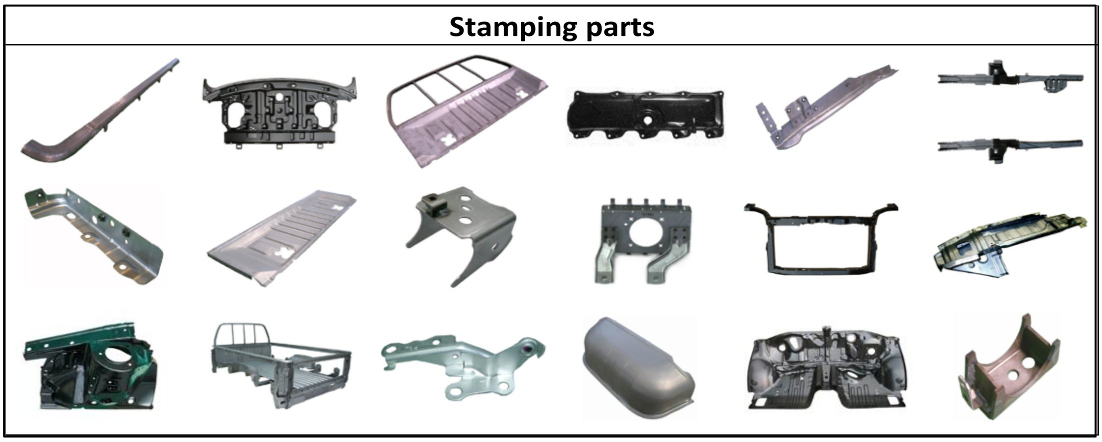

Figure 1.8. Main product of company Y.

1.1 Statement of the problems

From the Quality Control Department's report on the number of defect case of pickup truck (GCA issue report) during Aug’2017 – Aug’2018 found a total of 7,340 cases of defects from 177 parts. Pareto chart shown in Figure 1.9.

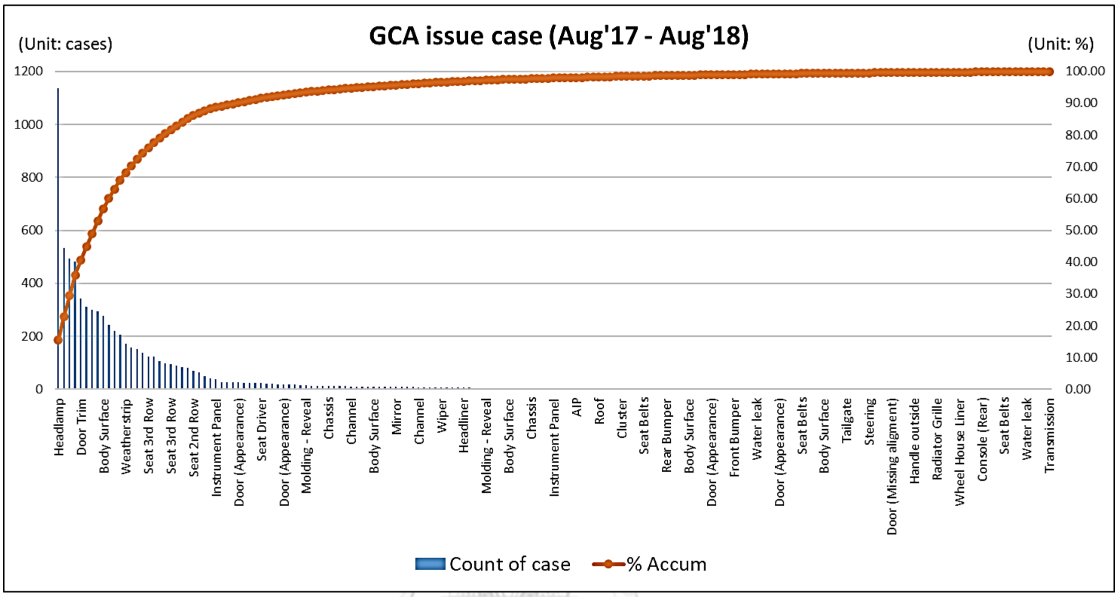

Figure 1.9. Pareto chart of GCA issue list during Aug’17 – Aug’18.

Considered only case which accumulate up to 80% (shown in Figure 1.10), have 20 parts must be considered as the first priority to improve. Table 1.4 shows the name of the component, GCA category, the number of cases, the percentage of case and the percentage of accumulative of top 20 parts list (80 percent accumulative).

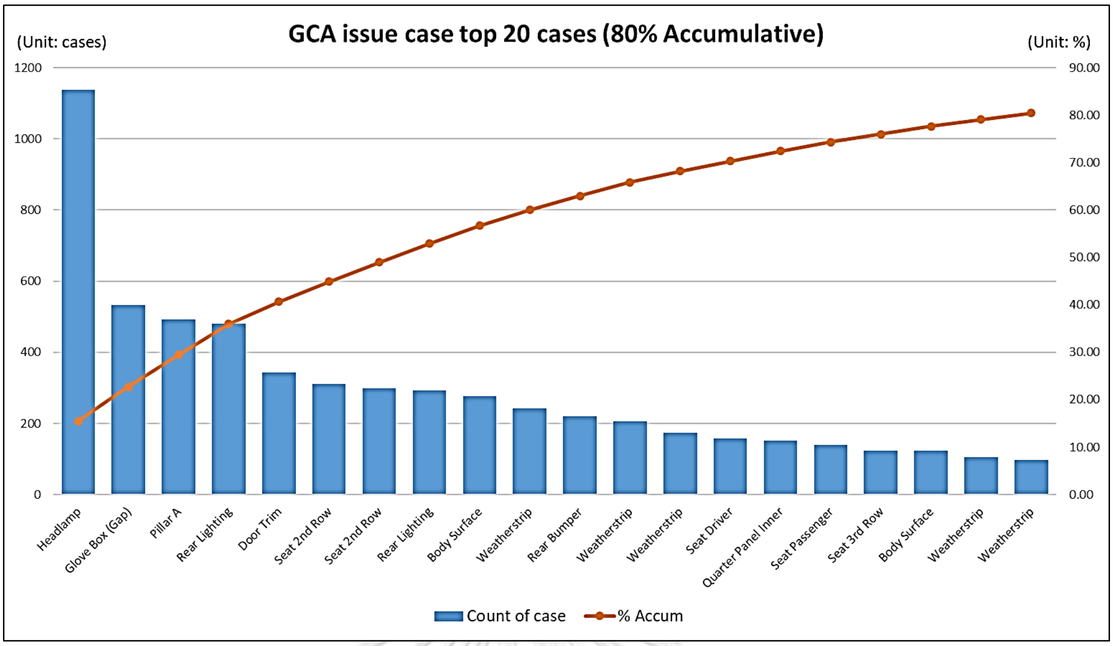

Figure 1.10. First priority 20 parts need to be improved.

Table 1.4

Top 20 parts list detail of case GCA issue report (Aug'17 – Aug'18)

No	SMT	Part	GCA Category	No of case (Case)	Case (%)	Accumulative (%)
1	Exterior	Headlamp	Exterior Trim	1,137	15.49	15.49
2	Interior	Glove Box (Gap)	Interior Trim	532	7.25	22.74
3	Body	Pillar A	Interior Trim	492	6.70	29.44
4	Exterior	Rear Lighting (Comp)	Exterior Trim	481	6.55	35.99
5	Interior	Door Trim	Interior Trim	343	4.67	40.67
6	Interior	Seat 2nd Row (L)	Interior Trim	310	4.22	44.89
7	Interior	Seat 2nd Row (R)	Interior Trim	299	4.07	48.96
8	Exterior	Rear Lighting (Light)	Exterior Trim	293	3.99	52.94
9	Exterior	Body Surface (FRT)	Paint	276	3.76	56.72
10	Exterior	Weatherstrip (DRR)	Interior Trim	242	3.30	60.01
11	Exterior	Rear Bumper	Exterior Trim	220	3.00	63.01
12	Exterior	Weatherstrip (DE)	Interior Trim	207	2.82	65.83
13	Exterior	Weatherstrip (DRL)	Interior Trim	173	2.36	68.19

Top 20 parts list detail of case GCA issue report (Aug'17 – Aug'18) (Continued)

No	SMT	Part	GCA Category	No of case (Case)	Case (%)	Accumulative (%)
14	Interior	Seat Driver	Interior Trim	158	2.15	70.34
15	Interior	Quarter Panel Inner	Interior Trim	152	2.07	72.41
16	Interior	Seat Passenger	Interior Trim	139	1.89	74.31
17	Interior	Seat 3rd Row	Interior Trim	124	1.69	75.99
18	Exterior	Body Surface (RR)	Paint	123	1.68	77.67
19	Exterior	Weatherstrip (DFL)	Interior Trim	105	1.43	79.10
20	Exterior	Weatherstrip (DFR)	Interior Trim	98	1.34	80.44
			Total	**5,904**		

Top 20 parts list was considered and found that item number 3 (A-Pillar) was assembled at the Body Assembly Line section, nevertheless other 19 parts were assembled at General Assembly Line section. In case there is an issue with A-Pillar parts, we need to scrap all the entire body in white parts with consisted of several parts. Estimated scrap cost of each issue shown in Table 1.5.

Table 1.5

Estimated GCA problem report defect value (Aug'17 – Aug'18)

No	Team	Part / Component	GCA Category	No of case (Case)	Scrap cost (Baht)	Scrap cost (%)
1	Exterior	Headlamp	Exterior Trim	1,137	3,587,008	6.79%
2	Interior	Glove Box (Gap)	Interior Trim	532	1,030,646	1.95%
3	Body	Pillar A	Interior Trim	492	27,019,652	51.15%
4	Exterior	Rear Lighting (Comp)	Exterior Trim	481	360,017	0.68%
5	Interior	Door Trim	Interior Trim	343	340,424	0.64%
6	Interior	Seat 2nd Row (L)	Interior Trim	310	3,564,287	6.75%
7	Interior	Seat 2nd Row (R)	Interior Trim	299	3,361,225	6.36%

Estimated GCA problem report defect value (Aug'17 – Aug'18) (Continued)

No	Team	Part / Component	GCA Category	No of case (Case)	Scrap cost (Baht)	Scrap cost (%)
8	Exterior	Rear Lighting (Light)	Exterior Trim	293	219,304	0.42%
9	Exterior	Body Surface (FRT)	Paint	276	980,525	1.86%
10	Exterior	Weatherstrip (DRR)	Interior Trim	242	56,248	0.11%
11	Exterior	Rear Bumper	Exterior Trim	220	782,977	1.48%
12	Exterior	Weatherstrip (DE)	Interior Trim	207	54,074	0.10%
13	Exterior	Weatherstrip (DRL)	Interior Trim	173	40,210	0.08%
14	Interior	Seat Driver	Interior Trim	158	2,564,284	4.85%
15	Interior	Quarter Panel Inner	Interior Trim	152	121,090	0.23%
16	Interior	Seat Passenger	Interior Trim	139	1,438,117	2.72%
17	Interior	Seat 3rd Row	Interior Trim	124	467,883	0.89%
18	Exterior	Body Surface (RR)	Paint	123	437,755	0.83%
19	Exterior	Weatherstrip (DFL)	Interior Trim	105	20,987	0.04%
20	Exterior	Weatherstrip (DFR)	Interior Trim	98	19,588	0.04%
	Other	Other	Other	1,436	6,361,704	12.04%
			Total	**7,340**	**52,828,004**	**100.00%**

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Taking into account the defect amount, it was found that the defect amount of the A-Pillar parts was 27,019,652 THB or 51.15% of the total defect amount over the past 13 months. It is a substantial amount of highly defective and must get rid of immediately.

The A-Pillar is the part of the body in white: in case A-Pillar has a flaw it will do scrap all the entire body in white with many parts (as shown in Figure 1.11). Therefore, the A-Pillar part need to be considered and improvement as the first priority.

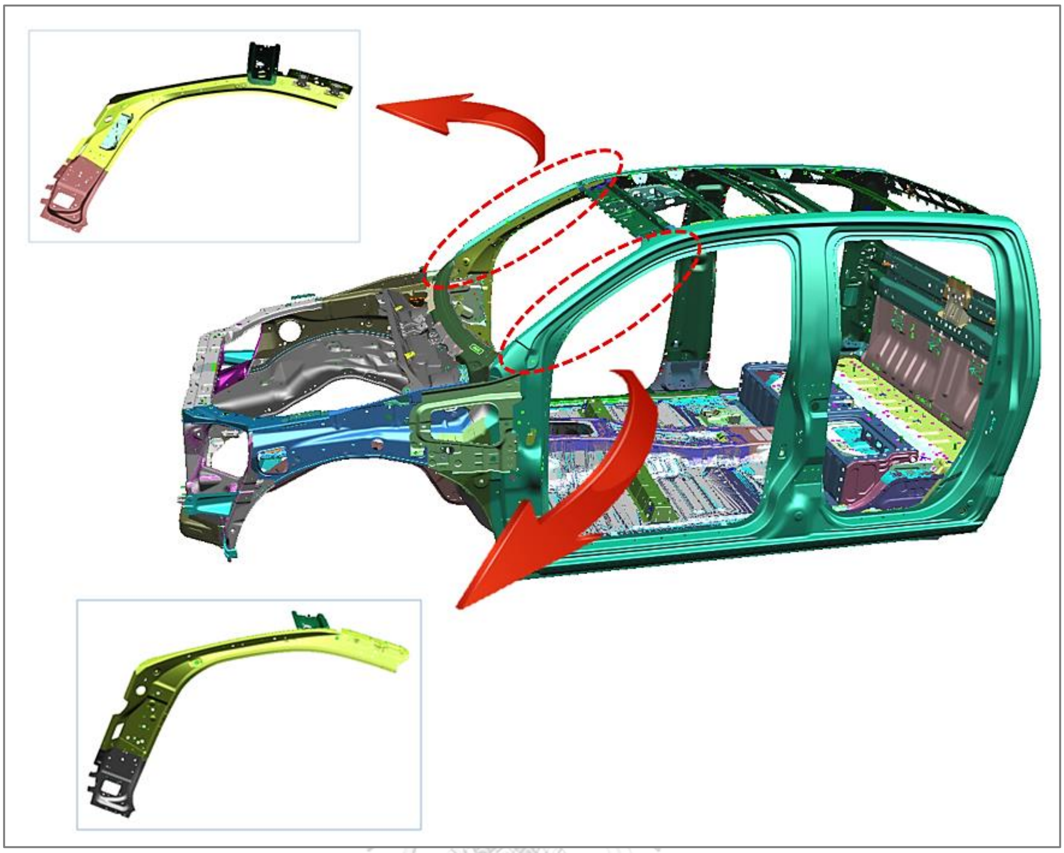

*Figure 1.11. P*ickup truck's BIW in Company X and A-Pillar assembled locations.

Total defect 492 cases of A-Pillar come from part missing alignment problem only. Figure 1.12 shown how to measurement the A-Pillar. By measuring the distance between the windshield and the A-Pillar's cover by measuring two locations (point A and B). If the space distance is greater than2 millimeters between point A and point B, this part will be rejected.

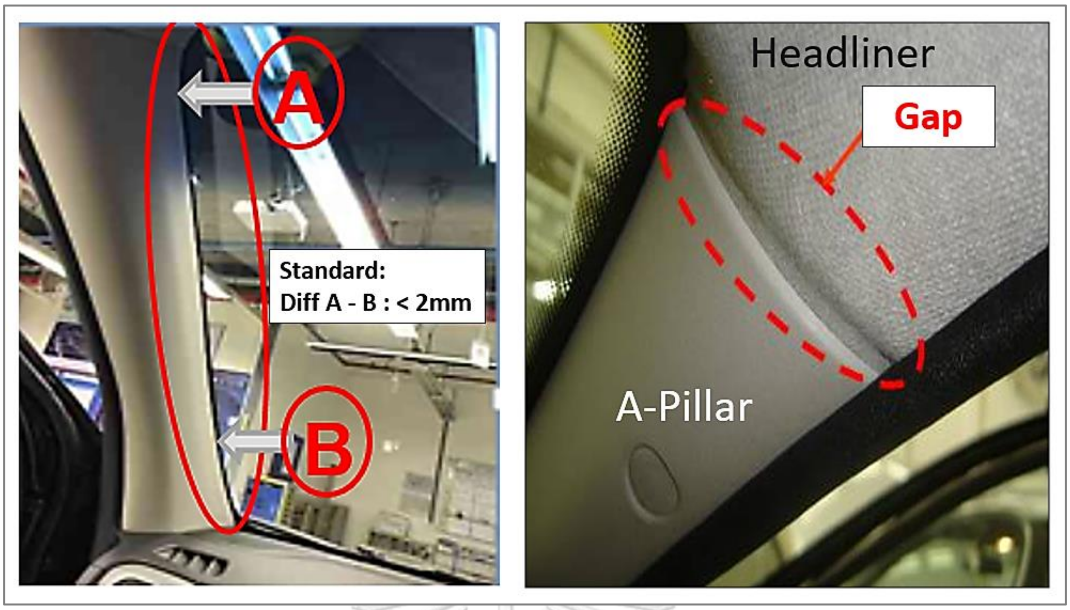

Figure 1.12. The measurement standard of missing alignment issue.

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This research introduces the method steps to define the cause and address defects solution of the stamping parts: A-Pillar of pickup truck. The problem is the parts missing alignment and not matched with the original design/drawing. After completing the design and die making process, the problem was occured. In addition, the parts will need to be used to assemble the pickup truck and deliver it to the customer. Which makes it impossible to take a long lead-time to find out the root cause with this time constraint.

1.2 Research objectives

This research focuses on the problem solving of stamping parts: A-Pillar that are missing alignment from the drawing/design. Therefore, the research objective is to reducing the number of defects in a timely manner and take less time to solve the problem. This research will use Failure Mode and Effect Analysis (FMEA) to analyze and reduce the number of defect from production process.

The selection of use FMEA technique to identify problems and determine the cause of A-Pillar parts due to FMEA tools can analyze the cause from both design (Design FMEA) and the cause from process (Process FMEA). It is expected to determine that the problems of A-Pillar part are caused by design or process.

1.3 Scope of study

1. This research studies only the defect from dimension missing alignment of A-Pillar for pickup truck of Company X and part A-Pillar was produced and supplied by Company Y.

2. This research studies the theories and use Failure Mode and Effect Analysis (FMEA) technique to reduce number of defect from production in the company Y. This research considers the root causes from design and process but solves the problems caused by improve process only. Since this A-Pillar part is currently in production, it is difficulty to solve the problems caused by the design of parts. For suggestions on how to solve the design problems, it is described in the last chapter of the research to be used for future work.

1.4 Organization of the thesis

This research has been conducted due to additional requirement of vehicle quality level increase, which has difficulty in developing, improving and implementing because the parts, tooling and station still be produce to support normal production.

Detail of vehicle quality level requirement are denoted in chapter I. The theory and literature reviews are denoted in chapter II. The research methodology and cause analysis are denoted in chapter III. Design of experiment is described in chapter IV.

Problem solutions is denoted in chapter V. Conclusion and recommendation are summarized in the chapter VI.

1.5 Expected outcome

The expected outcome of this research is to investigate the factors that affect the process causing a defect happened.

To reduce the A-Pillar part defect 50% from 492 cases (2.8% defect) to be 246 cases (1.4% defect) following Company X's KPI 2019. Therefore, we are expected to reduce the defect cost from 27 million Thai Baht to be 13.5 million Thai Baht.

1.6 Expected benefits

The other benefits that the Company X can gain is to applying this solution to other stamping parts that have a similar problem. The company is also able to prevent complaints from customers. As a result, it enhances the company to compete with other competitors.

1.7 Research schedule

Process step-by-step follow's Gantt chart is shown in Table 1.6.

Table 1.6

Gantt chart of research schedule

No	Task		2018		2019										
			Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1	Study the theory of related research articles	Plan													
		Actual													
2	Collect data of current process of A-Pillar and current problems	Plan													
		Actual													
3	- Analyze the causes by Cause and Effect Diagram - Do assessment the level of violence	Plan													
		Actual													
4	- Evaluate root cause of the defects by PFMEA technique - Define guidelines and methods for solving defect	Plan													
		Actual													
5	Design of Experiment	Plan													
		Actual													
6	Problem Solutions	Plan													
		Actual													
7	Implementing methods	Plan													
		Actual													
8	Summary of research and recommendations	Plan													
		Actual													

CHAPTER 2
THEORIES AND LITERATURE REVIEW

This chapter described the theory that will be used in this research. It consists stamping process, Cause and Effect Diagram, Failure Mode and Effects Analysis: FMEA and Process Capability. And discussing on the other research that has analyzed and solved the similar problem.

2.1 Stamping process

In general, the metal stamping process has nine primary process: Blanking, Piercing, Drawing, Bending, Air Bending, Bottoming and Coining, Forming, Pinch Trimming and Lancing (AmericanIndustrial, 2015). It depends on each person will design or select which process to make a part. The complex parts are necessary to have more than one process to capture all design and function. Mostly automotive parts required several stamping processes because it has a complexity, special functionally design, unique shape and must be compatible with surrounding parts.

2.1.1 Blanking

Blanking is the first step in the stamping process when necessary. Blanking is the cutting process of larger sheets or metal coils into smaller sheets. Usually blanking is done when a stamped piece of metal is drawn or formed (AmericanIndustrial, 2015).

2.1.2 Piercing

Piercing can be used if a component needs slots, holes, or other cutouts. Piercing, which can be done at the same time as blanking, punctures the appropriate shapes from the sheet of metal (AmericanIndustrial, 2015).

2.1.3 Drawing

Drawing is the real stamping in the process of metal stamping. A punch forces a metal section through a die, giving the part's primary shape. If the depth of the part is smaller than the primary opening, the drawing is considered shallow; sections with a depth greater than the opening are drawn deeply (AmericanIndustrial, 2015).

2.1.4 Bending

Bending is a mechanism that is quite self-explanatory. A specially designed die positions the part-in-progress, and a ram pushes against the steel, providing the appropriate bend. After drawing, bending is finished, as attempting to hit an already bent piece of metal causes the whole component to deform (AmericanIndustrial, 2015).

2.1.5 Air Bending

Air bending is when a part's flat surface is bent, often V-shaped, by a punch into a die. The gap between the punch and die is larger than the thickness of the material, resulting in a bend that slightly relaxes when removing the component. Air bending requires less stress and strength than other forms of bending (AmericanIndustrial, 2015).

2.1.6 Bottoming and Coining

Bottoming and coining are processes of bending similar to air bending. But use two to 30 times the pressure anywhere and the material is completely forced into a tightly fitting die. This leads to a more permanent bend (AmericanIndustrial, 2015).

2.1.7 Forming

Forming is a bending process similar to bending, bottoming, and coining. It creates multi-bended parts in one step, such as U-bends

(AmericanIndustrial, 2015).

2.1.8 Pinch Trimming

Pinch cutting is a method of cutting a piece from the sheet of metal, separating it from the metal scrap. It is a process that is unconventional: the metal is pinched against a smooth vertical surface. It is often used to cut deeply drawn round cups from the board, but not exclusively. (AmericanIndustrial, 2015).

2.1.9 Lancing

Lancing is a unique process, a type of metal cutting used to make winds or tabs. A section of a part is cut along three edges and bent at the same time. This creates the required opening or hook-like feature, but removes a scrap collection or secondary processing step (AmericanIndustrial, 2015).

2.2 Cause and Effect Diagram

Cause and Effect Diagram is a map used to analyze and find the various root cause of problem. It will give this a useful way. It diagram-based method, incorporating brainstorming with a form of Mind Map, takes into account all possible causes of a problem, rather than just the most obvious ones. (MindToolsContentTeam, 2014).

(MindToolsContentTeam, 2014) described Cause and Effect Analysis that it was conceived by Professor Kaoru Ishikawa, a pioneer of quality management, in the 1960s. They are called Ishikawa Diagrams or Fishbone Diagrams (because a completed diagram may look like a fish skeleton). While being originally developed as a quality control tool, the technique can be used in many ways as well as;

- Find out the root cause of an issue.
- Uncover gaps in your processes.
- Identify where and why a process does not work.

How to Use the Tool

Follow these steps to overcome a problem with Cause and Effect Analysis:

Step 1: Identify the Problem

- First of all, write down the exact issue you are facing. Identify who is involved, where necessary, what is the issue, and when and where it happens.
- Write the issue in a box on the left-hand side of a large sheet of paper, and draw a line horizontally across the paper from the box as shown in Figure 2.1. This design, which looks like a fish's head and backbone, gives you space for ideas to evolve.

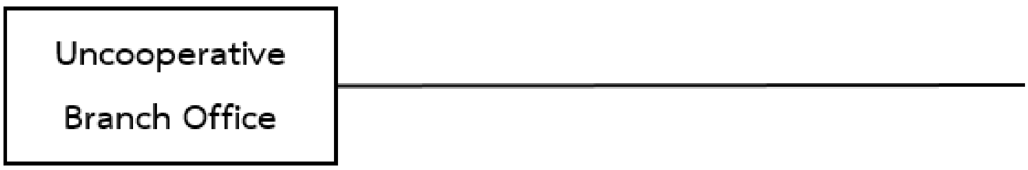

Figure 2.1. Step 1 to identify the problem in a Fishbone Diagrams.

Note. Source: (MindToolsContentTeam, 2014). Retrieved 10 May 2019, from www.mindtools.com

Step 2: Work Out the Major Factors Involved

- Next, identify the factors that might be part of the issue. These may include structures, equipment, materials, external forces, people involved with the issue, and so on.
- Try to draw out as many of these as possible.
- Brainstorm any other factors that could affect the situation.
- Then draw a line from the diagram’s "spine" for each element and mark each line.

  Example: The manager identifies the following factors, and adds these to his diagram: site, task, people, equipment and control, as shown in Figure 2.2.

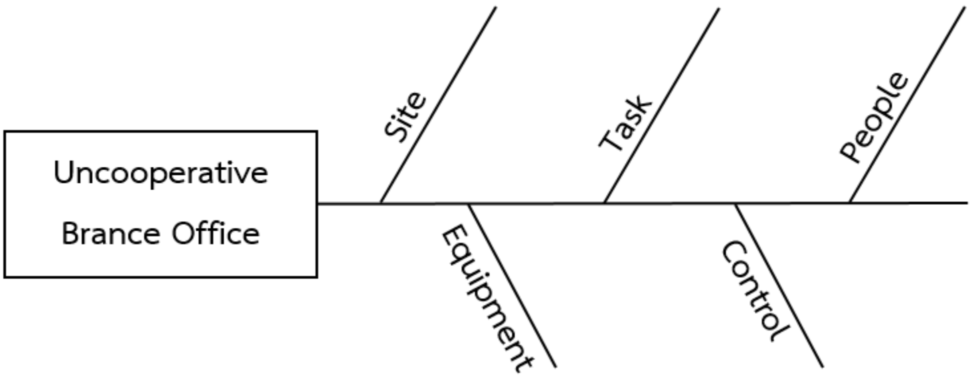

Figure 2.2. Step 2 to identify major factor involved in a Fishbone Diagrams.
Note. Source: (MindToolsContentTeam, 2014). Retrieved 10 May 2019, from www.mindtools.com

Step 3: Identify Possible Causes

- Now, for each of the factors considered in step 2, brainstorm possible causes of the factor-related problem.
- Show these possible causes as the "bones" of the diagram. If a cause is large or complex, it may be best to divide it into sub-causes. Show these as lines that come out of line of cause.

Example: For each factors he identified in step 2, the manager brainstorms the possible causes of issue, and adds these to his diagram, as shown in Figure 2.3.

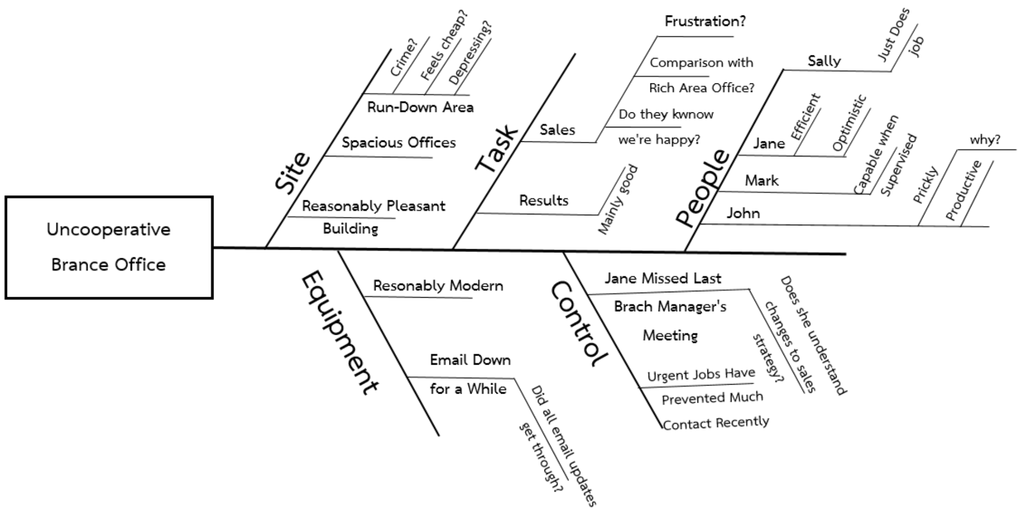

Figure 2.3. Step 3 to identify possible causes of factor in a Fishbone Diagrams.
Note. Source: (MindToolsContentTeam, 2014). Retrieved 10 May 2019, from www.mindtools.com

Step 4: Analyze Your Diagram

- At this point, there should be a diagram showing all of the possible causes of the issue that can think of.
- Depending on the complexity and importance of the issue, the most likely causes can now be further investigated. This may include setting up investigations, conducting surveys, etc. These will be designed to test which of the possible causes contribute to the issue.

A useful way to use this technique with a team is to write all of the possible causes of the problem down on sticky notes. Then group similar ones together on the diagram (MindToolsContentTeam, 2014).

2.3 Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis; FMEA is a methodology designed to enable organizations to predict failure during the design phase by recognizing all possible failures in a design or manufacturing process. FMEA was one of the first ways to improve standardized quality, developed in the 1950s. Today it is still a very effective way to reduce the likelihood of failure (Dawson, 2012).

2.3.1 Definition of Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) is a systematic method for identifying potential failures that may occur within the design of a product or process. Failure modes are the ways in which a system can fail. Effects are the ways in which they can contribute to waste, defects or harmful outcomes for the customer. Failure Mode and Effects Analysis is designed to identify, prioritize and restrict these failure modes (Dawson, 2012).

Prioritization of the potential failures or RPN regards the severity, occurrence, and detection relatively impacted on the product or process. Severity (S) is a score that corresponds to the intensity of a potential failure mode impact. Occurrence (O) is a score that corresponds to the frequency at which a first stage causes and its subsequent failure mode occurs over the design life of product or process, or before any additional process controls are implemented. Detection (D) is a score that corresponds to the probability that detection methods or current controls can detect the potential failure mode before the designed product released for production, or for process before leaving the production facility (Laosrimongkol, 2004).

2.3.2 RPN Rating Scale and Criteria

RPN is calculated by the multiplication of S, O, D as in equation 2-1 where scaled 1-10 for each (Laosrimongkol, 2004).

$$RPN = S \times O \times D \qquad \textit{(equation 2-1)}$$

Where S is the scaled of Severity; O is the scaled of Occurrence; D is the scaled of Detection. Therefore, the highest possible risk of each failure mode is 1,000 and the lowest is 1. According to the automotive standard 16949, the RPN score 75 is considered acceptable. The criteria of ranking the scale for severity, occurrence and detection are described in Table 2.1, Table 2.2, and Table 2.3, respectively (Laosrimongkol, 2004).

Table 2.1

Ranking scale for severity of potential failure mode

Ranking	Description	Criteria
1	None	Slight inconvenience to operation or operator or no effect.
2	Very Minor	A portion of the product (less than 100%) may need to be reworked without scrap, on-line but in-station.
3	Minor	A portion of the product (less than 100%) may need to be reworked without scrap, on-line but out-of-station.
4	Very Low	A portion of the product (less than 100%) may need to be sorted and reworked without scrap.
5	Low	100% of product may need to be reworked, or vehicle/ item repaired offline but does not go to the repair department.
6	Moderate	A portion (less than 100%) of the product may need to be scrapped without sorting or repaired at repair area with less than half an hour of repair time.
7	High	A portion (less than 100%) of the product may need to be scrapped without sorting or repaired at repair area and use time between half an hour and an hour.
8	Very High	Product may need to be scrapped 100 percent, or vehicle/item repaired at repair area and use time more than 1hr.
9	Hazardous with warning	The operator (machine or assembly) may be in danger with warning.
10	Hazardous without warning	The operator (machine or assembly) may be in danger without warning.

Note. Source: (Laosrimongkol, 2004).

Table 2.2

Ranking scale for probability and frequency of occurrence

Ranking	Description	Criteria
1	Remote: Failure is unlikely	≤ 0.01 per thousand parts; P_{pk} ≥ 1.67.
2	Low: Relatively few failures	0.1 per thousand parts; P_{pk} ≥ 1.30.
3	Low: Relatively few failures	0.5 per thousand parts; P_{pk} ≥ 1.20.
4	Moderate: Occasional failures	1 per thousand parts; P_{pk} ≥ 1.10.
5	Moderate: Occasional failures	2 per thousand parts; P_{pk} ≥ 1.00.
6	Moderate: Occasional failures	5 per thousand parts; P_{pk} ≥ 0.94.
7	High: Frequent failures	10 per thousand parts; P_{pk} ≥ 0.86.
8	High: Frequent failures	20 per thousand parts; P_{pk} ≥ 0.78.
9	Very High: Persistent failures	50 per thousand parts; P_{pk} ≥ 0.55.
10	Very High: Persistent failures	≥ 100 per thousand parts; P_{pk} ≥ 0.55.

Note. Source: (Laosrimongkol, 2004).

Table 2.3

Ranking scale for detection

Ranking	Description	Criteria
1	Very High	It is not possible to make discrepant parts because the process / product design proved the error of the component.
2	Very High	Error Proven Inspection or Gage Inspection. Error detection in-station (automatic gauging with automatic stop feature). Cannot transfer discrepant part.
3	High	Error Proven Inspection or Gage Inspection. Error detection in-station, OR in subsequent operations by multiple layers of acceptance: supply, select, install, verify. Cannot accept and transfer discrepant part.

Ranking scale for detection (Continued).

Ranking	Description	Criteria
4	Moderately High	Error Proven Inspection or Gage Inspection. Error detection in subsequent operations, OR gauging performed on setup and first piece check (for setup causes only).
5	Moderate	Gage Inspection. Control is based on variable gauging after parts left the station, R Go/No Go gauging performed on 100% of the parts after parts left the station.
6	Low Gauging or Manual Inspection	Charting tools such as SPC (Statistical Process Control) are used to maintain control.
7	Very Low Manual Inspection	Control is achieved with double visual inspection only.
8	Remote Manual Inspection	Control is achieved with visual inspection only.
9	Very Remote	Manual Inspection. Control is achieved with indirect or random checks only.
10	Almost Impossible Manual Inspection	Cannot detect or is not checked.

Note. Source: (Laosrimongkol, 2004).

2.3.3 FMEA Classification

(Dawson, 2012) described that the Design-FMEA (DFMEA) and the Process-FMEA (PFMEA) are two broad categories.

2.3.3.1 Design-FMEA

Design-FMEA (DFMEA) discusses the potential for product malfunctions, decreased product lifetime, regulatory and safety arising from:

- Properties of Material
- Product shape
- Toleration
- Other parts and/or device interfaces
- Engineering interference: conditions, profile of users, degradation, interactions of systems

2.3.3.2 Process-FMEA

Process FMEA (PFMEA) described failure affecting product quality, decreased process efficiency, customer disfavor, and safety arising from:

- Human Factors
- Methods followed while processing
- Materials used
- Machines utilized
- Measurement systems impact on acceptance
- Environment Factors on process performance

2.3.4 When to Perform Failure Mode and Effects Analysis (FMEA)

(Dawson, 2012) described that It is important to carry out a Failure Mode and Effects Analysis several times:

- When a new product, process or service was designed
- When you are planning to carry out an existing process in another way

- When you have an improvement in quality objective for a particular process
- When you need to consider and adjust the failures of a process

In addition, it is best to periodically perform an FMEA occasionally throughout the lifetime of a process. For optional results, quality and reliability need to be consistently reviewed and improved (Dawson, 2012).

2.3.5 FMEA Implementation

(Dawson, 2012) described that FMEA is carry out in 7 steps. The steps are divided to ensure that the suitable team members are required to be present for each step. The FMEA approach used by Quality-One has been developed to avoid typical risk, Which slow and ineffective analysis. The Quality-One Three Path Model allows tasks to be prioritized and team time to be used effectively.

There are Seven Steps to Developing an FMEA:

1) Pre-Work FMEA and conduct the FMEA Team
2) Path 1 Development (Severity Rating requirements)
3) Path 2 Development (Potential Causes and Occurrence Ranking and Prevention Controls)
4) Path 3 Development (Detection Rating screening and detection controls)
5) Response Priority and Assignment
6) Design Review and Actions Taken
7) Re-ranking RPN and Closure

The FMEA’s steps for conduct are as follows:

1) Pre-Work FMEA and conduct the FMEA Team

Pre-work involves gathering and processing key documents. FMEA works smoothly through the planning processes when it has been carrying out Investigation of previous shortcomings and preparatory records since its inception. Initial content may include:

- Failure Mode Avoidance (FMA) Past Failure
    - Eight Disciplines of Problem Solving (8D)
- Boundary/Block Diagram (For the DFMEA)
- Parameter Diagram (For the DFMEA)
- Process Flow Diagram (For the PFMEA)
- Characteristics Matrix (For the PFMEA)

It is recommended to use a pre-work checklist for an effective FMEA Checklist items may include:

- Requirements to be included
- Design and / or Process Assumptions
- Preliminary Bill of Material / Components
- Known causes from surrogate products
- Potential causes from interfaces
- Potential causes from design choices
- Potential causes from noises and environments
- Family or Baseline FMEA (Historical FMEA)
- Past Test and Control Methods used on similar products

2) Path 1 Development (Severity Rating requirements)

Path 1 Includes characteristics, failure modes, failure consequences and Severity ratings. Pre-work reports aid in this role by using previously collected data to fill the FMEA's first columns (depend on the chosen document worksheet).

- The functions should be written in the form of the verb noun. Each function must have a measurable association. Functions may include:

- Desires, wants and needs translated
- Design requirements
- Desired process outputs
- Characteristics of product to be analyzed
- Program-specific requirements

➢ Failure Modes are written as anti-functions or anti-requirements in five potential ways:

- Full-function failure
- Partial / degraded-function failure
- Intermittent-function failure
- Unintended-function failure
- Over-function failure

➢ Results are lack of success outcomes, where each effect is rated Severity. At this point, acts will be considered if the severity is 10 or 9

- Recommended Actions may be considered to have an effect to the design product or design process addressing Failure Modes on High Severity Rankings (Regulation and Safety)

3) Path 2 Development (Potential Causes and Occurrence Ranking and Prevention Controls)

Causes are picked from the design/process inputs or failures in the past and placed in the Cause column for a particular failure mode.

The completed columns in Path 2 are:

➢ Potential Causes of Failure

➢ Current Preventive Controls (i.e., working standard, previously successful designs, etc.)

➢ Occurrence Rankings for each cause

➢ Classification of Special Characteristics, if indicated

- Actions to mitigate high risk combinations of Severity and Occurrence, described in the Quality-One Criticality Matrix

4) Path 3 Development (Detection Rating screening and detection controls)

Path 3 Development involves adding Detection Controls to verify that the design meets requirements (for Design FMEA) or cause and/or failure mode, if undetected, may reach a customer (for Process FMEA).

- The columns completed in Path 3 are:
    - Ranking of Detection
    - Control of Detection
- That intervention is designed to improve controls if it is inadequate to meet the risks defined in Paths 1 and 2. Recommended Actions should address weakness in the testing and/or control strategy.
- Evaluate and modify of the Design Verification Plan and Report (DVP&R) or Control Plans are also possible outcomes of Path 3.

5) Response Assignment and Priority

A Risk Priority Number (RPN) is assigned to the actions previously identified in Paths 1, 2 or 3 for follow-up action. For each possible failure / effect, cause and control combination, RPN is calculated by multiplying the Severity, Occurrence and Detection Ratings. Actions on the basis of an RPN threshold value should not be calculated. This is commonly done and is an activity that results in poor team behavior. The completed columns are:

- Review Recommended Actions and assign RPN to further monitoring
- Assign Actions to suitable staff
- Assign action due dates

6) Design Review and Actions Taken

When countermeasures have been taken, FMEA actions are closed and are successful in reducing risk. The purpose of an FMEA is to discover and mitigate risk. FMEAs that do not consider risk are treated as low and added as non-value. There was no change in the team's performance and no time spent in the analysis.

7) Re-ranking RPN and Closure

The core team or team leader will re-rank the correct rating attribute (Severity, Occurrence or Detection) upon positive verification of risk mitigation behavior. To achieve the new RPN, the new rankings will be multiplied. According to the updated RPN, the original RPN has been verified and the relative change to the design or process. Columns completed in Step 7:

- Re-ranked Severity
- Re-ranked Occurrence
- Re-ranked Detection
- Re-ranked RPN
- Generate new Actions, repeating Step 5, until risk has been mitigated
- Comparison of initial RPN and revised RPN

2.3.6 <u>FMEA Document Analysis</u>

Deciding when to take an action on the FMEA has historically been determined by RPN thresholds. Quality-One does not recommend setting action goals by using RPN thresholds. These goals are thought to affect the team behavior negatively, since teams choose the lowest numbers that below the threshold and not the current risk, which needs mitigation.

An FMEA's analysis should include considerations at multiple levels, including:

- Severity of 9 / 10 or Regulation and Safety alone (Failure Mode Actions)
- Criticality combinations for Severity and Occurrence (Cause Actions)

- Control of Detection (Test and Control Plan Actions)
- Pareto chart of RPN score

Once done, activities push the risk to a lower risk level from its current position in the Quality-One FMEA Criticality Matrix (Dawson, 2012).

2.3.7 RPN score Action Priority

When risk is deemed not acceptable, Quality-One suggests that action objectives be implemented as follows:

1) Error Proofing (Dispose Failure Mode or Address Cause)
   - Failure Mode (Only Severity of 10 or 9)
   - Causes with High Occurrence score
2) Improve Potential Process Capability
   - Increase Tolerance (Design of Tolerance)
   - Reduce Process Variable (Statistical Process Control and Process Capability)
3) Improve Controls
   - Mistake Proofing of the process or tooling
   - Improve the inspection / evaluation tools

2.3.8 FMEA Relationship to Problem Solving

The Failure Modes in an FMEA are similar to problem solving problem statement or problem description. FMEA causes are similar to possible root causes of problem resolution. Examples of this relationship are:

- The claims and explanations of the problems are related between the two reports. Problem solving strategies are achieved more efficiently by using pre-brainstormed data from an FMEA that is easy to locate.
- Possible causes are used for jumping Fishbone or Ishikawa diagrams immediately in an FMEA. It is not a good use of time or resources to brainstorm knowledge that is already known.

- For future planning of new products or system efficiency, data collected from problem solving will be stored in an FMEA. It helps an FMEA to identify real failures, defined as modes and causes of failure, making the FMEA more functional and complete (Dawson, 2012).

2.4 Design of Experiment (DOE)

Process or system can be represented by the model (as Figure 2.4). The process is a blend of machines, methods, people, and other resources that transforms some input (material) into an output that has one or more observable responses (Montgomery, 2009).

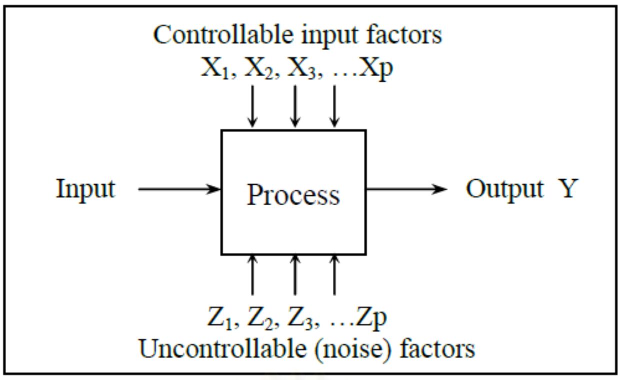

Figure 2.4. General model of a process or system.
Note. Source: Applied Statistics and Probability for Engineers (1994), p. 688.

Some of the process variables arecontrollable (X_1, X_2, ..., X_p), while other variables are uncontrollable (Z_1, Z_2, ..., Z_p).

2.4.1 <u>The experiment's goals may include:</u>

- Determine which variables affect the response Y the most.
- Determine where to set the influential X's so that Y is usually near the desired nominal value.

- Determine where the powerful X's are to be set so that Y variance is minimal.
- Determine where the powerful X's should be set to minimize the effect of the uncontrollable parameter Z1, Z2, ..., Zp (robust design) (Montgomery, 2009).

2.4.2 Application of DOE

Application of DOE early in process development can result in:

- Improved process yields.
- Reduced variability and closer conformance to nominal or target requirements.
- Reduced development time.
- Reduced overall cost.

2.4.3 Guidelines for experimental design

1. Recognition of the issue and its statement:

- A simple and generally accepted definition of the problem needs to be developed.
- Demand feedback from: engineering, QA, manufacturing, marketing, management, customer, operator (team approach is required).

2. Choice of factors, levels, and ranges:

- Process knowledge (Practical knowledge coupled with theoretical understanding) is required.
- Investigating all factors that may be significant and not being overly influenced by past experience is crucial.

3. Selection of the factor response:

   - The experimenter should be confident that the factor response actually provides useful knowledge about the system being studied.
   - Mean and S.D. are normally used.

4. Choice of experimental design:

   - Consideration of sample size (number of replicates), selection of an appropriate format, choice of an appropriate run order, and determination of whether or not there are blocking or other constraints on randomization.

5. Perform experiments:

   - To ensure that everything is done in accordance with the schedule, it is important to track the system carefully.

6. Statistical analysis of data:

   - In order to be accurate, statistical methods should be used to analyze the data.
   - Throughout data analysis and interpretation, simple graphical methods play an important role.

7. Conclusion and recommendation:

   - Sometimes, graphical methods are useful, particularly when communicating results to others.
   - To support the experiment's findings, follow-up runs and validation tests should be done.

(Montgomery, 2009).

2.4.4 Type of Experimental Design

The major types of Experimental Designs are:

1) Full Factorials
2) Fractional Factorials
3) Screening Experiments
4) Response Surface Design
5) EVOP
6) Mixture Experiments

1. Full Factorials

- As its name suggests, full factorial experiments fully examine all factors included in the experiment. (QualityTrainingPortal, 2010).
- We research all possible combinations of treatment that are correlated with the factors and their levels. We look at the effects on the measured responses of the main factors and all interactions between factors (QualityTrainingPortal, 2010).
- If we use more than two levels for each factor, we can also study whether the effect on the response is linear or if there is curvature in the experimental region for each factor and for the interactions (QualityTrainingPortal, 2010).
- Full factorial experiments can require many test runs if many factors are investigated at many levels (QualityTrainingPortal, 2010).

2. Fractional Factorials

- Factorial fractions analyze more variables with fewer runs (QualityTrainingPortal, 2010).

- The use of a factorial fraction includes making the main assumption that higher-order interactions (three or more factors) are not significant (QualityTrainingPortal, 2010).
- Through substituting higher-order interactions with new factors, fractional factorial models are extracted from complete factor matrices. (QualityTrainingPortal, 2010).
- In order to increase experimental efficiency, fractional factorials give up some power to evaluate the reaction effects. The main effects will still be examined by fractional factories. They lead to compromises when considering the effects of interaction (QualityTrainingPortal, 2010).
- This arrangement is referred to as uncertainty (QualityTrainingPortal, 2010).
- Just because we have confused the main factor and the effects of interaction do not mean that fractional factories are a poor choice. The threats we face are worth it. (QualityTrainingPortal, 2010).
- There are occasional three way and higher interactions, even two way interactions are not that ordinary. The experimental quality more than confuses the findings we obtain. (QualityTrainingPortal, 2010).

3. Screening Experiments

- The main factorial fractional tests were screening experiments. These experiments suppose that all interactions, even two way interactions, are not significant (QualityTrainingPortal, 2010).
- They literally screen the factors, or variables, in the process and define which are the serious variables that affect the process output (QualityTrainingPortal, 2010).

4. Response Surface Design

- Response surface design is the technique of off-line optimization. Two factors are normally studied; however, 3 or more can be studied (QualityTrainingPortal, 2010).
- With response surface design, we perform a series of complete factorial experiments and map the answer to produce mathematical equations explaining how the response factors affect (QualityTrainingPortal, 2010).

5. EVOP

- EVOP (evolutionary operations) is an on-line optimization technique (QualityTrainingPortal, 2010).
- Normally two factors are analyzed using minor, phase changes in factor rates to test the operational limits of the system incrementally. (QualityTrainingPortal, 2010).

6. Mixture Experiments

- Up to now, the models we looked at work fine for factors such as temperature, stress or time and even product replacements. They will not work in situations where we need to study how formulation changes affect the final properties of a material. (QualityTrainingPortal, 2010).
- When dealing with formulations, there are added constraints on the experimenter. When dealing with composition, the sum of all of the weight fractions of all the components must add up to 1.0 and each of the individual components must have a weight fraction between 0 and 1.0. Mixture experiments provide techniques to operate within these constraints (QualityTrainingPortal, 2010).

2.4.5 Experimental Strategy

- When setting up an experimental strategy, it is usually best to start with screening experiments to separate out the important (significant) factors from the many factors in a process (QualityTrainingPortal, 2010).
- From there we can experiment further on the significant factors and study their interactions with fractional factorial or full factorial experiments (QualityTrainingPortal, 2010).
- In some cases, once we have identified the power factors, we may want to optimize the response using the power factors in one of the two major DOE techniques for optimizing processes, Response Surface Analysis or EVOP (QualityTrainingPortal, 2010).

2.5 Process Capability

The process capability is to calculate the system efficiency when there are some noise factors and process inputs that influence the process because the process output could not be in the target line and could be deviated from the target. (Chitranshi, 2018).

Here the target refers to the customer's process target. With some specification constraints, customers give the target i.e. USL (Upper Specification Limit) and LSL (Lower Specification Limit), these are the goal boundaries already taken into account by customers. Yet obviously it is practically impossible to reach the exact goal, and therefore customers are giving the USL and LSL (Chitranshi, 2018).

If all our data points are within these specification limits, we may assume that our system is effective, if data points exceed the customer specification limits., it means the process is not effective enough to provide the data as per customers’ requirement (Chitranshi, 2018).

2.5.1 Key points to note about the capability of process

When addressing the ability of processes we must ensure that data is normal and in control. If data is not normal and in control, it is fruitless to check for the process capability.

- The capability of the process provides long-term performance once it is within the statistical limits.
- It also tests the ability of people, equipment, instruments and methods to execute the operation.
- In the manufacturing industries, upper and lower specification limits could be defined for any measurement. There may be a chance of a single limit in other industries, either maximum or minimum. The delivery of the product, for example, should have only the maximum limit, whereas passing an examination has a criterion of at least 60% (Chitranshi, 2018).

2.5.2 The Capability of Discrete/Attribute Data

The discrete data will either be defective for example pass or fail, no or go or; Binomial data 0 or 1. On the other side, discrete data can have defects e.g. Scratches and number of material or data defects in a single unit. This is called the Poisson. The efficiency of these data can be estimated using the Minitab or other software packages from binomial or Poisson distributions, data can also be transformed into continuous form and the normal processing power approach can be used

(Chitranshi, 2018).

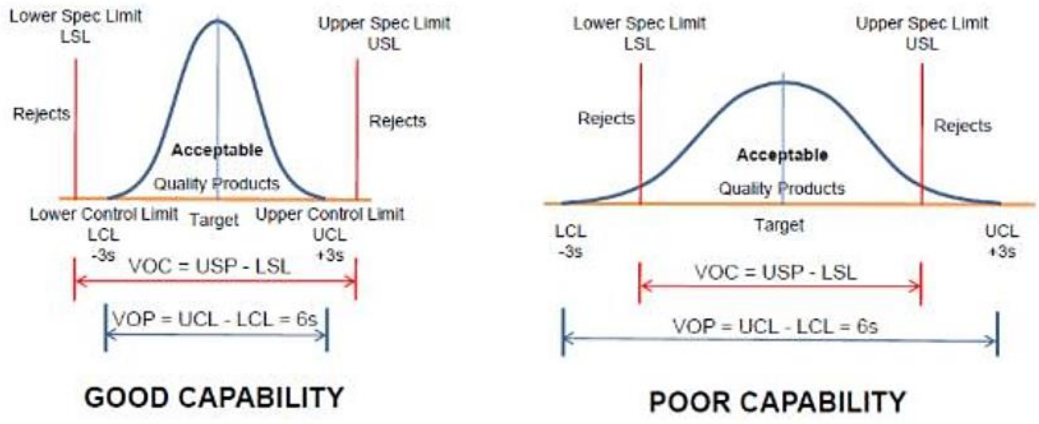

Figure 2.5. Graphical representation quantifying the process capability.

Note. Source: (Chitranshi, 2018). Retrieved 9 June 2019, from www.greycampus.com

This represents the poor capability when the process data has a wider spread, while a smaller distribution of variance indicates a good capacity as shown. Since it is within the specification limits, there is more room to commit the errors, whereas, in the poor capability figure, we can see process variation exceeding the specification limits. In Figure 2.5, we can differentiate between VOC and VOP. VOC is provided by the customer while VOP is the transmitted speech, coming directly from the data and generating the Upper Control Limit and Lower Control Limit. While VOC offers Upper Specification Limit and Lower Specification Limit, it can only be one-sided, but both sides must have control limits. (Chitranshi, 2018).

2.5.3 <u>Measures of Process Capability (Indices)</u>

Process Capability Formula (Cp, Cpk):

- Cp and Cpk are used for the short-term process, or within 6**σ**.

$$C_p = \frac{USL - LSL}{6\sigma} \qquad \text{(equation 2-2)}$$

$$C_{pk} = \min(C_{pu}\,, C_{pl}) \qquad \text{(equation 2-3)}$$

$$C_{pu} = \frac{USL - \mu}{3\sigma} \qquad \text{(equation 2-4)}$$

$$C_{pl} = \frac{\mu - LSL}{3\sigma} \qquad \text{(equation 2-5)}$$

- In the Cpk, k stands for off-target variation as expressed in equation 2-6

$$k = \frac{|\, m - \mu \,|}{(USL - LSL)/2} \qquad \text{(equation 2-6)}$$

$$m = \frac{(USL + LSL)}{2} \qquad \text{(equation 2-7)}$$

- While we talk about σ,

$$\sigma = \frac{\bar{R}}{d_2} \qquad \text{(equation 2-8)}$$

or; $$\sigma = \frac{\bar{S}}{c_4} \qquad \text{(equation 2-9)}$$

$\frac{\bar{R}}{d_2}$ are used for data if we see the average size of the subgroups and if we have a value of less than 10; whereas, $\frac{\bar{S}}{c_4}$ is used for the data points when we have subgroup size ≥ 10, where the d_2 and c_4 are the predefined control charts constants, as per the subgroup size we have taken. We get the constant value for d_2 and c_4 from statistical data (Chitranshi, 2018).

2.5.4 <u>Process Performance Indices Formula (Pp, Ppk)</u>

Process Performance Formula (Pp, Ppk):

$$P_p = \frac{USL-LSL}{6\sigma} \qquad \text{(equation 2-10)}$$

$$P_{pk} = \frac{\min(C_{pu}, C_{pl})}{6\sigma} \qquad \text{(equation 2-11)}$$

$$P_{pu} = \frac{USL-\mu}{3\sigma} \qquad \text{(equation 2-12)}$$

$$P_{pl} = \frac{\mu-LSL}{3\sigma} \qquad \text{(equation 2-13)}$$

$$\sigma = \sqrt{\frac{\sum(X-\bar{X})^2}{n-1}} \qquad \text{(equation 2-14)}$$

- $\bar{X}$ refers to the mean of the process, x refer to individual data point, where n represents the sample size and its degree of freedom reflects as n-1.
- Ppk and Ppk provide a description of the overall process capabilities or long-term process capabilities. This shows the exact strength of the process at the moment (Chitranshi, 2018).

2.5.5 <u>Difference between Cp, Cpk and Pp, Ppk</u>

Both Cp and Cpk offer process capability while Cp talks about data spread and data scope size, the Cpk talks about near-mean data points. Although both provide the process capability, Cpk provides a more reliable process capability. Because it uses the mean data point as opposed to Cp, which contains the data points between the USL and LSL. There are chances that data points lie between the specification limits, but far from the target. Therefore, if the distance between the points and the target is less, the process will be more capable. (Chitranshi, 2018).

Cpk just talks about the variability of common cause or short-term cycle in the subgroups. On the other hand, the Ppk calculates for all common cause and special cause, i.e. long-term processor, so that we can s ay total subgroups of processes. Cpk addresses the process capability potential, while Ppk offers the actual process capability status

(Chitranshi, 2018).

	Short Term Performance	Long Term Performance
Considers Centring	Cpk	Ppk
Does Not Consider Centring	Cp	Pp

Figure 2.6. Difference between Cp, Cpk and Pp, Ppk.
Note. Source: (Chitranshi, 2018). Retrieved 9 June 2019, from www.greycampus.com

The Figure 2.6 provides the detailed information of the process capability. The Cp and Cpk talk only about procedures in the short term. It is only CCV, where the long-term output is addressed by Pp and Ppk. The Cpk and Ppk recommend centering around the middle and showing the data points. Where Pp and Cp represent the distribution of data points between the upper and lower specification limits (Chitranshi, 2018).

2.5.6 Core Process Capability Assumptions

Cp and Pp cannot be found for the Unilateral process when we have only one specification limit, as the formula itself says, both specification limits are required. The Cpk and Ppk can be used to calculate the unilateral process. Cpk or Ppk are better options for process measurement because they find the centering and data points match with their target

(Chitranshi, 2018).

Pp and Cp, on the other hand, distribute the data points and do not find the target, Therefore, although the data points are between the specs limits, we are still unable to provide assurance that they are moving from the target mean (Chitranshi, 2018).

Cpk value can be found if we know the Cp and can calculate the k value by equation 2-15 below.

$$C_p = C_{p(1-k)} \qquad \text{(equation 2-15)}$$

where K can be any value from 0 to 1 (Chitranshi, 2018).

2.6 Literature review

(Krasaephol, 2017) QUALITY CONTROL PROCESS IMPROVEMENT OF FLEXIBLE PRINTED CIRCUIT BOARD BY FMEA

Author applied FMEA method to decrease proportion of defective in Flexible Printed Circuit Board (FPCB) that are found at the final inspection process. The Quality control process has to be improved by setting inspection gates and IPCQs at critical processes in order to filter the defective products. The critical processes are analyzed by the FMEA method. IPQC is used for detecting defective products and reducing chances of defective finished goods escaped to the customers. The result in decreasing of average proportion of defective finish goods and the average of Customer Manufacturers Lot Reject Rate (%LRR of CMs) from 6.08% and 4.78% to 1.01% and 2.10%, respectively.

(Laosrimongkol, 2004) APPLICATION OF MODIFIED FMEA APPROACH FOR IRON FOUNDRY'S PRODUCT DEFECTS REDUCTION

The purpose of this study is to reduce defects in cast iron products and to evaluate the return on quality investment. The defect symptom of interest is blowholes or pinholes defect (B111) which is the highest defect found in production. Author applied benchmarking technique to compare coal dust brand B and not using corn starch any more, brainstorming other related factors to B111 defect and applying cause and effect matrix, why-why analysis, and FMEA, the conclusion that coal dust A and corn starch are main effects to B111 defect on Fly Wheel ZE1 of the case company. Thus, the appropriate control is using coal dust B: bentonite at ratio 1: 4 and stop using cornstarch in sand molding.

(Termsaithong, 2011) DEFECTIVE REDUCTION IN METAL SHEET FORMING PROCESS FOR PICK UP METAL ROOF

Author applied the Six Sigma approach with the aim to reduce 50 % of defective rate due to wrinkling and out of standard defects. In the define phase, the problem, objective and scope were defined. Next, in the measure phase, attribute agreement analysis was evaluated for accuracy, precision and effectiveness of the measurement system. Then, process capability analysis was performed and possible causes of wrinkling and out of standard were brainstormed and analyzed in the cause and effect diagram, cause and effect matrix and failure mode and effects analysis (FMEA). In the analysis phase, the design of experiment was applied to test significant attribute factors affecting the defective. Next, in the improvement phase, factors were improved to yield the smallest proportion of defective. The improvement result was the defective rate of wrinkling and out of standard was decreased from 71.80 % and 77.11 % to 20 % and 11 % respectively. This reduction led to the net saving of 462,135 baht from 12,798 produced pieces or equivalent to 554,662 baht per year.

(Anuraksakul, 2002) ANALYSIS AND DEFECT REDUCTION FOR AUTOMOTIVE BODY PRESS PART BY FMEA TECHNIC

This thesis aim to reduce the defective rate that occur from the DRAW, TRIM/PIERCE and SEPARATE processes in automotive industry. Author applied the FMEA technique to identify, prioritize and limit these failure modes. Prioritization of the potential failures or RPN regards the severity, occurrence, and detection relatively impacted on the process. The improvement result was the defective rate of DRAW process was decreased from 2.02% to 0.22% in Feb 2003, the defective rate of the TRIM/PIERCE was decreased from 2.20% to 0.22% in Feb 2003. And the defective rate of the SEPARATE process was decreased from 2.25% to 0.18% in Feb 2003.

(Tiago Gomes, 2017) REDUCING THE SIMULATION COST ON DUAL-PHASE STEEL STAMPING PROCESS

This work has been developed around two DP (Dual-Phase) steel car parts that need to be obtained through the stamping process. The main objective of this work was to research the time that can be saved using simulation tools and to analyze the accuracy of this simulation specifically with regard to the springback effect typical of shaped steel parts of DP (Dual-Phase). This work was done to predict the shape of the stamping by simulating and reducing stamping deviations. By using simulation software, the problems associated with the springback effect can be predicted and reduced. Facilitate the perception and monitoring of complex component intermediate and final shapes. Consequently, the time and costs of the tool preparation can be drastically reduced after the analysis of the simulations and the performance of the respective tool compensation. Some guidelines have been drawn for improving the simulation process with the aim of adopting the best simulation procedures and saving dual-phase steels iterations and simulation time.

(L. Fernandes, 2017) IMPROVING THE PUNCH AND DIE WEAR BEHAVIOR IN TIN COATED STEEL STAMPING PROCESS

This study began by identifying the main wear mechanism developed in the stamping tool's main surfaces, promoted by the sheet of Tin coated steel used in the packages. Two advanced PVD coatings (B4C and Mo) have been tested, contributing to punch and die improvements in wear actions in these conditions of work. Testing the transfer of Tin content from the sheet of metal to the punch and die, as well as the friction coefficient of this sheet against certain selected coatings, while also attempting to reduce the resistance of Tin to the tool's surface. Tribological tests were performed under medium loads in order to determine what kind of coating offers better wear behavior in the conditions of work referred to. With regard to the results obtained, certain changes will be made to the coating structure to change the parameters of deposition so that industrial testing can be carried out. Worn surfaces were studied by Scanning Electron Microscopy (SEM) and material transfer was analyzed by Energy Dispersive Spectroscopy (EDS). Results obtained with some of the coatings tested indicate that it is possible to reduce the transfer of Tin from the covered steel sheet to the die and punch, ensuring a longer life of these components, decreasing the operations of tool maintenance and increasing the overall Equipment Efficiency (OEE) of this process.

(K.N.M. Tohit, 2007) IMPROVEMENT OF ACCURACY LEVEL USING PROCESS FAILURE MODE AND EFFECT ANALYSIS AND CONTROL PLAN TECHNIQUES FOR AUTOMOTIVE FENDER SHIELD ASSEMBLY

This research addressed the use of system failure mode and impact analysis (FMEA) and vehicle fender shield assembly control plan techniques to increase the level of accuracy. These techniques used as preventive tools to ensure high quality products are produced. To assess the root cause of errors, data analysis is conducted based on the coordinate of parts in X, Y and Z positions. Prototype data (P0 and P1) are used to demonstrate the effectiveness of PFMEA and CP techniques before and after both techniques have been applied to Front Fender Shield Assembly Left Hand in the product development process. Integration between PFMEA and CP has been achieved successfully and the minimum accuracy rate goal (85 percent).

(Sanongpong, 2000) IMPROVEMENT OF DEFECT MODES IN THE PROCESS OF METAL MACHINING FOR AUTOMOTIVE INDUSTRY

The objective of this thesis was to emphasize on the improvement of the cause of defect occurred during the matching process by using industrial engineering techniques as the following: an improvement of working standard; an improvement standard and modification of the machines and equipment; improvement of preventive maintenance system; FMEA and improvement of staff training program. From problem analysis method of a sample industry, it revealed that the defect, which is frequently occurred in the manufacturing process, comprises of unstandardized drilling hole pitch, unstandardized drilling hole diameter, unstandardized boring hole diameter and oblique drilling hole. The improvement result was defect rate was decreased from 9.5% to 1.8%.

2.6.1 Literature Review Summarize

The summary of literature reviews above was described in Table 2.4 below;

Table 2.4

Summary of literature reviews

No	Factor	Source	Conclusions
1	FMEA	(Krasaephol, 2017)	Applied FMEA method to decrease proportion of defective in the PCBA industry.
2	Cause & Effect Matrix / Why-Why / FMEA	(Laosrimongkol, 2004)	Reduce defect in cast iron product by Cause & Effect Matrix, Why-Why and FMEA.
3	Six Sigma / FMEA	(Termsaithong, 2011)	Reduce defect rate in stamping process of panel roof by Six Sigma and FMEA
4	Part Deform / FMEA	(Anuraksakul, 2002)	Reduce defect in stamping process by FMEA
5	Springback effect	(Tiago Gomes, 2017)	Reduce time and cost for simulation stamping process mainly regarding springback effect by using simulation software.
6	Die improvement	(L. Fernandes, 2017)	Study the main wear mechanism developed in the main surfaces of the stamping die. To minimize the tin transfer from cover sheet to punch and die. Decreasing the die maintenance operations.
7	PFMEA / CP Techniques	(K.N.M. Tohit, 2007)	Using PFMEA and Control Plan techniques as preventive tools to capture the failure from assembly process.
8	FMEA / Preventive Maintenance	(Sanongpong, 2000)	Reduce defect in metal machining process by FMEA and Preventive Maintenance System.

From the above-summarized literature reviews, it has been found that limited research has been carried out using the FMEA method to define and solve the issue of huge stamping parts by considering the overall process. Even with the work of

(Anuraksakul, 2002), it considered only reducing the defects step-by-step. This problem has never been done by FMEA tool before. This research is, therefore, considered as a pioneer in this area.

CHAPTER 3

RESEARCH METHODOLOGY AND CAUSE ANALYSIS

According the problem that presented in the chapter I. Refer GCA reports (Global Customer Audit reports) of company X found that the part defect A-Pillar is the first priority to studies and improvement due to it is only one item (from top 20 cases of the problem) that assembled in-house with other components and become body in white of 1-ton pickup truck.

The contents of this chapter will show details of the process of research studies of the problems that presented in the chapter I. This research focuses on solving the problem of stamping parts: A-Pillar that are missing alignment from the drawing/design and recommend the new process to reduce number of the defect.

This chapter shows the research study and production process of A-Pillar parts, theories related to this research that described in chapter II. This study applies it to this research studies to be able to successfully solve problems according to the research objectives.

3.1 Research methods

3.1.1 Study the theory of related research articles.

3.1.2 Collect data of current process of A-Pillar and current problems.

3.1.3 Analyze the causes by using Cause and Effect Diagram.

3.1.4 Conduct the assessment the level of violence (Severity-S), the risk of opportunity for defects (Occurrence-O) and ability to detect defects (Detection-D).

3.1.5 Evaluate the root cause of the defects by using technique FMEA

3.1.6 Conduct experiment study by considering potential factor.

3.1.7 Execute methods.

3.1.8 Analyze the results after improvement.

3.1.9 Summarize the research and recommendations.

3.2 Research framework

This research has set the framework for solving the issue by 3 methods. The investment cost is first priority to be considered. After that, the lead-time is second priority that to be considered. The methods are presented as Table 3.1.

Table 3.1

Research framework

Method	Pros.	Cons.	Investment Cost (Baht)	Lead Time (Months)
1. Stamping Die parameter adjustment	- No investment - Short lead time	- Might not solve the problem	-	-
2. Stamping Die modification	- Low investment	- Take time to modify - Need to make buffer stock	300,000	2
3. Additional Die process	- No need to make buffer stock - Can be solve the problem 100%	- High investment - Take time to make a new stamping die	700,000	4

3.3 A Study of the process

The method of making part A-Pillar in Company Y manufacturing until parts ready for shipment is shown as Figure 3.1, and each phase is defined as shown in Table 3.2.

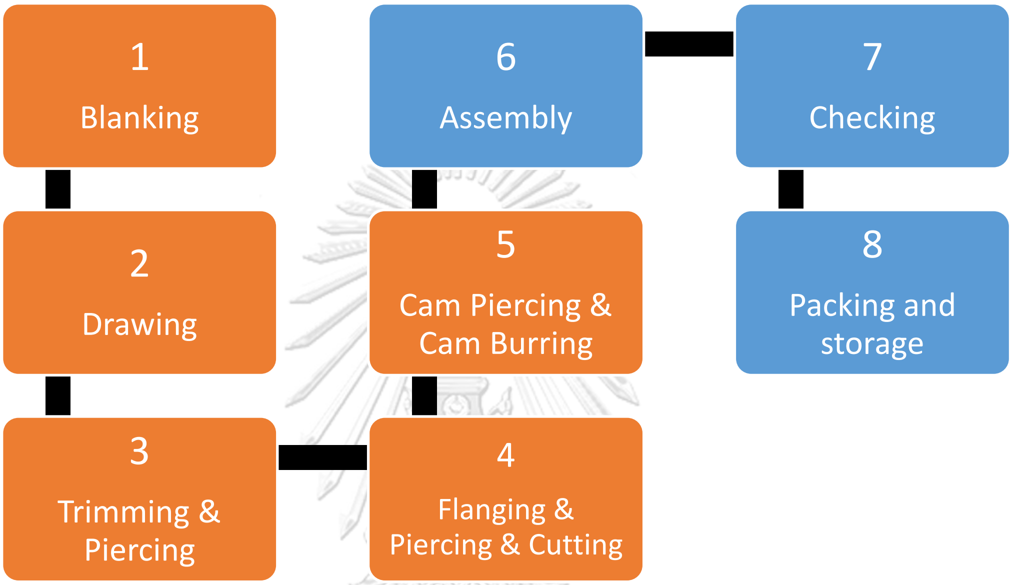

Figure 3.1. A-Pillar parts process flow chart of company Y.

Table 3.2

A-Pillar parts process descriptions of company Y

Process	Process Name	Descriptions
1	Blanking	This is first step in the the stamping process. It process will cutting a larger steel sheets to be shape of A-Pillar sheet.
2	Drawing	It is the process that pressing the upper die down to the lower die in the middle of A-Pillar sheet in order for the sheet to be forming.
3	Trimming & Piercing	It is the process that pressing the upper die down to the lower die in order to cutting the unwanted area of parts along with drilling holes or make a slot on the piece.
4	Flanging & Piercing & Cutting	It is the process that pressing the upper die down to lower die in order to folding the edge of piece along with make a slot and cut the unwanted parts in the one press.
5	Cam Piercing & Cam Burring	It is the process that press the upper die down to lower die in order to making a slot and making a burring on the side of piece. It is required cam driver to press from side instead.
6	Assembly	This step will be performed the main stamped part with other components by welding or spot welding.
7	Checking	This step will be checked dimension, shape of performed parts by using jig fixture to measurement.
8	Packing and storage	This step will be packed the finish goods into the approved packaging and ready to deliver.

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3.3 A Study of the part

The A-Pillar parts are huge, long length size and contact with several components of the vehicle body. To focus on the missing alignment issue, we will separate the parts into three zones; upper, middle and lower zone as shown in Figure 3.2. The zone that caused this issue is the middle zone.

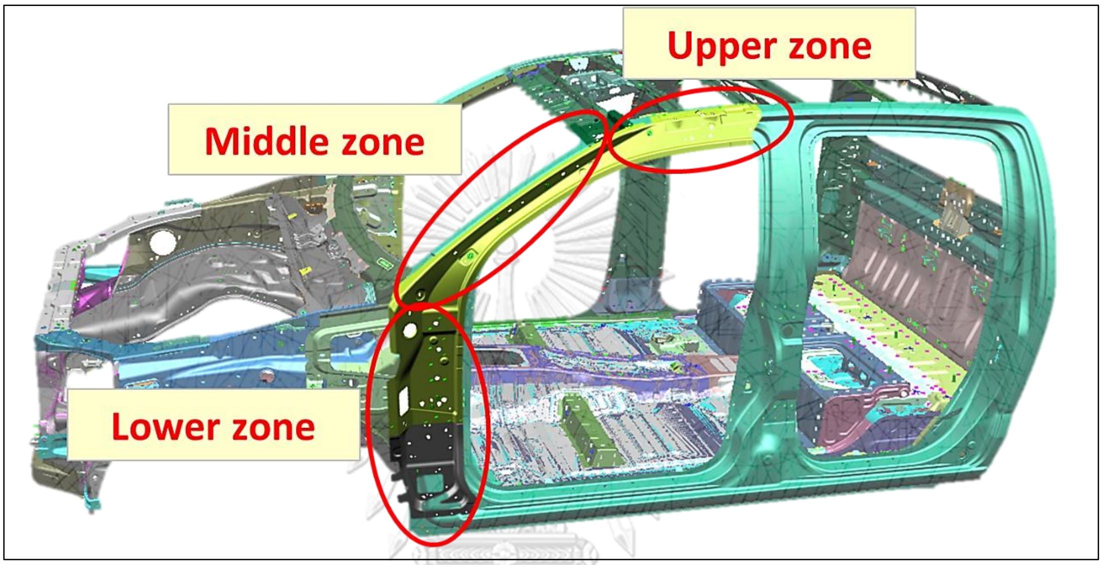

Figure 3.2. Location of A-Pillar parts on vehicle and zone of parts.

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When considering the current point control, the middle zone (top size) is missing identified and the product design of Company X found that, the point control for checking and inspection referred Geometric Dimensioning Tolerance (GD&T) does not cover the middle zone (top size). That why supplier do not check and aware the point of middle zone (top size). Figure 3.3 is the GD&T of A-Pillar that released by Company X, provided to Company Y for control the dimension of parts.

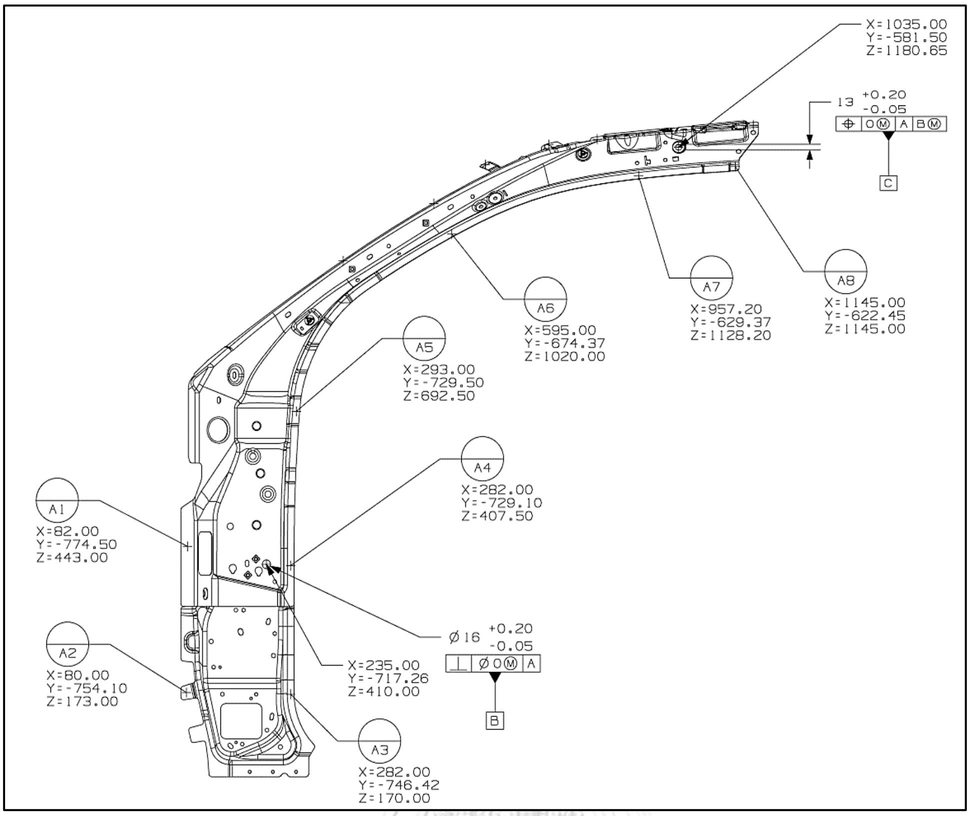

Figure 3.3. GD&T of A-Pillar parts original version.

3.4 Process Capability Analysis

The researcher randomly collected 30 parts of part number 52105468; A-Pillar on 15 January 2019. In the analysis using the Automotive Industrial Action Group (AIAG) standards by collected 30 sample sizes.

In data collection, the values are measured at position A1 – A8 follow GD&T as shown in Figure 3.3 above. For measurement, Company Y uses Coordinate Measuring Machine (CMM). The measurement quality tolerance is + /-1 millimeter (mm) when compared with the design of the drawing dimension. Consequently, the lower spec limit is -1 mm (LSL = -1 mm) and the upper spec limit is 1 mm (USL = 1 mm). As shown in Table 3.3, the measurement values of 30 sample parts (position A1 – A8) is in the range of + /-1 mm tolerance.

Table 3.3

Measurement values of 30 sample parts (current conditions)

Sample	Location (mm)							
	A1	A2	A3	A4	A5	A6	A7	A8
1	0.474	0.183	-0.087	-0.075	-0.219	0.880	0.260	-0.381
2	-0.961	0.706	-0.899	0.357	0.523	0.705	-0.955	-0.714
3	0.240	-0.705	0.924	-0.405	-0.368	-0.243	0.210	-0.217
4	0.646	-0.790	-0.408	-0.196	-0.080	-0.228	-0.431	0.159
5	-0.200	0.565	-0.455	0.159	0.382	0.195	-0.698	-0.834
6	-0.401	-0.403	-0.133	-0.629	0.140	-0.682	-0.584	0.182
7	0.448	-0.322	-0.372	0.737	-0.755	0.716	0.603	-0.254
8	0.080	-0.693	-0.200	0.430	-0.159	0.416	0.064	-0.373
9	-0.665	-0.986	0.681	-0.725	0.032	-0.109	-0.311	-0.718
10	-0.738	0.623	0.587	0.136	0.944	0.421	-0.371	0.630
11	-0.291	0.567	-0.585	0.404	-0.065	-0.111	0.290	-0.337
12	-0.809	-0.958	-0.938	-0.068	-0.727	0.779	0.386	0.471
13	0.916	-0.292	0.710	0.108	-0.633	-0.260	-0.888	0.284
14	-0.990	0.202	0.016	-0.486	0.178	-0.863	-0.147	-0.166
15	0.877	0.828	-0.779	0.160	-0.292	0.112	0.641	0.602
16	0.283	0.458	-0.040	-0.040	0.836	0.060	0.793	-0.144
17	-0.447	0.186	0.121	-0.740	-0.471	0.386	0.388	0.339
18	-0.086	-0.504	-0.368	-0.838	-0.843	-0.802	-0.546	-0.745
19	-0.066	-0.444	0.480	0.831	0.531	-0.109	0.195	0.434
20	0.770	0.430	0.444	-0.229	0.083	0.807	-0.889	-0.258
21	-0.253	-0.771	0.275	0.436	0.801	-0.504	-0.541	0.147

Measurement values of 30 sample parts (current conditions) (Continued)

Sample	Location (mm)							
	A1	A2	A3	A4	A5	A6	A7	A8
22	0.344	-0.504	0.768	-0.074	0.917	0.248	-0.444	-0.171
23	0.332	-0.032	-0.632	-0.794	0.626	-0.199	-0.097	-0.834
24	-0.089	0.062	0.618	0.047	0.999	0.265	-0.830	-0.500
25	0.330	0.438	-0.373	-0.452	-0.115	-0.008	-0.726	-0.995
26	0.216	0.955	-0.997	-0.896	-0.383	-0.432	-0.762	-0.847
27	0.088	0.268	-0.766	-0.613	0.820	-0.221	0.051	0.512
28	0.643	-0.299	0.854	-0.487	-0.703	-0.533	0.054	0.714
29	0.388	0.897	-0.364	-0.284	-0.221	0.200	-0.106	0.584
30	0.628	0.816	0.531	-0.489	0.790	0.594	-0.561	-0.381

However, the position for checking and controlling on the A-Pillar parts that have problems is not identified in the GD&T. Therefore, as shown in Figure 3.4, the team has set up additional 4 measurement points A9 – A12. The result after the measurement found that the positions A10 and A11 were out of specification tolerance. The measurement results are shown in Table 3.4.

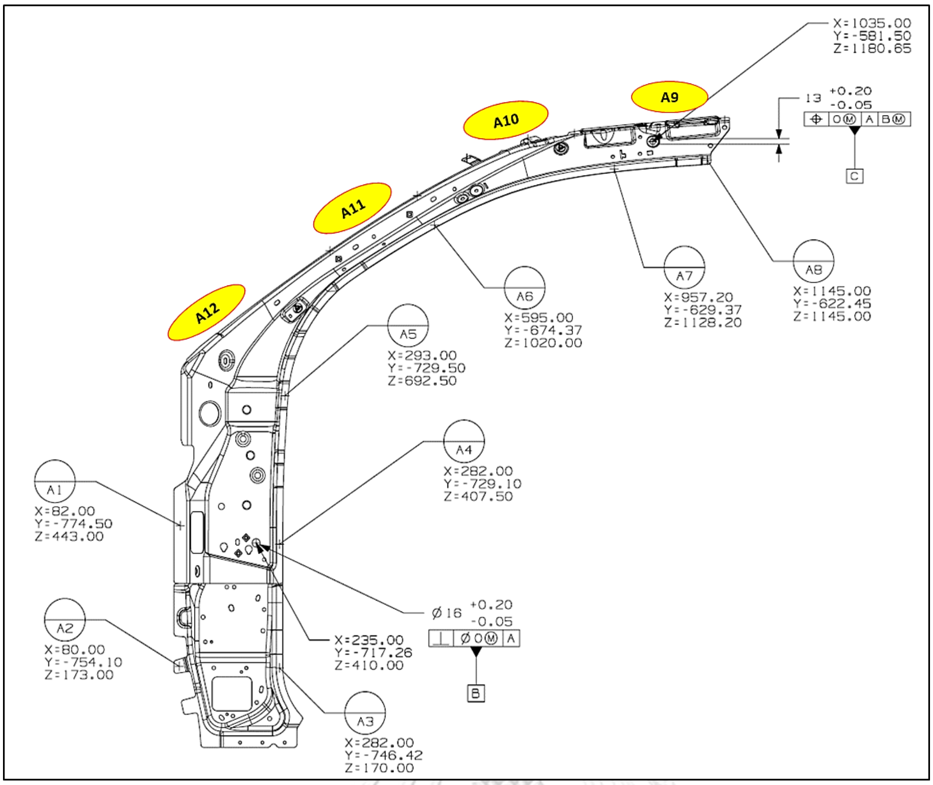

Figure 3.4. GD&T of A-Pillar parts (with additional point).

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Table 3.4

Measurement values of 30 sample parts (of additional points)

Sample	Location (mm)			
	A9	A10	A11	A12
1	-0.246	-1.277	-2.022	-0.645
2	0.019	-0.704	0.523	0.329
3	-0.311	1.126	3.171	-0.169
4	-0.443	2.282	0.226	0.965
5	-0.264	-0.827	2.427	-0.679
6	0.763	2.407	-1.062	0.452
7	-0.921	0.678	1.227	0.295

Measurement values of 30 sample parts (of additional points) (Continued)

Sample	Location (mm)			
	A9	A10	A11	A12
8	0.087	-0.593	-1.470	-0.294
9	-0.856	0.668	1.444	0.233
10	-0.276	2.277	1.859	0.444
11	0.644	2.699	0.534	0.501
12	-0.411	1.981	1.839	-0.698
13	0.009	0.095	3.124	0.420
14	0.448	1.506	-1.619	0.543
15	0.521	0.767	2.707	0.792
16	-0.197	0.387	3.062	0.875
17	-0.360	1.081	3.879	-0.476
18	-0.709	-0.713	-2.848	-0.849
19	0.491	1.845	1.977	0.558
20	-0.154	0.116	3.199	-0.291
21	-0.550	1.320	-2.003	0.300
22	-0.952	0.888	0.615	0.756
23	-0.537	1.649	-1.123	-0.673
24	-0.045	-0.559	-2.098	0.887
25	0.628	1.128	-0.390	-0.052
26	0.492	0.155	3.739	-0.569
27	0.695	2.447	3.975	0.032
28	-0.868	0.988	1.110	-0.212
29	0.791	0.791	-1.220	-0.629
30	-0.616	1.125	-2.251	0.269

The researcher analyzed the process capability analysis of the stamping process: A-Pillar parts by using the measured values of A10 and A11 positions to running and analyze by the Minitab program with confidence level 95 percent (α = 0.05) It was reported that the measurement values for the 30 parts of the sample were hypothesized as normal distribution and are controlled. Figures 3.5 and 3.6 show the results of Minitab's Process Capability Report for A10 and A11 positions.

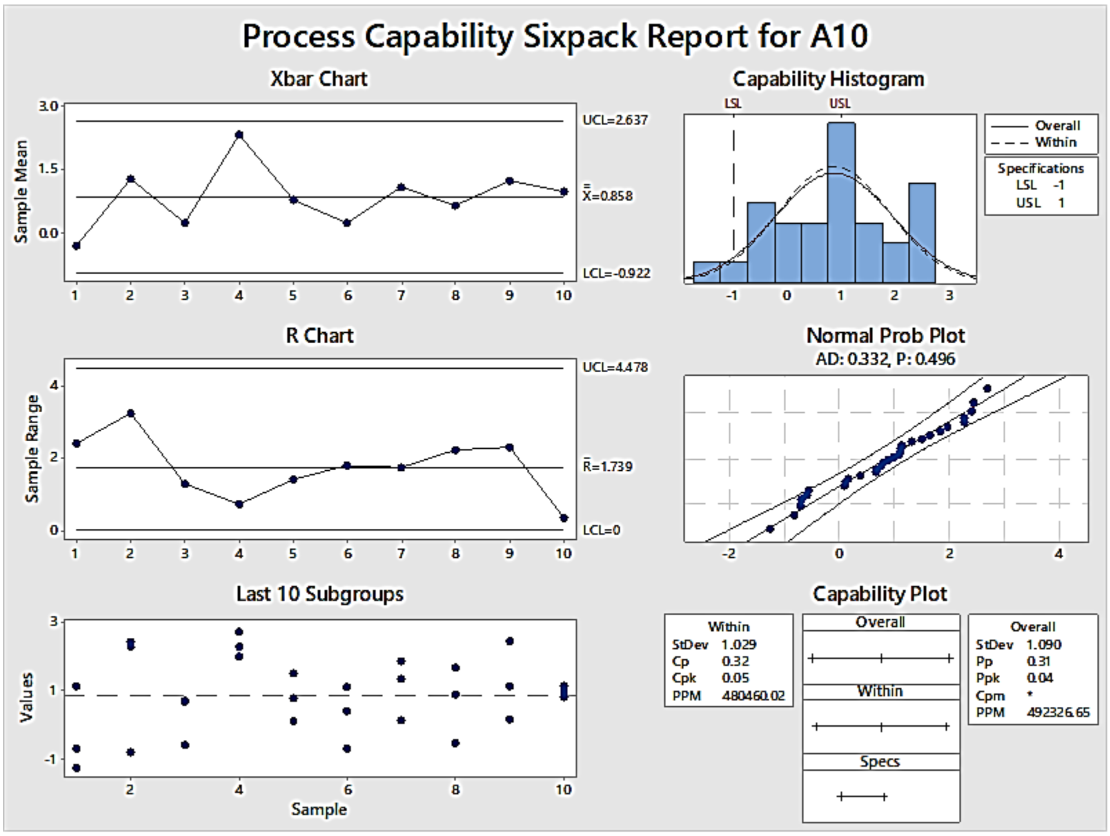

Figure 3.5. Process Capability Sixpack Report for A10 position.

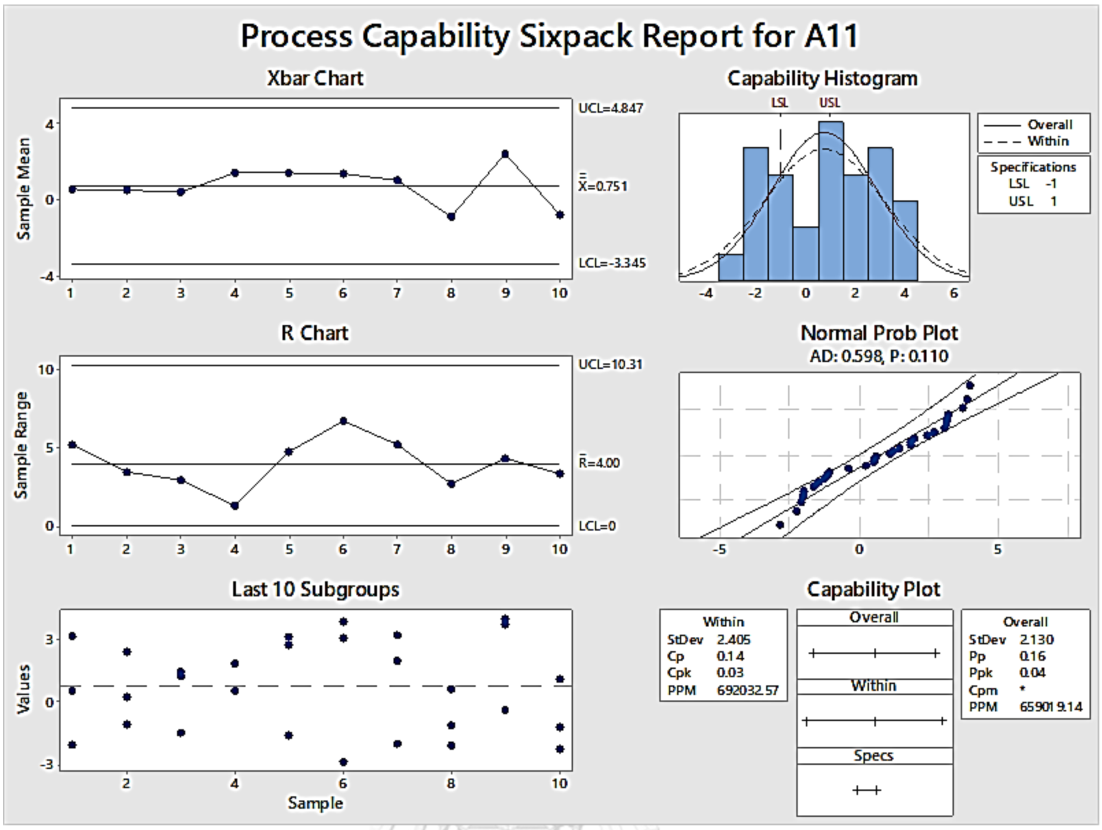

Figure 3.6. Process Capability Sixpack Report for A11 position.

Refer detail from Figures 3.5 and 3.6 above; found that Xbar-Chart and R-Chart has the value within control area. Therefore, it can be concluded that these 30-sample data has properties within controlled. The *P*-Value is greater than 0.05 both A10 and A11 positions, indicating that this data is a normal distribution at the significance level 0.05.

For the process's Cpk value measuring position A10 and A11 is 0.05 and 0.03, respectively. The acceptable standard value of Cpk is usually 1.33 or higher but the actual measurement values of Cp and Cpk are lower than the standard. The value of Cp and Cpk also has very different values, indicating that the process's average value deviates from the target value and that the process variance is higher than the acceptable level. Therefore, should improve by finding ways to improve the average value to approach the target value and finding ways to reduce the variation level of the process.

Therefore, the ability of this stamping process; A-Pillar of Company Y is still lower than the acceptable standard. The researchers have to improve the ability of this stamping process; A-Pillar of Company Y by finding a way to adjust the average value to the appropriate value and within acceptable tolerance.

3.5 Team setting up

To study and analyze the cause of problem, there has been a working group consisting of a team of experts, supervisors, engineers and production manager from the company Y. The responsibility of each department was described as below.

<u>Company X</u>

3.5.1 **Product Design**, responsible for designing the shape of car, shape of each component to be appropriated and meet the customer requirements.

3.5.2 **Purchasing**, responsible for sourcing the qualified suppliers to produce a part.

3.5.3 **Supplier Quality Engineer**, responsible for establishing inspection standards of parts and provide to supplier quality assurance department.

<u>Company Y</u>

3.5.4 **Production**, responsible for install stamping dies, set up machine parameter, produce the parts, inspection check in-process and moving the goods to warehouse area.

3.5.5 **Quality Control**, responsible for establishing inspection standards of part for the production department. As well as undertaking the final product inspection, analyzing the problems that occur in the process.

3.5.6 **Die Maintenance**, responsible for maintain, repair and rework the stamping die to be in a condition that is ready to use.

3.5.7 **Engineer**, responsible for trial new product, design process, prepare work instructions for production departments. As well as set up standard of machine and stamping die parameter.

3.5.8 **Quality Assurance**, responsible for communicating engineering information and assurance quality of product with customers. Collecting statistics data of product.

3.5.9 **Warehouse and Packaging**, responsible for design packaging to meet customer requirements and protect the product during transportation. As well as responsible for moving, packing and delivering product to customers.

Supplier Quality Engineer of company X will be leader to setup meeting and discussing the problem. Brainstorming to find out the root cause by using Cause and Effect Diagram. After that prioritizing, each root cause by given the score which using RPN (Risk Priority Number) rating assessment techniques.

3.6 Analyze the causes

The team brainstorms the potential factors that affecting to the missing alignment of A-Pillar parts. A lot of ideas come from stakeholders who have metal stamping parts experience. Short noted the idea in the small paper and categorized it by categories 4Ms and 1E (Man, Machine, Method, Material and Environment) as shown in Figure 3.7.

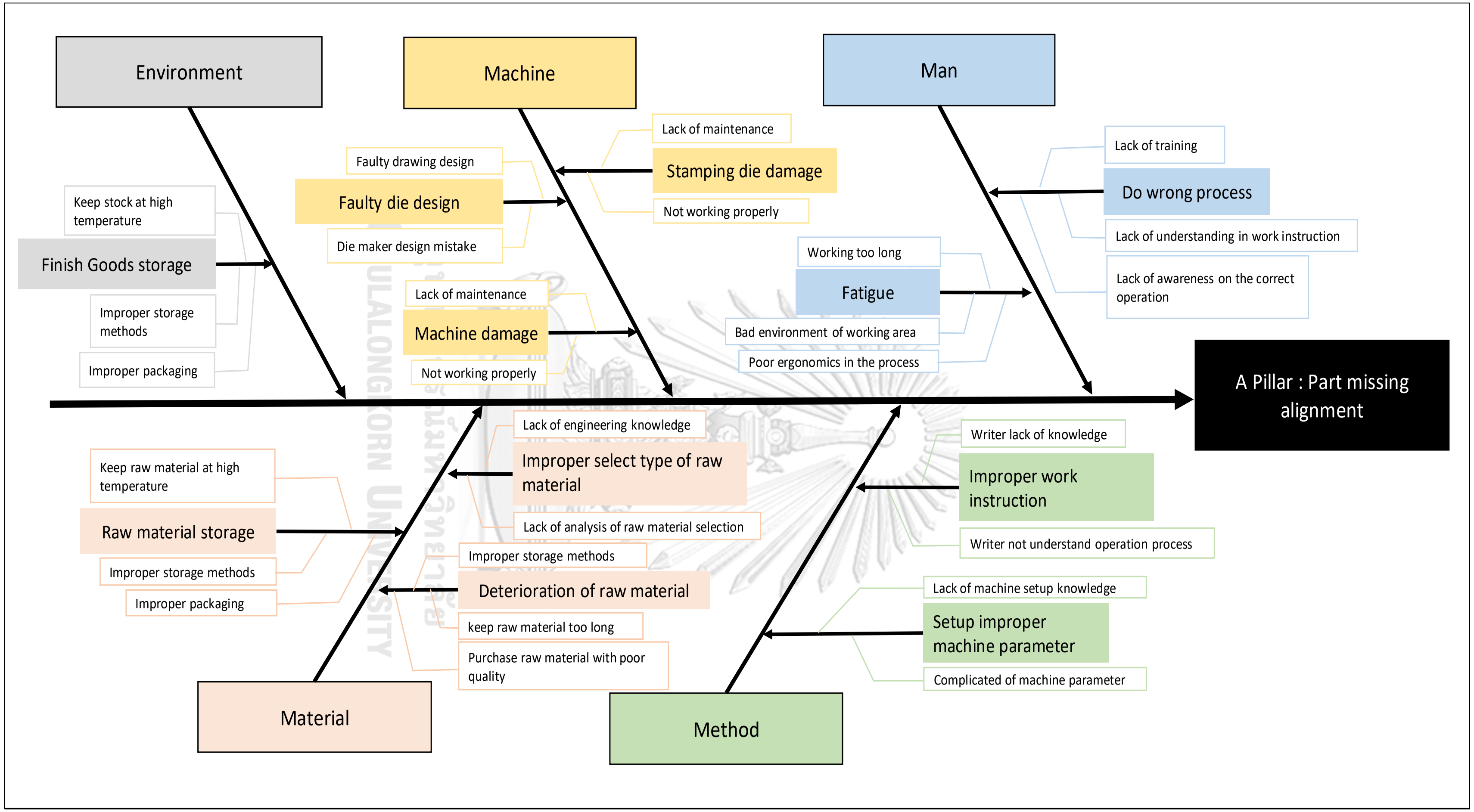

Figure 3.7. Cause and Effect Diagram of A-Pillar parts: Missing alignment problem.

After the team has completed the Cause and Effect Diagram of A-Pillar: Part missing alignment problem, summarize the possible causes of defect as shown below.

3.6.1 Man

- Worker do wrong process
- Fatigue

3.6.2 Machine

- Machine damage
- Faulty die design
- Stamping die damage

3.6.3 Method

- Improper work instruction
- Setup improper machine parameter

3.6.4 Material

- Improper select type of raw material
- Deterioration of raw material
- Raw material storage

3.6.5 Environment

- Finish Goods storage

Once team considers the possible factors contributing to missed alignment defects in A-Pillar, We may abstain from evaluating such processes because there is no effect of this issue. Furthermore, lead time and cost will be saved for the experiment.

The process Flanging & Piercing & Cutting, Assembly and Packing & Storage (as shown in Table 3.5) is the process that leads to parts missing alignment problems.

Table 3.5

Production process impact of A-Pillar: Parts missing alignment defect

No	Process Function	Impact
1	Raw material incoming	No
2	Blanking	No
3	Drawing	No
4	Trimming & Piercing	No
5	**Flanging & Piercing & Cutting**	**Impact**
6	Cam Piercing & Cam Burring	No
7	**Assembly**	**Impact**
8	Checking	No
9	**Packing & storage**	**Impact**

The next step is to map the causes with the effect of the process function with the Cause and Effect Diagram. Then, by giving score 1 – 10 for (S) Severity, (O) Occurrence and (D) Detection, the FMEA process is done by prioritizing the potential failures factor. The total score result (S x O x D) is called "RPN rating scale". Further solution and improvement will be considered for the significant high RPN. The potential failure mode and effects analysis (RPN score) are shown as Figures 3.8 and 3.9.

POTENTIAL
FAILURE MODE AND EFFECTS ANALYSIS

Part: 52105467 Rev. 0 FMEA Number: GM-BODY-001

Desc: REINFORCEENT ASM-BODY SI INR PNL (A-Pillar) Process Responsibility: Process Engineer Prepared by: SQE

Model Year(s)/Vehicle(s) Pickup Truck MY17 Key Date 28-Nov-18 Date (Or 28-Nov-18

Team: **Customer:** PE, Buyer, SQE. **Supplier:** PD, QC, Die Eng, Eng.,QA, WH. Date (Rev.)

Process Function/ Require-ments	No	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detec	R. P. N.	Recommen Actions	Responsib & Target Date	Action Results: Actions Taken	Sev	Occ	Det	R. P. N.
1. Flanging & Piercing & Cutting	1	Parts deform	Need to sorting and rework before delivery to next process	7	C	Place the parts not match with groove of die	3	Use fixture groove of die and 100% visual check	6	126							
						Place the parts not touch with stopper	3	Use fixture groove of die and 100% visual check	6	126							
	2	Parts cracks or broken	Parts cannot be used	8	C	Setting high value of press speed	3	Visual check the machine parameter setting	8	192							
						Raw material not meet specifications	3	100% visual check	8	192							
	3	Parts has wave, not smooth	Need to sorting and rework before delivery to next process	7	C	Setting low value of pres speed	5	Visual check the machine parameter setting	8	280							
						Setting die height not appropriate	5	Visual check the machine parameter setting	8	280							
						Place the parts not touch with stopper	3	Use fixture groove of die and 100% visual check	6	126							
						Uneven air pressure	3	Visual check the machine parameter setting	8	168							
	4	parts has distort or curve out	Need to sorting and rework before delivery to next process	7	C	The worker incorrectly remove parts from the die	5	100% visual check	8	280							
						Dirty die	5	100% visual check	8	280							
	5	Parts has overlap with scrap	Parts cannot be used	8	C	Have residual scrap in the die	5	100% visual check	8	320							
	6	Parts has burr	Need to sorting and rework before delivery to next process	7	C	Die is worn out	5	100% visual check	8	280							
						Low Pressure	3	Visual check the pressure gauge parameter	7	147							

Figure 3.8. Potential FMEA score of missing alignment defect.

POTENTIAL

FAILURE MODE AND EFFECTS ANALYSIS

Part: 52105467 Rev. 0 FMEA Number: GM-BODY-001

Desc: REINFORCEENT ASM-BODY SI INR PNL (A-Pillar) Process Responsibility: Process Engineer Prepared by: SQE

Model Year(s)/Vehicle(s) Pickup Truck MY17 Key Date 28-Nov-18 Date (Or 28-Nov-18

Team: **Customer:** PE, Buyer, SQE. **Supplier:** PD, QC, Die Eng, Eng.,QA, WH. Date (Rev.)

Process Function/ Require-ments	No	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls	Detec	R. P. N.	Recommen Actions	Responsib & Target Date	Action Results: Actions Taken	Sev	Occ	Det	R. P. N.
1. Flanging & Piercing & Cutting	7	Parts has surface pull	Need to sorting and rework before delivery to next process	7	C	Place the parts not touch with stopper	3	Use fixture groove of die and 100% visual check	6	126							
						Die is worn out	5	100% visual check	8	280							
	8	Parts has hole missing	Need to sorting and rework before delivery to next process	7	C	Die is worn out	5	100% visual check	8	280							
	9	Parts has cutting edge	Parts cannot be used	8	C	Setting high value of press speed	3	Visual check the machine parameter setting	8	192							
						Die is worn out	5	100% visual check	8	320							
2. Assembly	10	misalignment assembled	Need to sorting and rework before delivery to next process	7	C	Parts has a twist	5	Check by assembly fixture	8	280							
						The worker incorrectly assembly the parts	4	Follow Work Instructions	7	196							
	11	Spot welding loose	Need to sorting and rework before delivery to next process	7	C	Spot machine has electric down	3	Visual check the spot machine parameter before work	7	147							
						Parts has a dirty	5	100% visual check	8	280							
3. Packing and storage	12	Parts deform	Customer reject	8	C	Parts touch with packaging	5	Follow Work Instructions	7	280							
	13	Parts has rust	Customer reject	8	C	The warehouse has moisture in the air	5	100% visual check	8	320							

Figure 3.9. Potential FMEA score of missing alignment defect (Continued).

Based on the above RPN score, will considering the potential effect of failure that have significant high RPN score to be improved. Stakeholders agreed to choose the subject that has RPN score higher than 200 points to consider and improve first. However, some of subject (RPN score higher than 200 points) was not related to the missing parts of alignment. The selection of the effect to be improved will be defined as Table 3.6 below.

Table 3.6

Effect selection by FMEA with high RPN score (> 200 points)

No	Process	Failure	Potential Cause of Failure	RPN Score	Conclusion for next step
1	Flanging & Piercing & Cutting	Parts has wave, not smooth	- Setting low value of press speed	280	***Conduct experimental study**
2			- Setting die high not appropriate	280	***Conduct experimental study**
3		Parts has distort or curve out	- Worker incorrectly remove parts from die	280	Training to worker
4			- Dirty die	280	Adding cleaning die process
5		Parts has overlap with scrap	- Have residual scrap in the die	320	Not concerned issue
6		Parts has burr	- Die is worn out	280	Die maintenance, refurbish
7		Parts has surface pull	- Die is worn out	280	Not concerned issue
8		Parts has hole missing	- Die is worn out	280	Not concerned issue
9		Parts has cutting edge	- Die is worn out	320	Not concerned issue

Effect selection by FMEA with high RPN score (> 200 points) (Continued)

No	Process	Failure	Potential Cause of Failure	RPN Score	Conclusion for next step
10	Assembly	Misalignment assembled	- Parts has a twist	280	Add check point in assembly fixture
11		Spot Welding loose	- Parts has a dirty	280	Not concerned issue
12	Packing & Storage	Parts deform	- Parts touch with packaging	280	Improve packaging design
13		Parts has rust	- The warehouse has moisture in the air	320	Not concerned issue

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To simulate the solution of the preliminary problem (parts missing alignment defect). We must perform experimental studies in the first place, taking into account potential factors 1 and 2 from Table 3.6; While other factors not being evaluated because of this are not directly related to the issue. In the initial trial, certain factors can not be conducted.

When selecting factors that affect with average and standard deviation of the measurement value tolerance of position A10 and A11, the researcher will identify the impact of factors on various indicators and guidelines for improvement (as shown in Table 3.7).

Table 3.7

The impact of factors and improvement guidelines

No	Factor	Impact of factor	Improvement guidelines
1	Press speed	Press speed will affect the shape of the stamping parts. If press speed is high, the parts after stamping will have uneven flow of steel, which may cause the parts to be wavy. At the same time, if press speed is low, the flow of steel will be more stable but it takes longer cycle time.	Perform experiments at different press speed values to determine the hypothesis that the press speed affects to response variable significantly or not. If there is a significant effect, it will have an appropriate configuration of press speed.
2	Die height	The die height (or die shut height) is the distance between upper die and lower die when stamping. If setting too high value, the parts will have incomplete shape/dimension. At the same time, if setting too low value, the parts will easy to broken and make die damage.	Perform experiments at different die heights to determine the hypothesis that die height affects to response variable significantly or not. If there is a significant effect, it will have an appropriate configuration of die height.

In the next step, the researcher will design the experiment by considering the two factors that mentioned above. In order to find the best value and the most suitable value for solving the problems of A-Pillar parts currently.

CHAPTER 4
DESIGN OF EXPERIMENT

The purpose of this research is to design an experiment to find the optimal value of factors that cause the parts tolerance value to be close the zero. When the parts tolerance value close the zero value, the A-Pillar part can be assembled with other parts without gap issues.

4.1 Experimental model

The study is selected the Central Composite Design (CCD) for design of experiment due to the Central Composite Design (CCD) is used for finding the appropriate value. More than two levels need to be tested for each factor and totally have 13 trials. This research has two input factors and cannot be used Box-Behnken experiments because of this is an experimental model with three or more input factors. The composition of the Central Composite Design (CCD) is divided into 3 parts as follows.

- Factorial Runs have 2^k trials; where k is the number of factors. The experiment number is $2^2 = 4$ experiments.
- Axial Runs or Star Runs have a number of experiments equal to 2*k trials. With levels that are +/- α units from the experiment at the center at level 0. The experiment number is 2*2 = 4 experiments.
- Center Runs will have a number of experiments depending on the k value (number of factors). The experiment number is 5 experiments.

From the above calculations, the The total number of experiments is equal to 13 experiments, Which equals the number of experiments that shown in Figure 4.1.

Design		Continuous Factors								
		2	3	4	5	6	7	8	9	10
Central composite full	unblocked	13	20	31	52	90	152			
	blocked	14	20	30	54	90	160			
Central composite half	unblocked				32	53	88	154		
	blocked				33	54	90	160		
Central composite quarter	unblocked							90	156	
	blocked							90	160	
Central composite eighth	unblocked									158
	blocked									160
Box-Behnken	unblocked		15	27	46	54	62		130	170
	blocked			27	46	54	62		130	170

Figure 4.1. Number of experiments of Response Surface Designs.

4.2 Input factor

According to the result of Failure Mode and Effect Analysis, there are two factors; press speed and die height to be tested. These factors will be analyzed by Design of Experiment (DOE) to determine the part tolerance value. The level value of factor will be shown in Table 4.1.

Table 4.1

Value level of factor for Design of Experiment

Code	Control Factor	Unit	Data type	Levels of factor		
				(-1)	(0)	(+1)
A	Press speed	SPM	Variable data	10	20	30
B	Die height	mm	Variable data	647	648	649

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In selecting the experiment level of each factor with the following details as;

4.2.1 Press speed

Currently Company Y have control the press speed value of machine at 20 ±5 SPM. This number came from trial process since beginning of the vehicle model launch. Therefore, this research would like to study press speed value including another level as 10 SPM and 30 SPM.

4.2.2 Die height

Currently Company Y have control the die height value of machine at 648 ±0.5 mm. This number came from trial process since beginning of the vehicle model launch. Therefore, this research would like to study die height value including another level as 647 mm and 649 mm.

4.3 Response Variable

The response variable of this research is the parts tolerance value of position A10, A11 that measure by Coordinate Measuring Machine (CMM). The measurement results are shown in Table 4.2.

Table 4.2

Measurement values of positions A10 and A11 from 13 experiments

Run	Factor Run		Value Setting		Location (mm)	
	A	B	Press Speed (SPM)	Die Height (mm)	A10	A11
1	0	0	20	648	-0.338	-1.005
2	1	1	30	649	-1.792	-1.814
3	0	1	20	649	1.643	1.633
4	1	-1	30	647	2.145	1.755
5	0	0	20	648	0.348	-0.437
6	0	0	20	648	-1.049	-0.457
7	-1	1	10	649	1.110	1.345
8	1	0	30	648	2.521	1.627
9	-1	0	10	648	-1.321	-0.989
10	0	0	20	648	0.536	-1.021
11	0	-1	20	647	-1.473	-1.497
12	-1	-1	10	647	-1.841	-1.668
13	0	0	20	648	0.255	0.328

After trials with 13 experiments found that the position A10 and A11 are out of specification tolerance from different factor setting. Then researcher bring this actual data to analyze by ANOVA.

The results of positions A10 and A11 are shown in Table 4.3 and 4.4 respectively. The results was analyzed by Minitab (Version 17). The ANOVA result shows that two major effects of the influenced factors are not significant (*p*-value greater than 0.05), but there is a significant to interaction between both factors.

Table 4.3

The ANOVA test result for position A10

Source	DF	Adj SS	Adj MS	F-Value
Model	3	16.6615	5.5538	**4.81***
Linear	2	4.8004	2.4002	2.08
Press speed	1	4.0442	4.0442	3.50
Die height	1	0.7562	0.7562	0.66
Interaction	1	11.8611	11.8611	**10.28***
Error	9	10.3873	1.1541	
Lack-of-Fit	5	8.7115	1.7423	4.16
Pure Error	4	1.6758	0.4189	
Total	12	27.0488		

Note. * Significant at level $p < 0.05$; ** Significant at level $p < 0.01$.

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Table 4.4

The ANOVA test result for position A11

Source	DF	Adj SS	Adj MS	F-Value
Model	3	13.317	4.4391	**4.78***
Linear	2	2.487	1.2433	1.34
Press speed	1	1.382	1.3824	1.49
Die height	1	1.104	1.1042	1.19
Interaction	1	10.831	10.8307	**11.65****
Error	9	8.365	0.9295	
Lack-of-Fit	5	7.149	1.4298	4.70
Pure Error	4	1.216	0.3040	
Total	12	21.682		

Note. * Significant at level $p < 0.05$; ** Significant at level $p < 0.01$.

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Interestingly, the results are the same between A10 and A11 positions. The result of interaction plotted between factor A (press speed) and factor B (die height) for positions A10 and A11 is shown in Figures 4.2 and 4.3, respectively. There are 2 factors that affect positions A10 and A11 significantly.

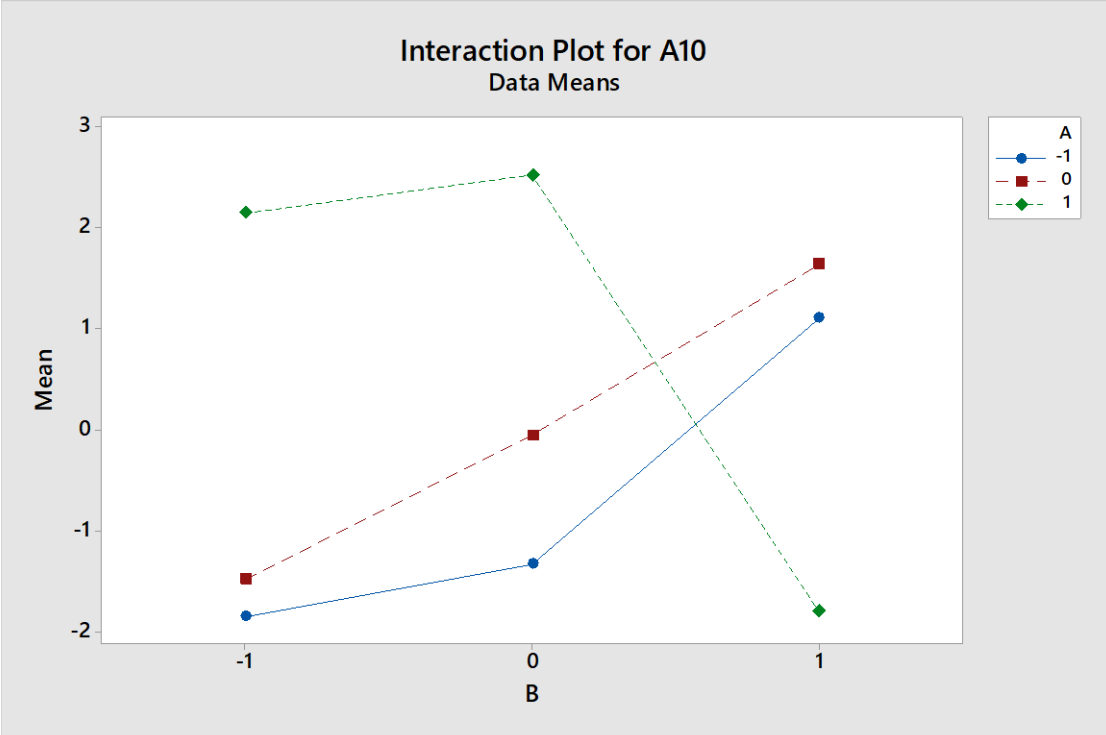

Figure 4.2. Interaction plot for position A10.

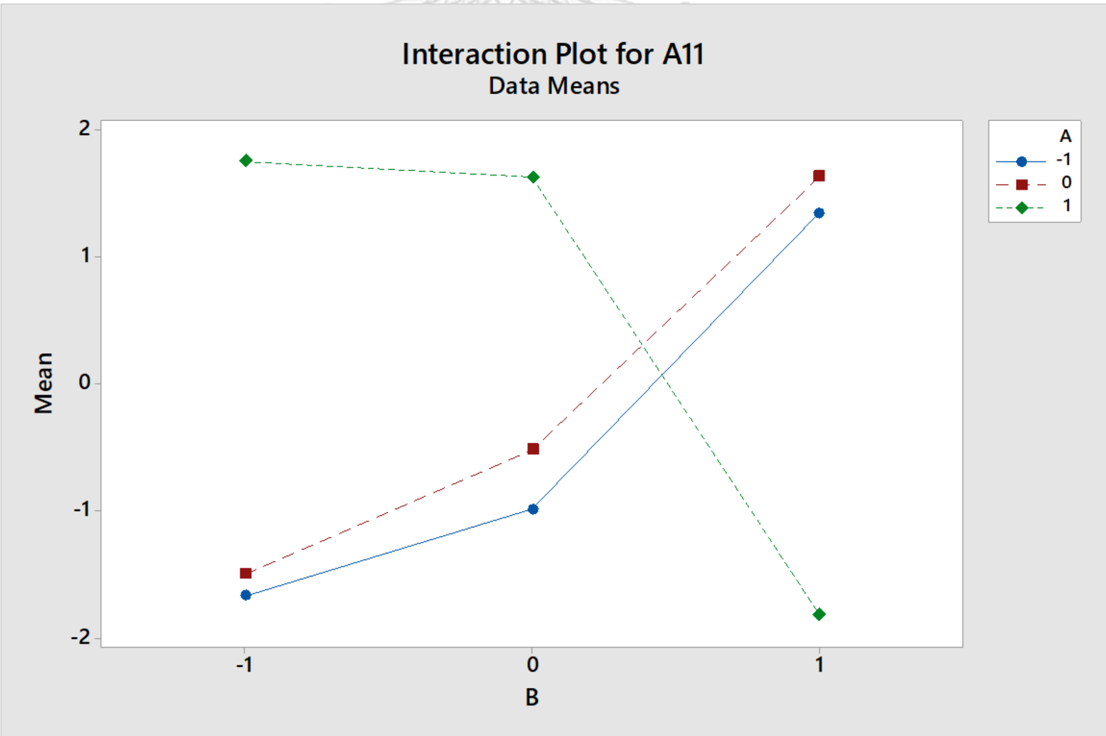

Figure 4.3. Interaction plot for position A11.

The interaction of factor A (press speed) and factor B (die height) is affects to the positions A10 and A11 based on the DOE results. Therefore, we continue to calculate the optimal condition for the value of factor A and factor B. The optimal setting value for factor A (press speed) is 13.6 SPM and factor B (die height) is 648.3 mm. The optimal value setting is shown in Table 4.5.

Table 4.5

Optimal value setting for factors A and B

Factor	Control Factor	Unit	Optimization (Minitab)	Optimal Setting
A	Press speed	SPM	-0.64	13.6
B	Die height	mm	0.32	648.3

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10 A-Pillar samples were collected randomly after setting the optimum value of factors A and B. After that, measure the values of these 10 samples by Coordinate Measuring Machine (CMM). The result showed that the collected samples still have value out of spec on positions A10 and A11 from the spec + /-1 millimeter. The measurement results are shown in Table 4.6.

From the experiment and optimal value setting above, found that the appropriated parameter setting does not solve the problem 100%. Therefore, we need to find other solutions to get rid of the problem.

Table 4.6

Measurement value of 10 sample parts (after setting optimal value)

Sample	Optimal value setting		Location (mm)	
	Press speed (SPM)	Die height (mm)	A10	A11
1	13.6	648.3	1.097	-0.851
2			-0.383	-0.515
3			-1.190	-1.019
4			-0.895	-0.387
5			0.437	-1.049
6			-1.202	1.451
7			-0.363	0.740
8			-0.716	-0.942
9			0.770	-0.262
10			-0.622	1.002

CHAPTER 5

PROBLEM SOLUTIONS

It has been found from the results of the experiment and optimization solution that setting factors A and B at different levels can not regulate the parts within the specified tolerance to have their specification. Therefore, we are considered next solution framework by stamping die modification.

5.1 Stamping die modification

The stamping die is operated continuously to support its normal production. The point where the die must be adequately corrected must be analyzed before the die is withdrawn to modify. The manual rework is the method to be considered to analyze and simulate the problem before move die to modify. After that we will know the locations on parts that need to modify on stamping die.

5.1.1 Manual Rework

We are conducted rework part of 10 sample parts manually by bending part on the A10 and A11 positions to have value within tolerance. Stakeholders has created methods and procedures for manual rework those parts, which have the details as below.

1) Preparing checking fixture (CF) of part (shown in Figure 5.1).

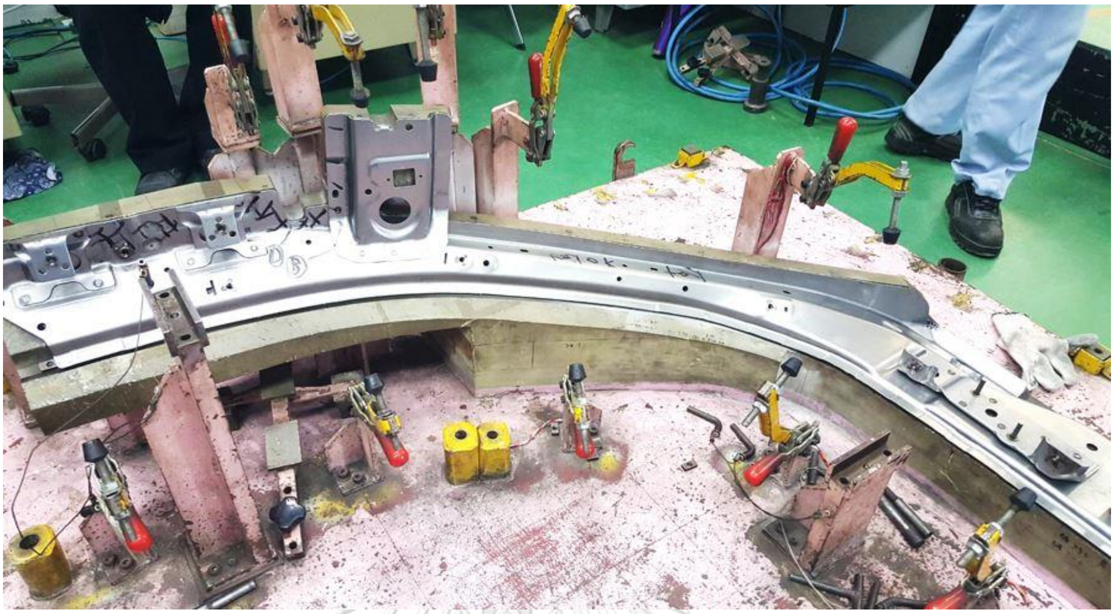

Figure 5.1. Prepare checking fixture of A-Pillar part.

2) Place the A-Pillar part into the CF (shown in Figure 5.2).

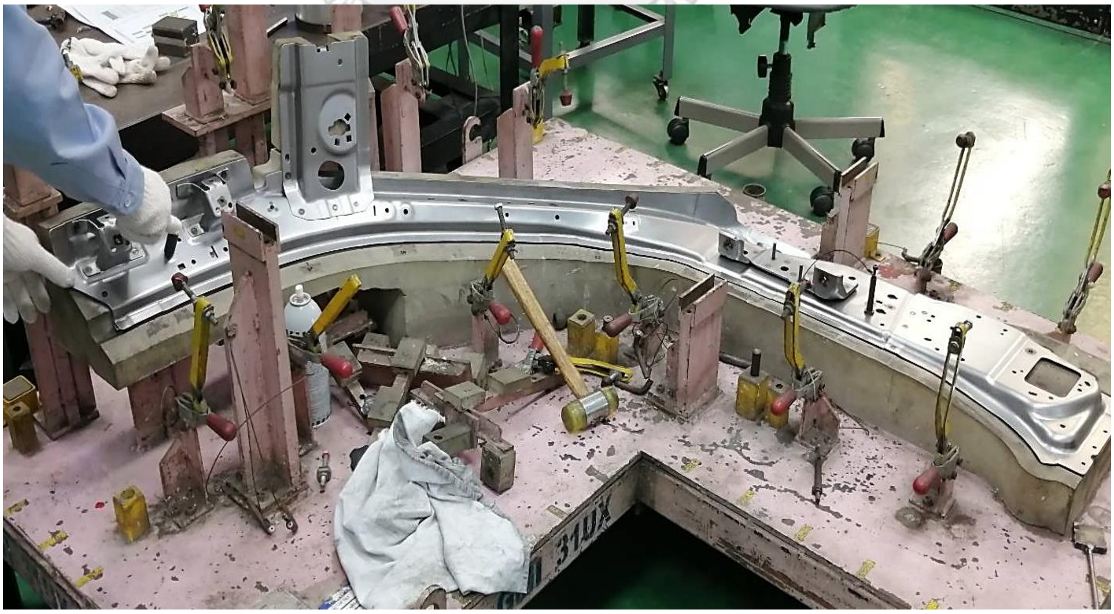

Figure 5.2. Place the A-Pillar part into the CF.

3) Manually rework it by bending the part around positions A10 and A11 until the part be close to the CF (shown in Figure 5.3).

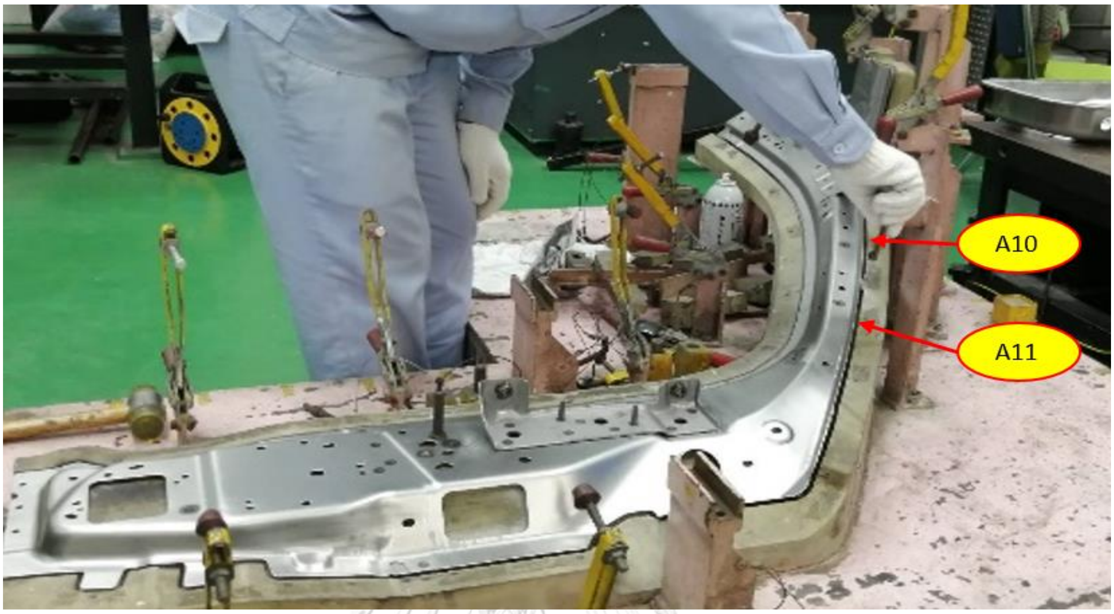

Figure 5.3. Manual rework the A-Pillar.

4) Mark “Rework” into the part (shown in Figure 5.4).

Figure 5.4. Marking the part.

5) Send the reworked A-Pillar part to the measure the value all points of part by CMM machine as Figure 5.5.

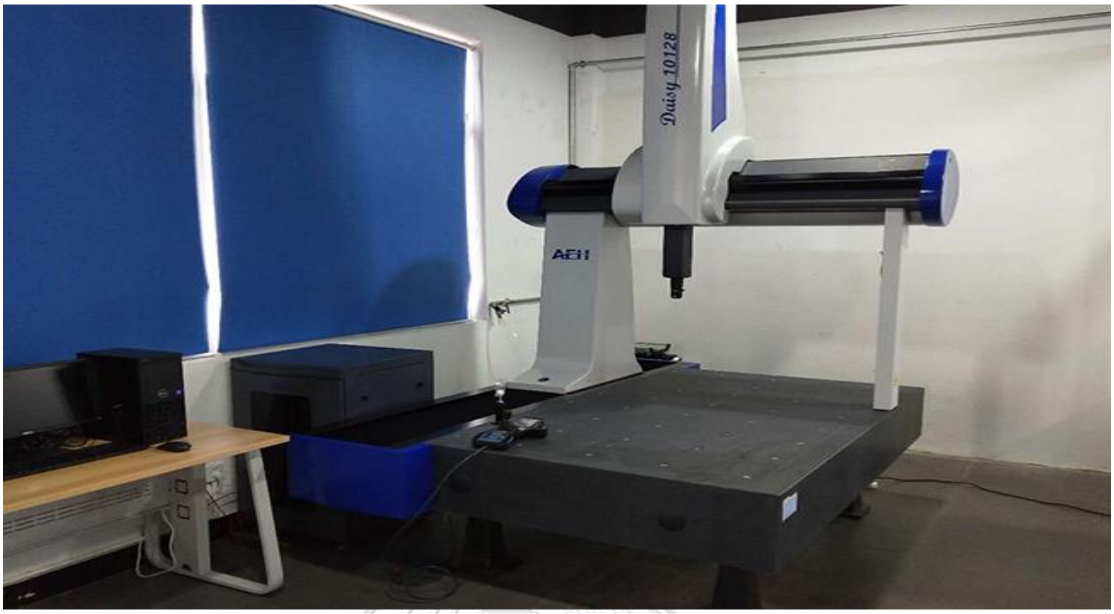

Figure 5.5. Measure the part by CMM machine.

We are measured the value of all points again after manual reworking of the parts. The measurement results are shown in Table 5.1.

Table 5.1

Measurement value of 10 sample parts (after manual rework)

Sample	Location (mm)											
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
1	0.323	0.091	0.24	0.653	-0.174	1.316	0.996	1.115	-0.595	0.141	0.055	-0.293
2	0.685	0.34	0.028	0.814	0.942	0.226	0.399	1.462	-0.038	0.026	0.03	-1.285
3	0.429	0.369	0.978	0.366	1.368	-1.215	0.495	1.17	0.143	0.327	0.244	0.784
4	0.654	0.162	0.676	0.303	1.915	-0.376	-1.144	-0.58	-1.353	0.156	0.083	-0.92
5	0.245	0.668	0.629	0.82	0.62	-0.382	0.569	-0.382	0.707	0.631	0.166	-0.69
6	0.936	0.66	0.077	0.702	-0.84	0.904	0.806	-1.27	0.882	0.006	0.413	1.312
7	0.809	0.569	0.713	0.6	0.931	0.176	-1.028	1.276	1.017	0.257	0.491	-0.737
8	0.723	0.642	0.886	0.701	-1.256	-0.122	0.811	0.629	-1.618	0.2	0.217	0.745
9	0.037	0.762	0.369	0.574	0.614	0.554	-0.574	-0.863	-0.03	0.379	0.269	1.116
10	0.169	0.118	0.139	0.88	0.243	1.184	0.036	-1.048	0.977	0.233	0.526	0.001

From the measuring results, we found that the measuring value of positions A10 and A11 is within the specified tolerance (+ /-1 mm) after manual reworking of the parts. Nevertheless, from their tolerance, it causes the measurement value at other points are out of spec. That means we cannot modify die just one or two positions in case the size of the part is huge due to the metal properties “springback” problem. We should add another die for the re-strike method (or double-bend technique) to solve this problem and not make another effect on other positions.

One of the most troublesome problems in die design is minimizing the spring back. If the springback can not be predicted accurately, it may be necessary to repeatedly attempt to obtain appropriate forming parameters to compensate for the springback. Therefore, it is important to predict springback when designing a die for bending (Jaw-Shi Shu, 1996).

In a bending or forming process, the springback is always present. The basic concept is to bend the part at different locations twice (we call the technique "double-bend") (Liu, 1984) to capture the springback affects.

5.2 Addition re-strike tooling die process

The process of re-strike die is basically a solid forming operation. The main difference is that after most of the large forming has already been completed, a re-strike die is used. The function of the re-strike die is to finish forming features that in a previous operation could not be obtained. Re-strike dies add details like sharp radii and little embosses. They also help to compensate for the springback during the initial forming (Hedrick, 2005).

After discuss in the meeting between company X and company Y, it was concluded that the problem arises from the stamping die have not design well enough. Company Y is responsible for designing the stamping die and laying the plans for produce of this A-Pillar part completely. Therefore, company Y agreed to be responsible for make new re-strike stamping die process. New re-strike stamping die shown as Figure 5.6.

Figure 5.6. New re-strike stamping die.

Once the re-strike stamping die has been added, the process to make A-Pillar part in the manufacturing of Company Y will have add another one station (re-strike process). The new process flow chart is presented as Figure 5.7.

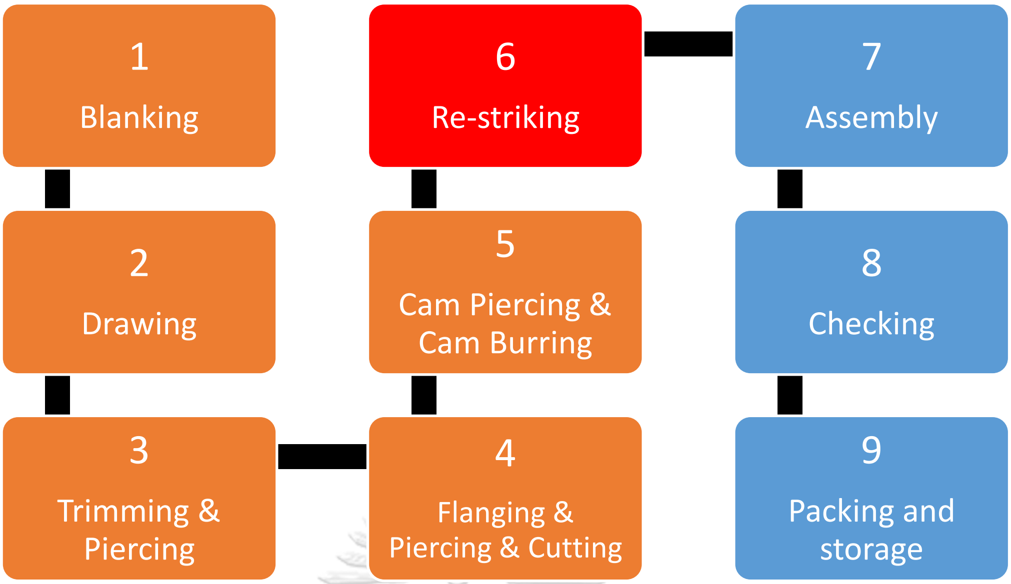

Figure 5.7. Process flow chart of A-Pillar parts (after added re-strike stamping die).

We randomly collected 30 sample parts of A-Pillar to measure their value again after adding the re-strike stamping die process. The measurement results are shown in Table 5.2.

Table 5.2

Measurement value of 30 sample parts (after added re-strike process)

Sample	Location (mm)											
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
1	0.754	-0.673	-0.074	0.37	-0.856	0.734	0.201	0.838	0.604	0.457	0.557	0.372
2	0.115	-0.728	-0.01	-0.835	-0.048	0.01	0.547	-0.865	0.142	0.364	0.22	0.206
3	0.478	-0.746	0.806	-0.333	0.753	-0.128	-0.878	-0.145	-0.346	-0.237	0.144	-0.06
4	0.723	-0.468	0.266	-0.719	-0.006	-0.553	0.665	0.985	0.412	0.166	0.251	0.117
5	0.069	0.253	-0.088	0.192	0.791	0.711	-0.733	0.129	0.562	0.037	0.326	0.215
6	0.94	0.753	0.85	-0.503	-0.042	0.593	-0.399	0.646	-0.225	-0.044	-0.126	-0.186
7	0.593	-0.389	-0.356	-0.264	-0.068	-0.49	-0.799	-0.98	-0.345	-0.531	0.031	0.101
8	0.377	0.598	-0.355	-0.82	-0.787	0.296	0.658	-0.291	0.4139	0.271	0.389	0.343
9	0.835	-0.055	0.773	0.127	0.304	-0.423	0.699	0.963	0.025	0.194	0.177	0.261
10	0.815	0.298	0.113	-0.873	0.754	0.712	0.177	0.924	0.315	0.272	0.17	0.15

Measurement value of 30 sample parts (after added re-strike process) (continue)

Sample	Location (mm)											
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
11	0.325	-0.845	0.481	0.856	-0.426	-0.396	0.445	-0.551	0.206	0.053	0.112	0.237
12	0.611	-0.904	-0.629	0.161	-0.957	0.204	-0.682	-0.659	-0.054	0.015	0.172	0.118
13	0.11	-0.056	-0.055	-0.352	-0.772	0.878	-0.814	-0.365	0.597	0.498	0.436	0.276
14	0.095	0.447	0.847	0.175	0.757	0.954	0.708	0.59	0.418	0.313	0.444	0.399
15	0.861	0.127	0.492	0.626	-0.197	-0.237	-0.571	0.77	0.624	0.686	0.465	0.312
16	0.603	-0.733	-0.272	-0.355	-0.56	-0.87	0.342	0.304	-0.09	-0.273	-0.197	0.035
17	0.974	-0.995	-0.902	-0.89	-0.846	0.755	-0.501	-0.854	-0.053	0.107	0.013	-0.276
18	0.208	-0.123	0.567	0.273	-0.283	-0.982	0.337	0.258	0.274	0.055	0.127	0.265
19	0.177	0.075	0.179	0.245	0.056	0.538	0.301	0.135	-0.212	-0.264	-0.119	-0.107
20	0.282	0.917	0.104	0.734	0.576	0.207	0.812	-0.822	0.398	0.376	0.461	0.435
21	0.303	-0.345	-0.865	0.218	0.429	-0.38	0.618	0.921	-0.347	-0.282	0.068	0.05
22	0.083	-0.916	-0.545	0.275	0.193	0.644	-0.699	0.031	0.474	0.468	0.493	0.41
23	0.853	0.628	0.991	-0.06	-0.265	0.998	0.886	-0.312	0.244	0.485	0.08	0.588
24	0.203	-0.431	-0.747	0.1	-0.226	-0.216	-0.539	0.654	0.744	0.51	0.692	0.644
25	0.386	-0.295	0.985	0.186	-0.934	0.559	0.405	0.012	0.067	0.068	0.143	0.122
26	0.387	-0.045	0.162	0.618	0.551	-0.797	0.344	-0.058	0.237	0.157	0.028	-0.009
27	0.477	0.695	0.819	-0.11	0.833	0.944	0.383	0.151	-0.181	-0.095	-0.124	-0.113
28	0.317	-0.677	-0.266	0.615	-0.443	-0.354	0.146	0.865	0.59	0.309	0.58	0.555
29	0.818	0.414	-0.44	0.079	-0.892	-0.582	-0.613	-0.708	0.147	0.005	0.109	0.292
30	0.857	-0.808	-0.156	-0.14	0.351	0.902	0.035	0.253	-0.423	-0.354	-0.291	-0.216

The result of the measurement value of 30 collected sample parts (positions A1 – A12) is within + /-1 mm tolerance. Then, these 30 parts are delivered to Company X for the assembly process of the vehicle. After the assembly process of the trial found that part of the missing alignment problem is no longer found.

The researcher used the process capability analysis to run and analyze the 30 collected sample parts by the Minitab software with confidence level 95 percent (α = 0.05). It was found that the measurement values of the 30 sample parts collected are hypothesized as normal distribution and are controlled. The result of Process Capability Report for A10 and A11 positions by Minitab software are shown as Figures 5.8 and 5.9, respectively.

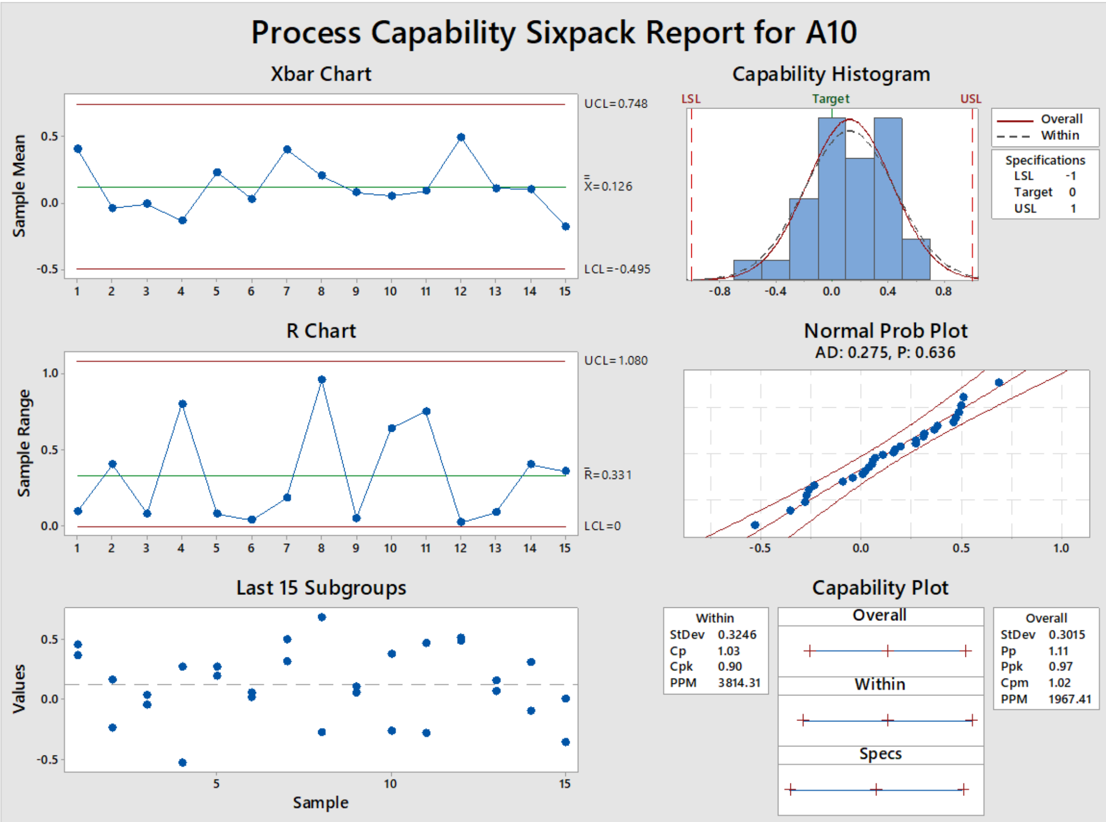

Figure 5.8. Process Capability Sixpack Report of A10 position (after added re-strike).

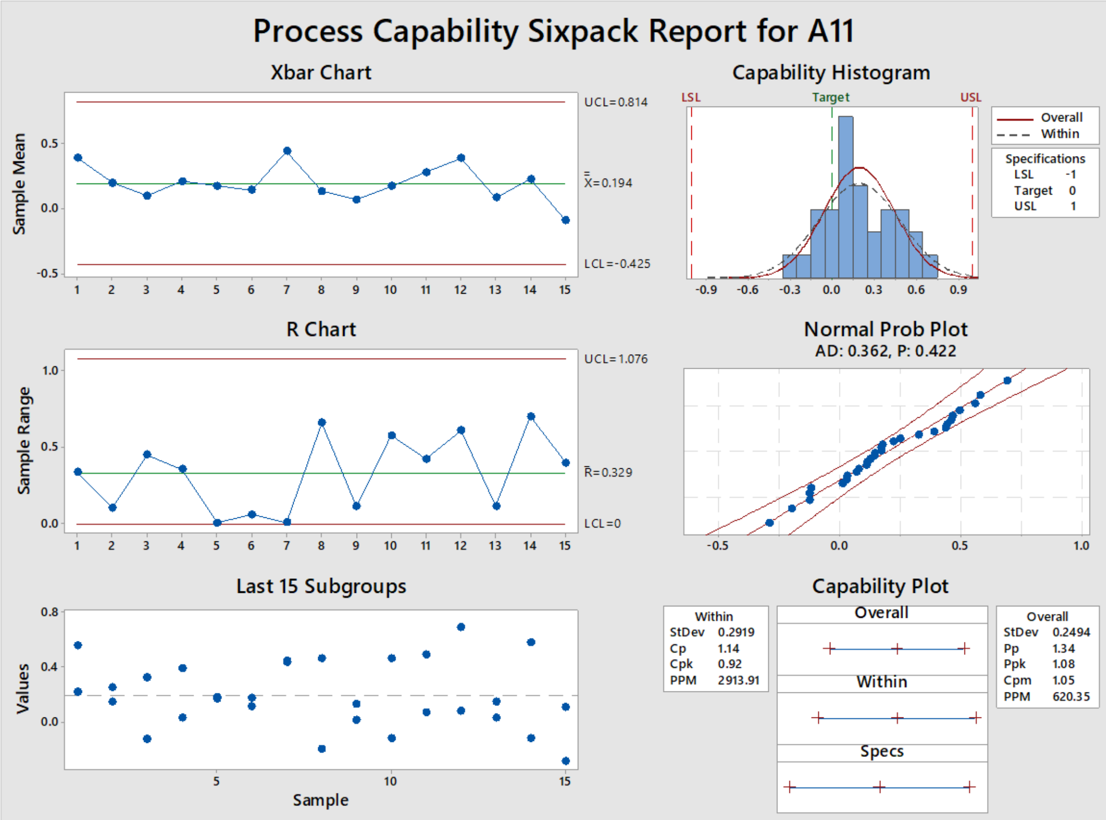

Figure 5.9. Process Capability Sixpack Report of A11 position (after added re-strike).

Refer detail from Figures 5.8 and 5.9 above; found that Xbar-Chart and R-Chart has the value within control area. Therefore, it can be concluded that these 30 collected sample data has properties within controlled. The *P*-Value is greater than 0.05 both A10 and A11 positions, indicating that this data is a normal distribution at the significance level 0.05.

For the Cpk value of the process that measures position A10 has improve from 0.05 to 0.90 and position A11 has improve from 0.03 to 0.92. The Cp values of improved process both positions are over than 1.00. Therefore, the process has capable to produce parts within specification limits.

After implementing new process by added re-strike stamping process since August 2019, the GCA issue report during August 2019 – October 2019 not found the defect of A-Pillar part missing alignment issue. Therefore, after improving the stamping process by adding re-strike stamping die; it is reduced the number of defect to be zero.

5.3 Research framework and result

Having done the methods in line with the framework agreement in chapter III found that, the 3rd method "additional die process" is the best solution method to eliminate the problem completely.

The additional a re-strike process can be done by combining the re-strike process with other current process or make it process separately. When considered the cost and timing, we can conclude that to make a re-strike process individually can reduce lead-time of stamping die making, reduce investment cost and can control quality level better than combine with other process. The framework method and result are described as Table 5.3.

Table 5.3

Research framework and result

Method	Result	Investment Cost (Baht)	Lead Time (Months)
1. Stamping Die parameter adjustment	- Cannot solve the issue	-	-
2. Stamping Die modification	- Can solve the issue but impact to other point	300,000	2
3. Additional Die process	- Can solve the issue 100%		
	Option I Make new stamping die by combine re-strike process with other	900,000	5
	Option II Make new stamping die by make re-strike process separately	700,000	4

CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The goal of this research is to use the Failure Mode and Effects Analysis (FMEA) method to evaluate and determine the root cause of the problem. Furthermore, the study used the Design of Experiment (DOE) to reduce the metal stamping process defect. Systematically, FMEA and DOE were used to find the appropriate factor to be improved. The defect amount after added re-strike process are reduces drastically to zero. Company X is expected to save its 27 million Thai Baht annual defect cost.

6.2 Recommendation

The stamping parts will measure the efficiency of the parts according to many quality defects. One of the most difficult to solve is springback problem. This problem will affect to the shape, size of precision and surface quality of the stamping parts. When the springback exceeds it is own limits, there will be affect to the assembly process.

It is necessary to consider the die design for large stamping parts to include the re-strike process. It can help control the dimensions of the parts and prevent the effects of the springback.

The adjustment of machine parameter and the modification of current stamping die cannot solve the issue 100% in case of the stamping parts have a large size.

6.3 Research limitations

During the study to solve the problem, it was found that the problems and obstacles that occurred in solving this problem are follows;

- The experiment to solving the defect in the production process of company Y is takes long lead-time to conduct the experiment due to the stamping dies and process of A-Pillar part still running as the normal production phase.
- We are done the experiment with limited quantity of sample due to the parts cost is expensive.
- The person who must monitor the progress of the work also lacked the progress check and follow up. Therefore, it making the problem solving possible slowly.

6.4 Future Plan

The new researcher can be applied this solution method to solve the issue of a large size of stamping parts. This solution also can be applied to stamping parts if those parts are required special control of part's shape.

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