BLACK DOT DEFECT REDUCTION IN PLASTIC INJECTION MOULDING PROCESS

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อิทธิวรรธน์ รัตนบัณฑิตสกุล : การลดข้อบกพร่องชนิดจุดดำในกระบวนการฉีดพลาสติกขึ้นรูป (BLACK DOT DEFECT REDUCTION IN PLASTIC INJECTION MOULDING PROCESS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร. ปารเมศ ชุติมา, 200 หน้า.

งานวิจัยนี้มีจุดประสงค์เพื่อลดสัดส่วนของเสียชนิดจุดดำที่เกิดในกระบวนการฉีดพลาสติกขึ้นรูป ซึ่งก่อนปรับปรุงกระบวนการพบปริมาณของเสียชนิดจุดดำที่เครื่องฉีดพลาสติกเบอร์ P24 และ P25 รวมกันเท่ากับ 0.65%

ซึ่งงานวิจัยนี้ได้ประยุกต์ใช้ตัวแบบ DMAIC ของ Six Sigma มาเป็นเครื่องมือในการดำเนินการปรับปรุงแก้ไขคุณภาพ ซึ่งประกอบไปด้วย5 ขั้นตอน คือ ขั้นตอนการกำหนดปัญหา ขั้นตอนการวัด ขั้นตอนการวิเคราะห์ ขั้นตอนการปรับปรุง และขั้นตอนการควบคุม ในขั้นตอนการกำหนดปัญหาได้ศึกษาสภาพปัญหา กำหนดคณะทำงาน กำหนดเป้าหมาย และขอบเขตของการปรับปรุง ซึ่งมุ่งเน้นไปที่การลดของเสียอันเนื่องมาจากจุดดำบนพื้นผิวชิ้นงานพลาสติกที่เครื่องฉีดพลาสติกเบอร์ P24 และ P25 ในขั้นตอนการวัดได้ทำการศึกษาความแม่นยำและความถูกต้องของระบบการวัด จากนั้นได้ระดมสมองผ่านแผนผังสาเหตุและผลกระทบเพื่อหาสาเหตุของปัญหา จากนั้นจัดลำดับความสำคัญของสาเหตุโดยประยุกต์ใช้ตารางวิเคราะห์สาเหตุและผลกระทบ และวิธีการวิเคราะห์ข้อบกพร่องและผลกระทบ ในขั้นตอนการวิเคราะห์ ได้ระดมสมองผ่านแผนผังทำไม-ทำไม เพื่อหาสาเหตุสาเหตุรากเหง้าของปัญหาและเพื่อหาแนวทางการปฏิบัติการแก้ไข จากนั้นได้ทำการประยุกต์ใช้การทดสอบสมมติฐานเพื่อทดสอบความมีนัยสำคัญของแต่ละปัจจัย ซึ่งผลลัพธ์ที่ได้พบว่าปัจจัยที่มีนัยสำคัญในการเกิดของเสียชนิดจุดดำนั้นมี 4 ปัจจัย ได้แก่ ความสะอาดของสกรูและกระบอกฉีด วัตถุดิบเก่าตกค้างในกระบอกฉีด การเสื่อมสภาพของวัตถุดิบ และการปนเปื้อนในถังกรวย เมื่อสามารถระบุถึงปัจจัยที่มีนัยสำคัญได้แล้ว ในขั้นตอนปรับปรุงจึงนำทั้ง 4 ปัจจัยมาทำการออกแบบการทดลองเพื่อหาสภาพที่เหมาะสมในกระบวนการ โดยใช้การทดลองแบบแฟคทอเรียล และทำการทดสอบเพื่อยืนยันผลก่อนนำไปใช้จริงในกระบวนการผลิต และสุดท้าย ในขั้นตอนการควบคุม ได้จัดทำคู่มือการปฏิบัติงาน แผนควบคุม และแผนภูมิความคุม เพื่อให้แน่ใจว่าสภาพที่เหมาะสมในกระบวนการอยู่ในสภาวะควบคุม

จากผลการประยุกต์ใช้ตัวแบบ DMAIC ของ Six Sigma พบว่าสามารถที่จะลดสัดส่วนของเสียชนิดจุดดำที่เกิดในกระบวนการฉีดพลาสติกขึ้นรูปที่เครื่องฉีดพลาสติกเบอร์ P24 และ P25 ลงมารวมกันจาก 0.65% ลงมาที่ 0.34% หรือ ลดลงถึง 47.69% หลังปรับปรุงกระบวนการ

ภาควิชา ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต ลายมือชื่อนิสิต .....

ลายมือชื่อ อ.ที่ปรึกษาหลัก .....

สาขาวิชา การจัดการทางวิศวกรรม

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ITTHIWAT RATTANABUNDITSAKUN: BLACK DOT DEFECT REDUCTION IN PLASTIC INJECTION MOULDING PROCESS. ADVISOR: ASSOC. PROF. PARAMES CHUTIMA, Ph.D., 200 pp.

The objective of this research is to reduce black dot defect in plastic injection moulding process. The total amount of black dot defect before process improvement in plastic injection moulding machine number P24 and P25, was 0.65%.

Six Sigma DMAIC methodology is applied as the approach for quality improvement in this research. The methodology consists of 5 phases, comprised of define, measure, analyse, improve, and control phases. In define phase, statement of problem, project team, objective, and scope of the research are identified and are used to emphasise on the reduction of black dot defect on moulded parts in plastic injection machine number P24 and P25. In measure phase, accuracy and precision is assessed by Gage Repeatability and Reproducibility. Then, the potential causes are brainstormed through Causes-and-Effect Diagram and are prioritised and selected by Cause-and-Effect Matrix, Failure Mode and Effects Analysis. In analyse phase, Why-Why Diagram were developed to identify the root causes of the problem and to recognise corrective action. The selected factors were then tested for reliability by hypothesis testing on statistical significance. The test results show that there are 4 factors influencing black dot defect, including carbonised and dirty barrel and screw, previous material trapped inside the barrel, raw material degradation, and contamination in the hopper. In improve phase, those 4 factors were tested to identify the optimum process conditions of the process by Design of Experiment. Next, the confirmation test is performed before implementing optimum condition in actual production. Finally, in control phase, work instruction, control plan, and control charts are constructed to ensure that the optimum process conditions are sustained over time.

The results after implementing Six Sigma DMAIC Methodology reveals that the total proportion of black dot defect in plastic injection moulding machine number P24 and P25 are reduced from 0.65% to 0.34%, a 47.69% reduction.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	.....
		Advisor's Signature	.....
Field of Study:	Engineering Management		
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A very special acknowledgment is presented to the owner of the plastic injection moulding factory who allowed the researcher to perform his research at the company, provides the helpful assistance about the information in plastic injection moulding processes, and suggests beneficial comments for the problems in the factory.

Lastly, I would like to express gratitude to my beloved family for their great love, endurance, and continuing supportive me throughout this thesis. A lot of appreciation is expressed to the friends that have given support whenever needed. So, thank you to everyone that was involved in any phase of this thesis, without them, it would not have been possible to completed

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CHAPTER 1
INTRODUCTION

Presently, there are numerous plastic conversions processing to produce a desire plastic products such as injection moulding, extrusion, blow moulding, thermoforming, reaction injection moulding, compression moulding, rotational moulding, etc. (Cybulski, 2009). Each of this plastic conversion processes have their different benefits and drawbacks depending on the specification, characteristic, and production batch size of the require products. Generally speaking, plastic injection moulding is one of a fast and flexible manufacturing process technique used in the global plastics conversions industry to fabricate plastic products that capable of a wide range of size, weight, shape and complex geometries for various applications (Rosato, Rosato, & Rosato, 2000). Moreover, this process has capability to produce the products from extensive choice of polymer materials from both thermoplastic and thermosetting materials (Cybulski, 2009). Plastic injection moulding has many advantages such as short cycles, high quality part surfaces, good mechanical properties, low cost, and produces lightweight products, so it has become increasingly considerable in today's plastic production industries.

Significantly, there are very aggressive competitions in plastic injection moulding industry from both domestic and international plastic injection moulding manufacturer. In addition, the plastic materials (resin) price is fluctuated and increasing considerably (Plastics Institute of Thailand, 2014). In the last decades, competitive pressures have been pushing companies towards cost reduction and performance improvement of operations to provide high quality products to very demanding markets (De Souza & Carpinetti, 2014; Swink, 1998). To satisfy the customer's requirements and stay competitive in the market, the manufactures has to adapted and improve the production processes and quality assurance to reduce cost and improve the company efficiency and effectiveness. The quality characteristics of injection moulded parts can be categorised to dimensional properties, surface properties, and mechanical properties. More significantly, defects are

the major quality concern in plastic injection moulding process due to the fact that defects are lead to defective parts which is the company loss and offered bad reputation to customers. Therefore, the defects are certainly the major concern in this plastic injection moulding industry. There are many types of moulded parts defects such as short mould, flash, burn mark, sink mark, blisters, weld line, scratch, pinhole, black dot etc.

1.1 Company Background

The case study company was established in 1986 with initial registered capital of 20 million Baht and located in the suburb of Bangkok on the area of 4 Rai (6,400 Square metres). The company is operating in plastic injection moulding process to produce a various kind of engineering plastic parts for the customers. Figure 1-1 and figure 1-2 illustrates the working area and layout of the company, respectively. Moreover, the business of this company is based on made-to-order process. Frequently, the customers of this company are come from contract manufacturer who do not have enough capacity to perform their work.

Figure 1-1: Working area of the company

Figure 1-2: Layout of the company

1.1.1 Organisational Structure

Currently, there are approximately 300 employees in the company. Figure 1-3 reveals the organisational structure of the company. It can be seen that the vice president administrators the works in the company through the managers in each main functional department and report back to the president. Purchasing and accounting department is responsible to contract with the suppliers, and procures the raw materials and necessary auxiliary equipment to feeds to the production process, and manages the budgets, cash flow, expenditures, and revenue of the organisation. Sale department is responsible to contact with the customer and acquire the order. Planning department has to plan control three sub division including customer services and delivery, raw material, and quality control. The factory department are responsible to producing the products and maintain the machine and operational in good condition. The human resource department has to manage and control to hiring, promotions, reassignments, and benefits of the workers.

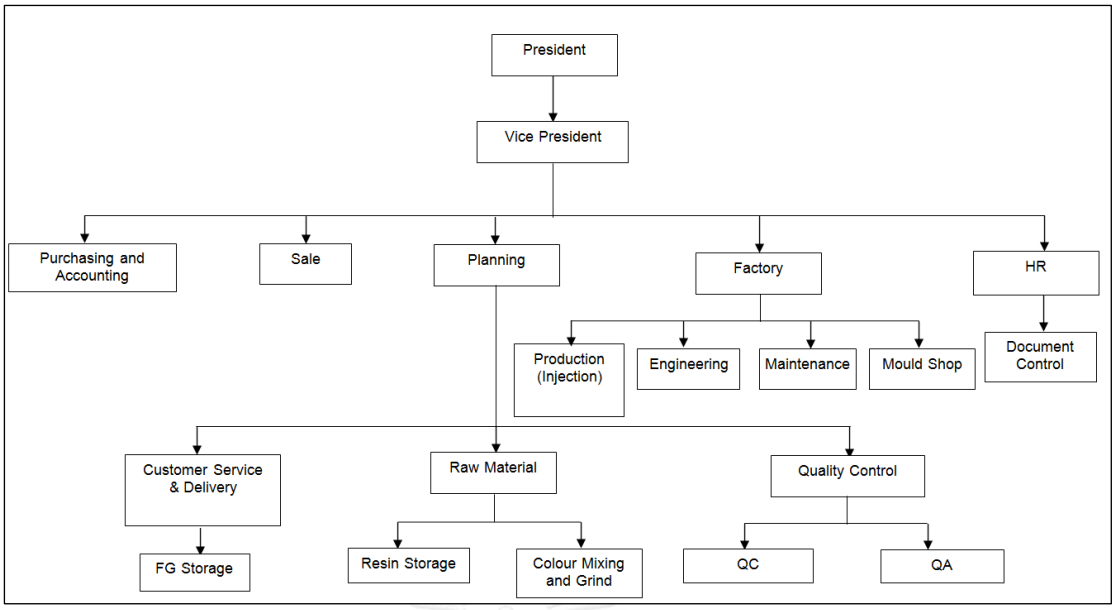


Figure 1-3: Organisational structure of the company

1.1.2 Injection Moulding Machine of the Company

In addition, injection moulding machine play significant roles here this company. There are 48 injection moulding machine that operated in the company at the moment. Table 1-1 illustrates the brand, model, clamping force, and machine number of the company.

Table 1-1: Machine lists of the company

Item	Brand	Model	Clamping Force (Ton)	Machine No.
1	JSW	J 450 SA II	450 T	P.1
2	TOYO	TOYO G2 TM-250	250 T	P.2
3	KAWAGUCHI	KM 550 B2	550 T	P.3
4	KAWAGUCHI	KM 550 B2	550 T	P.4
5	JSW	J 440 SA II	440 T	P.5
6	TOYO	TOYO G2 TM-250	250 T	P.6
7	TOYO	TOYO G2 TI-80	80 T	P.7
8	TOSHIBA	EC230S	230 T	P.15
9	TOSHIBA	EC230S	130 T	P.16
10	TOSHIBA	EC100E	100 T	P.17
11	TOYO	TOYO G2 TI-80	80 T	P.18
12	TOYO	TOYO G2 TI-80	80 T	P.19
13	TOYO	TOYO G2 TM-130	130 T	P.20
14	TOYO	TOYO G2 TM-130	130 T	P.21
15	TOYO	TOYO G2 TM-180	180 T	P.22
16	TOSHIBA	EC180S	180 T	P.23
17	TOSHIBA	EC230S	230 T	P.24
18	TOSHIBA	EC230S	230 T	P.25
19	TOYO	TOYO G2 TM-350	350 T	P.26
20	JSW	J 350 E II	350 T	P.27
21	KAWAGUCHI	KM 180	180 T	P.28
22	KAWAGUCHI	KM 180	180 T	P.29
23	TOSHIBA	EC180S	180 T	P.30
24	KAWAGUCHI	KM 180	180 T	P.31
25	TOYO	TOYO G2 TM-130	130 T	P.32
26	TOYO	TOYO G2 TM-130	130 T	P.33
27	TOYO	TOYO G2 TM-130	130 T	P.34
28	TOYO	TOYO G2 TM-130	130 T	P.35
29	TOYO	TOYO G2 TM-130	130 T	P.36
30	TOYO	TOYO G2 TM-350	350 T	P.37
31	TOYO	TOYO G2 TM-350	350 T	P.38
32	TOYO	TOYO G2 TM-250	250 T	P.39
33	TOYO	TOYO G2 TM-250	250 T	P.40
34	TOYO	TOYO G2 TM-250	250 T	P.41
35	TOYO	TOYO G2 TM-250	250 T	P.42
36	TOYO	TOYO G2 TM-250	250 T	P.43
37	TOYO	TOYO G2 TM-250	250 T	P.44
38	TOYO	TOYO G2 TM-250	250 T	P.45
39	TOSHIBA	EC230S	230 T	P.46
40	TOSHIBA	EC230S	230 T	P.47
41	TOSHIBA	EC230S	230 T	P.48
42	TOSHIBA	EC230S	230 T	P.49
43	TOSHIBA	EC100E	100 T	P.50
44	TOSHIBA	EC100E	100 T	P.51
45	TOSHIBA	EC100E	100 T	P.52
46	TOSHIBA	EC100E	100 T	P.53
47	TOYO	TOYO G2 TI-130	80 T	P.54
48	JSW	J 650 E II	650 T	P.55

1.1.3 Company's Product

Generally, the products of the company is the engineering part that ordered by the customers who are the contract manufacturer which they will bring the moulded parts to assembly with other components such as the vehicle car door handle, the cover of the rice cooker and kettle, bucket, container, pipe joint, etc. Therefore, the products of this company can be categories in to four main segments including: automotive (see figure 1-4), electronic appearance (see figure 1-5), household (see figure 1-6), and piping and construction (see figure 1-7).

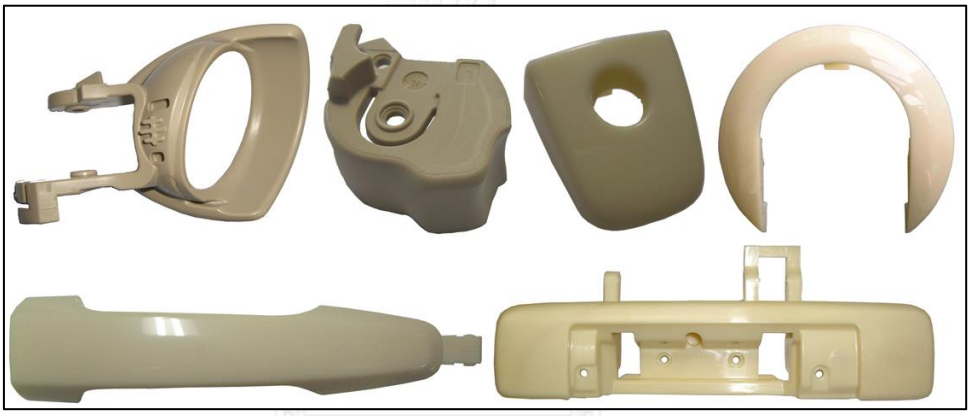


Figure 1-4: Sample moulded parts of automotive products

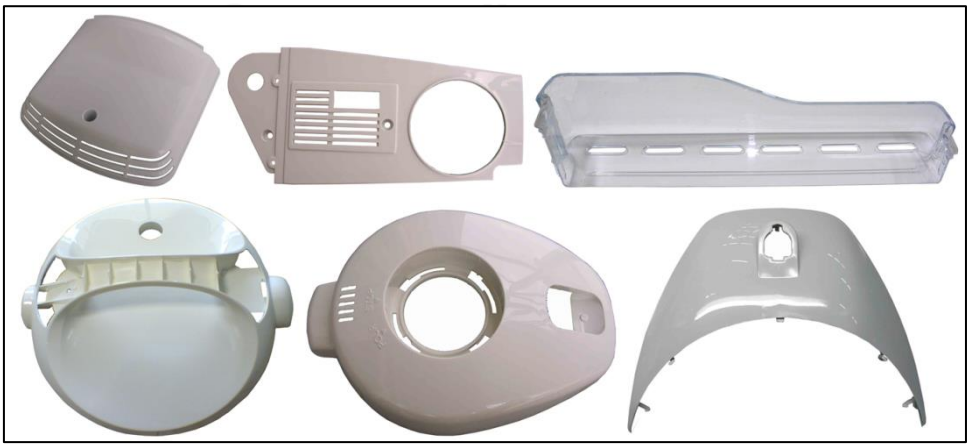


Figure 1-5: Sample moulded parts of electronic appearance products

Figure 1-6: Sample moulded parts of household products

Figure 1-7: Sample moulded parts of piping and construction products

1.2 Statements and Significance of Problem

For this research, the author has contact with the company that operating in plastic injection moulding process to conduct this research. From the observation and interview with the owner of the company, it is found out that the company is now facing with different type of defects in the plastic injection moulding process that causing the defective moulded parts. After continuous collecting data from company's production records from September 2013 to February 2014, it was found out that there are various

types of defects was detected on the moulded parts that is not pass the customer's requirement. The moulded parts defect such as short shot, black dot, pinhole, burn mark, etc. Table 1-2 and figure 1-8 reveals each kind of defect present in the moulded parts, and defect percentage from September 2013 to February 2014.

Table 1-2: Different type of defect on moulded parts from Sep-13 to Feb-14

Defect type	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14
Black Dot	32.30%	29.26%	35.57%	20.76%	33.20%	33.99%
Damage	1.06%	0.31%	0.79%	2.83%	0.00%	0.23%
Scratch	0.26%	0.73%	0.53%	1.04%	1.04%	0.96%
Black Line	0.67%	2.34%	4.31%	0.42%	1.56%	2.92%
Dirty	6.44%	4.28%	1.98%	3.05%	2.08%	3.94%
Burn Mark	5.30%	5.02%	6.11%	5.85%	3.82%	0.99%
Flow mark	6.60%	12.42%	4.44%	9.88%	10.88%	11.52%
Sink Mark	2.38%	2.71%	1.60%	3.43%	2.40%	1.20%
Mat'l Flow	21.17%	5.11%	8.59%	13.29%	10.02%	6.99%
Short shots	7.05%	14.62%	9.27%	14.51%	9.87%	6.17%
White Dot	0.07%	0.27%	9.25%	1.62%	0.00%	0.64%
Weld Line	4.19%	1.42%	3.96%	3.16%	2.27%	1.27%
Flash	0.14%	0.60%	0.56%	2.87%	0.33%	0.94%
Deform	0.57%	0.51%	0.62%	0.19%	0.08%	0.25%
Pinhole	11.80%	20.40%	12.42%	17.10%	22.45%	27.99%

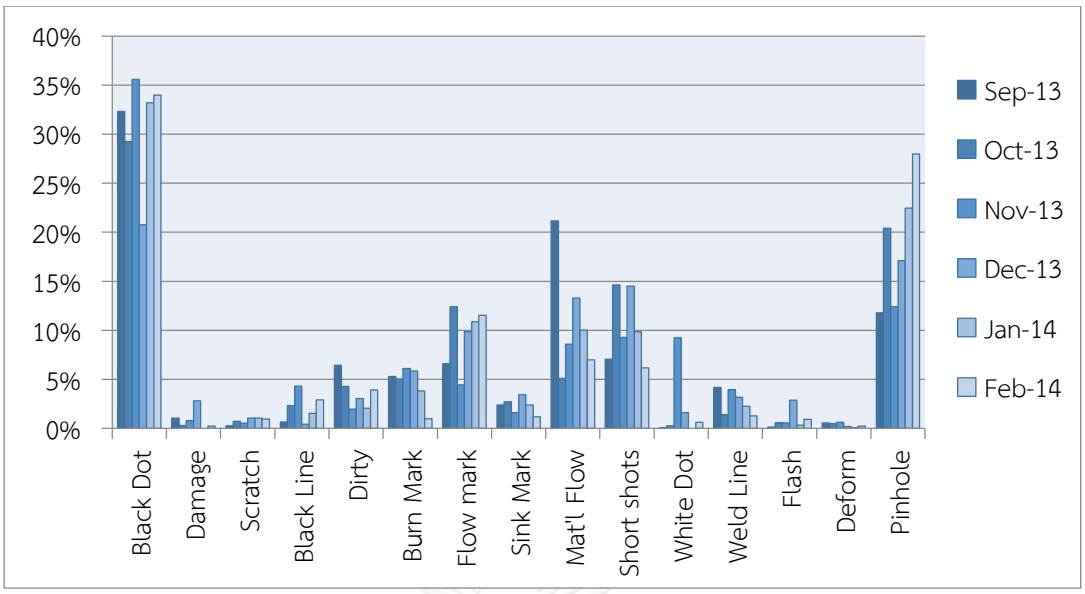


Figure 1-8: Different defect percentage from Sep-13 to Feb-14

According to Table 1-2 and figure 1-8, it can be seen that the most defect type that frequently appeared on the moulded parts is black dot type. Consequently, the author would like to emphasis on black dot defect reduction in the plastic injection moulding process. By reducing this type of defect, it will reduce the number of defective moulded parts in this company which lead to improve in productivity efficiency and effectiveness. To reduce the black dot defect, the use of quality tools and techniques is significant. Therefore, the application of Six Sigma DMAIC approach is implemented to improve the quality and reduce this black dot defect type.

1.3 Objective of Research

The objective of this research is to reduce black dot defects from the moulded parts in plastic injection moulding process.

1.4 Scope of Research

The scope of this research is concentrating only on two selected injection moulding machines (machine number P24 and P25) that produced the highest black dot defects. Moreover, these two machines are the same brand and model.

1.5 Expected Benefits

- Defect reduction on moulded part of black dot type.
- Improve customer confident and increase customer satisfaction from receiving quality product from the company.
- Could be the guideline and approach to reduce the black dot defect for other machines afterward.
- Could be the guideline and approach to reduce other type of defect.

1.6 Research Methodology

The methodology of this research can be described in the following:

1. Study the relevant theory and literature review
2. Study the manufacturing process of the case study company
3. Define Phase
    - Gathering data and information to study the problem that occur in the manufacturing process
    - Determine the objective of research
    - Determine the indicator to measure the result such as DPPM, yield, etc.

- Consider the current capability of the manufacturing process in term of production volume and number of defective
- Determine the scope and time duration of the research
- Forming a cross functional team and brainstorming to identify the root cause of the problem and effect of the selected process.
- Summary the define phase

4. Measure Phase
   - Analyse the accuracy of measurement system by using Gage Repeatability and Reproducibility (Gage R&R).
   - Brainstorming to identify the root cause of the problem by using Cause-and-Effect Diagram and Cause-and-Effect Matrix
   - Brainstorming to identify the failure mode and effect by using Failure Mode and Effect Analysis (FMEA)
   - Summary and selecting key input factor for further step
5. Analyse Phase
   - Explore the root cause of the problem and corrective actions through Why-Why Diagram
   - Test the key input factor via statistical analysis tools by using Hypothesis testing
   - Select the most significant factor for further experiment for the next step
   - Summary the analyse phase and plan for the next step
6. Improve Phase
   - Planning a Design of Experiment (DOE) to recognise the main and interaction effects between the key input and black dot defect
   - Perform the Design of Experiment and gathering data as planned
   - Deploy improvement in manufacturing process
   - Summary the improve phase and plan for the next step

7. Control Phase
    - Consider and identify the most appropriate control chart
    - Construct the control plan
    - Gather date after improvement
    - Summary the result and compare with the objective
8. Conclusion and Recommendations
9. Thesis Completion

CHAPTER 2
LITERATURE REVIEW

A literature review is vital and valuable part for the research because it is able to assists the researcher to review and provide the broadened scenario from past and current theory, and knowledge derived from the related sources such as theory, former research, and case studies.

The purpose of conducting a literature review in this research is to study a theoretical framework based on textbooks, journals, case studies, and related sources regarding the Six Sigma (philosophy, theory, tools, and methodology), and plastic injection moulding process in order to understand its theory and use this as a guideline to implement in the company to reducing the moulded part defects.

2.1 Six Sigma

Six Sigma is a disciplined and highly quantitative methodology to improving product or process quality (Hahn, Doganaksoy, & Hoerl, 2000). A similar view is held by Manual (2006). Manual (2006) claims that Six Sigma is a data-driven methodology to reduce defects in business process. Harry and Schroeder (2000) argues that Six Sigma is a business process that allows organisations to radically expand their outcome by designing and monitoring routine business activities in ways that minimise waste and resources whereas increasing customer satisfaction. However, Aboelmaged (2010) states that Six Sigma has developed from scientific management and continuous improvement theories by merging the optimum elements of many prior quality initiatives.

In addition, Six Sigma is the method to reduction of defects to no more than 3.4 per million opportunities (Hahn et al., 2000). The Sigma 'σ' is a Greek alphabet letter that used by statisticians to identify the variability in any processes (Mehrjerdi, 2011; Pyzdek, 2003a). A Sigma quality level indicates how often are likely to occur and organisation's

performance; though, the higher Sigma quality level defects is an indicator that the process would produce smaller defects (Mehrjerdi, 2011). According to Mehrjerdi (2011) and Pyzdek (2003a), traditionally, it is believed that most companies accepted three to four sigma quality levels as the average, which translated to approximately between 66,000 and 6,000 defects per million opportunities.

Furthermore, Chiarini (2012) expresses that Six Sigma is a management system comparable to TQM or Lean Principle and it is considered as an approach for achieving business excellence and it focuses on a particular roadmap called DMAIC.

2.2 Origin of Six Sigma

Aboelmaged (2010) and Hahn et al. (2000) states that Six Sigma programme was first launch and implemented by Motorola in the 1980s with the key objective of reducing defects of manufactured electronics products. Consequently, the Six Sigma aids the Motorola to saving 1.5 billion dollars in 5 years of all company processes, and winning the Malcom Balbridge award (Chiarini, 2012). Then, many companies such as Allied Signal, IBM, and General Electric adopted and generalised Six Sigma as a corporate requirement for strategic and tactical operations to produce high-level outcomes, improve work processes, develop employees' competencies and revolution the organisational culture. Parenthetically, Six Sigma is a federally registered trademark of Motorola (Raisinghani, Ette, Pierce, Cannon, & Daripaly, 2005).

Presently, Six Sigma is well recognised in almost all industry sectors and numerous organisations worldwide have adapted and generalised Six Sigma approach and tools to fit their own operations and business requirements (Aboelmaged, 2010; Hahn et al., 2000; Manual, 2006).

2.3 Definitions of Six Sigma

Six Sigma is defined by most practitioners, scholars, and academics as a statistics, a philosophy, a program, and a methodology as the following:

Six Sigma is an improvement program for reducing variation, which focuses on continuous and breakthrough improvement (Andersson, Eriksson, & Torstensson, 2006).

Six Sigma is a business performance improvement strategy that aims to reduce the number of mistakes or defects to as low as 3.4 occasions per million opportunities (Antony, 2002).

Six Sigma is a quality movement, a methodology and measurement. As a quality movement, Six Sigma is a major player in both manufacturing and service industries throughout the world. As a methodology, it is used to evaluate the capability of a process to perform defect-free, where defect is defined as anything that results in customer dissatisfaction (Black & Revere, 2006).

Six Sigma is a quality improvement program with a goal of reducing the number of defects to as low as 3.4 parts per million opportunities or 0.0003 per cent (Chakrabarty & Tan, 2007).

Six Sigma is a business strategy used to improve business profitability, to improve the effectiveness and efficiency of all operations to meet or exceed customer needs and expectations (Kwak & Anbari, 2006).

Six Sigma is an organised and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions on customer defined defect rates (Linderman, Schroeder, Zaheer, & Choo, 2003).

2.4 The Statistical Basis of Six Sigma

Product with many parts or complexity manufacturing processes typically has many opportunities for failure or defects to occur (Montgomery, 2009). The main concentration of Six Sigma implementation is to reducing variability in key product quality characteristics to the level at which defects are tremendously unlikely (Montgomery, 2009). Furthermore, the standard deviation (σ) illustrates the deviation or rate of defects from the statistical mean (Heckl, Moormann, & Rosemann, 2010). Figure 2-1 to 2-3 shows various aspects of a normal distribution as it applies to Six Sigma project measure and the consequence of the 1.5σ shift.

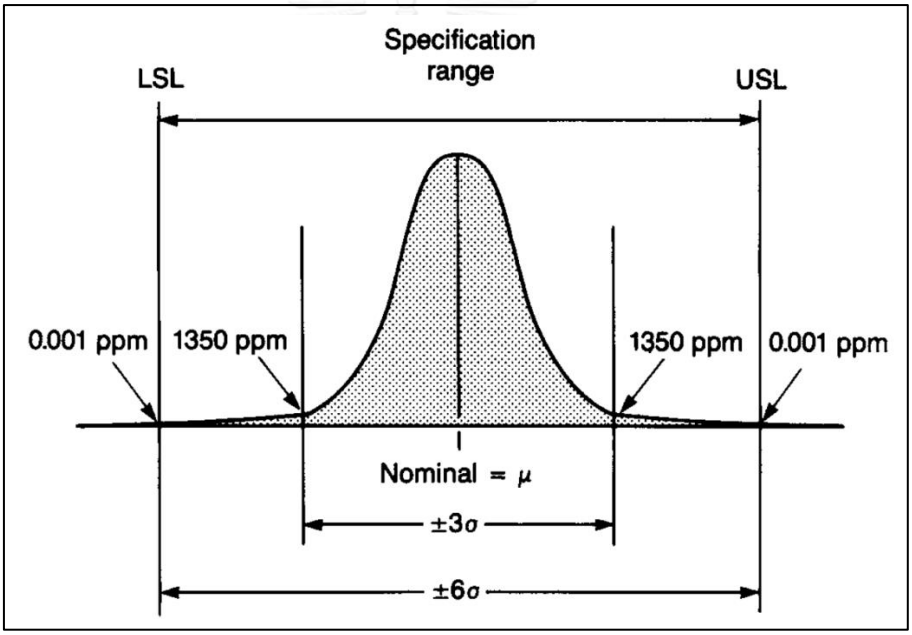
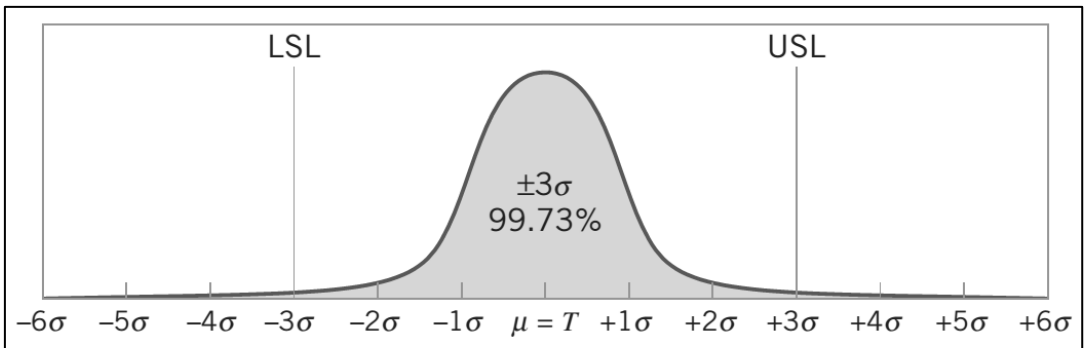


Figure 2-1: Normal distribution curve illustrates the Three Sigma and Six Sigma parametric conformance (Breyfogle, 2003)

As for figure 2-1, the graph displays the basic measurement concept of Six Sigma according to which parts are to be manufactured consistently and well within their specification range. Figure 2-2 illustrates a normal probability distribution as a model for a quality characteristic with the specification limits at three standard deviation on either side of the target mean and this is observed that in Three Sigma process the probability of

producing a product within these specifications is 0.9973 or 2700 parts per million (ppm) defective (Montgomery, 2009). However, with a centred normal distribution between Six Sigma limits, there will only be about two parts per billion defective fail to meet the specification target 0.9999998 per cent specification or 0.002 ppm defective (Breyfogle, 2003; Montgomery, 2009). In a Three Sigma method the values are widely spread along the centre line, presenting the higher variation of the process, whereas in a Six Sigma method, the values are closer to the centre line displaying less variation in the process.

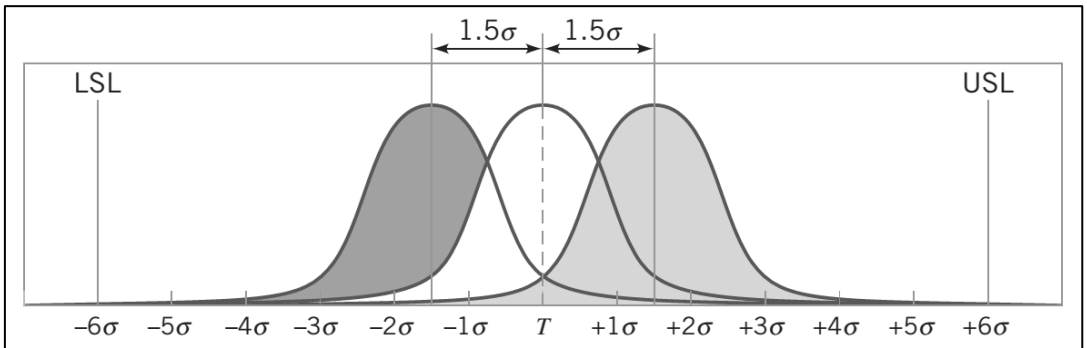


Spec. Limit	Percent Inside Specs	ppm Defective
±1 Sigma	68.27	317300
±2 Sigma	95.45	45500
±3 Sigma	99.73	2700
±4 Sigma	99.9937	63
±5 Sigma	99.999943	0.57
±6 Sigma	99.9999998	0.002

Figure 2-2: Normal distribution centred at the target (T) (Montgomery, 2009)

In reality practice, all company certainly desire that the process mean to be retained at the target value; however, the process mean during one time period is commonly diverse from that of another time period for numerous causes (Park, 2003). As a result, the process mean constantly shifts around the mean target value (Park, 2003). Breyfogle (2003); Park (2003); and Montgomery (2009) all emphasises the important that no process or system is ever truly stable and cause disturbance to the process and perpetual fluctuation of output. Thus, Motorola added correction of the shift value ±1.5σ to the process mean (Park, 2003) as shows in figure 2-3. According to figure 2-3, the effects of a

1.5σ shift for Six Sigma process would produce approximately only 3.4 ppm defective or 99.99966 per cent quality level (Breyfogle, 2003; Montgomery, 2009; Park, 2003).



Spec. Limit	Percent inside specs	ppm Defective
±1 Sigma	30.23	697700
±2 Sigma	69.13	608700
±3 Sigma	93.32	66810
±4 Sigma	99.3790	6210
±5 Sigma	99.97670	233
±6 Sigma	99.999660	3.4

Figure 2-3: Normal distribution with the mean shifted by ±1.5σ from the target (Montgomery, 2009)

2.5 Six Sigma Performance Measurements

One of the essential components of executing any quality control scheme is to measure whether there have been any effects. Six Sigma performance measurements is a review progression that should be performed on a regular basis (Sundaram & McDonough, 2013).

According to Ravichandran (2007), one of the performance measures of an organisation in a Six Sigma process is the Sigma quality level and defective parts per million (DPPM). Breyfogle (2003) states that the Sigma quality level or Sigma level is used as a measurement with a Six Sigma project includes a ±1.5σ value to account for typical shifts and drifts of the mean. Table 2-1 shows the Sigma quality level that associate to defect rate and organisational performances with and without the shift by 1.5σ. This sigma quality level relationship with the 1.5σ shift can be approximated by the equation 2.1

(Breyfogle, 2003) referred to (Schmidt & Launsby, 1997). In addition, figure 2-4 demonstrates the relationship between defect rate and Sigma quality level which considering the 1.5**σ** shift of the mean.

$$\text{Sigma quality level} = 0.8406 + \sqrt{29.37\text{-}2.221\times \ln(\text{dppm})} \qquad (2.1)$$

Table 2-1: The Six Sigma quality level scale (Park, 2003)

Sigma quality level	Process mean, fixed		Process mean, with 1.5σ shift	
	Non-defect rate (%)	Defect rate (ppm)	Non-defect rate (%)	Defect rate (ppm)
σ	68.26894	317,311	30.2328	697,672
2σ	95.44998	45,500	69.1230	308,770
3σ	99.73002	2,700	93.3189	66,811
4σ	99.99366	63.4	99.3790	6,210
5σ	99.999943	0.57	99.97674	233
6σ	99.9999998	0.002	99.99966	3.4

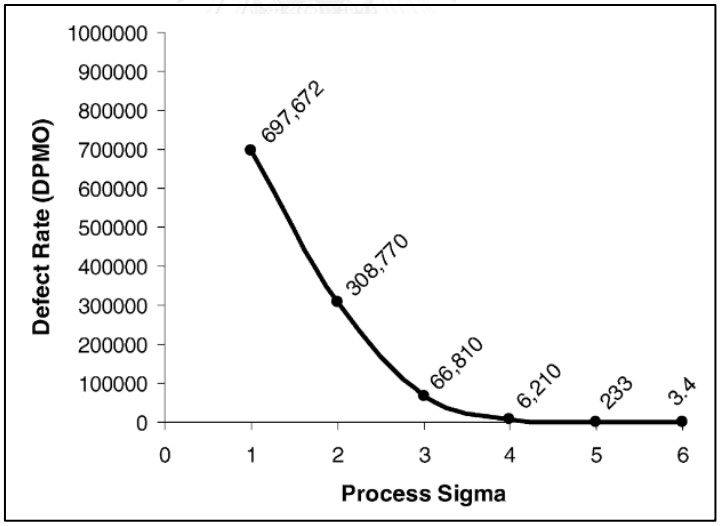


Figure 2-4: Defect rate (DPMO) versus Process Sigma Level (Linderman et al., 2003)

Harry (1998) suggests Table 2-2 that indicates how the industries are categorised based on the Sigma quality level and the number of defect parts per million (DPPM) and the organisation can be categorised as either 'world class' or 'industry average' or non-competitive'; moreover, this table would be applicable to any product, process, or service. The higher the Sigma level, lower the DPPM number. The Sigma level between 6.0 and 5.0

(3.4 to 233 defects per million) is considered as world class, The Sigma level of 4.0 and 3.0 (6,210 to 66,807 defects per million) is considered as industry average, and the Sigma level of 2.0 and 1.0 (308,537 to 690,000 defects per million) is considered as non-competitive.

Table 2-2: Sigma quality level and defect parts per million defining class of industry (Harry, 1998)

Sigma	Parts per million	Cost of poor quality	Category
6 sigma	3.4 defects per million	<10% of sales	World class
5 sigma	233 defects per million	10-15% of sales	
4 sigma	6,210 defects per million	15-20% of sales	Industry average
3 sigma	66,807 defects per million	20-30% of sales	
2 sigma	308,537 defects per million	30-40% of sales	Non-competitive
1 sigma	690,000 defects per million		

In addition, figure 2-5 proposes by Breyfogle (2003) shows that the Sigma quality level related with several processes (considering the 1.5σ shift of the mean). As for the figure 2-5, Breyfogle (2003) claims that the Six Sigma quality level of most organisation (industry average) is about four, whereas the world class performance is considered six; moreover, the Sigma quality level of the airline industry is above six.

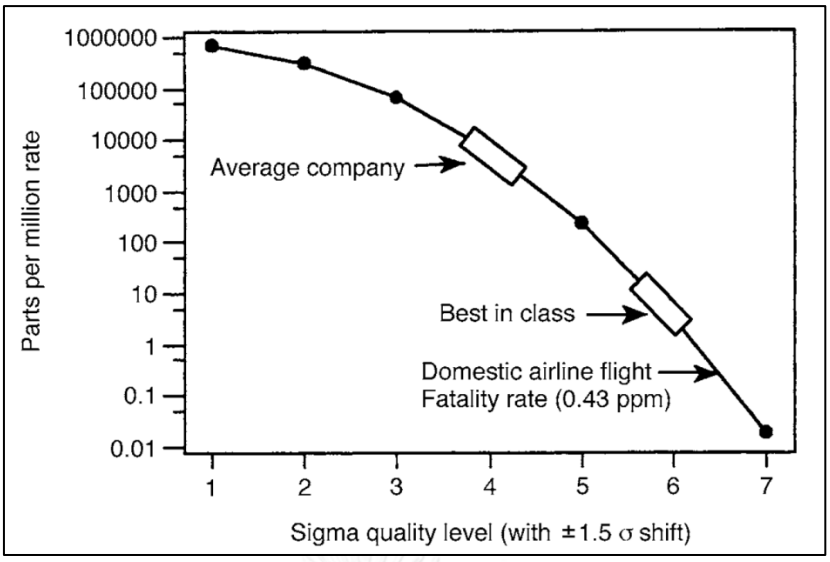


Figure 2-5: Implication of the Six sigma quality level and parts per million (ppm) rate for part or process step (Breyfogle, 2003)

On the other hand, another way to measure the quality performance is process capability. A Six Sigma quality level process can be converts to process capability index values for potential process capability index (C_p) and process capability index (C_{pk}) requirement of 2.0 and 1.5, respectively (Breyfogle, 2003). Table 2-3 shows the relationship between process capability index and sigma level.

Table 2-3: Relationship between C_p, C_{pk} and Sigma quality level (Breyfogle, 2003)

Cp	***Cpk* (5.1σ shift is allowed)**	**Quality level**
0.50	0.00	1.5 σ
0.67	0.17	2.0 σ
0.83	0.33	2.5 σ
1.00	0.50	3.0 σ
1.17	0.67	3.5 σ
1.33	0.83	4.0 σ
1.50	1.00	4.5 σ
1.67	1.17	5.0 σ
1.83	1.33	5.5 σ
2.00	1.50	6.0 σ

2.6 Six Sigma DMAIC Methodology

The tools of Six Sigma and operational excellence are most often applied within the DMAIC methodology. DAMAIC is an integral part of a Six Sigma initiative. DMAIC refers to a data-driven life-cycle approach to Six Sigma programme for improving process (Sokovic, Pavletic, & Pipan, 2010). Hahn et al. (2000) emphasises the important of implementation of the DMAIC process is heavily based on statistical tools and the statistical design of experiments and aimed mainly at reducing defect rates in existing products, processes, and services. In addition, a similar view is held by Aboelmaged (2010) states that DMAIC is used to improve already existing products and processes. Banuelas, Antony, and Brace (2005) takes the stance that the principal concentration of Six Sigma is to moderate potential variability from processes and products by using a continuous improvement methodology which referred to DMAIC methodology and is engaged in attempting problems or difficulties associated with current processes and products.

More significantly, the DMAIC methodology that use in process improvement provide a standardised method for the teams to follow, and advocate applicable tools to use at each step of the DMAIC methodology, as well as systematic project management tools, which improves their problem-solving capability (Kwak & Anbari, 2006; Zu, Fredendall, & Douglas, 2008).

DMAIC methodology assists the practitioners to define the potential causes that create the defect in existing process and analyse processes in order to eradicate source of undesirable defects or variations, and develop alternatives to eliminate or reduce these variation. After improvements are engaged, controls are put in place to certify sustained results (Harry, 1998). Hahn et al. (2000) and Aboelmaged (2010) claims that Six Sigma is a highly disciplined approach that typically involves the five fundamental stages including; Define, Measure, Analyse, Improve, and Control. Several author concluded each phases of DMAIC methodology as described below (Aboelmaged, 2010; Antony, Downey-Ennis,

Antony, & Seow, 2007; Hahn et al., 2000; Montgomery, 2009; Park, 2003; Pyzdek, 2003a; Stamatis, 2002a).

Define (D) the problem within a process: Identify the main steps in the process that is to be improved. Define the problem to be solved, including customer impact and potential benefits. Identify the critical-to-quality characteristics (CTQs) of the product or service. Define project scope and timescales.

Measure (M) the defects: Collect information on how well the existing process achieves the measures that were selected in the define stage. Identify measurement, variation, and determine data type. Verify measurement capability. Baseline the current defect rate and set goals for improvement.

Analyse (A) the causes of defects: Identify source of variation or factors that affect the process and that contribute to the problems that were identified in the measure stage. Understand root cases of why defects occur; identify key process variable that cause defects and perform testing and analysis to accomplish the goal.

Improve (I) the process performance to remove cause of defects: Use the understanding of the factors identified in the analyse phase to come up with possible improvement solution. Use systematic testing to decide between alternative approaches and confirm that the offered solutions work as anticipated. Quantify influences of key process variables on the CTQs, identify acceptable limits of these variables, and modify the process to stay within these limits, thereby reducing defect levels in the CTQs.

Control (C) the process to make sure defects does not return: Develop control strategy and control plan to put in place monitoring and control systems to lock in the improvement. Ensure that the modified process now keeps the key process variables within acceptable limits, in order to maintain the gains long term.

DMAIC is an integral part of Six Sigma project (Pyzdek, 2003a). Moreover, Pyzdek (2003a) and Montgomery (2009) holds the view that DMAIC methodology is a 'gated process' (Pyzdek, 2003a) or 'tollgates' (Montgomery, 2009) between each major phases in DMAIC process for a project control. Gates/Tollgates are where the project is reviewed to confirm that is on track and determined that all of the criteria have been met, and they offer an on-going opportunity to assess whether the team can effectively complete the project on schedule (Montgomery, 2009; Pyzdek, 2003a). Figure 2-6 and figure 2-7 illustrates the DMAIC process on a Six Sigma project and typical DMAIC process, respectively.

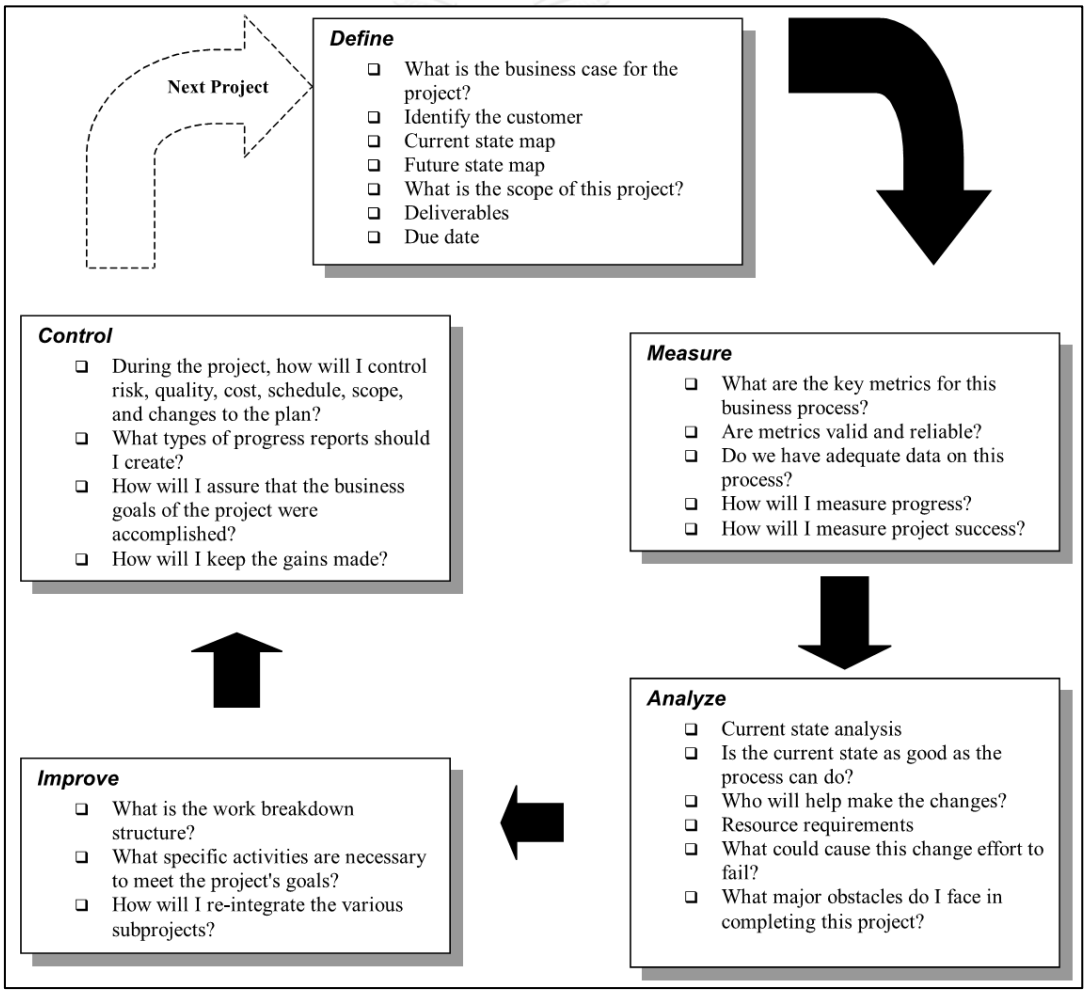


Figure 2-6: DMAIC process on a Six Sigma project (Pyzdek, 2003a)

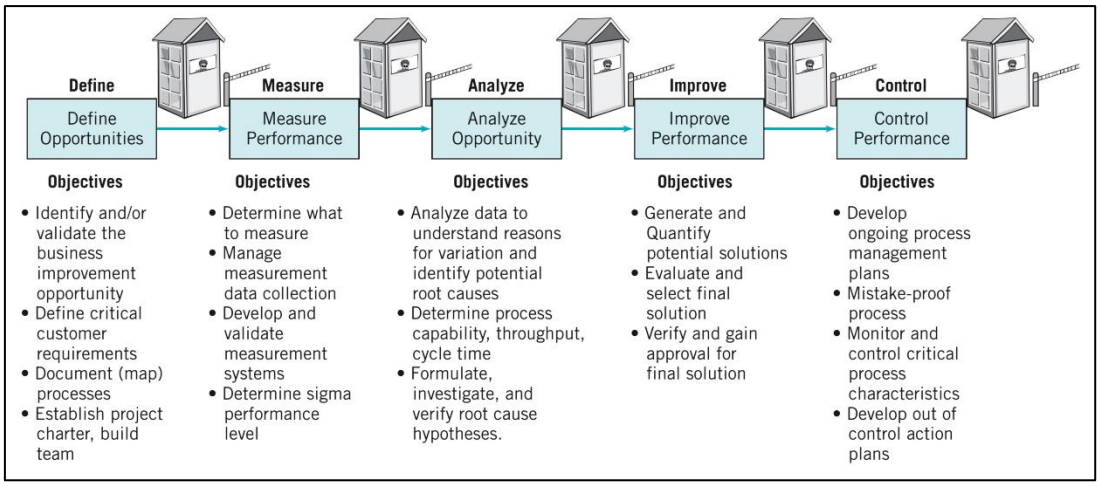


Figure 2-7: The DMAIC process (Montgomery, 2009)

According to Aboelmaged (2010), there are various tools and techniques that can implement in Six Sigma DMAIC methodology by Six Sigma project teams to attack quality related issues for fostering performances improvement. Examples of Six Sigma tools include Pareto analysis, process mapping, root cause analysis, run charts, Gantt chart, affinity diagrams, histograms, brainstorming, quality function deployment (QFD), Kano model, etc. (Aboelmaged, 2010). Examples of Six Sigma techniques include Supplier-Input-Process-Output-Customer (SIPOC), statistical process control (SPC), process capability analysis, benchmarking, SERVQUAL, etc. (Aboelmaged, 2010). Table 2-4 reveals the most obvious tools, laterally with the DMAIC methodology where are almost certainly to be used (Montgomery & Woodall, 2008).

Table 2-4: Several tools use in DMAIC process (Montgomery & Woodall, 2008)

Tool	Define	Measure	Analyze	Improve	Control
Project charter	X				
Process maps & flow charts	X	X			
Cause and effect analysis		X			
Process capability analysis		X			
Hypothesis tests, confidence intervals			X		
Regression analysis, other multivariate methods			X		
Gauge R&R		X			
Failure mode & effects analysis			X		
Designed experiments			X	X	
SPC and process control plans		X	X		X

2.6.1 Define Phase

The objective of the define step of DMAIC is to recognise the project opportunity and to validate that it epitomises legitimate breakthrough potential. A project must be important to customers (voice of the customer) and important to the business (Montgomery, 2009).

Project Charter

One of the first items that must be finalised in the define step is a project charter (Montgomery, 2009). Project charter comprises of a description of the project and its scope, the start and the anticipated completion dates and the charter should also identify the customer's critical-to-quality characteristics (CTQs) or customer satisfactions that are influenced by the project (Montgomery, 2009).

The documents in the project charter are including:

- Business Case

This is a sentence that labels why this project should be done, why it has priority over other projects, and specifies the strategic business objective the project influences (Eckes, 2003).

- Problem Statement

This is a short measurable statement about the problem. It should specify how long the problem has been going on, be stated as explicitly as possible, describe the gap between the current and desired state, define the influence of the problem, and be stated in neutral terms with no blame, perceived solutions or root causes (Eckes, 2003).

- Objective Statement

The goals and objectives are what the team should attempt to accomplish in the four to six months they exist. Typically, a first wave Six Sigma team should aim at improving the problem by 50 per cent (Eckes, 2003).

- Project Scope

Project scope denotes to what the team must focus on, but more significantly what the team should try to avoid. Six Sigma teams frequently fail when they don't noticeably define what to focus on and what not to focus on (Eckes, 2003).

- Project Plan

Project plan or schedule indicates to the team where they should be in the DMAIC process and when. For instance, Define and Measure phases should take no more than 8 weeks of the project. Analyse phase should take no more than 6 weeks after Measure phase. Improve phase should be implemented in the next 12 weeks. As a consequence of this plan, the team should be ready to implement Control phase at the end of those 12 weeks devoted to Improvement implementation (Eckes, 2003).

- Six Sigma Team

Six Sigma team working on projects are the principal mean of implementing Six Sigma and achieving the goals of the organization (Pyzdek, 2003a). In addition, Six Sigma team are consisted of groups of individuals who bring authority, knowledge, skills, abilities, and personal attributes to the Six Sigma project (Pyzdek, 2003a).

Voice of Customer (VOC)

Customers play significant roles in a Six Sigma initiative and customer satisfaction is one of the major objectives for a Six Sigma company (Park, 2003). Therefore, the company should identify the acceptance criteria from the customer or what is customer really wants. (Stamatis, 2002a) and (Montgomery, 2009) states that VOC data is usually acquired by customer interviews, a direct interaction with and observation of the customer, through focus group, by surveys, and by analysis of customer satisfaction data as shows in figure 2-5.

In addition, the main purposes of VOC activities are to develop a set of critical to quality (CTQs) requirement for the product or service (Antony et al., 2007; Montgomery, 2009). CTQs are one that impacts on the fitness for use of the product or service produced

by the process (Pyzdek, 2003b). This is in line with view of De Mast (2004). De Mast (2004) states that CTQs are those quality characteristics that are the subject of the improvement project or process.

Montgomery (2009) claims that quality characteristics may be of several types:

- Physical: length, weight, voltage, viscosity, etc.
- Sensory: taste, appearance, colour
- Time orientation: reliability, durability, serviceability

Table 2-5: Customer requirements collection method interrelation matrix (Stamatis, 2002a)

Intervention level	Structure	Methods
High intervention	Unstructured interviews	Phone call to customer Visit with management or customer group Customer visit
↕	Process participation	Visit with customer in their environment Contextual inquiry (involves the collection of data by asking questions while observing and documenting customers' behaviors)
↕	Observing customers	Focus groups Gathering evidence of customer behavior (passive observation)
Low intervention		

Process Maps & Flow Chart

A process is defined as a combination of factors or activities that lead to the production of some output, whether that is a product or a service. A process is certainly a conversion of inputs to outputs (Stamatis, 2002a). According to Montgomery (2009), graphic aids are beneficial in the define step; the most frequent ones used consist of process maps and flow charts, and the SIPOC diagram. A process map is a graphic illustration of a process, presentation the structure of tasks (Pyzdek, 2003a). The SIPOC diagram (see figure 2-8) is a high-level map of a process (Breyfogle, 2003; Montgomery, 2009). SIPOC is an acronym for Suppliers, Input, Process, Output, and Customers, defined as:

S: Supplier is whoever provides the inputs to your process

I: Input is materials, resources, and data required to execute the process

P: Process is Value-added transformation of inputs to outputs

O: Output is the tangible or services that results from the process

C: Customer is whoever receives the outputs of that process

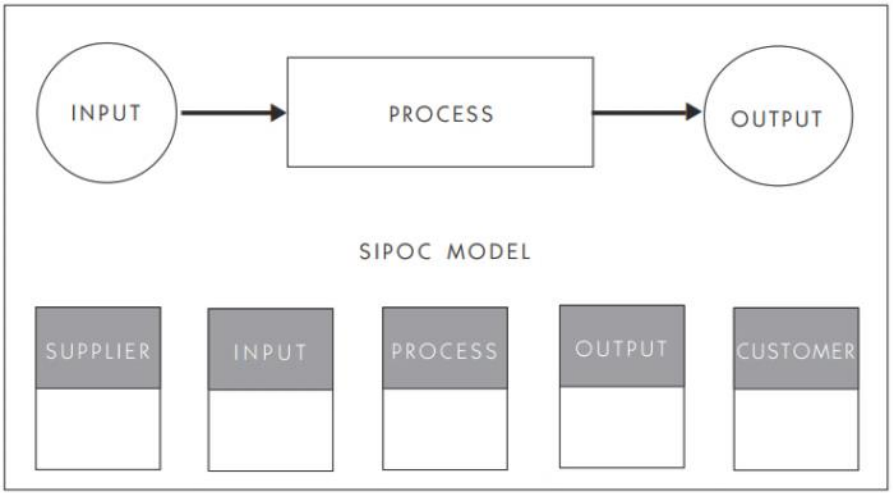


Figure 2-8: SIPOC Diagram (Khanduja & Kaushik, 2008)

A process flow chart is basically a tool that graphically shows the inputs, actions, and outputs of a given system (Pyzdek, 2003a). A process flow chart provides a complete graphic sequence of what happens from start to finish of a procedure (Breyfogle, 2003). Figure 2-9 demonstrates the form of a process flow chart.

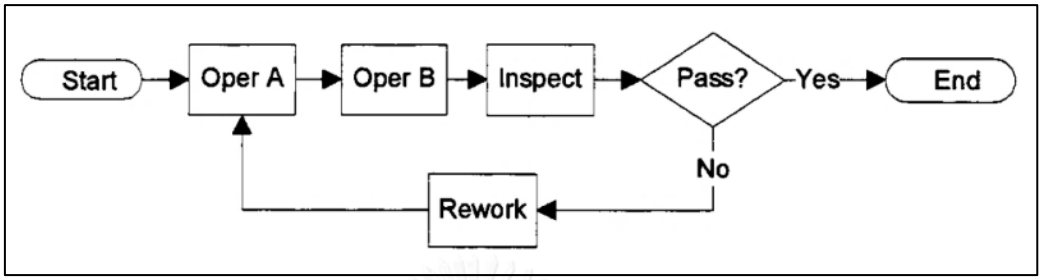


Figure 2-9: Process flow chat (Breyfogle, 2003)

2.6.2 Measure Phase

The measure phase identifies the defects in the product, gathers valid baseline information about the process (Khanduja & Kaushik, 2008), and to evaluate and understand the current state of the process (Montgomery, 2009).

Measurement System Analysis (MSA)

Montgomery (2009) claims that measurements are an important element of any quality system. According to Automotive Industry Action Group (AIAG) (2002) referred to Eisenhart (1963), measurement is defined as "the assignment of numbers or values to material things to represent the relations among them with respect to particular properties."

Measurement Systems Analysis (MSA) is used comprehensively in DMAIC, essentially during the measure phase (Montgomery, 2009). MSA is a collection of statistical methods which includes the Gage Repeatability and Reproducibility (Gage R&R) study for the analysis of measurement system capability (Automotive Industry Action Group (AIAG),

2002). In addition, a measurement is characterised by location and width (spread) (Automotive Industry Action Group (AIAG), 2002; Breyfogle, 2003).

- Location variation

Accuracy is the degree of agreement of individual or average measurements with an accepted reference value or level (Breyfogle, 2003), or closeness to the true value, or to an accepted reference value (Automotive Industry Action Group (AIAG), 2002).

Bias is the different between the observed average of measurements and the reference value (Automotive Industry Action Group (AIAG), 2002).

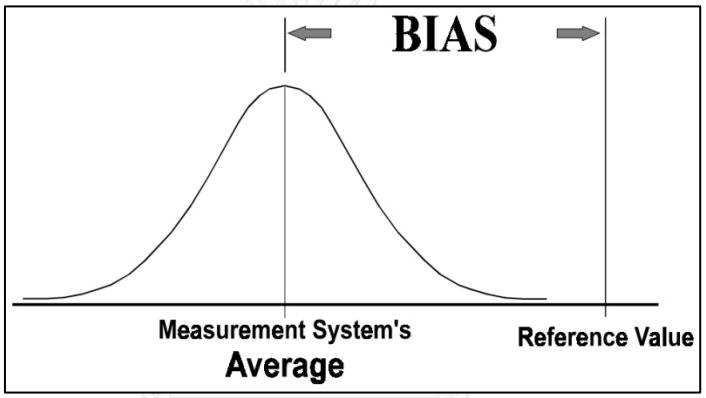


Figure 2-10: Bias illustrated (Automotive Industry Action Group (AIAG), 2002)

Stability is the total variation in the measurements obtained with a measurement system on the same master or parts when measuring a single characteristic over an extended time period or a change in bias over time (Automotive Industry Action Group (AIAG), 2002).

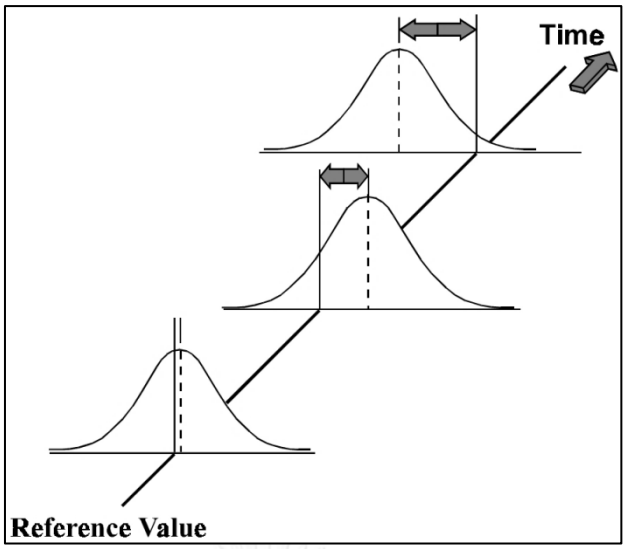


Figure 2-11: Stability illustrated (Automotive Industry Action Group (AIAG), 2002)

Linearity is the differences in observed accuracy and/or precision experienced over the range of measurements made by the system (Montgomery, 2009), or the change in bias over the normal operating range (Automotive Industry Action Group (AIAG), 2002).

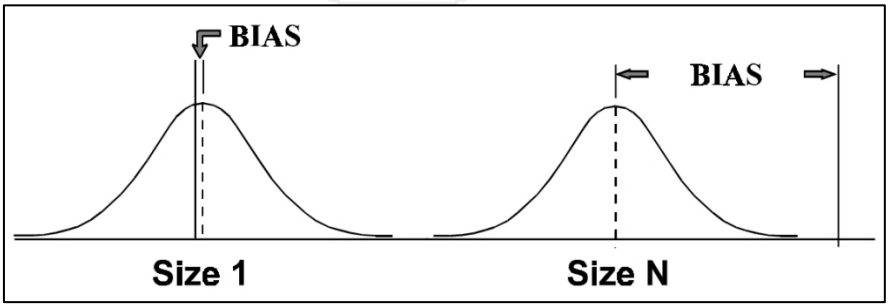


Figure 2-12: Linearity illustrated (Automotive Industry Action Group (AIAG), 2002)

- Width variation

Precision is the degree of mutual agreement among individual measurements made under prescribed like conditions (Breyfogle, 2003), or closeness of repeated reading to each other (Automotive Industry Action Group (AIAG), 2002).

Repeatability is a variation in measurements obtained with one measuring instrument when used numerous times by one appraiser while measuring the identical characteristic on the same part (Automotive Industry Action Group (AIAG), 2002). In simple expression, do we get the same observed value if we measure the same unit several times under identical conditions (Montgomery, 2009). Repeatability is regularly referred to as equipment variation (EV), although this is misleading. In fact, repeatability is the common cause (random error) variation from successive trials under defined conditions of measurement (Automotive Industry Action Group (AIAG), 2002).

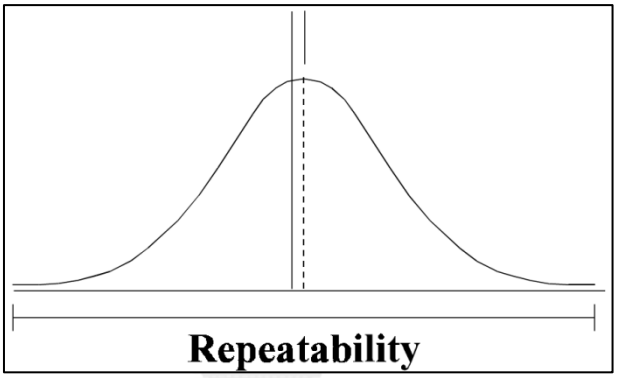


Figure 2-13: Repeatability illustrated (Automotive Industry Action Group (AIAG), 2002)

Reproducibility is variation in the average of the measurements made by different appraisers using the same gage when measuring the identical characteristic on the same part (Automotive Industry Action Group (AIAG), 2002). In simple expression, how much difference in observed values do we experience when units are measured under different conditions, such as different operators, time periods, and so forth (Montgomery, 2009). This is frequently true for manual instruments subjective by the expertise of the appraiser.

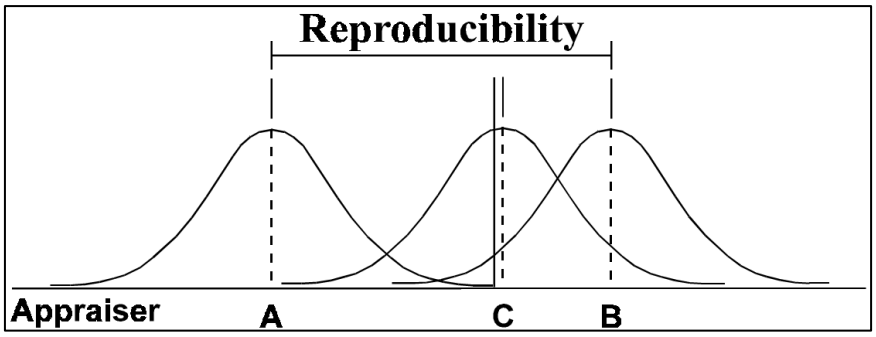


Figure 2-14: Reproducibility illustrated (Automotive Industry Action Group (AIAG), 2002)

In addition, figure 2-5 reveals the concepts of accuracy and precision.

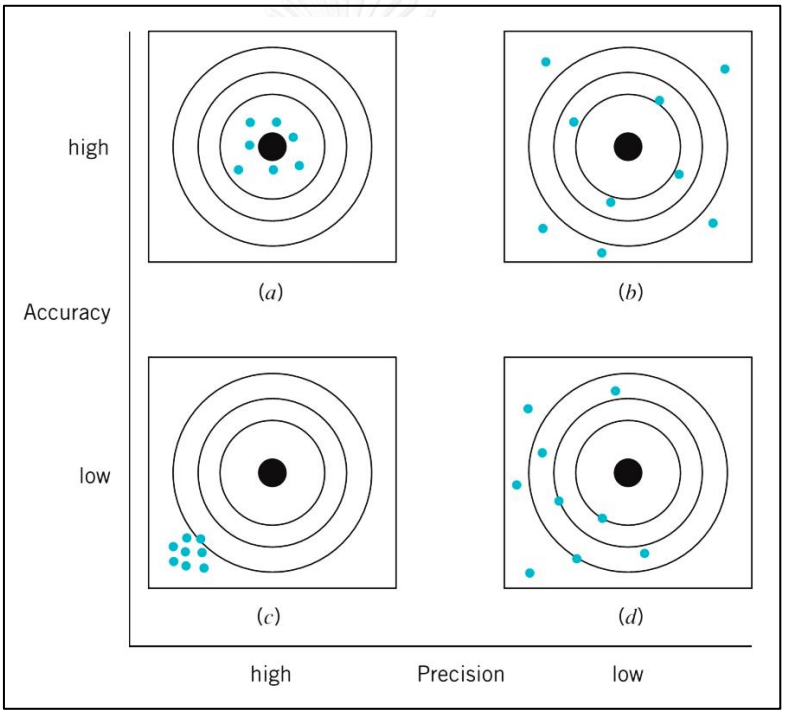


Figure 2-15: The concepts of accuracy and precision. (a) the gage is accurate and precise. (b) the gage is accurate but not precise. (c) the gauge is not accurate but it precise. (d) the gauge is neither accurate nor precise (Montgomery, 2009)

Gage Repeatability & Reproducibility (Gage R&R) is implemented for analysing measurement variation of a gage (repeatability) and determining the variation of measurements by appraisers (reproducibility). Moreover, gage capability analysis is a vital element to improve a measurement system and is an integral part of efficient process

control (Lyu & Chen, 2008). Wooall and Borror (2008) claims that Gage R&R studies are widely used to assess measurement system variation relative to process variation and tolerance limits.

MSA for Attribute Data

Attribute data consist of classifications rather than measurements (Pyzdek, 2003a). Attribute inspection involves determining the classification of an item such as pass/fail, good/bad, go/no go, accept/reject, etc. (Montgomery, 2009; Pyzdek, 2003a) In addition, nominal or ordinal data is also relatively common (Montgomery, 2009).

An attribute gage either accepts or rejects a part after comparison to a set of limits. Unlike a variable gage, an attribute gage cannot quantify the degree to which a part is good or bad (Breyfogle, 2003). MSA factors impacting variation in attribute study including gage, appraiser, method, part, and environment.

According Automotive Industry Action Group (AIAG) (1995), attribute gage study can be categorise into two method including long method and short method. For long method attribute gage study, the concept of Gage Performance Curve (GPC) is used for developing a gage study, which is used to assess the amount of repeatability and the bias of the gage and this analysis can be used on both single and double limit gage. Generally, the attribute measurement system study consists of obtaining the reference values for several selected parts. These parts are evaluated a number of times with the total number of accepts for each part being recorded. From the results, repeatability and bias can be assessed (Automotive Industry Action Group (AIAG), 2002). To determine if the bias is significantly different from zero, the following statistic is used:

$$t = \frac{31.3 \times |\text{Bias}|}{\text{Repeatability}} \qquad (2.2)$$

The repeatability is determined by finding the differences of the reference value measurements corresponding a Pa = 0.995 and a Pa =0.005 and dividing by an adjustment factor of 1.08 (Automotive Industry Action Group (AIAG), 2002).

Automotive Industry Action Group (AIAG) (1995); Chieh (2010); and Gygi, DeCarlo, and Williams (2005) suggests the step to perform short method attribute gage study as explains below:

1. Select the test samples of what is being measured that represent the full range of variation that is normally encountered. Essentially, it is desirable that some of the parts are slightly below and above both specification limit. For maximum confidence, a half of the samples being ‘good’ and the other half ‘bad’ is recommended.
2. Have a master appraiser (master standard) categorise each test sample into its true attribute category.
3. Select two to three appraisers and have them categorise each test sample without knowing what the master appraiser has rated them.
4. Place the test samples in a new random order and have the appraisers repeat their assessments.
5. For each appraiser, count the number of times his or her two readings agree. Divide this number with the total inspected to obtain the percentage of agreement. This is the repeatability for each appraiser.
6. Calculate the number of times each appraiser’s two assessments agree with each other and also the standard produced by the master appraiser.
7. Calculate the percentage of times all appraisers’ assessments agree for the first and second measurement for each sample item and calculate the percentage of the time all the appraisers’ assessments agree with each other and with the standard. This is the reproducibility for the measurement system.

This percentage gives the overall effectiveness of the measurement system (Chieh, 2010). Moreover, a typical form for the short method attribute gage study is illustrated in table 2-6.

Table 2-6: Attribute Gage Study (short method) (Automotive Industry Action Group (AIAG), 1995)

SAMPLE	APPRAISER A		APPRAISER B	
	1	2	1	2
1	G	G	G	G
2	G	G	G	G
3	NG	G	G	G
4	NG	NG	NG	NG
5	G	G	G	G
6	G	G	G	G
7	NG	NG	NG	NG
8	NG	NG	G	G
9	G	G	G	G
10	G	G	G	G
11	G	G	G	G
12	G	G	G	G
13	G	NG	G	G
14	G	G	G	G
15	G	G	G	G
16	G	G	G	G
17	G	G	G	G
18	G	G	G	G
19	G	G	G	G
20	G	G	G	G

Cause-and-Effect Diagram

After a defect or problem has been recognised and isolated for further study, it is essential to analyse potential causes of this undesirable effect (Montgomery, 2009). The cause-and-effect diagram is a formal tool regularly useful in un-layering potential causes (Montgomery, 2009). Cause-and-effect diagram is popular diagram that are used to organise and graphically display all of the knowledge a group has relating to a particular problem (Pyzdek, 2003a), and also known as an Ishikawa diagram or fishbone diagram was developed in 1950 by the late Professor Kaoru Ishikawa (Breyfogle, 2003; Juran & Godfrey, 1999). Cause-and-effect diagram is an effective tool as part of a problem-solving process and this technique is suitable to generate ideas and promote a balanced approach in group brainstorming meetings where individuals list the perceived sources (causes) with respect to outcomes (effect) (Breyfogle, 2003; Park, 2003).

Figure 2-16 shows the cause-and-effect diagram. It can be seen that the effect is written in a rectangle on the right-hand side, and the causes are listed on the left-hand side. They are connected with arrows to show the cause-and-effect relationship (Park, 2003). Furthermore, When constructing a cause-and-effect diagram, it is often applicable to consider six main causes that can contribute to an outcome response (effect): so-called 5M1E (man, machine, material, method, measurement, and environment) (Breyfogle, 2003; Park, 2003). Each one of these characteristics is then investigated for sub-causes. Sub-causes are specific items or difficulties that are identified as a factual or potential cause to the problem (effect) (Breyfogle, 2003).

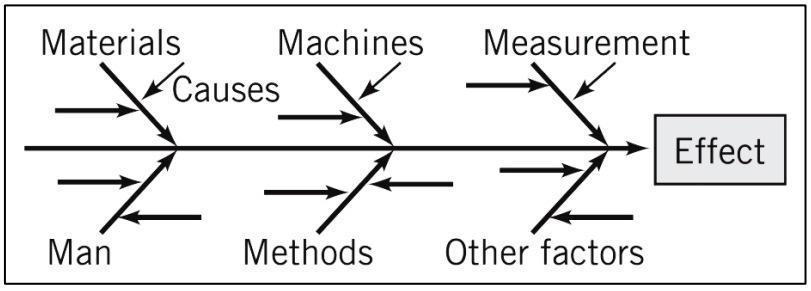


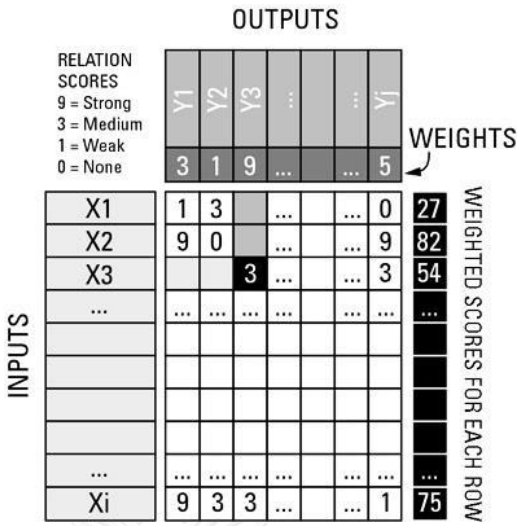
Figure 2-16: Cause-and-Effect Diagram (Montgomery, 2009)

The first step of constructing a cause-and-effect diagram is to agree on the specific wording of the effect and then to identify the main causes that can possibly produce the effect (Park, 2003). The major causes can often be identified as any of 5M1E, and using brainstorming techniques, each main cause is analysed (Park, 2003). The same procedure is then followed for each of the other main causes. In addition, with the cause-and-effect diagram, the technique can be useful, for example, to generate the inputs to a cause-and-effect matrix (Gygi et al., 2005), and to determine the factors to consider within a regression analysis or DOE (Breyfogle, 2003).

Cause-and-Effect Matrix

The cause-and-effect matrix is a tool that can support with the prioritisation of significance of process input variables. This relational matrix prioritisation by a team can help with the selection of what will be monitored to determine if there is a cause and effect relationship and whether key process input controls are required (Breyfogle, 2003). The cause-and-effect matric is an extension of the cause-and-effect diagram which helps to identify, explore, and graphically display all of the possible causes related to a problem or condition and search for the root cause (Gygi et al., 2005). The results of a cause-and effect matrix can be carry forward into future activities such as failure mode and effect analysis (FMEA), multi-vari charts, correlation analysis, and DOE (Breyfogle, 2003; Gygi et al., 2005). An example of cause-and-effect matrix is shown in table 2-7.

Table 2-7: Example of cause-and-effect matrix (Gygi, DeCarlo, & Williams, 2014)



The step to construct a cause-and-effect matrix (Breyfogle, 2003) are describe following:

1. List horizontally the key process output variables that were identified when documenting the process. These variables are to represent what the customer of the process considers important and crucial.

2. Allocate a prioritisation number for each key process output variable, where higher numbers have a larger priority (e.g., using values from 1 to 10). These values do not need to be sequential.

3. List vertically on the left side of the cause-and-effect matrix all key process input variables that may cause variability or non-conformance to one or more of the key process output variables.

4. Reach by consensus the amount of effect each key process input variable has on each key process output variable. Rather than use values from 1 to 10 (where 10 indicates the largest effect), consider a scale using levels 0, 1, 3, and 5 or 0, 1, 3, and 9.

5. Determine the result for each process input variable by first multiplying the key process output priority (step 2) by the consensus of the effect for the key process input variable (step 4) and then summing these products.

6. The key process input variables can then be prioritized by the results from step 5 and/or a percentage of total calculation.

Pareto Chart

Pareto charts are a tool that can be supportive in identifying the source of chronic common causes in a manufacturing process (Breyfogle, 2003). Pareto analysis is the process of ranking opportunities to determine which of many potential opportunities should be chased first (Pyzdek, 2003a). The Pareto principle fundamentally states that a vital few of the manufacturing process characteristics cause most of the quality problems on the line, while a trivial many of the manufacturing process characteristics cause only a small portion of the quality problems (Breyfogle, 2003). It is also known as ‘‘separating the vital few from the trivial many’’ (Pyzdek, 2003a). Figure 2-17 displays the example of Pareto chart. It can be seen that Pareto Chart combines a bar graph with a cumulative line graph. The bars are placed from left to right in descending order. The cumulative line graph shows the per cent contribution of all preceding bars. The Pareto Chart shows where effort can be focused for maximum benefit. It may take two or more Pareto Charts to focus the problem to a level that can be successfully analysed.

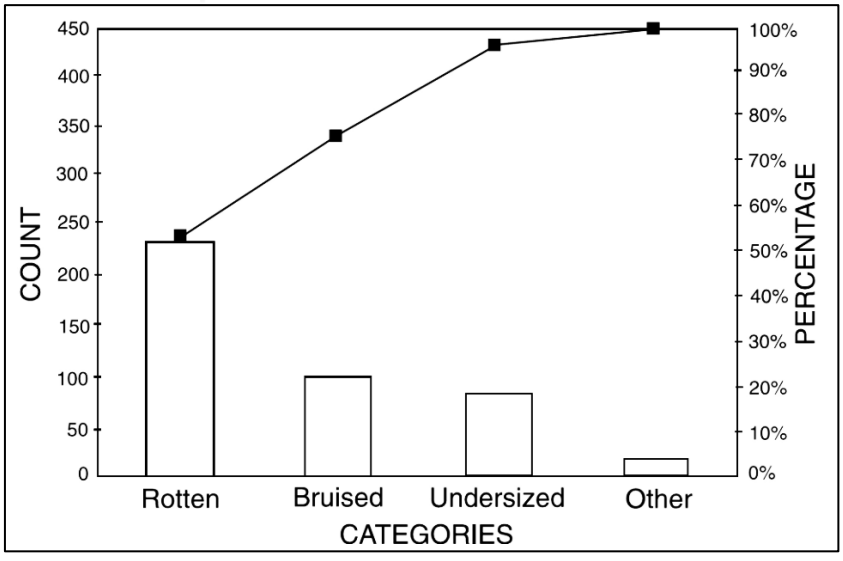


Figure 2-17: Example of Pareto Chart (Pyzdek, 2003a)

Significantly, Pareto chart has two primary applications in the Six Sigma improvement methodology. One is for selecting appropriate improvement projects in the define phase. Here it offers a very objective basis for selection, based on, for instance, frequency of occurrence, cost saving and improvement potential in process performance (Park, 2003). The other primary application is in the analyse phase for identifying the vital few causes that will constitute the greatest improvement in if appropriate measures are taken (Park, 2003).

Failure Mode and Effect Analysis (FMEA)

Failure mode and effects analysis (FMEA) was first proposed by NASA in 1963 for their obvious reliability requirements (Bahrami, Bazzaz, & Sajjadi, 2012). FMEA is a recognised technique for quality improvement of products and processes (Breyfogle, 2003; De Souza & Carpinetti, 2014). FMEA technique is a very powerful and effective analytical tool which is widely used in engineering projects based on team working which normally can be used for identify activities which can reduce or eliminate the unintended of potential error occurrence in a system or process and will manage on the implementation and documentation of these activities (Bahrami et al., 2012; Yu, Yang, Liu, & Pan, 2011). FMEA can be defined as a set of organised activities that are used to identification and estimation of potential errors in a product or process and outcomes results from these errors, and determination of activities which can reduce or eliminate probability occurrence of potential errors (Bahrami et al., 2012).

Basically, FMEA is a systematic approach for prioritisation of improvement actions based on the analysis of severity, occurrence and detectability of failure modes (De Souza & Carpinetti, 2014). In addition, Montgomery (2009) claims that FMEA is another useful tool during analyse phase of DMAIC methodology. FMEA is used to prioritize the different potential sources of variability, failures, errors, or defects in a product or process by using the steps outlined in Table 2-8.

Table 2-8: Three phases of FMEA (Kmenta & Ishii, 2001)

Task	Method
Identify *what can go wrong*	Determine failure dependencies: (Causes → Failure Modes → Effects)
Evaluate *how likely is it to occur and what are the consequences*	Assess Risk Priority Numbers (**RPN**): (failure occurrence × effects severity × detection difficulty = **RPN**)
Decide *what can be done to reduce the risk*	Optimize design improvements, trade-offs, test plans, manufacturing changes, etc.

The FMEA procedure for defining priorities of improvement is based on the risk priority number (RPN) which in turn is based on the multiplication of three indices (De Souza & Carpinetti, 2014; Press, 2003) resulting from evaluation of:

Severity (S): Severity is the significance of the effects of the failure, ranging from 1 to 10. Severity is an assessment of the failure effects on the end user, local area and in-between areas. The severity rating applies only to the effects. The severity can be reduced only through a change in the design. If such a design change is attainable, the failure can possibly be eliminated.

Occurrence (O): Occurrence is the frequency of the failure - that is, how often the failure can be expected to take place, ranging from 1 to 10.

Detection (D): Detection is the ability to identify the failure before it occurs or reaches the end user/customer, ranging from 10 to 1 (higher the effectiveness, lower the index).

The multiplication of these three measures generates the risk priority number (RPN) to reflect the priority of the failure modes identified. The RPN is basically calculated by multiplying the severity rating, times the occurrence probability rating, times the detection probability rating as illustrates in figure 2-18.

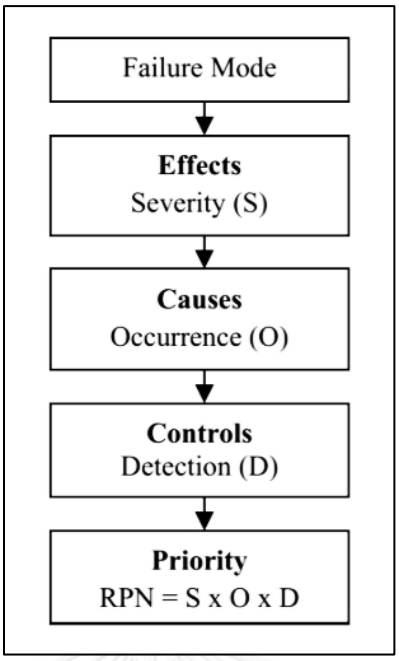


Figure 2-18: The calculation of risk priority number (RPN) (Ben-Daya, Duffuaa, Raouf, Knezevic, & Ait-Kadi, 2009)

Types of FMEA

According to Stamatis (2003), there are numerous kinds of FMEA, but the main ones are:

- System FMEA - These are driven by system functions. A system is an organised set of parts or subsystems to complete one or more functions.
- Design FMEA - A design FMEA is driven by part or component functions. A design/part is a unit of physical hardware that is considered a single replaceable part with respect to repair.
- Process FMEA - A process FMEA is driven by process functions and part characteristics. A manufacturing process is a sequence of tasks that is organised to fabricate a product.

The different types of FMEA are reveals in figure 2-19.

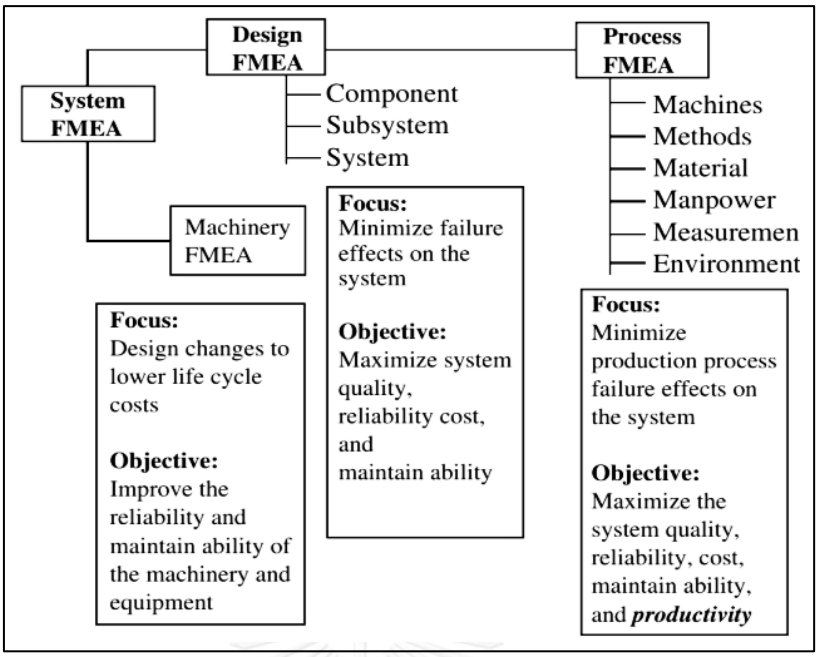


Figure 2-19: Types of FMEA (Stamatis, 2003)

FMEA Process

During an FMEA implementation, the product/process/service/system being reviewed is broken down into smaller items/subsystems. For each item, the following steps are performed (Ben-Daya et al., 2009):

1. Select a high-risk process - The first thing that has to do is to select the process to analyse. The importance of the process in terms of the impact of potential failures is a parameter that has to be taken into account as selection criteria.

2. Review the process - Gather a team that includes people with several job responsibilities and levels of experience. The process could be analysed and described in a flowchart. The purpose of an FMEA team is to take a variety of perspectives and experiences to the project.

3. Brainstorm potential failure modes - Look at each step of the process and identify ways it might potentially fail, or things that might go wrong.

4. List potential effects of each failure mode - List the potential effect of each failure next to the failure. If a failure has more than one effect, write each in a

separate row. To identify the effects and the causes of the effects, the use of Cause and Effects analysis is effective.

5. Assign a severity rating for each effect - Give each effect its own severity rating (from 1 to 10, with 10 being the most severe).

6. Assign an occurrence rating for each failure mode - Collect data on the failures of product's competition. Using this information, determine how likely it is for a failure to occur and assign an appropriate rating (from 1 to 10, with 10 being the most likely).

7. Assign a detection rating for each failure mode and effect - List all controls presently in place to prevent each effect of a failure from occurring and assign a detection rating for each item (from 1 to 10, with 10 being a low likelihood of detection).

8. Calculate the risk priority number (RPN) for each effect - Multiply the severity rating by the occurrence rating by the detection rating.

9. Prioritise the failure modes for action - Decide which items need to be worked on right away. For instance, focusing on the highest RPN first.

10. Take action to eliminate or reduce the high risk failure modes - Determine what action to take with each high risk failure and assign a person to implement the action.

11. Calculate the resulting RPN as the failure modes are reduced or eliminated - Reassemble the team after completing the initial corrective actions and calculate a new RPN for each failure as a mean of monitoring the redesigned improved product or process.

A typical way of documenting the FMEA process is by using a FMEA form shown in Table 2-9. In addition, assigning severity, occurrence, and detection ratings is generally done on a scale from 1 to 10 using tables similar to the ones shown in Tables 2-10, 2-11, 2-12, respectively.

Table 2-9: FMEA Form (Breyfogle, 2003)

POTENTIAL																												
FAILURE MODE AND EFFECTS ANALYSIS																												
FMEA Type (Design or Process):					Project Name/Description:														Date (Orig.):									
Responsibility:								Prepared By:											Date (Rev.):									
Core Team:																			Date (Key):									
Design FMEA (Item/ Function) Process FMEA (Function/ Requirements)	Potential Failure Mode	Potential Effect(s) of Failure	S e v	C l a s s	Potential Cause(s)/ Mechanism(s) of Failure	O c c u r	Current Controls Prevention	Current Controls Detection	D e t e c	R P N	Recommended Actions	Responsibility & Target Completion Date	Actions Taken	S e v	O c c u r	D e t e c	R P N											

Table 2-10: Typical severity evaluation criteria (Ben-Daya et al., 2009)

Effect	Criteria: severity of effect	Ranking
Hazardous – without warning	Very high severity ranking when a potential failure mode affects safe operation and/or involves noncompliance with regulations without warning	10
Hazardous – with warning	Very high severity ranking when a potential failure mode affects safe operation and/or involves noncompliance with regulations with warning	9
Very high	Product/item inoperable, with loss of primary function	8
High	Product/item operable, but at reduced level of performance. Customer dissatisfied	7
Moderate	Product/item operable, but may cause rework/repair and/or damage to equipment	6
Low	Product/item operable, but may cause slight inconvenience to related operations	5
Very low	Product/item operable, but possesses some defects (aesthetic and otherwise) noticeable to most customers	4
Minor	Product/item operable, but may possess some defects noticeable by discriminating customers	3
Very minor	Product/item operable, but is in noncompliance with company policy	2
None	No effect	1

Table 2-11: Typical occurrence evaluation criteria (Ben-Daya et al., 2009)

Probability of Failure	Possible failure rates	Ranking
Very high: failure is almost inevitable	≥ 1 in 2	10
	1 in 3	9
High: repeated failures	1 in 8	8
	1 in 20	7
Moderate: occasional failures	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low: relatively few failures	1 in 15,000	3
	1 in 150,000	2
Remote: failure is unlikely	≤ 1 in 1,500,000	1

Table 2-12: Typical detection evaluation criteria (Ben-Daya et al., 2009)

Detection	Criteria: likelihood of detection by design control	Ranking
Absolute uncertainty	Design control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no design control	10
Very remote	Very remote chance the design control will detect a potential cause/mechanism and subsequent failure mode	9
Remote	Remote chance the design control will detect a potential cause/mechanism and subsequent failure mode	8
Very low	Very low chance the design control will detect a potential cause/mechanism and subsequent failure mode	7
Low	Low chance the design control will detect a potential cause/mechanism and subsequent failure mode	6
Moderate	Moderate chance the design control will detect a potential cause/mechanism and subsequent failure mode	5
Moderately high	Moderately high chance the design control will detect a potential cause/mechanism and subsequent failure mode	4
High	High chance the design control will detect a potential cause/mechanism and subsequent failure mode	3
Very high	Very high chance the design control will detect a potential cause/mechanism and subsequent failure mode	2
Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode	1

2.6.3 Analyse Phase

The objective in analyse phase is to determine the potential causes of the defects, quality problems, customer issues, or waste and inefficiency that motivated the project. Analyse step is to discover and recognise tentative relationships between and among process variables and to develop awareness about potential process improvements (Montgomery, 2009).

Why-Why Diagram

Why-why diagram is a method helps to detect the cause-effect relationships and the root causes of a problem in a systematic approach which is serves the same purpose as the cause-and-effect diagram (Higgins, 1994; Tan & Platts, 2005). However, Why-why diagram builds a structure out of a problem statement and generates a hierarchy of causes and sub-causes by repeatedly asking the question "why?" (Higgins, 1994; Tan & Platts, 2005) until the root causes are explored. Then, the potential corrective actions are taking place to eliminate the root cause of nonconformities in order to stop recurrence (Tomić & Brkić, 2011). Figure 2-20 shows the systematic structure of why-why diagram.

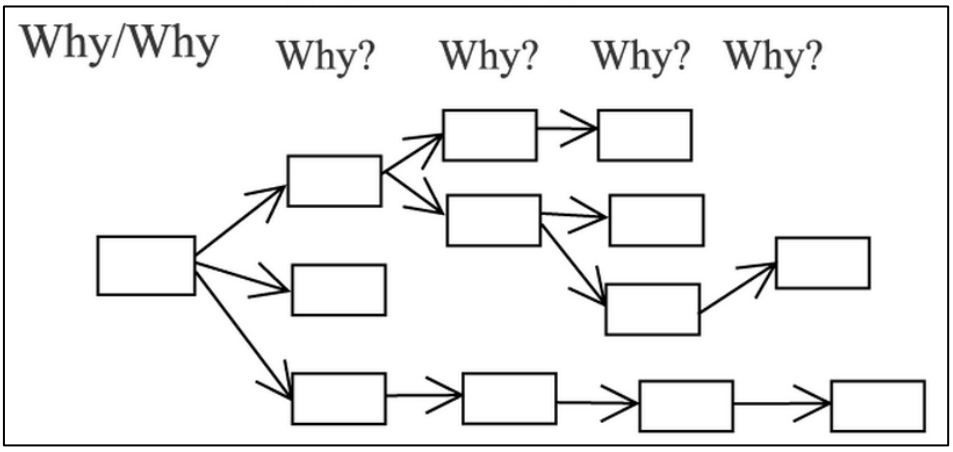


Figure 2-20: Why-Why Diagram (Tan & Platts, 2005)

Hypothesis Test

Statistical hypothesis is a statement about a population, often about some parameter of a population (Juran & Godfrey, 1999). A process leading to a decision about a specific hypothesis is called a test of a hypothesis (Montgomery & Runger, 2003). Tests of hypothesis were designed so that experimenters would not attribute causes to variations in data that were in fact due simply to random variation, and therefore did not need a cause to explain them (Juran & Godfrey, 1999). There are two hypotheses that must be stated in any statistical testing process that including the null hypothesis and the alternative hypothesis (Mason, Gunst, & Hess, 2003).

Null Hypothesis (H_0). Hypothesis of no change or experimental effect

Alternative Hypothesis (H_1). Hypothesis of change or experimental effect

Hypothesis Testing Process

Privitera (2012) suggests four steps to hypothesis testing in the following:

Step 1: State the hypotheses - Being by stating the null and alternative hypothesis. The null hypothesis (H_0), stated as the null, is a statement about a population parameter, such as the population mean, that is assumed to be true. The objective is to test whether the value stated in the null hypothesis is likely to be true. On the other hand, an alternative hypothesis (H_1) is a statement that directly opposes a null hypothesis by declaring that that the actual value of a population parameter is less than, greater than, or not equal to the value stated in the null hypothesis. The alternative hypothesis states what we consider is incorrect about the null hypothesis.

Step 2: Set the criteria for a decision - To set the criteria for a decision, it is necessary to state the level of significance for a test, refers to a condition of judgment upon which a decision is made concerning the value stated in a null hypothesis. The significance level is usually set at 5% in behavioural research studies. When the probability

of obtaining a sample mean is less than 5% if the null hypothesis were true, then we reject the value stated in the null hypothesis.

Step 3: Compute the test statistic - Test statistic is a mathematical formula that permits researchers to determine the probability of gaining sample outcomes if the null hypothesis were true. The value of the test statistic is used to make a decision regarding the null hypothesis.

Step 4: Make a decision - The value of the test statistic is use to make a decision about the null hypothesis which is refers to p-value. P-value is the probability of gaining a sample outcome, given that the value stated in the null hypothesis is true, and compared to the level of significance. When the p-value is less than 5% ($p < .05$), reject the null hypothesis. When the p-value is equal to 5% ($p = .05$), the decision is also to reject the null hypothesis. When the p-value is greater than 5% ($p > .05$), fail to reject the null hypothesis. However, it is possible that a conclusion may be wrong. According to Juran, & Godfrey (1999) and Montgomery, & Runger (2003), rejecting the null hypothesis when it is true is defined as a type I error. Its probability is called the level of significance and is denoted by α, while failing to reject the null hypothesis when it is false is defined as a type II error. Its probability is usually denoted by β. Table 2-13 displays that there are four decision alternatives regarding the truth and falsity of the decision that make about a null hypothesis.

Table 2-13: Hypothesis testing error types (Park, 2003)

		True state of nature	
		H_0	H_1
Conclusion made	H_0	Correct conclusion	Type II error (β)
	H_1	Type I error (α)	Correct conclusion

2.6.4 Improve Phase

The objectives of the Improve phase are to develop a solution to the problem and to pilot test the solution. A wide range of tools can be implement in the improve step but the most important statistical tool is design of experiment (Montgomery, 2009).

Design of Experiment (DOE)

The design of experiments (DOE) techniques is regularly related with manufacturing processes. A well-designed DOE can help establish process parameters to improve a firm's efficiency. The techniques provide a structured, efficient approach to experimentation that can provide valuable process improvement information (Park, 2003). Stamatis (2002b) claims that DOE is a process of planning and conducting experiments such that applicable information will be collected that can be easily analysed and concluded into valid and objective conclusions about a situation. The benefits of design of experiment in process development are improved yield, reduced variability and closer conformance to the nominal, reduce development time, and reduce overall costs (Montgomery, 2009; Montgomery & Runger, 2003).

DOE is a statistical procedure permitting an experimentalist to create statistical correlation between a set of input variables with a selected outcome of the process under study under certain uncertainties, called uncontrolled inputs. The process, as reveals in figure 2-21, can be visualised as various integration of machines, methods, and people that transforms an input material into an output product (y). This output product has one or more noticeable quality characteristics or responses (Montgomery, 2009); (x_1, x_2,...x_p) are p controllable process inputs; (z_1, z_2,...z_q) are q uncontrollable process inputs (often referred to as noise) (Davim, 2012; Montgomery, 2009). Hence, design of experiment methods can be implemented either in process development or process troubleshooting to improve process performance (Montgomery, 2009).

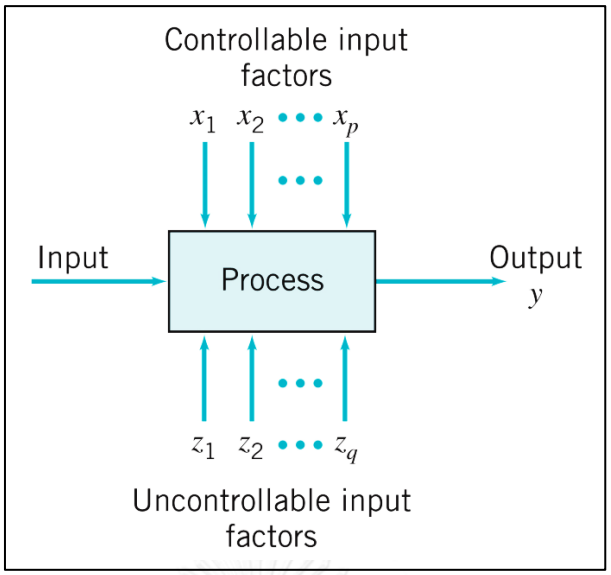


Figure 2-21: General model of a process (Montgomery, 2009)

Terminology of Design of Experiment

Factor - A factor is one of the controlled or uncontrolled variables whose influence upon a response is being studied in the experiment. A factor may be quantitative, for instance, temperature in degrees, time in seconds, etc. A factor may also be qualitative, for instance, different machines, different operators etc. (Juran & Godfrey, 1999)

Levels - The levels are the chosen conditions of the factor under study (Davim, 2012). The levels of a factor are the specific values of the factor being examined in the experiment (Juran & Godfrey, 1999).

Treatment (test condition) - A treatment is the condition or a factor associated with a specific level in a specific experiment, or settings of factor levels (Davim, 2012). A treatment is a single level assigned to a single factor during an experimental run. A treatment combination is the set of levels for all factors in a given experimental run (Juran & Godfrey, 1999).

Effect – Effect is a change in the average response between two factor level combinations or between two experimental conditions (Mason et al., 2003).

Response - The response variable is the observation value or measured value obtained from the experimental run (Stamatis, 2002b), or outcome or result of an experiment (Mason et al., 2003).

Interaction – Interaction is an existence of mutual factor effects in which the effect of each factor depends on the levels of the other factors (Mason et al., 2003).

Experimental Design - Experimental design is the formal plan for steering the experiment. It includes the choice of the responses, factors, levels, blocks, and treatments and the use of certain tools called planned randomisation, blocking, and replication (Juran & Godfrey, 1999).

Principle to conduct Design of Experiment

Randomisation - Randomisation is a method that protects against an unknown bias distorting the results of the experiment (Davim, 2012). Randomisation of run order is essential before beginning the experimentation. For valid interpretation of the analysis, the individual runs must be conducted in a random order to assure valid estimates of experimental error (Stamatis, 2002b). The randomisation can be accomplished in numerous ways including selecting numbers from a random number table, generating numbers with a random number generator (Stamatis, 2002b).

Replication – Replication is the repetition, the rerunning, of an experiment in order to increase precision (Juran & Godfrey, 1999). Replication increases the signal-to-noise ratio when the noise originates from uncontrollable input factor common in real-world manufacturing (Davim, 2012).

Blocks/Blocking - Block is a group of homogenous portion of the experimental environment or materials that tolerates certain variation effects on the responses where it

is a method for increasing precision by eliminating the effect of known uncontrollable input factor (Davim, 2012).

Design of Experiment Process

Montgomery (2009) gives an outline of the recommended procedure to perform design of experiment in the following:

1. Recognition of and statement of the problem - It is completely vital to completely develop all ideas about the problem and about the specific objectives of the experiment. A clear statement of the problem and the objectives of the experiment often contribute significantly to better process understanding and ultimate solution of the problem.

2. Choice of factors and levels - The experimenter must select the factors to be varied in the experiment, the ranges over which these factors will be varied, and the particular levels at which runs will be made.

3. Selection of the response variable - In selecting the response variable, the experimenter should be assured that the variable really provides suitable information about the process under study. Most often the average or standard deviation (or both) of the measured characteristic will be the response variable.

4. Choice of experimental design - Choice of design comprises selection of sample size (number of replicates), selection of a suitable run order for the experimental trials, and whether or not blocking or other randomisation restrictions are included.

5. Performing the experiment - it is important to carefully monitor the process to ensure that everything is being done according to plan when running the experiment.

6. Data analysis - Statistical methods should be used to analyse the data so that results and conclusions are impartial rather than judgmental. Various software packages are available to assist in the data analysis, and simple graphical methods play an

important role in data interpretation. Residual analysis and model validity checking are also significant.

7. Conclusions and recommendations - The experiment must draw practical conclusions about the results and recommend a course of action

Types of Design of Experiment

There are several different types of design of experiment. They may be classified as follows according to the allocation of factor combinations and the degree of randomisation of experiments.

- Completely Randomised Design

The completely randomised design is suitable when a total of N experimental units are available for the experiment and there are k treatments (or levels of the factor) to be investigated. Of the total number N, it is usual to assign randomly an equal number of trials n to each of the k treatments (Juran & Godfrey, 1999). The completely randomised design is simple to organise and analyse and may be the best choice when the experimental material is homogeneous and when background conditions can be well controlled during the experiment (Juran & Godfrey, 1999).

In planning the experiment, the data would appear as in table 2-14, suppose we have ‘a’ treatments that we which to compare, ‘y_{ij}’ is represents the jth observation taken under treatment ‘i’, and ‘n’ observations under the ith treatment (Montgomery & Runger, 2003).

Table 2-14: Completely Randomised Design (Montgomery & Runger, 2003)

Treatment	Observations				Totals	Averages
1	y_{11}	y_{12}	$\cdots$	y_{1n}	$y_{1\cdot}$	$\bar{y}_{1\cdot}$
2	y_{21}	y_{22}	$\cdots$	y_{2n}	$y_{2\cdot}$	$\bar{y}_{2\cdot}$
$\vdots$	$\vdots$	$\vdots$	$\vdots\vdots\vdots$	$\vdots$	$\vdots$	$\vdots$
a	y_{a1}	y_{a2}	$\cdots$	y_{an}	$y_{a\cdot}$	$\bar{y}_{a\cdot}$
					$y_{\cdot\cdot}$	$\bar{y}_{\cdot\cdot}$

The model of the data is:

$$y_{ij} = \mu + \tau_i + \epsilon_{ij} \begin{cases} i = 1, 2, \ldots, a \\ j = 1, 2, \ldots, n \end{cases} \quad (2.3)$$

Where, μ is overall mean

τ_i is ith treatment effect

ϵ_{ij} is random error

- Randomise Block Design

Randomised block design is one in which each of the treatments appears exactly once in every block. The treatments are allocated to experimental units at random within a given block (Juran & Godfrey, 1999). The can help to make the experimental error as small as possible by remove the variability from the experimental error.

In planning the experiment, the data would appear as in table 2-15, suppose we have ‘a’ treatments that are to be compared and ‘b’ block. There is one observation per treatment in each block, and the order in which the treatments are run within each block is determined randomly (Montgomery & Runger, 2003).

Table 2-15: Randomise Block Design (Montgomery & Runger, 2003)

	Blocks					
Treatments	1	2	…	*b*	Totals	Averages
1	y_{11}	y_{12}	⋯	y_{1b}	$y_{1\cdot}$	$\bar{y}_{1\cdot}$
2	y_{21}	y_{22}	⋯	y_{2b}	$y_{2\cdot}$	$\bar{y}_{2\cdot}$
⋮	⋮	⋮		⋮	⋮	⋮
a	y_{a1}	y_{a2}	⋯	y_{ab}	$y_{a\cdot}$	$\bar{y}_{a\cdot}$
Totals	$y_{\cdot 1}$	$y_{\cdot 2}$	⋯	$y_{\cdot b}$	$y_{\cdot\cdot}$	
Averages	$\bar{y}_{\cdot 1}$	$\bar{y}_{\cdot 2}$	⋯	$\bar{y}_{\cdot b}$		$\bar{y}_{\cdot\cdot}$

The model of the data is:

$$y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij} \begin{cases} i = 1, 2, \dots, a \\ j = 1, 2, \dots, b \end{cases}$$

Where, μ is overall mean

τ_i is ith treatment effect

β_j is the effect of jth block

ϵ_{ij} is random error

- Factorial Design

Factorial designs is a very useful class of designed experiments (Davim, 2012), and most commonly employed in engineering and manufacturing experiments (Juran & Godfrey, 1999). In a factorial experiment, several factors are controlled at two or more levels, and their effects upon some response are investigated. The experimental plan consists of taking an observation at each of all possible combinations of levels that can be formed from the different factors. Each different combination of factor levels is called a treatment combination (Juran & Godfrey, 1999). Consequently, if there are two factors A and B with a level of factor A and b levels of factor B, then each replicate contains all ab possible combinations (Montgomery, 2009).

In the analysis of factorial experiments, the effect of a factor is defined as the change in response produced by a change in the level of the factor which is called a main effect (Montgomery, 2009). Estimated main effects of a given factor are always functions of the average yield response at the various levels of the factor (Juran & Godfrey, 1999). The difference in response between the levels of one factor is not the same at all levels of the other factors is called an interaction between the factors. In this factorial design, both the factors A and B have two levels, denoted by "-" and "+." These two levels are called "low" and "high," respectively. The model of interaction can be clarified graphically. Figure 2-22a plots the sample data against the levels of A for both levels of B. It can be seen that the B^- and B^+ lines are roughly parallel, indicating that factors A and B do not interact. Figure 2-21b plots the sample data, it can be seen that the B^- and B^+ lines are not parallel, indicating the interaction between factors A and B (Montgomery, 2009).

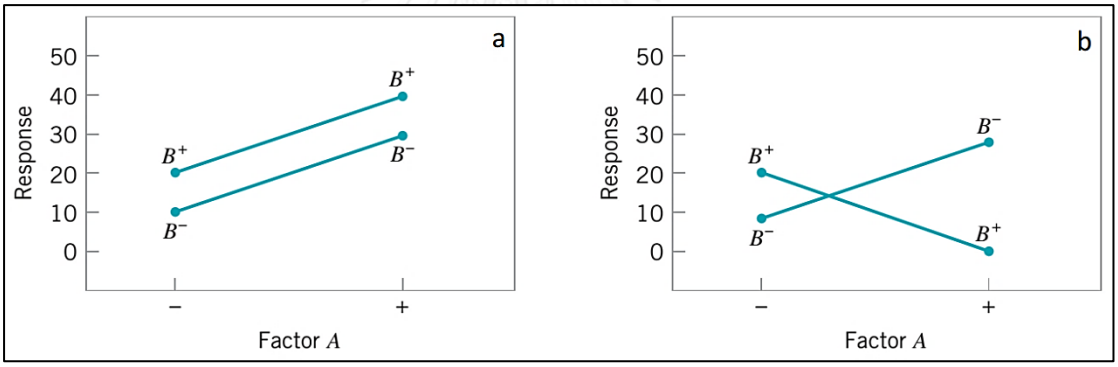


Figure 2-22: a.) Factorial experiment, no interaction. B.) Factorial experiment with interaction (Montgomery, 2009)

In addition, Davim (2012) states that the use a small number of levels for each of the factors are commonly implemented, often just two levels, in which case a design with k factors, each at only two levels (high and low) has a complete replicate of such a design require 2 x 2 x . . . x 2 = 2^k treatments is called a 2^k factorial design (Montgomery & Runger, 2003).

Montgomery (2009) suggests the sequence of steps to employ to analyse factorial experiments in the following:

1. Estimate the factor effects
2. Form preliminary model
3. Test for significance of factor effects
4. Analyse residuals
5. Refine model, if necessary
6. Interpret results

2.6.5 Control Phase

The objective of control phase is to ensure that the potential problem or defect does not recur by construct the process control plan. Control charts are vital statistical tool used in the control phase of DMAIC; many process control plans involve control charts on critical process metrics (Montgomery, 2009).

Statistical Process Control (SPC)

Statistical process control (SPC) involves the use of statistical techniques to inspecting a random sample of the output from a process and deciding whether the process is producing products with characteristics that fall within a predetermined range (Gygi et al., 2005). Montgomery (2009) concludes that statistical process control is a powerful collection of problem-solving tools useful in accomplishing process stability and improving capability through the reduction of variability.

The major tools of statistical process control are:

1. Histogram
2. Pareto chart
3. Cause-and-effect diagram
4. Defect-concentration diagram

5. Control chart
6. Scatter diagram
7. Check sheet

However, the most significant of the SPC tools for monitoring the production process is the control chart (Montgomery, 2009).

Control Chart

A control chart is a graph that shows of a quality characteristic whether a sample of data falls within the common or normal range of variation (Montgomery, 2009). A control chart, as shown in figure 2-23, contains a centre line (CL) that represents the average value of the quality characteristic corresponding to the in-control stage. The two horizontal lines are upper control limit (UCL) and lower control limit (LCL) that separate common from assignable causes of variation. The common range of variation is defined by the use of control chart limits. Basically, as long as the points plot within the control limits, the process is assumed to be in control; however, a process is out of control when a plot of data reveals that one or more samples fall outside the control limits (Montgomery, 2009). Furthermore, in some control charts, the control limits are based on the within-sample or within-subgroup data plotted on the chart; in others, the control limits are based on adopted standard or specified values applicable to the statistical measures being plotted on the chart (Juran & Godfrey, 1999).

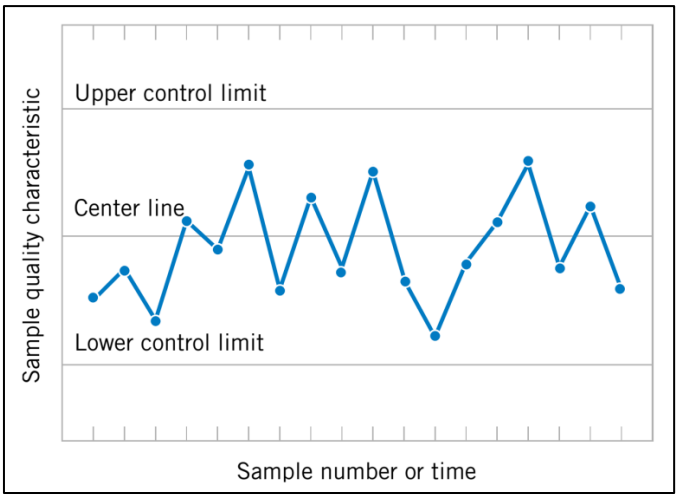


Figure 2-23: A typical control chart (Montgomery, 2009)

Types of Control Chart

There are several different types of control charts, depending on the type of process measurement that are tracking. These different types of control chars are classified into two general types including variable/continuous data control chart and attribute/discrete data control charts (Montgomery, 2009). Variable control charts are based on variable data that can be measured on a continuous scale. For instance, weight, volume, temperature, etc. (Montgomery, 2009). Attribute control charts are based on data that can be grouped and counted as present or not, and measured only with whole numbers. In attribute control charts, a subgroup is the group of units that were inspected to acquire the number of defects or the number of defective parts (Montgomery, 2009).

Table 2-16 and figure 2-24 displays the type of control chart and the method to select the control chart, respectively. Moreover, table 2-17 and table 2-18 shows the formula of centre line, upper control limit, and lower control limit for variable control chart and attribute control chart, respectively.

Table 2-16: Type of control chart (Meran, John, Roenpage, & Staudter, 2013)

Data type		Sample size (subgroup)	Control Chart
Continuous data		1	IMR Chart
		< 10 (usually 3 to 5); constant	Xbar-R Chart
		> 10 and/or variable	Xbar-S Chart
Discrete data	Defect per part	Constant (usually > 50); number of defects > 5	c-Chart
		Variable (usually > 50); number of defects > 5	u-Chart
	Defective parts	Constant (usually > 50)	np-Chart
		Variable (usually > 50)	p-Chart

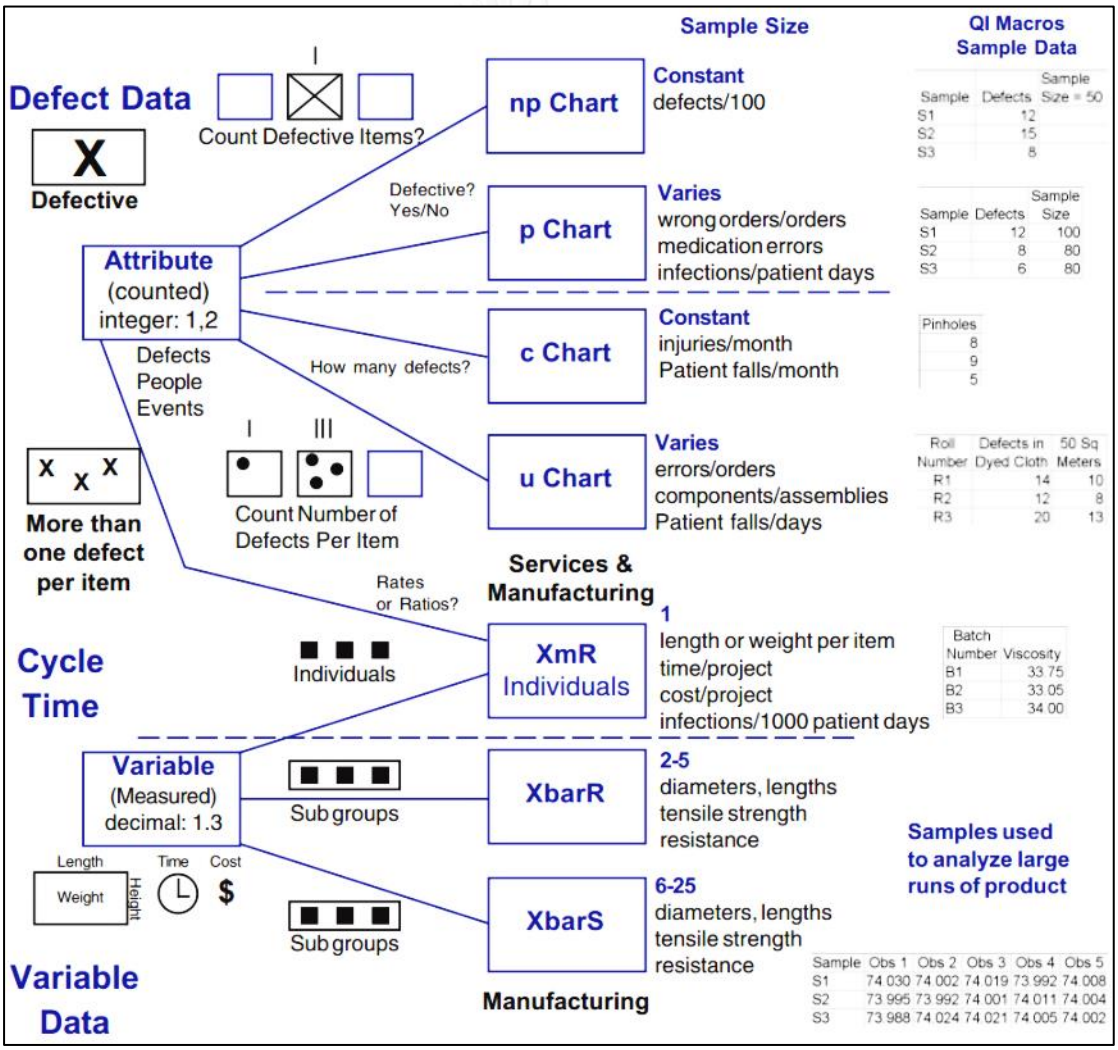


Figure 2-24: How to selecting the right control chart (Authur, 2009)

Table 2-17: The formula of centre line, upper control limit, and lower control limit for variable control chart (Meran et al., 2013)

Type of Control Charts	Subgroup samples	Center line	Control limits	
Average and Range	Constant and <10, but usually 3 to 5	$\bar{\bar{x}}=\frac{\left(\bar{x}_1+\bar{x}_2+\ldots\bar{x}_k\right)}{k}$	$UCL_{\bar{x}}=\bar{\bar{x}}+A_2\bar{R}$	$LCL_{\bar{x}}=\bar{\bar{x}}-A_2\bar{R}$
Xbar-R		$\bar{R}=\frac{\left(R_1+R_2+\ldots R_k\right)}{k}$	$UCL_R=D_4\bar{R}$	$LCL_R=D_3\bar{R}$
Average and Standard Deviation	Variable or ≥10	$\bar{\bar{x}}=\frac{\left(\bar{x}_1+\bar{x}_2+\ldots\bar{x}_k\right)}{k}$	$UCL_{\bar{x}}=\bar{\bar{x}}+A_3\bar{s}$	$LCL_{\bar{x}}=\bar{\bar{x}}-A_3\bar{s}$
Xbar-S		$\bar{s}=\frac{\left(s_1+s_2+\ldots s_k\right)}{k}$	$UCL_s=B_4\bar{s}$	$LCL_s=B_3\bar{s}$
Individual values and Moving Ranges	1	$\bar{x}=\frac{\left(x_1+x_2+\ldots x_k\right)}{k}$	$UCL_x=\bar{x}+\frac{3}{d_2}\bar{R}_m$	$LCL_x=\bar{x}-\frac{3}{d_2}\bar{R}_m$
IMR		$\bar{R}_m=\frac{\left(R_1+R_2+\ldots R_{k-1}\right)}{k-1}$ $\bar{R}_m=\left\|\left(x_{j+1}-x_j\right)\right\|$	$UCL_{Rm}=D_4\bar{R}_m$	$LCL_{Rm}=D_3\bar{R}_m$

Table 2-18: The formula of centre line, upper control limit, and lower control limit for attribute control chart (Meran et al., 2013)

Type of Control Charts	Sample size	Center line	Control limits	
Proportion defective parts p-chart	Variable usually n > 50	$\bar{p}=\frac{\sum\hat{p}_i}{k}$ whereby $\hat{p}_i=\frac{\#\text{ defective parts}}{n_i}$	$UCL_p=\bar{p}+3\sqrt{\frac{\bar{p}\left(1-\bar{p}\right)}{n_i}}$	$LCL_p=\bar{p}-3\sqrt{\frac{\bar{p}\left(1-\bar{p}\right)}{n_i}}$
Proportion defective parts np-chart	Constant usually n > 50	$\bar{p}=\frac{\sum\hat{p}_i}{k}$ whereby $\hat{p}_i=\frac{\#\text{ defective parts}}{n}$	$UCL_{np}=n\bar{p}+3\sqrt{n\bar{p}\left(1-\bar{p}\right)}$	$LCL_{np}=n\bar{p}-3\sqrt{n\bar{p}\left(1-\bar{p}\right)}$
No. of defects per unit u-chart	Variable	$\bar{u}=\frac{\sum u_i}{k}$ where $u_i=\frac{\#\text{defects}}{n_i}$	$UCL_u=\bar{u}+3\sqrt{\frac{\bar{u}}{n_i}}$	$LCL_u=\bar{u}-3\sqrt{\frac{\bar{u}}{n_i}}$
No. of defects per unit c-chart	Constant	$\bar{c}=\frac{\#\text{ defects}}{\#\text{ units}}$	$UCL_c=\bar{c}+3\sqrt{\bar{c}}$	$LCL_c=\bar{c}-3\sqrt{\bar{c}}$

2.7 Plastic Injection Moulding

2.7.1 Injection Moulding Process

Injection moulding is a fast and flexible manufacturing process techniques used in the global plastics industry to fabricate objects or products that capable of a wide range of part size, weight, shape and complex geometries that is process by injection moulding machine (Harper, 2006; Rosato et al., 2000). Harper (2006) referred to the Injection Moulding Division of the Society of Plastics Engineers, injection moulding is defined as a method of producing parts with a heat-meltable plastics material.

The injection moulding machine comprises of three main apparatuses including the injector unit, the mould and the clamping unit as illustrates in figure 2-25 (Cybulski, 2009). Moreover, this process has ability to produce the products from both thermoplastic and thermosetting materials.

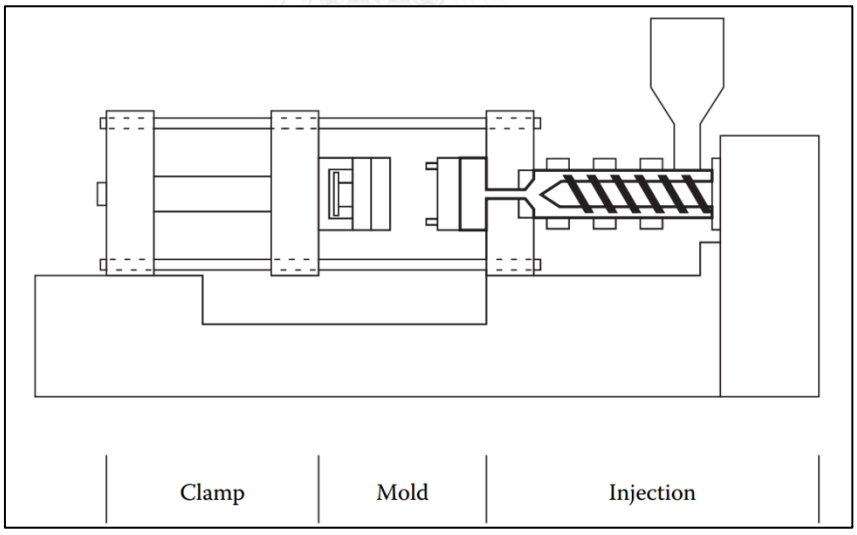


Figure 2-25: Basic elements of injection moulding machine (Cybulski, 2009)

The overall process thus involves the plastic granules or pellets to softening and melted (plasticised) in a heated cylinder in injection unit and injecting the melt plastic under high pressure and temperature conditions with controlled-volume shot into the closed mould cavity, the mould might comprise of a single cavity or multiple cavities,

where it hardens by cooling inside the mould for thermoplastic or heating inside the mould for thermosetting, the clamping unit of the machine provided the clamping force to retain the mould close and open the mould when the part is solidify. During the mould close, the injection unit is plasticising for the next cycle. Then, the moulded part is then ejected and removed from the mould cavity at the end of the cycle (Rosato et al., 2000). Figure 2-26 reveals the steps and cycle time of injection moulding.

Accordingly, three key operations take place. First, heating and melting plastic material in the injection unit so that it will flow under pressure. Second, the plastic then solidify in the mould. Third, the mould is opened to take out the moulded part. In addition, each stage is performed in an isolated region of the same apparatus in the repeated process.

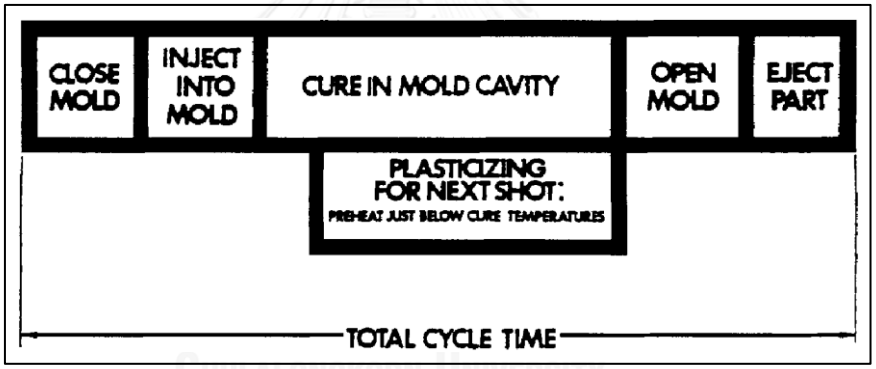


Figure 2-26: Steps and cycle time of injection moulding (Rosato et al., 2000)

2.7.2 Injection Moulding Machine

Nowadays, there are variety types and capacities of injection moulding machine to meet diverse product and cost criteria. Injection moulding machine are characterised by their injection capacity (shot size), injection pressure and clamping force (Harper, 2006; Rosato et al., 2000).

Beginning with the injection capacity, the injection capacity characterises the maximum volume of melt plastic that is injected into the mould that usually range from less than an ounce to at least 400 oz. (Rosato et al., 2000). Turning to injection pressure,

injection pressure represents the barrel pressure that to force melted plastic into the mould cavities and it is range from 2,000 to 30,000 psi (Rosato et al., 2000). As for the clamping force, clamping force is the force that assists to retain the pressure in the mould cavities which range up to 10,000 tons (Rosato et al., 2000).

Therefore, the bigger the machine, the higher in shot size, injection pressure and clamping force. Figure 2-27 shows the general layout of an injection moulding machine.

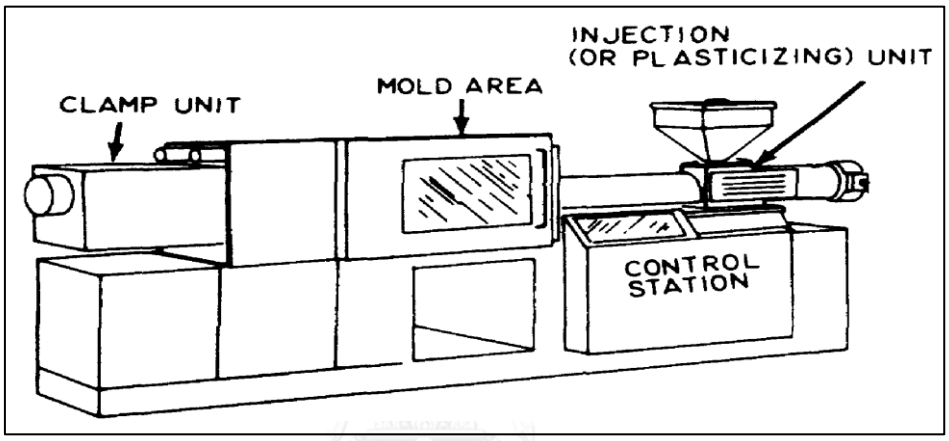


Figure 2-27: Layout of an injection moulding machine (Rosato et al., 2000)

However, Rosato et al. (2000) claims that there are three main kinds of injection moulding machine operating system in use today which is hydraulic, electrical and electrohydraulic (hybrid) operating system.

For hydraulic system, the main power to turn the screw in injection unit to melt the plastic, injecting force, close, hold and release clamp and eject the mould part is mainly perform by oil pressure in hydraulic system (Rosato et al., 2000).

For electrical system, this system all electric components to provide the power and force for the machine that provides faster operation, quieter and environmental friendly and cleaner due to the removal of oil that is use in hydraulic system. Nevertheless, the electrical injection moulding machine is still less used than hydraulic system and hybrid system in the industry (Rosato et al., 2000).

For hybrid system, the system combine the characteristics from both the hydraulic and electrical system that provide benefits such as high pressure from hydraulic system, accuracy and low energy consumption from electrical system (Rosato et al., 2000).

Moreover, Rosato et al. (2000) state that the two most implemented type of injection moulding machine are horizontally reciprocating-screw and two-stage injection moulding machine.

For reciprocating-screw machine, the plastic pellets are feed into the barrel that have reciprocating-screw inside, the screw then feed and plasticises by friction heating between the barrel and screw, moreover; the heating bands surrounding along in each section of the barrel to maintain the desired temperature of the melt. Then, the screw injects the melt plastic into the mould by screw drive motor. After injection, the screw reverses to plasticise for the next cycle. The reciprocating-screw consists of three sections: feed, transition (melting) and metering section, additionally; each screw section have different cross-section (Rosato et al., 2000). Figure 2-28 and 2-29 shows sequence of operations for a reciprocating screw machine and a section of reciprocating-screw, respectively.

For two-stage machine, this type of machine consists of fixed plasticising screw (first stage) to feed the melted plastics through a valve mechanism into injection accumulator (second stage). The process then can be accounts as two steps. First, the screw is feed the melted plastic and supplied to injection chamber and after reaching the volume of melts the screw moves forward to shutoff the fluid path to prevent the backflow of the melt. Then, the second stage, the ram injector moves forward to inject the melt plastic into mould. After injection complete, the screw moves backward to open the fluid path and rotate again to plasticise the pellet and direct flow from the first stage into the second stage to repeat the production cycle (Rosato et al., 2000). Figure 2-30 reveals two-stage screw injection machine with right-angle design.

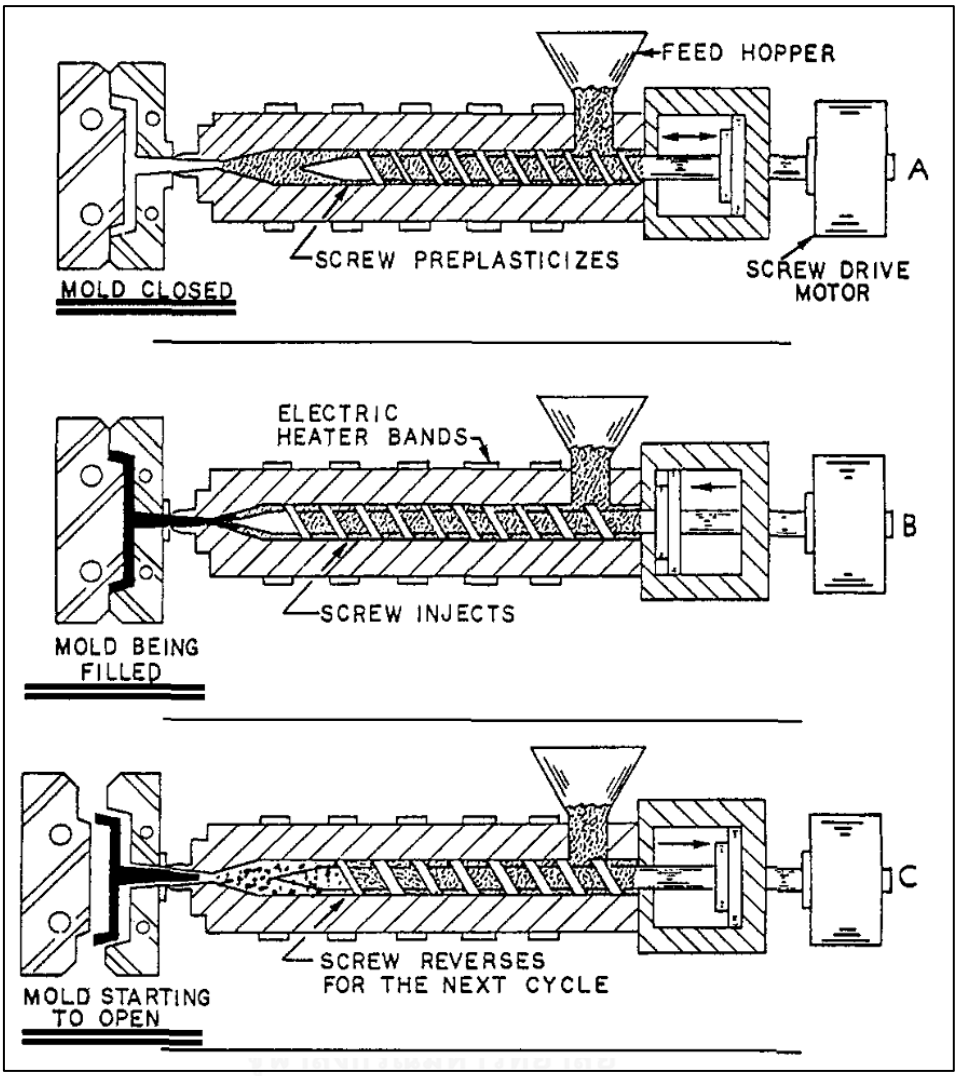


Figure 2-28: Sequence of operations for a reciprocating screw machine (Rosato et al., 2000)

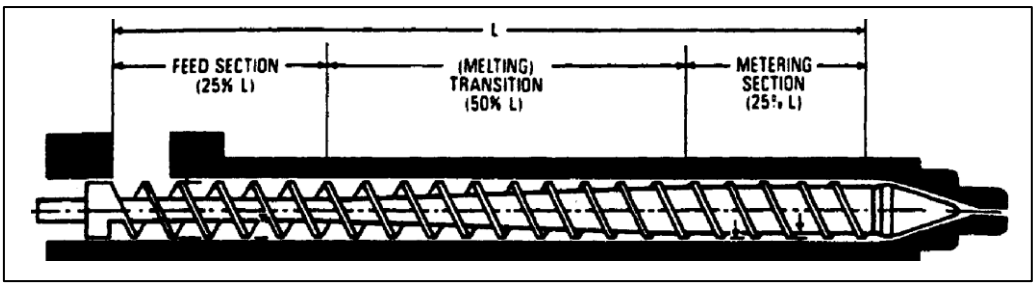


Figure 2-29: Section of reciprocating-screw (Rosato et al., 2000)

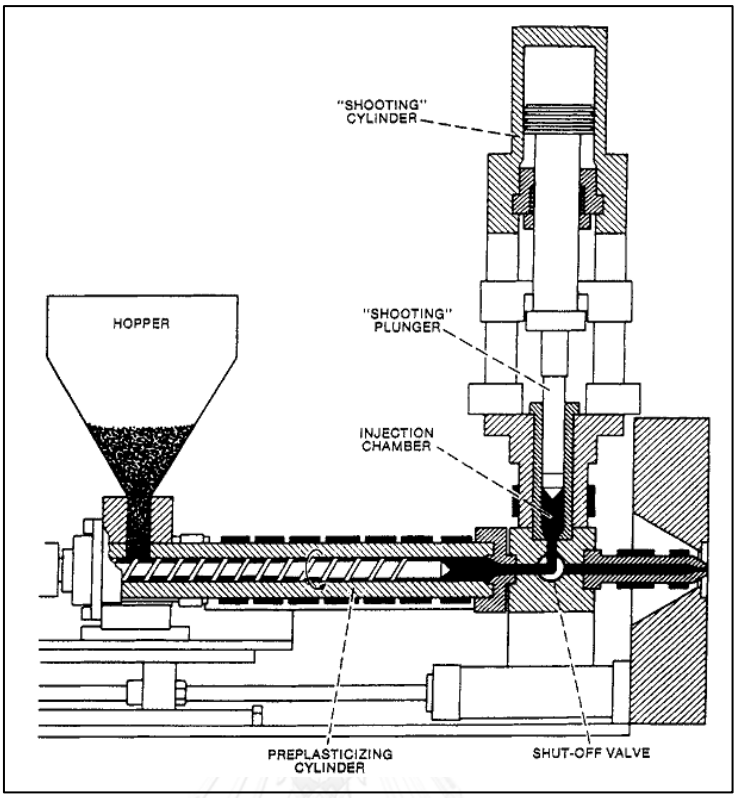


Figure 2-30: Two-stage screw injection machine with right-angle design (Rosato et al., 2000)

2.7.3 Equipment and Tooling of Injection Moulding Machine

Essentially, the main equipment of injection moulding machine are hopper, barrel, screw, heater bands, nozzle, stationary platen, moving platen and tie rod (Rosato et al., 2000). In addition, the tooling to produce the moulded parts is mould (Rosato et al., 2000). The following bullets point will describe the function of each equipment and tooling:

- Hopper - The hopper is funnel like shape that holds and feed the plastic granule to the feed section of the barrel by gravity (see figure 2-31).
- Barrel - Barrel is a cylinder that houses a screw and provides the melt plastic delivery route to the mould (see figure 2-31).
- Screw - As mention above, the purpose of the screw is to feed, melt and inject the melt plastic into the mould. The plasticising occurs by the shear and friction force of unmelt pellets between barrel wall and the screw (see figure 2-28 and 2-29).

- Heater bands - Heater bands are surrounding along the barrel section which providing different temperature in each barrel section to maintain a constant temperature of the plastic in the barrel (see figure 2-31).
- Nozzle - The nozzle offered the boundary between the extruder and mould that is locate at the end or tip of the barrel and aligned to the sprue bushing hole in the mould, where the melt flow into to the mould (see figure 2-32).
- Stationary platen - The sprue side of the mould are place at stationary platen. This platen is not moving but provide as the surface against the clamping force from clamping unit to remain the mould close (see figure 2-32).
- Moving platen - The ejector side of the mould is place at moving platen. This platen is moving by the clamping unit to close the mould (see figure 2-32).
- Tie rods - The functions of tie rods is to support and guide the stationary and moving platen on which mould is attached and work as equally distribution load tensions support members of the clamp when the mould is close (see figure 2-32).
- Mould - Principally, the mould comprises of a sprue, runner, cavity gate, cavity, ejector pin and plate. The purpose of the mould is the tooling that to shape the plastic products according to the cavity shape (see figure 2-32 and 2-33).

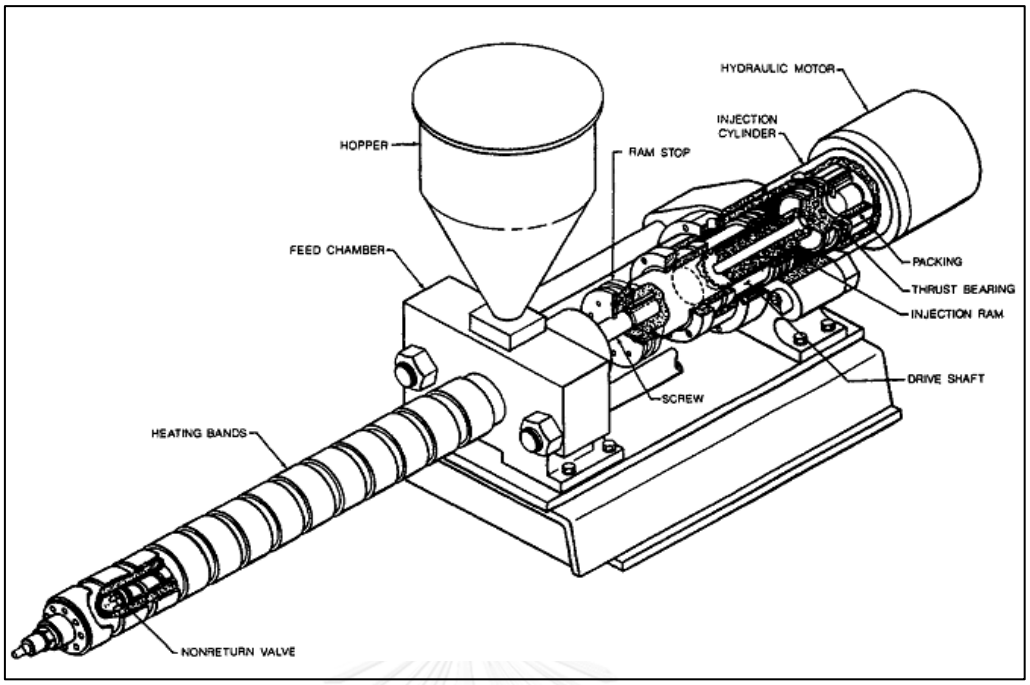


Figure 2-31: Schematic of a reciprocating screw plasticator (Rosato et al., 2000)

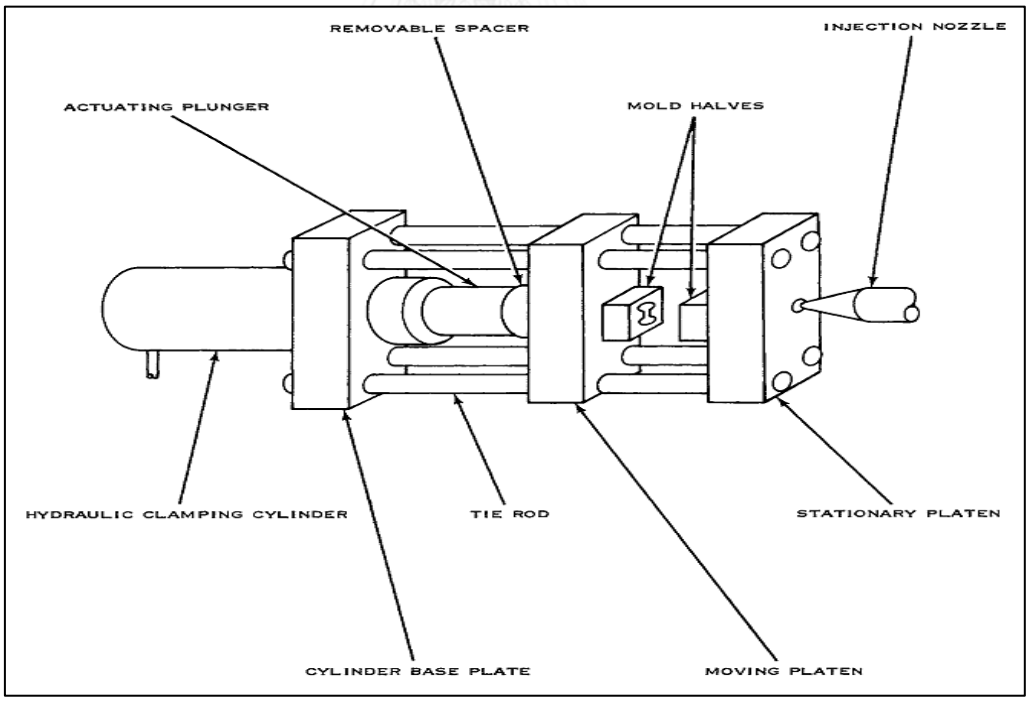


Figure 2-32: Schematic of a clamping unit (Rosato et al., 2000)

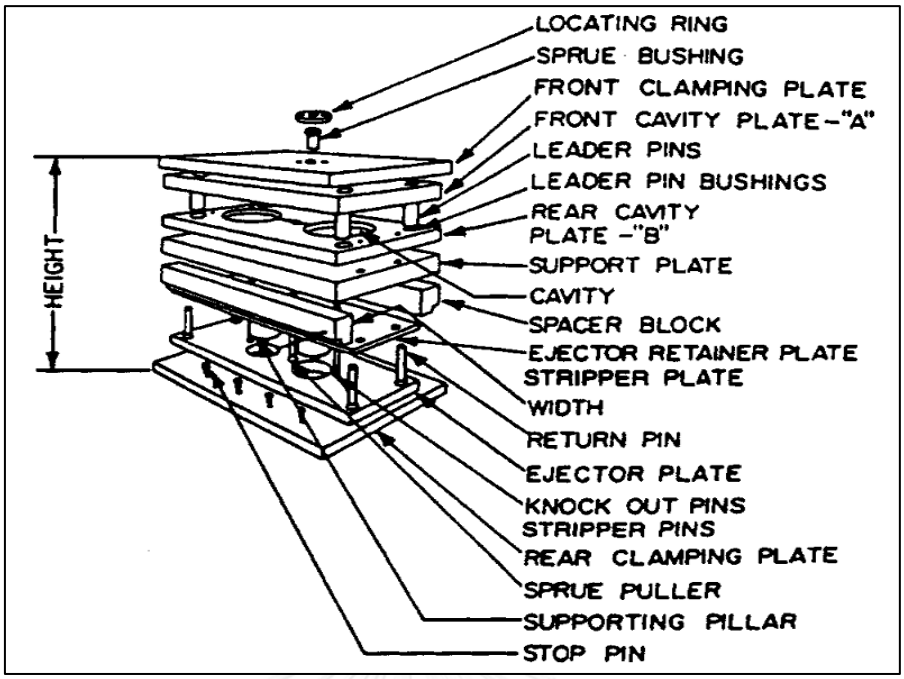


Figure 2-33: Exploded view of mould base (Rosato et al., 2000)

2.8 Related Research

Dwivedi, Anas, and Siraj (2014) studied Six Sigma DMAIC methodology for analysis and research on removing the black specks (small dark particles on the surface of the opaque parts) on the appearance of the plastic product in the injection moulding process. The objective of the research is to identify the root cause of black specks that moderate the quality, and to propose measure for improvement in the injection moulding operation. After collecting and analysis the data suggestion in recommended to reduce the black speaks defect are to clean barrel and use of cleaning agent for cleaning screw and barrel screw.

Solanki and Bangar (2013) implemented Six Sigma methodology and quality control tools to reduce black dot rejection during manufacturing of plastic moulding jar. The research was conducted at Vimal Plastics Ltd., Noida, India (manufacturer of plastic moulding jar). According to the research, it has been found that black dot appearance of the product is the major rejection issue in the production process. As a result, the research suggests a new cleaning material agent to solve the black dot defect problem which led to

reduction of number of rejection per day after cleaning of screw barrel. Moreover, the overall result collected after this research at plastic injection part production line reveals that the sigma level is increase from 4.2356 to 4.3301 and the defects per million opportunities (DPMO) is decrease from 3084.9 to 2301.1

Tayal and Kumar (2012) applied DMAIC approach for reduction in the defects (blush, burn, cold flows, cold slug, contamination, peeling, gloss) occurred in the injection moulding by controlling parameters. From the outcome of the application of DMAIC approach in this plastic injection shop floor are shown in the following. The defect rate of blush was reduced from 2.5 per cent to 0.86 per cent. The defect rate of burn was reduced from 2.68 per cent to 0.78 per cent. The defect rate of cold flow was reduced from 1.2 per cent to 0.68 per cent. The defect rate of contamination was reduced from 1.06 per cent to 0.43 per cent. Overall, the result after applying DMAIC approach shows that the rejection rate has reduced from 7.44 per cent to 2.75 per cent.

Jirasukprasert, Garza-Reyes, Soriano-Meier, and Rocha-Lona (2012) applied the DMAIC methodology to study defects, root causes and provide a solution to reduce theses defects in a rubber gloves manufacturing process. Regarding to the research, it has been found that the oven's temperature and conveyor's speed influenced the quantity of defective gloves manufactured. Moreover, the design of experiment (DOE) and two-way analysis of variance (ANOVA) techniques both are used to identify the optimum value that is required to eliminate the defects. Consequently, the rate of gloves defect of the leaking type is reduce by 50 per cent which assists the factory to reduce its defects from 195,095 DPMO to 83,750 DPMO and thus increase its Sigma value from 2.4 to 2.9.

Khekale, Chatpalliwar, and Thakur (2010) employed DMAIC to reduce cord wastages in belt manufacturing factory by identified the processes issues that related to cord wastage and its root causes. It has been found that factory achieved breakthrough in reducing cord waste due to Six Sigma DMAIC Methodology. As a result, the research in reduction in cord wastages in belt manufacturing is decreased its cord wastages from

549,531 DPMO to 17,240 DPMO; correspondingly the Sigma level is enhanced from 1.37 to 3.6.

Reddy and Reddy (2010) implemented DMAIC process in Six Sigma project in ball-bearing manufacturing factory located in Hyderabad and focus on reducing the variation and rejection rate of inner rings and outer rings of ball bearing because the outer rings of ball bearing required tight tolerances. Moreover, various statistical tools were applied. The study shown Six Sigma can be successfully implemented in a Small and medium sized enterprises (SMEs). The result of the study reveals that the rejection rate of bearing rings has been reduced from 2.7per cent to 0.65 per cent and Sigma level improved from 4.04 to 4.44.

Jenjiwattanakul (2011) applied the Six Sigma technique to reduce the defect in the plastic printing process of plastic bag manufacturer. The research follows the five step of DMAIC process and it has been found that the printing process has the highest defects. After performed DMAIC, the result shows that the amount of defect rate is reduced from 11.68 per cent to 1.53 per cent.

Thinkohkaew (2002) employed Six Sigma approach to reduce the defective part of can production process and performed this experiment in four months .The research used four steps of statistical control process including: measure, analyse, improve, and control. The result of the research reveals that the number of can defects is decreasing from 4,400 DPM to 2,849 DPM.

Panumpai (2010) applied five phase of Six Sigma approach (DMAIC), failure mode and effect analysis (FMEA) and various quality tools to reduce the defective rate of evaporator production process in studied factory. The result has exposed that evaporator product defect rate from production error was reduced from 0.216 per cent to 0.107 per cent or 50.46 per cent reduction. In addition, the core plate part can be reduced from

3,333 to 648 pieces per month which led to evaporator product defect value to be decreased from 0.19 per cent to 0.007 per cent or 63.16 per cent reduction.

Hongsapan (2010) studied the approach to reduce rework cost and defects per unit in car bodywork painting process by using Six Sigma approach. Regarding to the research, there are seven major kinds of defects needed to eliminate which are fibre, paint stain, scratch, dust, sagging surface dust, and crater. The outcome reveals that the improvement results in 57 per cent defect reduction (0.37 to 0.16 defects per unit) and 55 per cent reduction of rework cost (88 to 40 Thai Baht).

Senprom (2007) implemented Six Sigma approach for improving plastic lens production with the aim to reduce proportion of defectives parts from scratch of glass mould because the glass mould used in the production of high index lens is very expensive and it is often scratched and unable to be reworked. Consequently, it has been found that the defective rate is reduced from 0.25 per cent or 2,512 PPM to 0.083 per cent or 826 PPM and the Sigma level is increased from 4.31 to 4.65.

Boonkliang (2009) applied Six Sigma approach for improving acrylic foam tape slitting process with the objective to reduce loss due to width parameter is out of specification. Moreover, acrylic foam tape is used in automotive industry and it is quite expensive. Thus, if the width is out of specification, it will consider as scrapped. The result of the studied shown that the mean width is enhanced from 12.0324 millimetre to 12.0171 millimetre, which is closer to the target of 12 millimetre, and the standard deviation is decreased from 0.1088 millimetre to 0.0504 millimetre. So, the saving of loss due to scrap is 99.7 per cent or 4,713,992 Thai Baht per year.

CHAPTER 3
DEFINE PHASE

The define phase is essential element of Six Sigma DMAIC methodology because it is the initial phase to determine the direction to deal with the issue. This phase intended to define the critical problem in the process, scope and goals of the improvement plan, and define the team charter. This chapter will begin with the manufacturing process of this company which is plastic injection moulding process. SIPOC diagram is then constructed for more understand the relationship between supplier, input, process, output, and customer of the company. The major problem is then defines, and forms a project steering team to brainstorm and identify the causes of the problem. Lastly, all the information is summarise in project charter.

3.1 Manufacturing Process

The manufacturing process to produces the moulded parts of the company is plastic injection moulding process. Figure 3-11 illustrates the process flow chart of the manufacturing process of the company. The details of each production step are described below:

1. Received Production Assignment

The production (injection) division received the information of production planning from the planning department. The information including: the type of plastic resin to be use, batch size, and other essential specific information that involve with the production.

2. Raw Material Requisition

Then, production (injection) division will request for required plastic resin from the plastic resin storage. Figure 3-1 shows the plastic resin storage and raw plastic resin.

Figure 3-1: Plastic resin storage and raw plastic resin

3. Resin Preheat

The plastic resin is then preheated in the ground hopper drier to get rid of moisture, and then transfer the heated plastic resin to the overhead hopper that mounted on the top of injection unit of the plastic injection moulding machine. Figure 3-2 shows the ground hopper drier and overhead hopper.

Figure 3-2: Ground hopper drier and overhead hopper

4. Mould and Machine Setup

Assemble the mould on the mould unit of the injection moulding machine, and setup the parameter of the injection moulding machine according to product's specification and setup guideline. Figure 3-3 shows the mould and machine setup.

Figure 3-3: Mould and machine setup

5. First-Run

After competed with mould assembly and machine set up, the first trail run is then perform to observed the quality of appearance of the moulded parts. Figure 3-4 shows the first run trial.

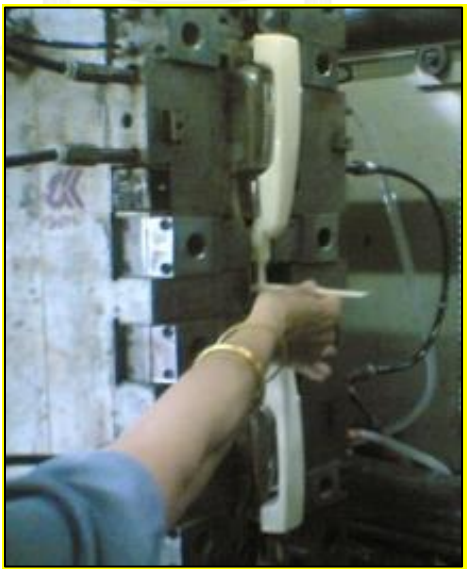


Figure 3-4: First-run trial

6. First Run Checking and Appearance Approval

The appearance of the moulded parts of the first run have to be inspect and approved before going for continuous production to ensure the moulded parts is meet with the quality standard. If the moulded parts are not passing with the quality standard, it is necessary to readjust the mould and machine setup until the moulded parts meet with the quality standard. Figure 3-5 shows the moulded parts checking and appearance approval process.

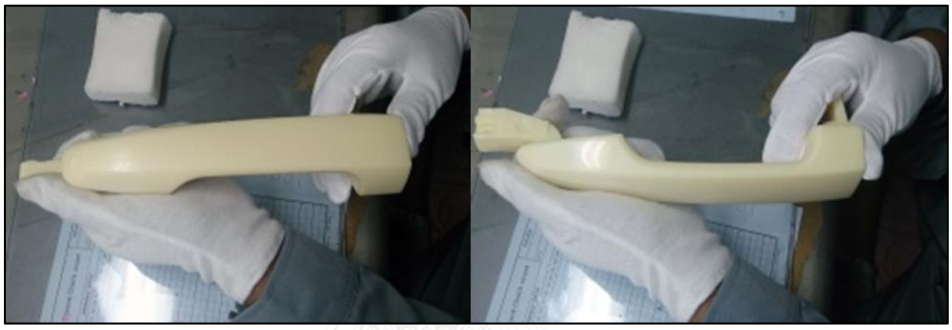


Figure 3-5: Checking and Appearance Approval

7. Continuous Injected running

After approval of the first run, the machine than can be perform in continuous injected running to produce the moulded parts. Figure 3-6 shows the continuous injected running.

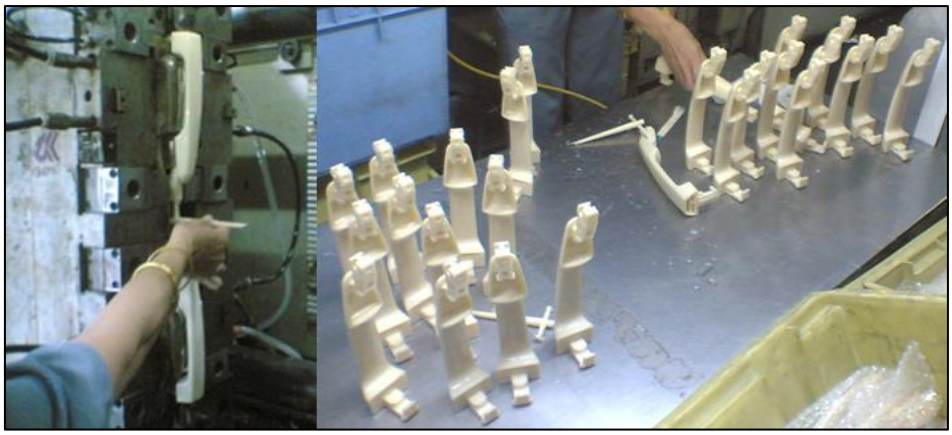


Figure 3-6: Continuous injected running

8. Inspection and Appearance Approval

During each cycle that moulded parts that come out of the machine, the machine operator have to inspect every moulded parts for the potential defect. If the moulded parts do not have any defects, then it can be carry on to packing. In case of the defect can be repair such as trim or deflash, the moulded parts then can be repair and inspect again before packing. If the moulded parts are cannot repair, then it have to go to scrap or crush.

9. Packaging

The packing of moulded parts is then pack as specify by the customers. Figure 3-7 shows different kinds of boxing and packaging.

Figure 3-7: Boxing and packaging

10. Final Inspection

The final inspection is responsible to make sure that the moulded parts and packaging are not damages. Figure 3-8 shows the final inspection process.

Figure 3-8: Final inspection process

11. Storage

The finish goods are then storage in the storage areas. Figure 3-9 shows the storage areas of the company.

Figure 3-9: Storage areas

12. Dispatch

Delivery the finished goods to the customers. Figure 3-10 shows the sample of delivery truck of the company.

Figure 3-10: Delivery truck

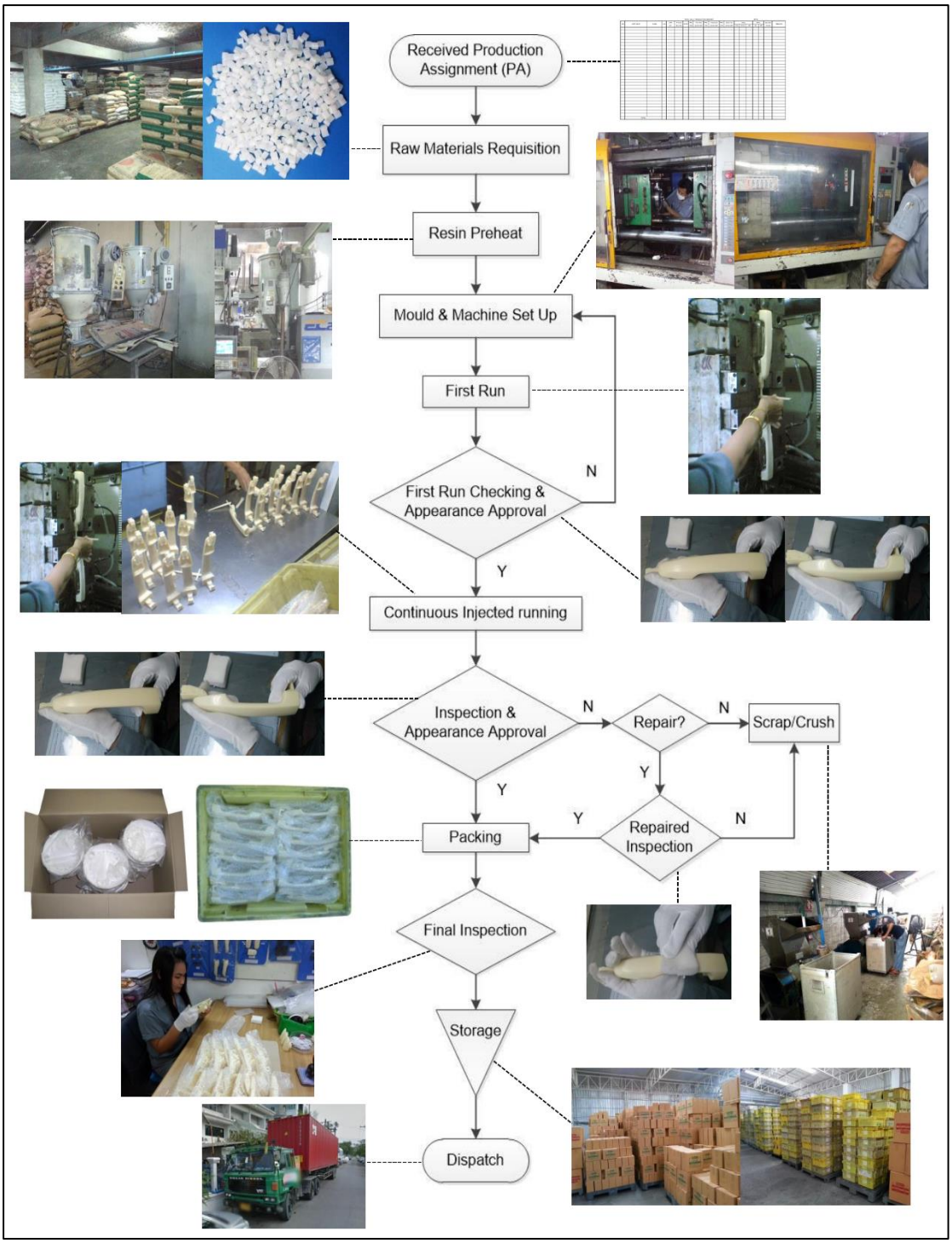


Figure 3-11: Process flow chart of the company

3.2 SIPOC Process Mapping

After the study of plastic injection moulding process of the company, the SIPOC process mapping is then construct to having more recognise of who is the supplier and input to the process, and who is the customer and output of the process. Table 3-1 shows the SIPOC process mapping of the company.

Table 3-1: SIPOC Process mapping of the company

Supplier	Input	Process	Output	Customer
Raw Materials Store	Raw materials	Production Assignment	Finished Product (Moulded parts)	Storage areas
	Process Consumables	Raw Materials Requisition	Regrind Material	Regrind Department
Maintenance Department	Mould and Machine Repairs	Resin Preheat	Defective Product	Regrind Department
		Mould & Machine Setup		
Quality Department	Quality Control	First Run	Quality Records	Quality Department
Production Management	Production Plan	First Run Checking & Appearance Approval		
		Continuous Injected Running		
		Inspection & Appearance Approval		
		Packing		
		Final Inspection		
		Storage		
		Dispatch		

3.3 Define Problem

After the study of plastic injection moulding process and process mapping of the company, the author have collected necessary information and study the potential problem that appear in plastic injection moulding process. From the observation of the company monthly production during September 2013 to February 2014, it is found out that the production volume is gradually increasing, while the defective rate is increasing as well. Table 3-2 reveals the detail information about production and defective parts from September 2013 to February 2014. It can be seen that the total defect part per million from this pass six month is 5,491 DPPM.

Table 3-2: Production data and defective parts

Month-Year	Production	Number of Defective Parts	DPPM
Sep-13	4,927,247	28,318	5,747
Oct-13	4,544,479	31,884	7,016
Nov-13	6,056,331	29,306	4,839
Dec-13	4,778,682	21,776	4,557
Jan-14	8,661,318	53,126	6,134
Feb-14	7,619,166	36,485	4,789
Total	36,587,223	200,895	5,491

As stated in chapter 1, the issue that needs to be focused is defects that were caused chiefly during the production process. There are various type of defect was detected from the moulded parts from this company that is not pass the customer's requirement. The moulded parts defect such as short shot, black dot, pinhole, burn mark, etc. However, the major defect problem that are regularly occurs in the manufacturing process of this company is the black dot defect that appeared on the moulded parts as shows in Table 3-3.

Table 3-3: Different defect type and the percentage defect of the total defect from Sep-13 to Feb-14

Type of Defects	Number of Defects	%Defects
Black Dot	63,460	31.59%
Damage	1,331	0.66%
Scratch	1,591	0.79%
Black Line	4,184	2.08%
Dirty	6,975	3.47%
Burn Mark	8,557	4.26%
Flow mark	19,265	9.59%
Sink Mark	4,467	2.22%
Mat'l Flow	20,909	10.41%
Short shots	20,029	9.97%
White Dot	3,403	1.69%
Weld Line	5,157	2.57%
Flash	1,538	0.77%
Deform	681	0.34%
Pinhole	39,348	19.59%

As for table 3-2, it can be seen that the black dot defect that appear on the moulded parts from September 2013 to February 2014 is account for 31.59 per cent of the total defect or 63,460 pieces.

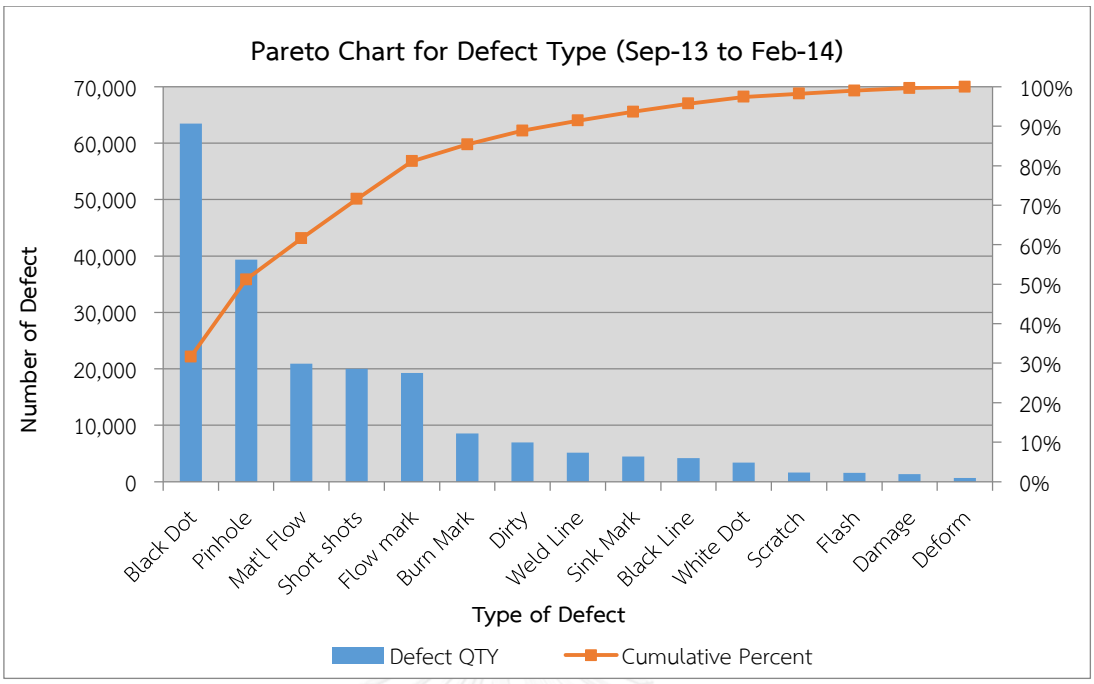


Figure 3-12: Pareto chart for defect type from Sep-13 to Feb-14

In addition, the Pareto analysis of each defect type shows in the figure 3-12 point out that black dot and pinhole are the two most frequent defects that appear on the moulded parts which account for approximately 51% of the total defect. However, most of pinhole defect can be repaired; on the other hand, black dot defect are regularly do not pass the customer's standard and have to be a scrap. Figure 3-13A and 3-13B illustrated a comparison of black dot and pinhole defect that can be repair or pass the standard, and scrap. In addition, Mat'l flow, short shots, and flow mark defects are occur approximately at the same rate and other kind of defects such as burn mark, dirty, weld line, sink mark, black line, white dot, scratch, flash, damage, and deform are occur at lower rate. All type of defects are needed to be eliminate as philology of Six Sigma mentioned, but in real practice, we cannot cope with every problem at the same time. Therefore, the possible solution in initial step of defect reduction in the process that is to first focus on the type of defect that are most frequency occur, and have major impact to the company. Since black dot contributes to highest defective and result to high losses each month and need an effective solution to reduce the black dot defective percentage. As a result, the black dot defect is selected in this research.

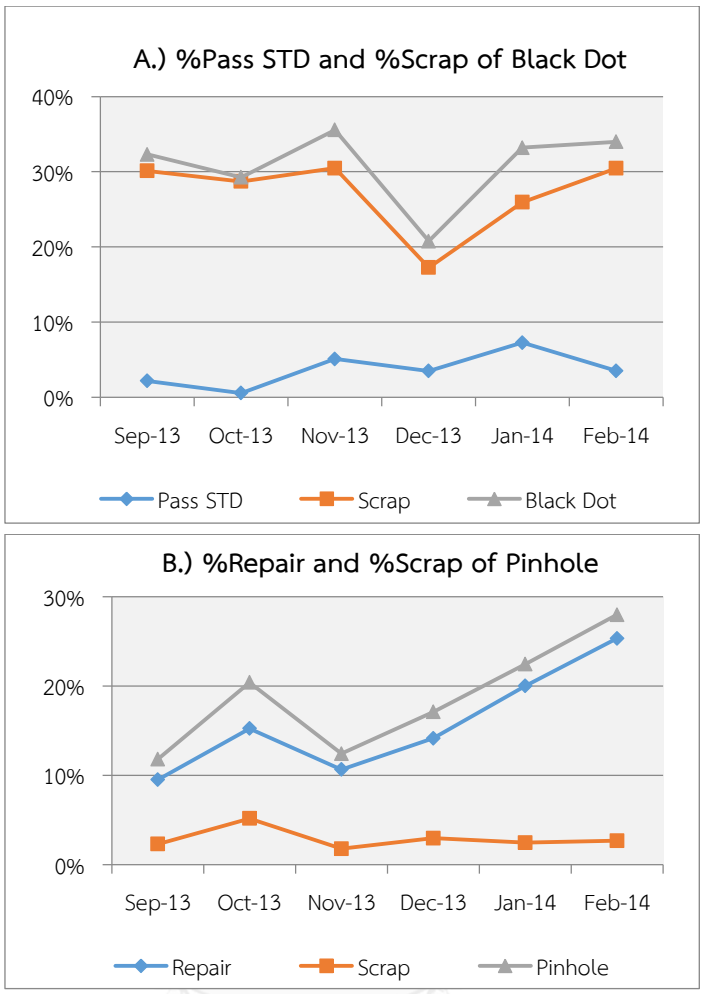


Figure 3-13: A.) Pass standard and scrap percentage of black dot. B.) repair and scrap percentage of pinhole

3.4 Sample of Black Dot Defect

Black dot defect is the highest defect rate that leads to defective moulded parts in this company and this black dot defect can be detected on every product that have white or natural raw material colour. Figure 3-14 shows the sample of black dot defected parts from three different products.

Figure 3-14: Sample of black dot moulded defect parts

3.5 Selection of Machine for this Research

Since the business of the company is operated in made-to-order fashion by receiving the order from the customers. Therefore, the company have to regularly change the mould to produce another product when the previous products are finished. To perform this research by focus on the products type is limited. Consequently, the author would like to observe which injection moulding machine that produce the highest number of defect and particularly on black dot type.

Currently, the company have 48 injection moulding machine in active operation at the moment. After gathering the number of defect from each machines it is found out that machine number P24 and P25 are the most two machine that produce higher number of defect than other machine from September 2013 to February 2014. Figure 3-15 reveals the Pareto analysis for defect of each injection machine.

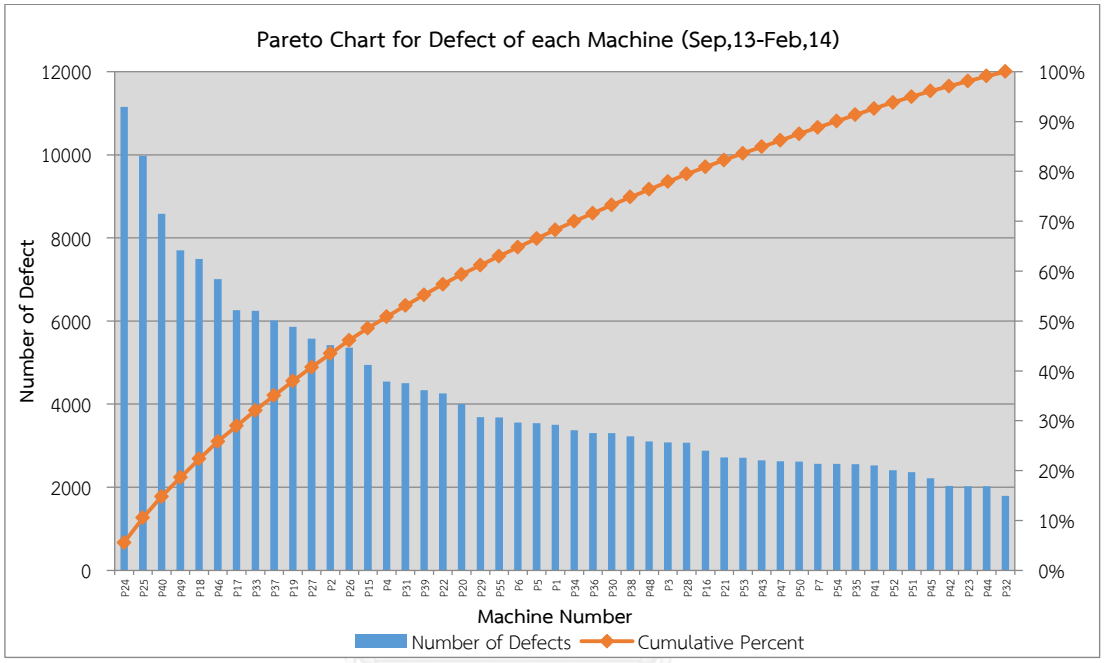


Figure 3-15: Pareto chart for defect of each machine

Moreover, after gathering deeper data of each defect type that generate from machine number P24 and P25, it is confirmed by the Pareto analysis of each defect type of machine number P24 and P25 shows in figure 3-16 that black dot is the highest defect that generated by machine number P24 and P25 which account for 41.38% (combine of machine number P24 and P25) of the total defect.

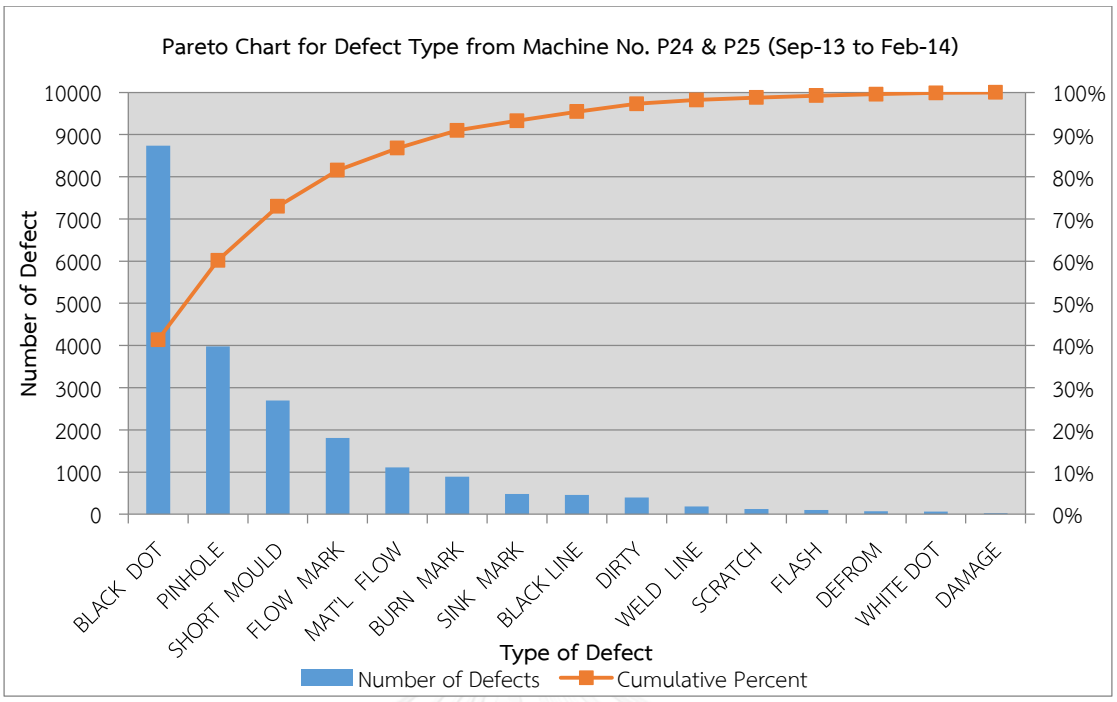


Figure 3-16: Pareto chart for defect type from machine No. P24 and P25

Moreover, table 3-4 shows the number of black dot defect of machine number P24 and P26 from September 2013 to February 2014. As for figure 3-4, the percentage defective due to black dot of machine number P24 and P25 are 0.72% and 0.59%, respectively and the percentage defective due to black dot of combine machine number P24 and P25 is 0.65%. Therefore, the research will be focused mainly on these two injection moulding machines as a pilot. These two machines are the same brand and model which is Toshiba - EC230S. Figure 3-17 shows the injection moulding machine number P24 and P25.

Table 3-4: Black dot defect from machine No. P24 and P25

Month-Year	Machine No.		Combine P24 and P25
	P24	P25	
Sep-13	398	433	831
Oct-13	1,410	1,058	2,468
Nov-13	612	485	1,097
Dec-13	422	252	674
Jan-14	1,230	1,372	2,602
Feb-14	734	334	1,068
Total Black Dot	4,806	3,934	8,740
Total Production	671,589	666,113	1,337,702
%Black Dot	0.72%	0.59%	0.65%

Figure 3-17: Injection moulding machine No.P24 (left) and No.25 (right)

3.6 Forming Project Team

Forming an effective project team for driving process improvement projects throughout an organisation is essential. Project teams are vital to improving an organisation's existing quality to enhance bottom-line performance. By forming a cross functional team within the company to acquire different knowledge and expertise of each functional area can help to tackle with the problem effectively. The team is then brainstorming to identify the root cause of the problem and effect of the selected problem. The formed team members that help to reduce this black dot defect of this research including:

- Factory Manager
- Production Manager
- Production Engineer
- Production Supervisor
- Quality Assurance Engineering
- Maintenance Engineer
- Researcher

The team are responsible to select an appropriate tools and techniques to identify the root cause of the black dot defect.

3.7 Project Charter

The project charter, in other words, summarised the project's background, scope, voice of customer, goal and the team's role in this research project. The project charter of this research is presented in Table 3-5.

Table 3-5: Project charter of this research

Project Title:	Black dot defect reduction in plastic injection moulding process
Background and reasons for selecting the project:	
A large amount of defective moulded parts in plastic injection moulding process are mainly cause by black dot defect	
Project Goal:	
To reduce the moulded defect parts from the black dot type in plastic injection moulding process	
Voice of Customer:	Product's quality
Project Scope:	Focusing only black dot defect on the moulded parts from selected injection moulding machines (Machine No.P24 and No.P25)
Team members:	Factory manager, Production manager, production engineer, production supervisor, QA engineer, Maintenance Engineer, and Researcher
Expected Benefits:	-Defect reduction on moulded part of black dot type - Improve customer confident and increase customer satisfaction from receiving quality product from the company -Could be the guideline and method to reduce the defect for other machines afterward

3.8 Summary of Define Phase

In define phase, after understanding the manufacturing process, process mapping, and current situation of the company, it is found out that the major problem in the process are defect that appeared on the moulded part. The most frequently type of defect that is occurs in the process is black dot type which it lead to defective moulded parts and it have to go to regrind. In addition, the operation of the company is based on made-to-order fashion, thus selecting particular product to perform the research is not appropriate. Consequently, the identification of which machine is produce the highest black dot defect rate is implemented here. All in all, the objective of this research is to reduce the moulded defect parts from the black dot type in plastic injection moulding process, and use selected injection moulding machines as a pilot (machine number 24 and 25). To achieve this objective, an effective cross-functional project team is then formed to support and brainstorm to identify the potential cause of the black dot issue.

CHAPTER 4
MEASURE PHASE

The problem was identified in the previous chapter. In this chapter, measure phase, is the measurement procedure to assure the quality control mechanism of the process that is meeting with the quality standard and identify the cause of the problem by using the statistical tools and techniques in the research. This phase presents the evaluation of the existing system and to pinpoint the source of problem. Attribute Agreement Analysis command in Minitab Release 16 is use to perform Gage Repeatability and Reproducibility (Gage R&R) of attribute data to analyse the accuracy of measurement system in plastic injection moulding process by visual inspection process to assure the perfection of data from the measurement before performing the experimentation for analysis of issue to select key process input variable (KPIV) for future study that is selected by Cause-and-Effect Diagram and Cause-and-Effect Matrix. Then, the key process input variable obtained from Cause-and-Effects Diagram and Cause-and-Effects Matrix will be explore in Failure Mode and Effects Analysis (FMEA) to determine the potential causes and major factors that cause the black dot defect, and selected the factors that have the most high RPN value to analysis.

4.1 Measurement System Analysis

Since the measurement system to inspect the defect of moulded parts in plastic injection moulding process is done by using direct visual inspection which might lead to error or inaccuracy due to human error. To reduce the number of defect in the plastic injection moulding process, the accuracy and precision of the measurement system analysis is significant. If the process do not have a precise measurement system, there is possible error might occur in the experiment. Therefore, the appraiser who inspects the defect must be assured 100% in accuracy and precision of measurement. In addition, the measurement system of this company is based on attribute data. Attribute inspection involves determining the classification of an item such as pass/fail, good/bad,

accept/reject. The accuracy is inspect by compare the results of appraisers with the standard references. The precision is inspecting by compare the result of repeatability of each appraiser.

4.1.1 Moulded Parts Appearance Inspection

The black dot defect inspection of the moulded parts in this company is performed by direct visual inspection to determine the soundness of the moulded parts. Figure 4-1 illustrates the direct visual inspection procedure performed by appraiser. The moulded parts have to inspect for defect to assure the quality before delivery to the customer. Figure 4-2 reveals the sample of Good (G) and No Good (NG) moulded parts.

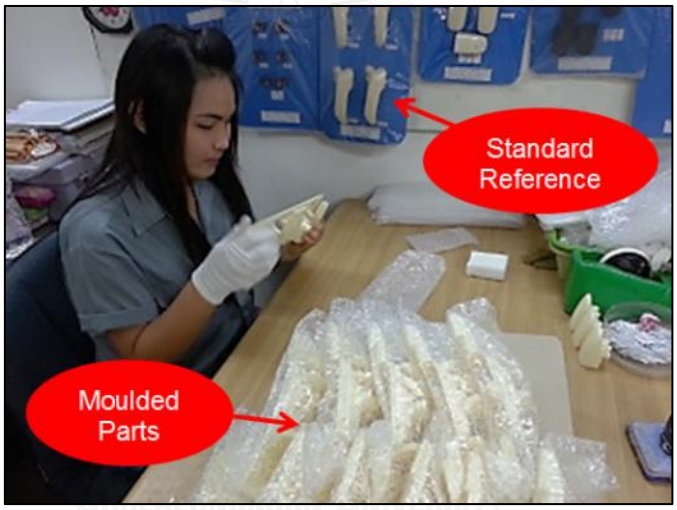


Figure 4-1: Direct visual inspection

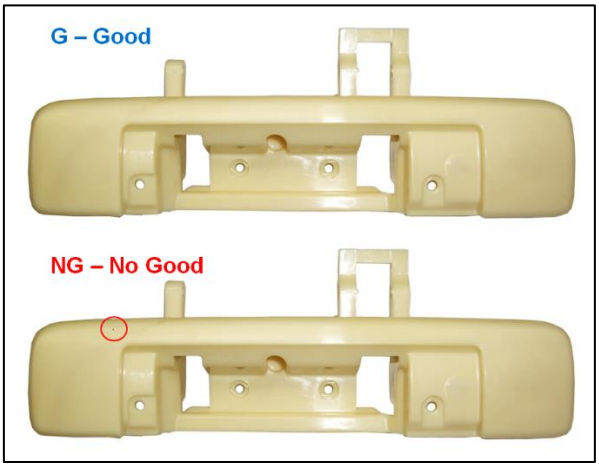


Figure 4-2: Good (G) and No Good (NG) moulded parts

4.1.2 Attribute Gage R&R Procedure

The procedure of Attribute Gage R&R of direct visual inspection on the moulded parts of the company is described as following:

1. Select 3 verification appraisers who have great experience in direct visual inspection of the moulded parts and have ability to distinguish between non-defected and defected moulded parts. In addition, all of these appraisers have passed the direct visual inspection training.

2. Assign 40 different pieces of the sample moulded parts (standard reference) where 20 pieces of sample moulded parts are defected with black dot, and the remaining 20 pieces of sample moulded parts are non-defected moulded parts.

3. Perform the experiment as verification plan in table 4-2 which the appraisers will be completely randomised design, and each appraiser wills verity the sample moulded parts 2 times.

4. Record the experiment result in the record form.

5. Analyse and summarise the measurement of data analysis by the help of Minitab Software to obtained various indexes including %Repeatability of Appraisers, %Reproducibility of Appraisers, %Effectiveness of Repeatability of Verification, and %Effectiveness of Reproducibility of Verification

Acceptance Criterion

The acceptance criterion of the measurement system with the direct visual inspection of the company quality standard is shows in the table 4-1. Table 4-1 reveals that the acceptances criterion of all indexes: %Repeatability of Appraisers, %Reproducibility of Appraisers, %Effectiveness of Repeatability of Verification, and %Effectiveness of Reproducibility of Verification must be 100%

Table 4-1: Acceptance criterion of measurement system

Index	Acceptance Criterion
%Repeatability of Appraisers	100%
%Reproducibility of Appraisers	100%
%Effectiveness of Repeatability of Verification	100%
%Effectiveness of Reproducibility of Verification	100%

Table 4-2: Measuring data (G=Good, NG=No Good)

Sample	Standard Reference	Inspector A		Inspector B		Inspector C	
		1	2	1	2	1	2
1	G	G	G	G	G	G	G
2	G	G	G	G	G	G	G
3	G	G	G	G	G	G	G
4	NG	NG	NG	NG	NG	NG	NG
5	NG	NG	NG	NG	NG	NG	NG
6	G	G	G	G	G	G	G
7	NG	NG	NG	NG	NG	NG	NG
8	G	G	G	G	G	G	G
9	G	G	G	G	G	G	G
10	NG	NG	NG	NG	NG	NG	NG
11	NG	NG	NG	NG	NG	NG	NG
12	G	G	G	G	G	G	G
13	NG	NG	NG	NG	NG	NG	NG
14	G	G	G	G	G	G	G
15	G	G	G	G	G	G	G
16	NG	NG	NG	NG	NG	NG	NG
17	G	G	G	G	G	G	G

Table 4-2: Measuring data (G=Good, NG=No Good) [Cont.]

Sample	Standard Reference	Inspector A		Inspector B		Inspector C	
		1	2	1	2	1	2
18	NG	NG	NG	NG	NG	NG	NG
19	G	G	G	G	G	G	G
20	NG	NG	NG	NG	NG	NG	NG
21	NG	NG	NG	NG	NG	NG	NG
22	NG	NG	NG	NG	NG	NG	NG
23	G	G	G	G	G	G	G
24	NG	NG	NG	NG	NG	NG	NG
25	G	G	G	G	G	G	G
26	G	G	G	G	G	G	G
27	NG	NG	NG	NG	NG	NG	NG
28	NG	NG	NG	NG	NG	NG	NG
29	G	G	G	G	G	G	G
30	NG	NG	NG	NG	NG	NG	NG
31	NG	NG	NG	NG	NG	NG	NG
32	G	G	G	G	G	G	G
33	G	G	G	G	G	G	G
34	G	G	G	G	G	G	G
35	G	G	G	G	G	G	G
36	NG	NG	NG	NG	NG	NG	NG
37	NG	NG	NG	NG	NG	NG	NG
38	NG	NG	NG	NG	NG	NG	NG
39	G	G	G	G	G	G	G
40	NG	NG	NG	NG	NG	NG	NG

4.1.3 Measurement Analysis Result

Within appraiser analysis

Minitab evaluates the repeatability of appraisers by examining how often the appraiser ‘‘agrees with him/herself across trials.’’ It does this by looking at all of the classifications for each part and counting the number of parts where all classifications agreed (Pyzdek, 2003a). For this analysis, each appraiser looked at 40 sample moulded parts two times each. Minitab’s output, shown in Figure 4-3, indicates that Appraiser 1 rated 100% of the parts consistently, Appraiser 2 100%, and Appraiser 3 100%. The 95% confidence interval on the percentage agreement is also shown. The results of Within Appraisers are displayed graphically in Figure 4-8.

Within Appraisers

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	40	40	100.00	(92.78, 100.00)
2	40	40	100.00	(92.78, 100.00)
3	40	40	100.00	(92.78, 100.00)

Matched: Appraiser agrees with him/herself across trials.

Figure 4-3: Minitab within appraiser assessment agreement

Accuracy Analysis

Minitab evaluates accuracy by looking at how often all of an appraiser’s classifications for a given part agree with the standard (Pyzdek, 2003a). Figure 4-4 shows the Minitab’s output for this measurement analysis, indicates that Appraiser 1 rated 100% of the parts consistently, Appraiser 2 100%, and Appraiser 3 100%. The results of Each Appraisers vs Standard are displayed graphically in Figure 4-8.

Each Appraiser vs Standard

Assessment Agreement

Appraiser	# Inspected	# Matched	Percent	95% CI
1	40	40	100.00	(92.78, 100.00)
2	40	40	100.00	(92.78, 100.00)
3	40	40	100.00	(92.78, 100.00)

Matched: Appraiser's assessment across trials agrees with the known standard.

Figure 4-4: Minitab appraiser vs standard agreement

Moreover, Minitab looks at whether or not there is a distinct pattern in the disagreements with the standard. It does this by counting the number of times the appraiser classified an item as a 1 when the standard said it was a 0 (the # NG/G per cent column), how often the appraiser classified an item as a 0 when it was a 1 (the # G/NG per cent column), and how often the appraiser's classifications were mixed, i.e., is not repeatable (the # Mixed Percent column) (Pyzdek, 2003a). The results are shown in Figure 4-5. The results indicate that there is no consistent bias, defined as consistently putting a unit into the same wrong category and appraisers A, B and C are repeatable.

Assessment Disagreement

Appraiser	# NG / G	Percent	# G / NG	Percent	# Mixed	Percent
1	0	0.00	0	0.00	0	0.00
2	0	0.00	0	0.00	0	0.00
3	0	0.00	0	0.00	0	0.00

NG / G: Assessments across trials = NG / standard = G.
G / NG: Assessments across trials = G / standard = NG.
Mixed: Assessments across trials are not identical.

Figure 4-5: Minitab appraiser assessment disagreement analysis

Between Appraiser Assessments

Then, Minitab looks at all of the appraiser assessments for each part and counts how often every appraiser agrees on the classification of the part (Pyzdek, 2003a). The results, shown in Figure 4-6, indicate that all appraisers' assessments agree with each other 100%.

Between Appraisers

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
40	40	100.00	(92.78, 100.00)

Matched: All appraisers' assessments agree with each other.

Figure 4-6: Minitab between appraisers assessment agreement

All Appraisers vs Standard

Lastly, Minitab looks at all of the appraiser assessments for each part and counts how often every appraiser agrees on the classification of the part and their classification agrees with the standard (Pyzdek, 2003a). The results, shown in Figure 4-7, indicate that all appraisers' assessments agree with the know standard 100%.

All Appraisers vs Standard

Assessment Agreement

# Inspected	# Matched	Percent	95% CI
40	40	100.00	(92.78, 100.00)

Matched: All appraisers' assessments agree with the known standard.

Figure 4-7: Minitab assessment vs standard agreement across all appraisers

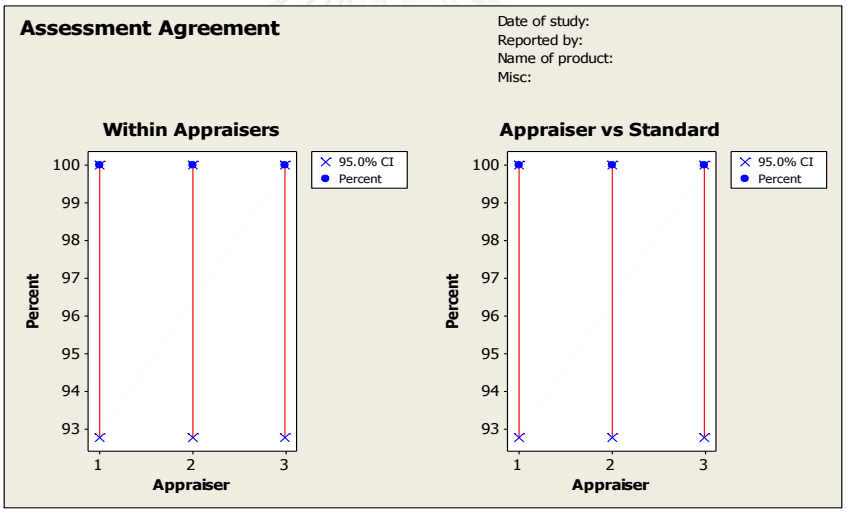


Figure 4-8: Plot of within appraiser assessment agreement and plot of appraiser vs standard assessment agreement

From the above outcome from Minitab Software, all the results can be summarising in the table 4-3. Table 4-3 reveals that the %Repeatability of Appraisers of Appraiser 1, 2, and 3 are all 100%. %Reproducibility of Appraisers of Appraiser 1, 2, and 3 are all 100%. The result of evaluation found the each appraiser has very good repeatability and reproducibility. Therefore, the result from the inspection is dependable. Moreover, %Effectiveness of Repeatability of Verification is 100% and %Effectiveness of Reproducibility of Verification is 100%. The result of measuring capability of all appraisers is

effective in both repeatability and reproducibility aspect perfectly. Thus, the data from this counting is dependable.

Table 4-3: Results of measurement system analysis

Index	Appraiser 1	Appraiser 2	Appraiser 3	All Appraiser
%Repeatability of Appraisers	100%	100%	100%	
%Reproducibility of Appraisers	100%	100%	100%	
%Effectiveness of Repeatability of Verification				100%
%Effectiveness of Reproducibility of Verification				100%

4.2 Cause-and-Effect Diagram

Cause-and-Effect Diagram will be used as the tool for brainstorming from the team members from different functional department in the company that are knowledgeable and have experience in plastic injection moulding process to obtain the cause of the black dot defect, and prove the fact for solving the black dot defect and improvement. In determining the possible causes, the cause-and-effect diagram of this research will consider six main causes that can contribute to an outcome effect including: Man or staffs involved, Machine, Material, Method, Measurement, and Environment in the organisation (5M1E).

Brainstorming session is conducted with six people different department consists of Factory Manager, Production Manager, Production Engineer, Production Supervisor, QA Engineer, and Maintenance Engineer for identifying the possible causes.

The procedure to identify the most possible cause of black dot defect by brainstorming of the team members is described in following:

1. Appoint the team members for meeting to study and share the knowledge of plastic injection moulding process in detail to the team.

2. Brainstorming among the team member to identify all possible causes that create or contribute to black dot defect that appeared on the moulded parts based on six main area causes (Man, Machine, Material, Method, Measurement, and Environment).

3. Construct cause-and-effect diagram by putting those possible causes in categories of causes to provide a visual image that display relationships of the problem and potential categories of causes and shows all causes simultaneously.

The causes identified for black dot are placed in the cause-and-effect diagram illustrates in figure 4-9. Several causes contributed towards the formation of black dot in the moulded parts produced. The diagrams show in numerous of factors that should be investigated; however, the focus should be given to the most likely causes that contribute towards the rejection of the black dot. Consequently, cause-and-effect matrix is used to narrow all of suspected factors down to a more manageable one.

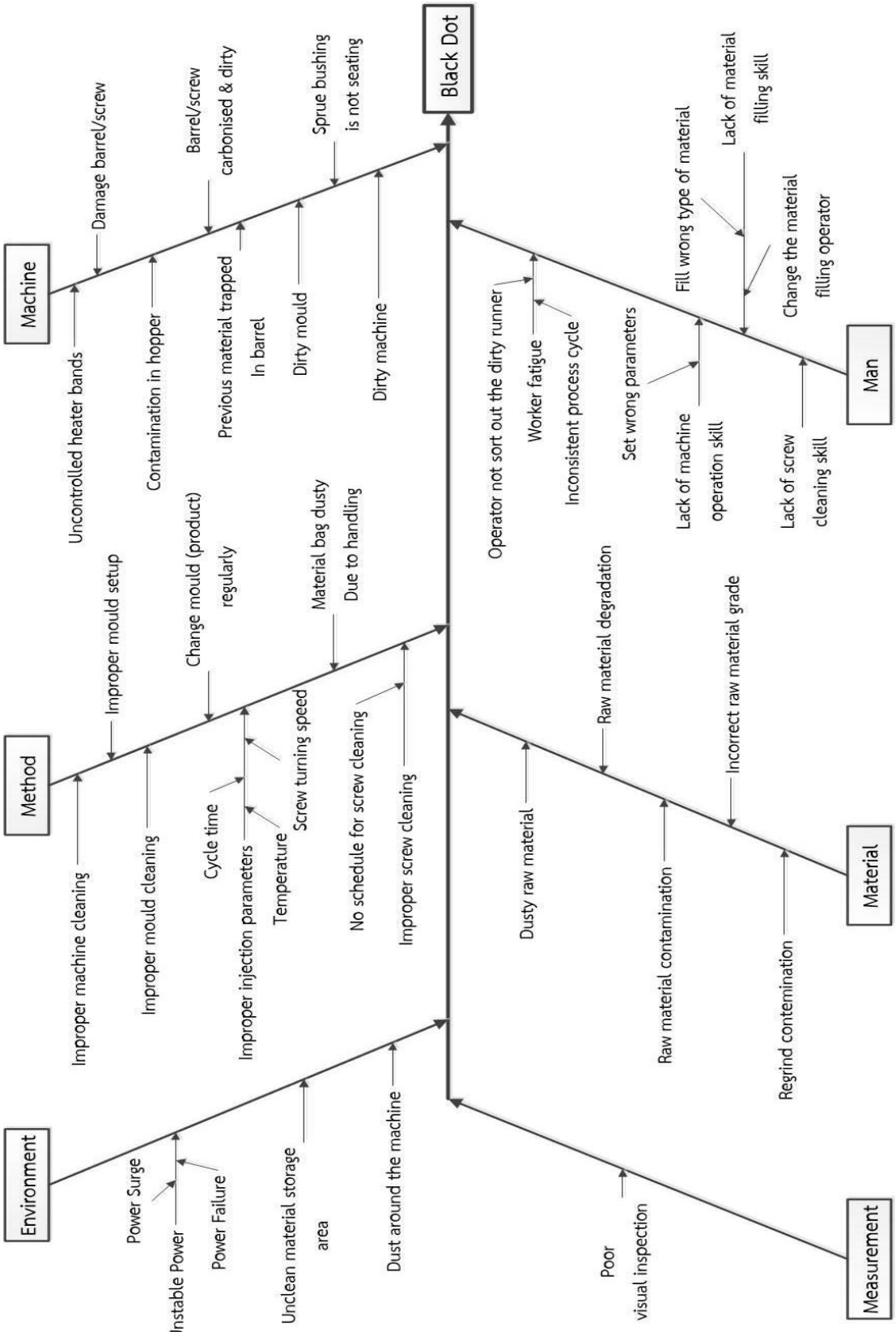


Figure 4-9: Cause-and-effect of Black Dot Defect

4.3 Cause-and-Effect Matrix

The outcomes of brainstorming to identify the root cause of black dot defect on the moulded parts and construct a cause-and-effect diagram indicates that there various possible causes of black dot defect. Therefore, it is essential to determine and prioritise the main factor that results in the problem by scoring the cause-and-effect relationship of the problem. Cause-and-effect matrix can be used to perform this task. The procedure to construct cause-and-effect matrix is described in following:

1. Use the information from cause-and-effect diagram obtained from brainstorming to fill in the cause-and-effect matrix table.

2. Each member will score the important relationship of each factor in the form. The score is range from 0 to 10 point, where

   0 = No relation – input factor does not affect and relate to the cause of the problem.

   1 = Low relation – input factor slightly affect and slightly relate to cause of the problem.

   5 = Moderate relation – input factor moderately affect and moderately relate to cause of the problem.

   10 = High relation – input factor highly affect and highly relate to cause of the problem.

3. Sum up all point in each factor and summarise the score result in the cause-and-effect matrix. Prioritise the importance of each factor by sorting with Pareto chart in descending order.

Cause-and-effect matrix of black dot defect is displays in table 4-4.

Table 4-4: Cause-and-effect matrix of black dot defect

Area Cause	Item	Code	Key Process Input Variables (KPIV)	Score								Total Score from each Area Cause
				Factory manager	Production manager	Production engineer	Production supervisor	QA engineer	Maintenance Engineer	Total		
Machine	1	MAC1	Uncontrolled heater bands	4	6	4	5	6	7	32	348	
	2	MAC2	Damage barrel/screw	8	10	9	10	9	10	56		
	3	MAC3	Contamination in hopper	9	10	10	10	10	10	59		
	4	MAC4	Previous material trapped in barrel	8	10	10	10	9	9	56		
	5	MAC5	Barrel/screw carbonised and dirty	9	9	10	10	10	10	58		
	6	MAC6	Sprue bushing in not seating properly	2	5	5	6	5	7	30		
	7	MAC7	Dirty mould	6	5	5	6	7	8	37		
	9	MAC9	Dirty machine	3	3	6	2	4	2	20		
Man	1	MAN1	Operator not sort out the dirty runner	6	8	6	7	6	7	40	222	
	2	MAN2	Inconsistent process cycle	6	8	8	6	5	7	40		
	3	MAN3	Set wrong parameters	9	9	10	8	8	10	54		
	4	MAN4	Lack of screw cleaning skills	10	10	10	10	10	10	60		
	5	MAN5	Fill wrong type of material	2	3	4	1	3	1	14		
	6	MAN6	Change the material filling operator	3	2	2	2	1	4	14		

Table 4-4: Cause-and-effect matrix of black dot defect (Cont.)

Area Cause	Item	Code	Key Process Input Variables (KPIV)	Score								
				Factory manager	Production manager	Production engineer	Production supervisor	QA engineer	Maintenance Engineer	Total	Total Score from each Area Cause
Material	1	MAT1	Dusty raw material	7	6	7	5	8	8	41	208
	2	MAT2	Raw material degradation	9	10	10	10	8	9	56	
	3	MAT3	Raw material contamination	8	9	7	7	7	8	46	
	4	MAT4	Incorrect raw material grade	2	4	1	4	3	2	16	
	5	MAT5	Regrind contamination	8	8	9	9	7	8	49	
Method	1	MET1	Improper machine cleaning	5	7	6	5	5	8	36	352
	2	MET2	Improper mould cleaning	8	7	8	7	8	9	47	
	3	MET3	Improper mould setup	2	1	1	2	1	3	10	
	4	MET4	Improper injection cycle time	5	6	8	7	5	6	37	
	5	MET5	Improper injection temperature	8	8	8	9	8	7	48	
	6	MET6	Improper injection screw turning speed	7	8	8	8	8	7	46	
	8	MET8	Change mould (product) regularly	3	4	3	2	6	8	26	
	9	MET9	Improper screw cleaning	10	10	10	10	10	10	60	
	10	MET10	Material bag dusty due to handling	8	6	8	5	8	7	42	

Table 4-4: Cause-and-effect matrix of black dot defect (Cont.)

Area Cause	Item	Code	Key Process Input Variables (KPIV)	Score								
				Factory manager	Production manager	Production engineer	Production supervisor	QA engineer	Maintenance Engineer	Total	Total Score from each Area Cause
Measurement	1	MEA1	Poor visual inspection	1	0	0	0	0	0	1	1
Environment	1	ENV1	Power Surge	1	1	1	2	1	2	8	72
	2	ENV2	Power Failure	1	1	2	2	2	1	9	
	3	ENV3	Unclean material storage area	3	4	5	2	3	4	21	
	4	ENV4	Dust around the machine	4	6	6	7	6	5	34	

The Pareto chart in figure 4-10 and 4-11 shows the total score of each factor, and total score of each area causes that cause black dot defect, respectively.

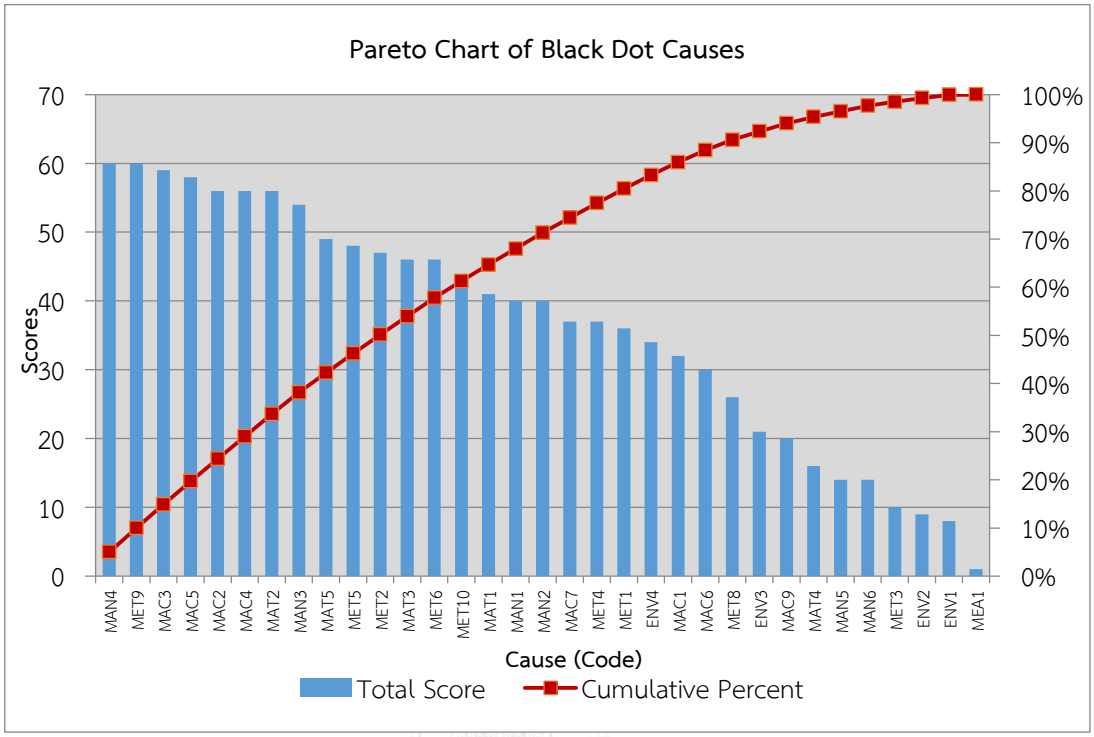


Figure 4-10: Pareto chart of black dot causes

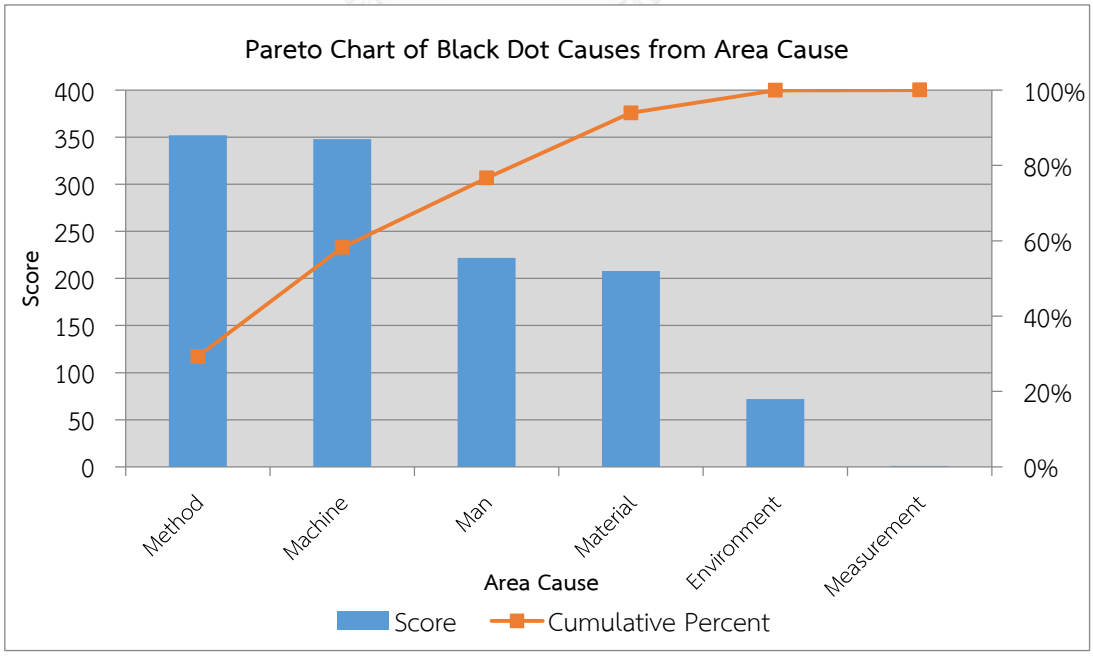


Figure 4-11: Pareto chart of black dot causes from area cause

According to figure 4-11, it can be seen that the three main area causes that influences black dot defect are Method, Machine, and Man which account for 29.26, 28.93, and 18.45 per cent, respectively. Moreover, as for figure 4-10, the result of total of each factor are assess by the team which found out that the summation of entire factor score is 1203 point. The prioritise of potential factors are listed and selected to future study in Failure Mode and Effect Analysis in next section to explores the main influence factors where 20 factors are selected which account for 968 point 80.47% as reveals in table 4-5.

Table 4-5: Causes of black dot defect

Item	Code	Causes of Black Dot Defect	Total Score
1	MAN4	Lack of screw cleaning skills	60
2	MET9	Improper screw cleaning	60
3	MAC3	Contamination in hopper	59
4	MAC5	Barrel/screw carbonised and dirty	58
5	MAC2	Damage barrel/screw	56
6	MAC4	Previous material trapped in barrel	56
7	MAT2	Raw material degradation	56
8	MAN3	Set wrong parameters	54
9	MAT5	Regrind contamination	49
10	MET5	Improper injection temperature	48
11	MET2	Improper mould cleaning	47
12	MAT3	Raw material contamination	46
13	MET6	Improper injection screw turning speed	46
14	MET10	Material bag dusty due to handling	42
15	MAT1	Dusty raw material	41
16	MAN1	Operator not sort out the dirty runner	40
17	MAN2	Inconsistent process cycle	40
18	MAC7	Dirty mould	37
19	MET4	Improper injection cycle time	37
20	MET1	Improper machine cleaning	36

4.4 Failure Mode and Effects Analysis (FMEA)

The outcome from Cause-and-effect matrix shows that all of the causes of black dot defect can be eliminate to 20 factors. All of these 20 factors are then input to explore the factors in Failure Mode and Effects Analysis (FMEA) to study the characteristic of the problem caused by these factors and defining priorities of improvement is based on the risk priority number (RPN) which in turn is based on the multiplication of three indices resulting from evaluation of:

Severity (SEV): Severity is the significance of the effects of the failure

Occurrence (OCC): Occurrence is the frequency of the failure

Detection (DET): Detection is the ability to identify the failure before it occurs or reaches the end user/customer.

Severity, Occurrence, and Detection index are ranging from 1 to 10 which mean that the lowest possible RPN are 1 x 1 x 1 which indicate that significance of the effects of the failure is low, the frequency of the failure is low, and ability to identify the failure before it occurs is high. On the other hand, the highest possible RPN is 1000 resulting from 10 x 10 x 10 which indicate that significance of the effects of the failure is high, the frequency of the failure is high, and ability to identify the failure before it occurs is low.

In this process, the team members from different functional department in the company that are knowledgeable and have experience in plastic injection moulding process are guided the FMEA procedure and emphasised on the meaning of each score level of the Severity, Occurrence, and Detection index based on table 4-6, 4-7, and 4-8, respectively. For each process step, brainstorm a list of the potential failure modes or the way which the product might fail. Identify the potential effects of each failure mode and rate the severity of the effects. Identify the potential causes of the failure modes and rate their likelihood of occurrence. List current control in place and rate the ability of the control to detect or prevent the failure mode or cause. Then, multiply the three ratings to

get the Risk Priority Number (RPN). Identify improvement actions to reduce or eliminate the risk associated with high RPN's.

The result of Failure Mode and Effects Analysis of black dot defect is illustrates in table 4-9.

Table 4-6: Typical severity evaluation criteria (Ben-Daya et al., 2009)

Effect	Criteria: severity of effect	Ranking
Hazardous – without warning	Very high severity ranking when a potential failure mode affects safe operation and/or involves noncompliance with regulations without warning	10
Hazardous – with warning	Very high severity ranking when a potential failure mode affects safe operation and/or involves noncompliance with regulations with warning	9
Very high	Product/item inoperable, with loss of primary function	8
High	Product/item operable, but at reduced level of performance. Customer dissatisfied	7
Moderate	Product/item operable, but may cause rework/repair and/or damage to equipment	6
Low	Product/item operable, but may cause slight inconvenience to related operations	5
Very low	Product/item operable, but possesses some defects (aesthetic and otherwise) noticeable to most customers	4
Minor	Product/item operable, but may possess some defects noticeable by discriminating customers	3
Very minor	Product/item operable, but is in noncompliance with company policy	2
None	No effect	1

Table 4-7: Typical occurrence evaluation criteria (Ben-Daya et al., 2009)

Probability of Failure	Possible failure rates	Ranking
Very high: failure is almost inevitable	≥ 1 in 2	10
	1 in 3	9
High: repeated failures	1 in 8	8
	1 in 20	7
Moderate: occasional failures	1 in 80	6
	1 in 400	5
	1 in 2,000	4
Low: relatively few failures	1 in 15,000	3
	1 in 150,000	2
Remote: failure is unlikely	≤ 1 in 1,500,000	1

Table 4-8: Typical detection evaluation criteria (Ben-Daya et al., 2009)

Detection	Criteria: likelihood of detection by design control	Ranking
Absolute uncertainty	Design control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no design control	10
Very remote	Very remote chance the design control will detect a potential cause/mechanism and subsequent failure mode	9
Remote	Remote chance the design control will detect a potential cause/mechanism and subsequent failure mode	8
Very low	Very low chance the design control will detect a potential cause/mechanism and subsequent failure mode	7
Low	Low chance the design control will detect a potential cause/mechanism and subsequent failure mode	6
Moderate	Moderate chance the design control will detect a potential cause/mechanism and subsequent failure mode	5
Moderately high	Moderately high chance the design control will detect a potential cause/mechanism and subsequent failure mode	4
High	High chance the design control will detect a potential cause/mechanism and subsequent failure mode	3
Very high	Very high chance the design control will detect a potential cause/mechanism and subsequent failure mode	2
Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode	1

Table 4-9: Failure Mode and Effects Analysis of Black Dot Defect

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA									
Process: Plastic Injection Moulding		Project Name: Black dot defect reduction						Page: 1 of 6	
Core Team: Factory Manager, Production Manager, Production Engineer, Production Supervisor, QA Engineer, Maintenance Engineer, and Researcher									
Item	KPIV	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended Action	RPN
1	Lack of screw cleaning skills	Molten resin is trapped on the screw which will becomes carbonised and will flake away and enter the melt stream	8	Operator clean the screw and barrel unclean	4	Use acetylene torch to clean the screw	2	Provide hands-on training to improve the operator on screw cleaning skills	64
2	Improper screw cleaning	Molten resin is trapped on the screw which will becomes carbonised and will flake away and enter the melt stream	8	Do not have schedule for screw cleaning	4	Run to failure maintenance (when the black dot appear in large amount)	2	Set a monthly schedule to clean the screw	64
3	Contamination in hopper	Foreign material trapped in hopper	8	- Operator clean hopper improperly - Damage filter	7	Inspect the cleaned hopper by supervisor	7	Install magnet in hopper to block up the steel chips	392
4	Barrel/screw carbonised and dirty	Molten resin is trapped on the screw and barrel which will becomes carbonised and will flake away and enter the melt stream	9	- Damaged screw - Do not have schedule for screw cleaning	8	-Purge screw and barrel by using Polypropylene (PP) -Clean screw when the black dot appear in large amount	7	Clean the barrel/screw by polishing the screw with round copper wire brush and using copper gauze on barrel brush to clean the barrel	504

Table 4-9: Failure Mode and Effects Analysis of Black Dot Defect (Cont.)

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA										
Process: Plastic Injection Moulding		Project Name: Black dot defect reduction							Page: 2 of 6	
Core Team: Factory Manager, Production Manager, Production Engineer, Production Supervisor, QA Engineer, Maintenance Engineer, and Researcher										
Item	KPIV	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended Action		RPN
5	Damage barrel/screw	- Crack on the screw surface and/or barrel lead to ineffective plasticisation - Foreign material trapped in crack hole	9	Run to failure maintenance	2	weld the damage screw and barrel	1	Replace the cylinder liner and screw with new stock		18
6	Previous material trapped in barrel/screw	Molten resin is trapped on the screw which will becomes carbonised and will flake away and enter the melt stream	9	Operator not completely purge all the previous raw material	7	Purge the screw and barrel by using Polypropylene (PP)	7	Purge screw and barrel with special purging compound		441
7	Raw material degradation	Overheated/ overdried raw material (Polycarbonate, PC) can degrade and lead to black dot.	9	Dry the resin (Polycarbonate) for an excessively high temperature in hopper	7	Dry the resin (Polycarbonate) at 160°C in dehumidifying hopper dryer	7	Dry the resin (Polycarbonate) at 120°C for in dehumidifying hopper dryer		441

Table 4-9: Failure Mode and Effects Analysis of Black Dot Defect (Cont.)

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA									
Process: Plastic Injection Moulding		Project Name: Black dot defect reduction						Page: 3 of 6	
Core Team: Factory Manager, Production Manager, Production Engineer, Production Supervisor, QA Engineer, Maintenance Engineer, and Researcher									
Item	KPIV	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended Action	RPN
8	Set wrong parameters	Incorrect parameters condition can lead to several defects including black dot	8	Unawareness of new operator setting wrong parameter	2	Set the parameter by referred to customer's standard condition sheet	1	Provide hands-on training to improve the operator on machine and parameter setup skills	16
9	Regrind contamination	High regrind content with contamination can lead to contamination with virgin raw material when mixed	9	Operator sift the regrind not properly	8	Use filter to sift the regrind	6	Cleaning plastic crusher machine	432
10	Improper injection temperature	Excessive high temperature can burn the resin result in black dot	9	Operator set the injection temperature over the tolerance limit	3	Set the injection temperature from reference standard offered by customer	3	Ensure the injection temperature that not under/over the tolerance limit in reference standard offered by customer	81

Table 4-9: Failure Mode and Effects Analysis of Black Dot Defect (Cont.)

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA									
Process: Plastic Injection Moulding		Project Name: Black dot defect reduction						Page: 4 of 6	
Core Team: Factory Manager, Production Manager, Production Engineer, Production Supervisor, QA Engineer, Maintenance Engineer, and Researcher									
Item	KPIV	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended Action	RPN
11	Improper mould cleaning	Dirty mould cavity can contaminate moulded parts	7	-Grease that is used for lubricating cams, ejector pins, etc. can seep into the mould cavity -Use of external mould releases	2	Hand cleaning with spray cleaners	1	Clean the mould before and after running to keep the mould as clean as possible	14
12	Raw material contamination	Resin contaminants can enter the melt stream which can produce black dot	7	-Dust around the machine and storage area -Bad supplier issue	2	Employees check only the quantity received from supplier	1	-Ensure any open bags are covered while in use -Examine resin for possible contamination - Perform material supplier audit	14
13	Improper injection screw turning speed	Excessive screw turning speed can produce high melt friction that result in material degradation that created black dot	9	Operator set the injection screw turning speed over the tolerance limit	3	Set the injection screw turning speed from reference standard offered by customer	3	Ensure the screw turning speed that not under/over the tolerance in reference customer's standard	81

Table 4-9: Failure Mode and Effects Analysis of Black Dot Defect (Cont.)

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA									
Process: Plastic Injection Moulding		Project Name: Black dot defect reduction						Page: 5 of 6	
Core Team: Factory Manager, Production Manager, Production Engineer, Production Supervisor, QA Engineer, Maintenance Engineer, and Researcher									
Item	KPIV	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended Action	RPN
14	Material bag dusty due to handling	Dust might contaminates during improper handling such as tear and pierce on material bags	3	Material handlers tow the resin bag on the floor	2	Handling the material bags by carry on the back	1	-Properly trained material handlers -Use 2 Wheel Trolley	6
15	Dusty raw material	Dusty raw material can enter the melt stream which can produce black dot	7	Impurity of the plastic resin (Low quality) from material supplier	2	Employees check only the quantity received from supplier	2	-Store raw material in a dust-free place -Perform material supplier audit	28
16	Operator not sort out the dirty runner	The regrind from dirty runner lead to contamination with virgin raw material when mixed	7	Operator not aware about sorting out the dirty runner	4	Sorting out the dirty runner during each cycle in separate container	2	Instruct all employees on the importance of sorting out the dirty runner	56
17	Inconsistent process cycle	Excessive residence time of the material in the injection barrel lead to degrade the material	8	Operator not aware about excessive residence time of the material in the injection barrel	4	Use Cartesian robot to run the machine on automatic cycle	1	Instruct all employees on the importance of maintaining consistent cycles	32

Table 4-9: Failure Mode and Effects Analysis of Black Dot Defect (Cont.)

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA									
Process: Plastic Injection Moulding		Project Name: Black dot defect reduction						Page: 6 of 6	
Core Team: Factory Manager, Production Manager, Production Engineer, Production Supervisor, QA Engineer, Maintenance Engineer, and Researcher									
Item	KPIV	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended Action	RPN
18	Dirty mould	Dirty mould cavity can contaminate moulded parts	8	-Grease that is used for lubricating cams, ejector pins, etc. can seep into the mould cavity -Use of external mould releases	3	No proper mould cleaning time	1	Perform routine mould cleaning	24
19	Improper injection cycle time	Too long cycle time lead to excessive residence time of the material in the injection barrel	9	Operator set the injection cycle time over the tolerance limit	3	Set the injection cycle time from reference standard offered by customer	3	Ensure the injection cycle time that not under/over the tolerance limit in reference standard offered by customer	81
20	Improper machine cleaning	The oil leakage will burn at the temperatures needed for moulding and will degrade and char.	7	Leakage from hydraulic system may get into raw material storage containers and find its way into hopper	2	Weekly oil leakage checking for injection machine	2	-Eliminate all hydraulic leaks as soon as possible after they occur -Perform routine machine cleaning	28

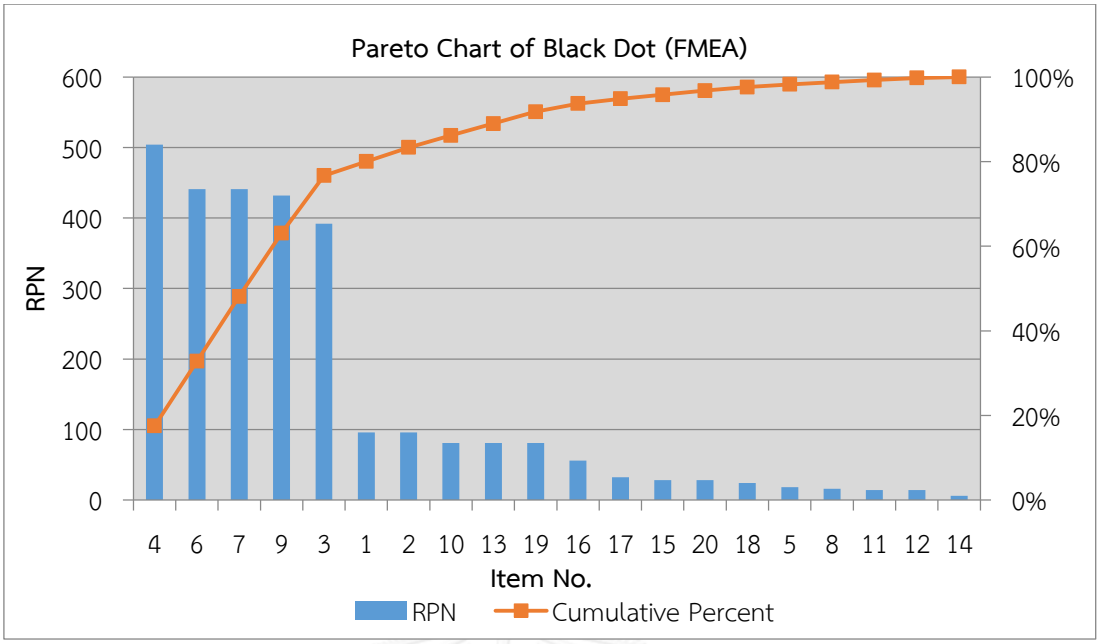


Figure 4-12: Pareto chart of FMEA of black dot defect

The results of RPN from Failure Mode and Effects Analysis are placed from left to right in descending order shows in Pareto chart in figure 4-12. As for figure 4-12, the first 5 factors are having the RPN value of 2,210 point from the total RPN from every factor is 2,881 point which account for 76.71 per cent of total RPN. The 5 key process input variables that are most critical to black dot defect are shown in table 4-10.

Table 4-10: Selected causes of black dot defect and its RPN value

Item	Key Process Input Variable	RPN
4	Barrel/screw carbonised and dirty	504
6	Previous material trapped in barrel	441
7	Raw material degradation	441
9	Regrind contamination	432
3	Contamination in hopper	392

Afterward, the selected five factors are experiments by hypothesis testing are performed to confirm the statistically significant of the causes of the black dot defect in the next chapter.

4.5 Summary of Measure Phase

In measure phase, the cause of the problem were determine by focusing on possible cause of the problem and selection of main factors is most influence to the problem which consists of measurement system analysis, cause-and-effect diagram, cause-and-effect matrix, and failure mode and effect analysis.

In measurement system analysis, the measurement system that is implemented in this company to inspect the defect of moulded parts in plastic injection moulding process is complete by using direct visual inspection to check the appearance of the moulded parts. From the result, %Repeatability of Appraisers, %Reproducibility of Appraisers, %Effectiveness of Repeatability of Verification, and %Effectiveness of Reproducibility of Verification are all 100% which mean that the result from the inspection is dependable. To identify the causes of the defect, the brainstorming session is conducted in the company by the team members from different functional department in the company that are knowledgeable and have experience in plastic injection moulding process to obtain the cause of the black dot defect which the team have identify 33 factors, and summarise in cause-and-effect diagram (fishbone diagram). Then, cause-and-effect matrix is used to prioritise the main factor that results in the problem by scoring the cause-and-effect relationship of the problem and prioritise the score in Pareto chart that minimise the factors to 20 main factors that will input to explore the factors in Failure Mode and Effect Analysis (FMEA). The outcome from FMEA indicated that 5 factors are the most critical to the process including: barrel/screw carbonised and dirty, previous material trapped, raw material degradation, regrind contamination, and contamination in hopper.

CHAPTER 5
ANALYSE PHASE

The possible factors that contributed to black dot defect were explored in the previous chapter. This chapter, analyse phase, is to learning about data in order to verify the possible root causes and their relationship of the outcome by discover and recognise tentative relationships among process variables and to develop awareness about potential process improvements, and statistically reviews the families of variation to determine which significant contributors to the output are. Why-Why diagram is used as a tool to assists the team to identify to the root causes of black dot defect for each factor and determined the potential corrective action. Then, statistical analysis is performed by implementing hypothesis testing of those selected factors to screen and confirm the statistically significant of the causes of black dot defect. In addition, the tool used to perform hypothesis tests is done by Minitab Release 16 in 2 Proportions command that is based on two proportion z-test.

5.1 Corrective action for each cause

The major five factors from Failure Mode and Effects Analysis in previous chapter are explored to identify the root causes of black dot defect. The team performed brainstorming by using Why-Why diagram to obtains the root causes. The root causes for each factor and recommended action to remedy the black dot defect is reveals in figure 5-1. The details clarification for each cause of factors and corrective action will be mention in the upcoming section.

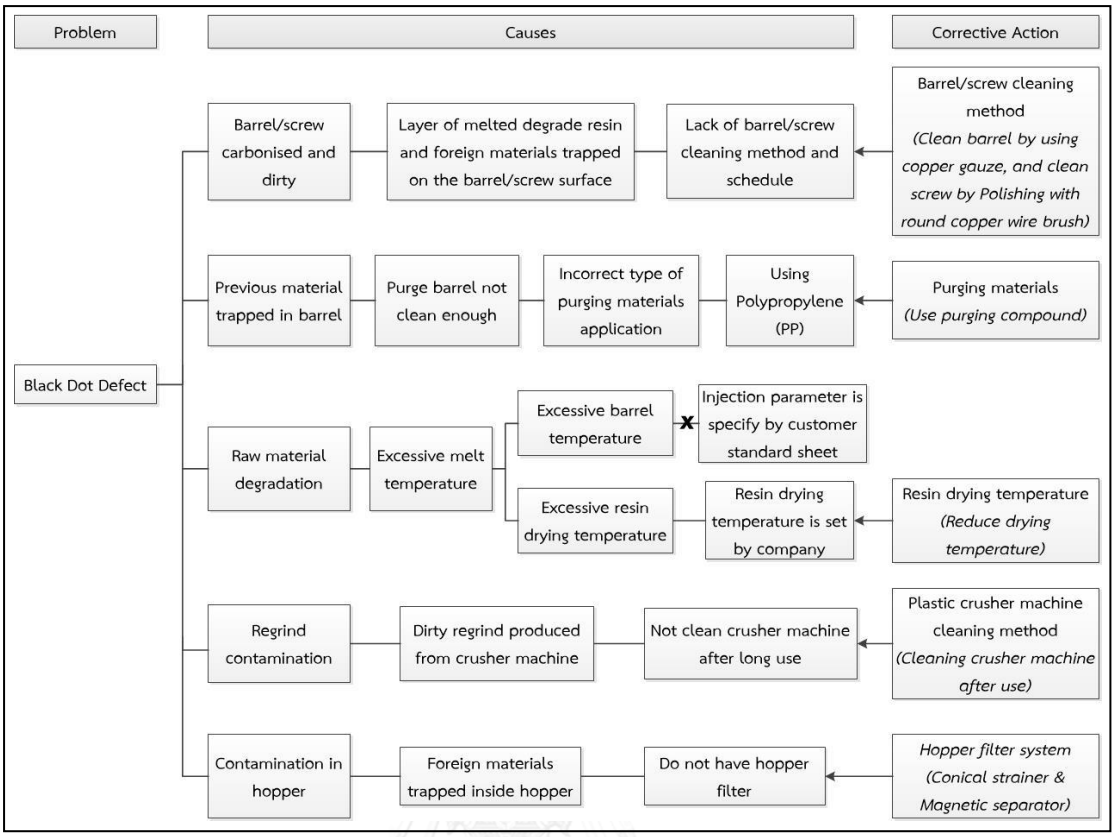


Figure 5-1: Why-Why diagram of the black dot defect causes and corrective action

5.2 Factors to test the Hypothesis

From the previous section, the factors that vastly effect to black dot defect are listed below.

- Barrel/screw cleaning method
- Purging materials
- Resin drying temperature
- Plastic crusher machine cleaning method
- Hopper filter system

5.3 Hypothesis tests of Black Dot Defect

The following tests are focused on the factors that influence black dot defective parts. A test for two proportions is used to determine whether two proportions significantly differ. To determine whether the percentage of black dot defective parts significantly differs for samples collected from two independent processes and since the data type of this black dot defect is attribute data, '2 Proportions' command in Minitab Software that based on 'Two proportion z-test' is used to perform a hypothesis test of this black dot defect. The purpose of the tests is to test for significantly differ for each level of each factor; moreover, each factor consist of two level of condition.

Due to time and cost limit of the company, two identical injection moulding machines (Machine number P24 and P25) are used to tests different level of the same factor concurrently as mentioned in scope of the research in chapter 1. Additionally, two moulds with the identical products that used to perform the experiment for both machine, and the team agrees to use daily production quantity of each machine as a sample size for each level of factors in order to minimise time and effects of routine production process. The daily production capacity of the selected products is approximately 3,650 per day.

5.3.1 Confirmed two injection moulding machine are identical

First of all, it is essential that to ensure that two selected injection moulding machine are produce black dot defect at the same rate. Therefore, a test for two proportions is used to determine whether two proportions of black dot defect produced by these two injection moulding machine is significantly differ or not. Therefore, the test of machine number P24 and P25 with two moulds of the same products are implemented for 1 week.

Experiment Procedure

1. Prepare two identical injection moulding machine with same model, specification, and life (Machine number P24 and P25)
2. Both machine are having the same size, type, and life of reciprocating screw and barrel
3. Prepare two identical moulds with same life that produce same product (Mould number M04A and M04B)
4. Assemble Mould number M04A to Machine number P24, and Assemble Mould number M04B to Machine number P25
5. Load the same batch of raw material (Polycarbonate, PC) into both machine's hopper
6. Setting both machine with same injection conditions
7. Perform production of both machines concurrently within the same work shift for 1 week
8. Perform visual inspection to check for black dot defect on the moulded parts from both machine and record the data
9. Perform analysis of collected data by using 2 Proportions command in Minitab Software

Hypothesis

$H_o : P_1 = P_2$; There is no different proportions of black dot defective parts caused from injection moulding machine number P24 and P25

$H_1 : P_1 \neq P_2$; There is different proportions of black defective parts caused from injection moulding machine number P24 and P25

P_1 = Proportion of black dot defective parts from injection moulding machine number P24

P_2 = Proportion of black dot defective parts from injection moulding machine number P25

Experiment Result

Table 5-1: The proportions of black dot defect from injection moulding machine number P24 and P25

Injection machine	Production	Black Dot
Injection moulding machine No. P24	7,252	65
Injection moulding machine No. P25	7,216	58

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       65  7252  0.008963
2       58  7346  0.007895

Difference = p (1) - p (2)
Estimate for difference:  0.00106759
95% CI for difference:  (-0.00189913, 0.00403431)
Test for difference = 0 (vs not = 0):  Z = 0.71  P-Value = 0.481

Fisher's exact test: P-Value = 0.526
```

Figure 5-2: Results of the test for two proportions of black dot produce by injection moulding machine no. P24 and P25.

Result Interpretation

Table 5-2 shows the proportions of black dot defect from injection moulding machine number P24 and P25. According to figure 5-2, the Z-Score is 0.71. The normal approximation test reports a P-Value of 0.481, and Fisher's exact test reports a p-value of 0.526. Both of these P-Values are larger than commonly chosen α levels of 0.05 ($p > 0.05$). Therefore, the data are consistent with the null hypothesis that the population proportions are equal. In other words, the proportion of black dot defective parts of injection moulding machines number P24 is not significantly different from the proportion of black dot defective parts of injection moulding machine number P25.

5.3.2 Barrel/screw cleaning method

The highest influence factor that caused black dot defects are barrel and screw carbonised and dirty that is cause by improper barrel and screw cleaning method. During moulding, resins are fed through hopper into a heated barrel and reciprocating screw. However, the unclean barrel and screw can cause a peeling off thin layers of melt which form on the surface of the barrel and screw that can carbonised the screw. The carbon at screw will moulded to form a part and produce black dot. At present, the company do not have a proper barrel and screw cleaning process and there is no standard routine barrel and screw maintenance. Therefore, the team recommended to using copper gauze on barrel brush to clean the barrel (see figure 5-3) and polishing the screw with round copper wire brush (see figure 5-4).

Experiment Procedure

1. Prepare two identical injection moulding machine with same model, specification, and life (Machine number P24 and P25)
2. Both machine are having the same size, type, and life of reciprocating screw and barrel
3. The machine number P24 is not clean the screw at all, whereas the screw and barrel on machine number P25 is clean by polishing the screw with round copper wire brush and using copper gauze on barrel brush to clean the barrel
4. Prepare two identical moulds with same life that produce same product (Mould number M04A and M04B)
5. Assemble Mould number M04A to Machine number P24, and Assemble Mould number M04B to Machine number P25
6. Load the same batch of raw material (Polycarbonate, PC) into both machine's hopper
7. Setting both machine with same injection conditions
8. Perform production of both machine concurrently within the same work shift for 1 day

9. Perform visual inspection to check for black dot defect on the moulded parts from both machine and record the data
10. Perform analysis of collected data by using 2 Proportions command in Minitab Software Release 16

Figure 5-3: Cleaning barrel by using barrel brush

Figure 5-4: Cleaning screw by polishing

Hypothesis

$H_o : P_1 = P_2$; There is no different proportions of black dot defective parts caused from both screw

$H_1 : P_1 \neq P_2$; There is different proportions of black dot defective parts caused from both screw

P_1 = Proportion of black dot defective parts when not clean the screw and barrel

P_2 = Proportion of black dot defective parts when clean the screw and barrel by polishing the screw with round copper wire brush and using copper gauze on barrel brush to clean the barrel

Experiment Result

Table 5-2: The proportions of black dot defect from different barrel/screw cleaning method

Barrel/Screw cleaning method	Sample	Black Dot
Not clean the screw and barrel	3675	37
Clean the screw and barrel by polishing the screw with round copper wire brush and using copper gauze on barrel brush to clean the barrel	3636	15

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       37  3675  0.010068
2       15  3636  0.004125

Difference = p (1) - p (2)
Estimate for difference:  0.00594261
95% CI for difference:  (0.00210092, 0.00978431)
Test for difference = 0 (vs not = 0):  Z = 3.03  P-Value = 0.002

Fisher's exact test: P-Value = 0.003
```

Figure 5-5: Results of the test for two proportions of black dot by different barrel/screw cleaning method.

Result Interpretation

Table 5-2 shows the proportions of black dot defect from different barrel/screw cleaning method. According to figure 5-5, the Z-Score is 3.03. The normal approximation test reports a P-Value of 0.002 and Fisher's exact test reports a p-value of 0.003. Both of these P-Values are less than commonly chosen α levels of 0.05 ($p < 0.05$). Therefore, the data are inconsistent with the null hypothesis that the population proportions are not equal. In other words, the proportion of black dot defective parts when not clean the screw and barrel is significantly different from the proportion of black dot defective parts when clean the screw and barrel by polishing the screw with round copper wire brush and using copper gauze on barrel brush to clean the barrel.

5.3.3 Purging materials

After changing raw material to produce new product with another raw material in plastic injection moulding process, the previous molten resin may trapped on the barrel and screw surface which it will stay there until it degrades. The degraded resin can becomes carbonised, then chars and becomes brittle which will flake away from the area of entrapment and enter into melt stream of another resin appearing as black dot. To avoid this situation, currently, the company use Polypropylene (PP) material to purge the barrel and screw when change new material and start up machine (see figure 5-6). However, after the researched about purging materials, the team suggests to trial purging compound (see figure 5-7) to purge the screw.

Experiment Procedure

1. Prepare two identical injection moulding machine with same model, specification, and life (Machine number P24 and P25)
2. Both machine are having the same size, type, and life of reciprocating screw
3. The machine number P24 is clean the screw and barrel by purging with Polypropylene (PP) material before machine start up, whereas the screw and

barrel on machine number P25 is purge by special purging compound before machine start up

4. Prepare two identical moulds with same life that produce same product (Mould number M04A and M04B)
5. Assemble Mould number M04A to Machine number P24, and Assemble Mould number M04B to Machine number P25
6. Load the same batch of raw material (Polycarbonate, PC) into both machine's hopper
7. Setting both machine with same injection conditions
8. Perform production of both machine concurrently within the same work shift for 1 day
9. Perform visual inspection to check for black dot defect on the moulded parts from both machine and record the data
10. Perform analysis of collected data by using 2 Proportions command in Minitab Software Release 16

Figure 5-6: Barrel purging

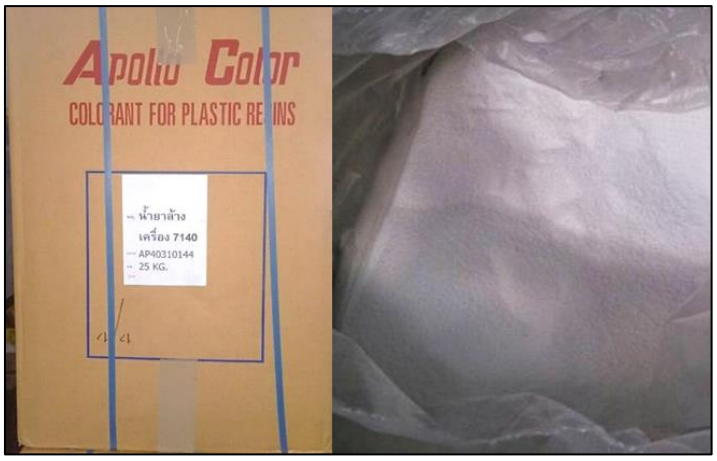


Figure 5-7: Purging compound

Hypothesis

$H_o : P_1 = P_2$; There is no different proportions of black dot defective parts caused from both screw purging method

$H_1 : P_1 \neq P_2$; There is different proportions of black dot defective parts caused from both screw purging method

P_1 = Proportion of black dot defective parts when purging with Polypropylene (PP) material

P_2 = Proportion of black dot defective parts when purging with special purging compound

Experiment Result

Table 5-3: The proportions of black dot defect from different purging material

Purging materials	Production	Black Dot
Purging with Polypropylene (PP) material	3606	42
Purging with special purging compound	3672	20

Test and CI for Two Proportions

Sample	X	N	Sample p
1	42	3606	0.011647
2	20	3672	0.005447

Difference = p (1) - p (2)
Estimate for difference: 0.00620063
95% CI for difference: (0.00196622, 0.0104350)
Test for difference = 0 (vs not = 0): Z = 2.87 P-Value = 0.004

Fisher's exact test: P-Value = 0.005

Figure 5-8: Results of the test for two proportions of black dot by different purging material

Result Interpretation

Table 5-3 shows the proportions of black dot defect from different purging material. According to figure 5-8, the Z-Score is 2.87. The normal approximation test reports a P-Value of 0.004, and Fisher's exact test reports a p-value of 0.005. Both of these P-Values are less than commonly chosen α levels of 0.05 ($p < 0.05$). Therefore, the data are inconsistent with the null hypothesis that the population proportions are not equal. In other words, the proportion of black dot defective parts when purging with Polypropylene (PP) material is significantly different from the proportion of black dot defective parts when purging with special purging compound.

5.3.4 Resin drying temperature

Excessive melt temperature is another factor that causes black dot defects which came from two possible cause, barrel temperature and resin drying temperature. However, the team is ignoring the barrel temperature due to the fact that this barrel temperature is specifying by the customer standard for each products and the company must follow the customer standard. Thus, the team will focus on resin drying temperature. Dehumidifying of plastics resin is applied to minimise problems and polymer chain degradation that may be caused by too much or too little moisture in a plastic resin during processing. Moreover, pre-dry resins are essential before processing, but over dried plastic materials can degrade and it can enter to the melt stream with much higher melt temperature with a fiction from the screw. This heating will degrade the resin, resulting in the black dot defects. At the moment, the company dries the Polycarbonate resin at 160°C in dehumidifying hopper dryer. At 160°C, the resin will dry very fast resulting in high productivity but high black dot defects as well. However, the team have consult with the plastic resin's supplier about the drying temperature for this Polycarbonate resin and they proposed to reduce the resin drying temperature to 120°C. Figure 5-9 shows the dehumidifying hopper dryer.

Experiment Procedure

1. Prepare two identical injection moulding machine with same model, specification, and life (Machine number P24 and P25)
2. Both machine are having the same size, type, and life of reciprocating screw
3. Prepare two identical moulds with same life that produce same product (Mould number M04A and M04B)
4. Assemble Mould number M04A to Machine number P24, and Assemble Mould number M04B to Machine number P25
5. Separate same amount of raw material (Polycarbonate, PC) into two group (Group A and B).

6. Dry group A Polycarbonate material at 160°C in dehumidifying hopper dryer, and dry group B Polycarbonate material at 120°C in dehumidifying hopper dryer
7. Load group A heated Polycarbonate material into machine number P24, and Load group B heated Polycarbonate material into machine number P25
8. Setting both machine with same injection conditions
9. Perform production of both machine concurrently within the same work shift for 1 day
10. Perform visual inspection to check for black dot defect on the moulded parts from both machine and record the data
11. Perform analysis of collected data by using 2 Proportions command in Minitab Software Release 16

Figure 5-9: Dehumidifying hopper dryer

Hypothesis

$H_o : P_1 = P_2$; There is no different proportions of black dot defective parts caused from both resin (Polycarbonate) drying method

$H_1 : P_1 \neq P_2$; There is different proportions of black dot defective parts caused from both resin (Polycarbonate) drying method

P_1 = Proportion of black dot defective parts when dry the resin (Polycarbonate) at 160°C for 4 hour in dehumidifying hopper dryer

P_2 = Proportion of black dot defective parts when dry the resin (Polycarbonate) at 120°C for 4 hour in dehumidifying hopper dryer

Experiment Result

Table 5-4: The proportions of black dot defect from different resin drying temperature

Resin Drying temperature	Production	Black Dot
Dry the resin at 160°C in dehumidifying hopper dryer	3681	78
Dry the resin at 120°C in dehumidifying hopper dryer	3642	54

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       78  3681  0.021190
2       54  3642  0.014827

Difference = p (1) - p (2)
Estimate for difference:  0.00636288
95% CI for difference:  (0.000275827, 0.0124499)
Test for difference = 0 (vs not = 0):  Z = 2.05  P-Value = 0.040

Fisher's exact test: P-Value = 0.043
```

Figure 5-10: Results of the test for two proportions of black dot by different resin drying temperature

Result Interpretation

Table 5-4 shows the proportions of black dot defect from different resin drying temperature. According to figure 5-10, the Z-Score is 2.05. The normal approximation test reports a P-Value of 0.040, and Fisher's exact test reports a p-value of 0.043. Both of these P-Values are less than commonly chosen α levels of 0.05 ($p < 0.05$). Therefore, the data are inconsistent with the null hypothesis that the population proportions are not equal. In other words, the proportion of black dot defective parts when dry the resin at 160°C is significantly different from the proportion of black dot defective parts when dry the resin at 120°C.

5.3.5 Plastic crusher machine cleaning method

To reduce the production cost, regrind or recycle plastic are mixed with virgin raw material to produce the moulded parts. Regrind material are come from the crush of the runner. However, there is a possibility of contamination in regrind material as well. The contaminants such as dust, foreign material, different colour material, etc. but the major source of regrind contamination might come from the cleanliness of plastic crusher machine. The plastic crusher machine is operate with various type of runner material which may lead to contamination to the component inside plastic crusher machine such as crushing blades and sieving screen. Therefore, the test between clean and not clean plastic crusher machine is performed to observe the different (see figure 5-11).

Experiment Procedure

1. Prepare two identical injection moulding machine with same model, specification, and life (Machine number P24 and P25)
2. Both machine are having the same size, type, and life of reciprocating screw
3. Prepare two identical moulds with same life that produce same product (Mould number M04A and M04B)
4. Assemble Mould number M04A to Machine number P24, and Assemble Mould number M04B to Machine number P25

5. Separate same amount of Polycarbonate runner into two group (Group X and Y)
6. Crush group X runner with unclean plastic crusher machine, and crush group Y runner with clean plastic crusher machine to produce a regrind material group X and Y, respectively.
7. Mix regrind material group X with Polycarbonate raw material, and Mix regrind material group Y with Polycarbonate raw material to produce group X polycarbonate mixture and group Y polycarbonate mixture, respectively.
8. Load group X polycarbonate mixture into machine number P24, and Load group Y polycarbonate mixture into machine number P25
9. Setting both machine with same injection conditions
10. Perform production of both machine concurrently within the same work shift for 1 day
11. Perform visual inspection to check for black dot defect on the moulded parts from both machine and record the data
12. Perform analysis of collected data by using 2 Proportions command in Minitab Software Release 16

Figure 5-11: Cleaning of plastic crusher machine

Hypothesis

$H_o : P_1 = P_2$; There is no different proportions of black dot defective parts caused from both plastic crusher machine cleaning method

$H_1 : P_1 \neq P_2$; There is different proportions of black dot defective parts caused from both plastic crusher machine cleaning method

P_1 = Proportion of black dot defective parts when not clean plastic crusher machine

P_2 = Proportion of black dot defective parts when clean plastic crusher machine

Experiment Result

Table 5-5: The proportions of black dot defect from not clean and clean plastic crusher machine

Plastic crusher machine cleaning method	Production	Black Dot
Not clean plastic crusher machine	3624	95
Clean plastic crusher machine	3657	84

Test and CI for Two Proportions

Sample	X	N	Sample p
1	95	3624	0.026214
2	84	3657	0.022970

Difference = p (1) - p (2)
Estimate for difference: 0.00324448
95% CI for difference: (-0.00387119, 0.0103601)
Test for difference = 0 (vs not = 0): Z = 0.89 P-Value = 0.371

Fisher's exact test: P-Value = 0.405

Figure 5-12: Results of the test for two proportions of black dot by not clean and clean plastic crusher machine

Result Interpretation

Table 5-5 shows the proportions of black dot defect from not clean and clean plastic crusher machine. According to figure 5-12, the Z-Score is 0.89. The normal approximation test reports a P-Value of 0.371, and Fisher's exact test reports a p-value of 0.405. Both of these P-Values are larger than commonly chosen α levels of 0.05 ($p > 0.05$). Therefore, the data are consistent with the null hypothesis that the population proportions are equal. In other words, the proportion of black dot defective parts when not clean plastic cruncher machine is not significantly different from the proportion of black dot defective parts when clean plastic cruncher machine.

5.3.6 Hopper filter system

Foreign materials from many possible sources can be trapped inside hopper that which can enter into melt stream and result in black dot defect. To avoid this issue, ensure the hopper's cover is completely closed and seal to avoid dust fell into hopper can be help. Presently, the company have only conical strainer (see figure 5-13) place inside the hopper to screen foreign material. Since, there is the possibility that metal chip may be contaminate in raw material and regrind. Consequently, the team suggests to fabricate magnetic separator (see figure 5-14) from magnetic bars to place over the conical strainer becoming hopper magnetic strainer (see figure 5-15) before place inside the hopper.

Experiment Procedure

1. Prepare two identical injection moulding machine with same model, specification, and life (Machine number P24 and P25)
2. Both machine are having the same size, type, and life of reciprocating screw
3. Prepare two identical moulds with same life that produce same product (Mould number M04A and M04B)
4. Assemble Mould number M04A to Machine number P24, and Assemble Mould number M04B to Machine number P25

5. Load the same batch of raw material (Polycarbonate, PC) into both machine's hopper
6. Hopper on machine number P24 does not equip with magnetic separator inside, whereas hopper on machine number P25 is equip with magnetic separator inside
7. Setting both machine with same injection conditions
8. Perform production of both machine concurrently within the same work shift for 1 day
9. Perform visual inspection to check for black dot defect on the moulded parts from both machine and record the data
10. Perform analysis of collected data by using 2 Proportions command in Minitab Software Release 16

Figure 5-13: Conical strainer

Figure 5-14: Magnetic separator

Figure 5-15: Hopper magnetic strainer

Hypothesis

$H_o : P_1 = P_2$; There is no different proportions of black dot defective parts caused from both hopper

$H_1 : P_1 \neq P_2$; There is different proportions of black dot defective parts caused from both hopper

P_1 = Proportion of black dot defective parts when not using magnetic separator inside hopper

P_2 = Proportion of black dot defective parts when using magnetic separator inside hopper

Experiment Result

Table 5-6: The proportions of black dot defect of not using and using magnetic separator inside hopper

Hopper filter system	Production	Black Dot
Not using magnetic separator inside hopper	3630	93
Using magnetic separator inside hopper	3702	68

Test and CI for Two Proportions

```
Sample   X     N  Sample p
1       93  3630  0.025620
2       68  3702  0.018368

Difference = p (1) - p (2)
Estimate for difference:  0.00725139
95% CI for difference:  (0.000533651, 0.0139691)
Test for difference = 0 (vs not = 0):  Z = 2.12  P-Value = 0.034

Fisher's exact test: P-Value = 0.038
```

Figure 5-16: Results of the test for two proportions of black dot of not using and using magnetic separator inside hopper

Result Interpretation

Table 5-6 shows the proportions of black dot defect of not using and using magnetic separator inside hopper. According to figure 5-16, the Z-Score is 2.12. The normal approximation test reports a P-Value of 0.034, and Fisher's exact test reports a p-value of 0.038. Both of these P-Values are less than commonly chosen α levels of 0.05 ($p < 0.05$). Therefore, the data are inconsistent with the null hypothesis that the population proportions are not equal. In other words, the proportion of black dot defective parts when not using magnetic separator inside hopper is significantly different from the proportion of black dot defective parts when using magnetic separator inside hopper.

5.4 Summary of Analyse Phase

In analyse phase, statistical analysis is done by implementing hypothesis testing of those selected factors from FMEA in measure phase and each factor consists of two level to confirm the statistically significant of the causes of the black dot defect. The statistical analysis of these factors is completed by the aids of Minitab Release 16 in 2 Proportions command that is based on two proportion z-test.

As a result, it can be confirmed that the proportion of black dot defective parts of injection moulding machines number P24 is not significantly different from the proportion of black dot defective parts of injection moulding machine number P25. Moreover, the results of the tested five factors by statistical analysis reveals in Table 5-7. Hence, it can be concluded that 4 factors including: barrel/screw cleaning method, purging materials, resin drying temperature, and hopper filter system are have an effect of the black dot defect and differs at the 0.05 level of significant.

Table 5-7: Summary of test statistic of the 5 factors

Key Process Input Variable (KPIV)	Effect that considered from statistically significant difference
1. Barrel/screw cleaning method	Have an effect
2. Purging materials	Have an effect
3. Resin drying temperature	Have an effect
4. Crusher machine cleaning method	No effect
5. Hopper filter system	Have an effect

CHAPTER 6
IMPROVE PHASE

After the analysis of each factor that influence black dot defect in previous chapter, the result reveals that there are four significant factors including barrel/screw cleaning method, purging materials, resin drying temperature, and hopper filter system. In this chapter, improve phase, is to considering the causes found in the analysis phase, and to selecting the optimum solutions to reduce black dot defects. The Design of Experiment (DOE) technique is implement to determine the individual and interactive effects of four factors describes earlier. So the team can be able to fix these problems and identify the optimum conditions and parameter prior going into plastic injection moulding process to reduce the black dot defects. In addition, the tool used to perform Design of Experiment is done by Minitab Release 16 in DOE command.

6.1 Design of Experiment of Black Dot Defect

Design of Experiment (DOE) technique allows the team to determine instantaneously the individual and interactive effects of selected factors that could affect the black dot defect in plastic injection moulding process. To accomplish this, DOE command in Minitab Release 16 is the tool that assists the team. This section consists of the identification of factors and levels of each factor, the response or outcome of the experiment to be used, type of design, experiment procedure, and the results of the experiment.

6.1.1 Factors and Levels

Four key process input variables from previous chapter are the factors that have to be tested with Design of Experiment. The four selected factor comprising barrel/screw cleaning method, purging materials, resin drying temperature, and hopper filter system. In this experiment, the team considered two levels of each factor which are low level (-1) and high level (+1).

Barrel/screw cleaning method

According to hypothesis test of barrel/screw cleaning method, it is found out that the proportion of black dot defective parts when clean the screw and barrel by polishing the screw with round copper wire brush and using copper gauze on barrel brush to clean the barrel is lower than not clean the screw and barrel method. Thus, the team assigned not clean the screw and barrel as low level, whereas clean the screw and barrel as high level.

Purging materials

According to hypothesis test of purging materials, it is found out that the proportion of black dot defective parts when purging with special purging compound is lower than purging with Polypropylene (PP) material. Hence, the team assigned polypropylene (PP) material as low level, while purging compound as high level.

Resin drying temperature

According to hypothesis test of resin drying temperature, it is found out that the proportion of black dot when dry the resin at 120°C is lower than dry the resin at 160°C. Thus, the team assigned drying temperature of 120°C as low level, while drying temperature of 160°C as high level.

Hopper filter system

According to hypothesis test of hopper filter system, it is found out that the proportion of black dot when using magnetic separator inside hopper is lower than not using magnetic separator inside hopper. Accordingly, the team assigned without magnetic separator as low level, whereas with magnetic separator as high level.

The factors and their levels that are used in the experiment are summarising in table 6-1.

Table 6-1: Factors and levels to be tested

Factors	Acronym	Levels	
		Low (-1)	High (+1)
1.Barrel/screw cleaning method	Screw	Not clean the screw and barrel	Do clean the screw and barrel
2.Purging materials	Purge	Polypropylene (PP)	Purging compound
3.Resin drying temperature	DryTemp	120°C	160°C
4.Hopper filter system	Hopper	Without magnetic separator	With magnetic separator

6.1.2 Response of the experiment

The purpose of this experiment is to investigate the factors that influences black dot defect on the surface of the moulded parts in plastic injection mouldings process. Subsequently, the response of this experiment is the proportion of black dot defective parts.

6.1.3 Type of Design

The experiment is tested by full 2^k factorial design which is widely used in industrial experimentation. There are k factors, each at 2 levels (low and high levels). Moreover, the experiment also involving replication for each factor and randomisation. For this experiment, there are 4 factors to be tested. Thus, full 2^k factorial design is 2^4 which are 16 runs. The team decide to use 2 replicates for each factor. So, 32 full factorial runs are requisite to conduct the experiment.

6.1.4 Experiment Procedure

1. Prepare two identical injection moulding machine with same model, specification, and life (Machine number P24 and P25)
2. Both machine are having the same size, type, and life of reciprocating screw
3. Prepare two identical moulds with same life that produce same product (Mould number M04A and M04B)
4. Assemble Mould number M04A to Machine number P24, and assemble Mould number M04B to Machine No. P25
5. Load the same batch of raw material (Polycarbonate, PC) into both machine's hopper
6. Setting both machine with same injection conditions
7. Perform production of both machines with different combination of the level of the factors (treatment), where run each treatment for 1 day shift
8. Perform visual inspection to check for black dot defect on the moulded parts from both machine and record the data for each treatment
9. Perform analysis of collected data of each treatment by using DOE command in Minitab Software Release 16

6.1.5 Result of the experiment

As mentions in previous chapter, the team agrees to use daily production quantity of each machine as a sample size for each treatment in order to minimise time and effects of routine production process. The daily production capacity of the selected products is approximately 3,650 per day. In this experiment, 2 set of treatment were run per day (each machine responsible for 1 treatment per day). There are 4 factors to be tested including barrel/screw cleaning method (Screw), purging materials (Purge), resin drying temperature (DryTemp), and hopper filter system (Hopper). The experiment is performed in 16 treatments with 2 replicates where the response is the proportion of black dot defective part (BlackDot). The experiment result is illustrates in table 6-2.

Table 6-2: Design matrix and result of the experiment

StdOrder	RunOrder	CenterPt	Blocks	Screw	Purge	DryTemp	Hopper	BlackDot
4	1	1	1	1	1	-1	-1	0.0021
5	2	1	1	-1	-1	1	-1	0.0195
14	3	1	1	1	-1	1	1	0.0080
10	4	1	1	1	-1	-1	1	0.0062
13	5	1	1	-1	-1	1	1	0.0188
12	6	1	1	1	1	-1	1	0.0021
16	7	1	1	1	1	1	1	0.0040
3	8	1	1	-1	1	-1	-1	0.0148
8	9	1	1	1	1	1	-1	0.0020
15	10	1	1	-1	1	1	1	0.0143
6	11	1	1	1	-1	1	-1	0.0082
11	12	1	1	-1	1	-1	1	0.0140
1	13	1	1	-1	-1	-1	-1	0.0175
7	14	1	1	-1	1	1	-1	0.0155
9	15	1	1	-1	-1	-1	1	0.0172
2	16	1	1	1	-1	-1	-1	0.0077
21	17	1	1	-1	-1	1	-1	0.0185
29	18	1	1	-1	-1	1	1	0.0186
32	19	1	1	1	1	1	1	0.0048
17	20	1	1	-1	-1	-1	-1	0.0175
23	21	1	1	-1	1	1	-1	0.0145
28	22	1	1	1	1	-1	1	0.0021
27	23	1	1	-1	1	-1	1	0.0160

Table 6-2: Design matrix and result of the experiment (Cont.)

StdOrder	RunOrder	CenterPt	Blocks	Screw	Purge	DryTemp	Hopper	BlackDot
23	21	1	1	-1	1	1	-1	0.0145
28	22	1	1	1	1	-1	1	0.0021
27	23	1	1	-1	1	-1	1	0.0160
18	24	1	1	1	-1	-1	-1	0.0070
30	25	1	1	1	-1	1	1	0.0079
26	26	1	1	1	-1	-1	1	0.0068
25	27	1	1	-1	-1	-1	1	0.0189
22	28	1	1	1	-1	1	-1	0.0095
20	29	1	1	1	1	-1	-1	0.0028
24	30	1	1	1	1	1	-1	0.0024
31	31	1	1	-1	1	1	1	0.0153
19	32	1	1	-1	1	-1	-1	0.0145

Model Adequacy Checking

It is essential to test the Analysis of Variance (ANOVA) assumptions (Normality, Constant variance, and Independence) by residual analysis (Montgomery, 2009), before drawing conclusions. Different kinds of plots of residuals deliver information on the suitability of dissimilar aspects of the model including:

Checking the normality assumption

The normality assumption, the observations within each treatment group have a normal distribution, can be checked by creating a normal probability plot of the residuals (Montgomery, 2009). The normality plot of the residuals obtained from Minitab Release 16 is used to check the normality of the treatment data shows in figure 6-1 indicates that the residuals follow a normal distribution since the plot is resemble a straight line. Thus, the normality assumption is satisfied.

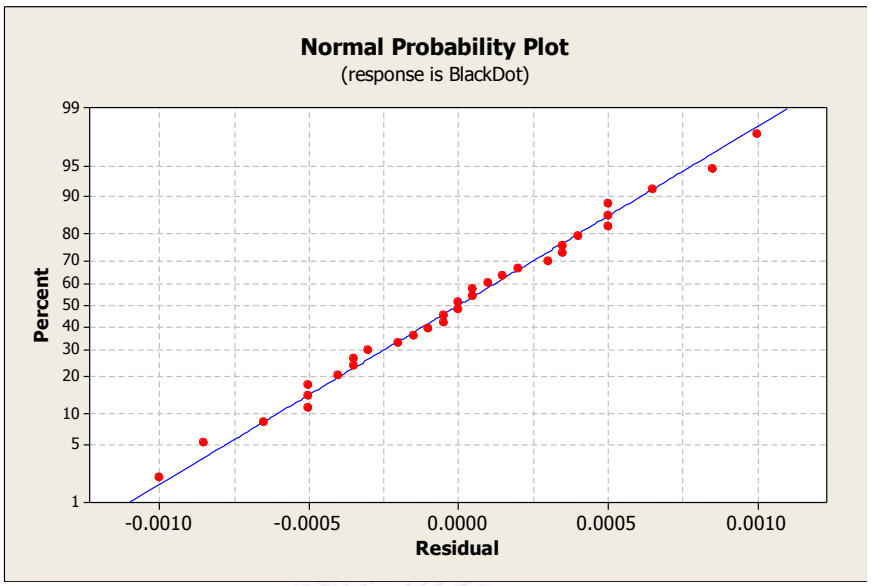


Figure 6-1: Normal probability plot of the residuals

Checking the constant variance assumption

The constant variances assumption, the variance is the same for all observations, of at each factor level can be checked by plotting the residuals against fitted value (Montgomery, 2009). The plot of residuals versus fitted values obtained from Minitab Release 16 shows in figure 6-2 does not reveal any recognisable pattern, and the residuals are randomly distributed around zero which means that there is no drift in the process. Thus, the constant assumption is satisfied.

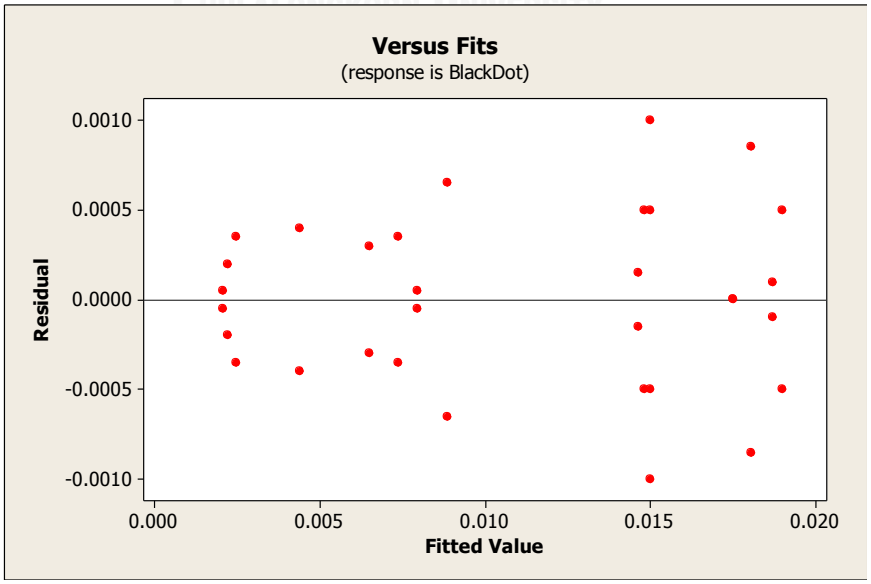


Figure 6-2: Plot of residuals versus fitted values

Checking the independence assumption

The independence assumption, all observations are independent, can be checked by plotting the residuals against the run order of the data in which the experiment was performed (Montgomery, 2009). The plot of residuals versus the run order of the data obtained from Minitab Release 16 shows in figure 6-3 does not reveal any pattern. Thus, the independence assumption is satisfied.

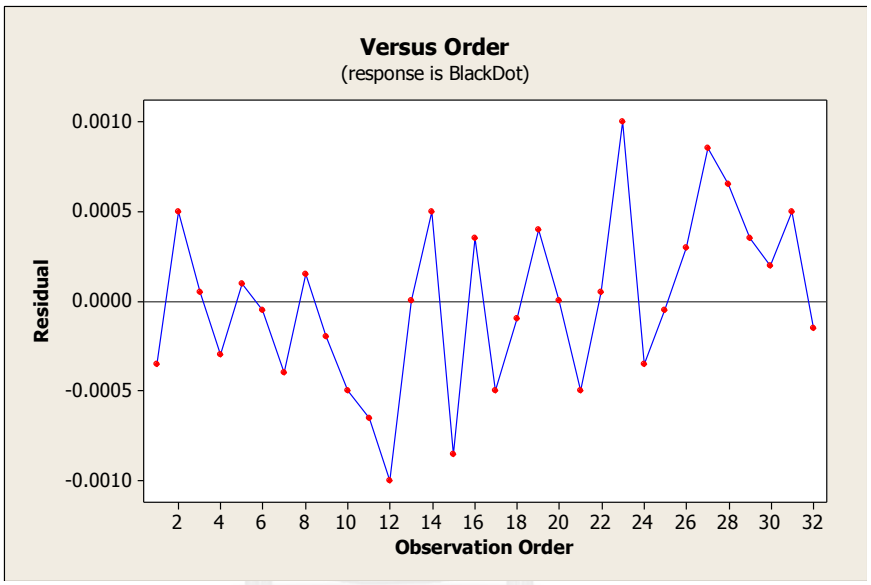


Figure 6-3: Plot of residuals versus the run order

6.1.6 The Experiment Analysis

The result of the experiment is analyse by Minitab Release 16 in DOE command to calculate the significant, main effect, and interactive effect of selected factors that affect the black dot defect in plastic injection moulding process. The outcomes of this experiment from Minitab including session window output (see figure 6-4), and graph window output (see figure 6-5, figure 6-6, figure 6-7, and figure 6-8).

The estimated effects and coefficients and analysis of variance in figure 6-4 shows the p-values associated with each individual model term. According to Figure 6-4, the p-value indicate that there are three main effects, and one two-way interaction effects that are statistically significant (p-values are less than 0.05) to the proportion of black dot

defective part. The significant main effect consists of Screw (p=0.000), Purge (p=0.000), and DryTemp (p=0.001). The significant two-way interaction effect is Screw* Purge (p=0.007). Moreover, the normal probability plot of the standardised effects (see figure 6-5) and the Pareto chart of the standardised effects (see figure 6-6) can support to visually recognise the significant effects influence the black dot defect, and compare the relative magnitude of the various effects which is strongly confirm that Screw, Purge, DryTemp, and Screw*Purge are all significant.

The main effects plot and an interaction plot are displays in figure 6-7 and figure 6-8, respectively. The main effects plot indicates that both Screw and Purge have similar effects on yield. For both factors, the yield decreased considerably as it moves from the low level to the high level of the factor. For DryTemp, the yield increased slightly as it moves from the low level to the high level of the factor. Conversely, the interaction plot in figure 6-8 shows that the proportion of black dot defective parts were reduced when Screw is in high level (clean the screw and barrel) and Purge is in high level (using purging compound). For DryTemp, the increase in yield is greater when DryTemp is high level (160°C) than when DryTemp is low (120°C).

Factorial Fit: BlackDot versus Screw, Purge, DryTemp, Hopper

Estimated Effects and Coefficients for BlackDot (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		0.010906	0.000116	93.74	0.000
Screw	-0.011362	-0.005681	0.000116	-48.83	0.000
Purge	-0.004163	-0.002081	0.000116	-17.89	0.000
DryTemp	0.000912	0.000456	0.000116	3.92	0.001
Hopper	0.000062	0.000031	0.000116	0.27	0.792
Screw*Purge	-0.000713	-0.000356	0.000116	-3.06	0.007
Screw*DryTemp	0.000338	0.000169	0.000116	1.45	0.166
Screw*Hopper	-0.000037	-0.000019	0.000116	-0.16	0.874
Purge*DryTemp	-0.000363	-0.000181	0.000116	-1.56	0.139
Purge*Hopper	0.000438	0.000219	0.000116	1.88	0.078
DryTemp*Hopper	0.000138	0.000069	0.000116	0.59	0.563
Screw*Purge*DryTemp	0.000137	0.000069	0.000116	0.59	0.563
Screw*Purge*Hopper	0.000462	0.000231	0.000116	1.99	0.064
Screw*DryTemp*Hopper	0.000487	0.000244	0.000116	2.10	0.052
Purge*DryTemp*Hopper	0.000362	0.000181	0.000116	1.56	0.139
Screw*Purge*DryTemp*Hopper	0.000288	0.000144	0.000116	1.24	0.234

S = 0.000658122 PRESS = 0.00002772
R-Sq = 99.42% R-Sq(pred) = 97.69% R-Sq(adj) = 98.88%

Analysis of Variance for BlackDot (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F
Main Effects	4	0.00117815	0.00117815	0.00029454	680.03
Screw	1	0.00103285	0.00103285	0.00103285	2384.65
Purge	1	0.00013861	0.00013861	0.00013861	320.03
DryTemp	1	0.00000666	0.00000666	0.00000666	15.38
Hopper	1	0.00000003	0.00000003	0.00000003	0.07
2-Way Interactions	6	0.00000772	0.00000772	0.00000129	2.97
Screw*Purge	1	0.00000406	0.00000406	0.00000406	9.38
Screw*DryTemp	1	0.00000091	0.00000091	0.00000091	2.10
Screw*Hopper	1	0.00000001	0.00000001	0.00000001	0.03
Purge*DryTemp	1	0.00000105	0.00000105	0.00000105	2.43
Purge*Hopper	1	0.00000153	0.00000153	0.00000153	3.54
DryTemp*Hopper	1	0.00000015	0.00000015	0.00000015	0.35
3-Way Interactions	4	0.00000481	0.00000481	0.00000120	2.78
Screw*Purge*DryTemp	1	0.00000015	0.00000015	0.00000015	0.35
Screw*Purge*Hopper	1	0.00000171	0.00000171	0.00000171	3.95
Screw*DryTemp*Hopper	1	0.00000190	0.00000190	0.00000190	4.39
Purge*DryTemp*Hopper	1	0.00000105	0.00000105	0.00000105	2.43
4-Way Interactions	1	0.00000066	0.00000066	0.00000066	1.53
Screw*Purge*DryTemp*Hopper	1	0.00000066	0.00000066	0.00000066	1.53
Residual Error	16	0.00000693	0.00000693	0.00000043	
Pure Error	16	0.00000693	0.00000693	0.00000043	
Total	31	0.00119828			

Figure 6-4: Estimated effects and ANOVA for Black Dot

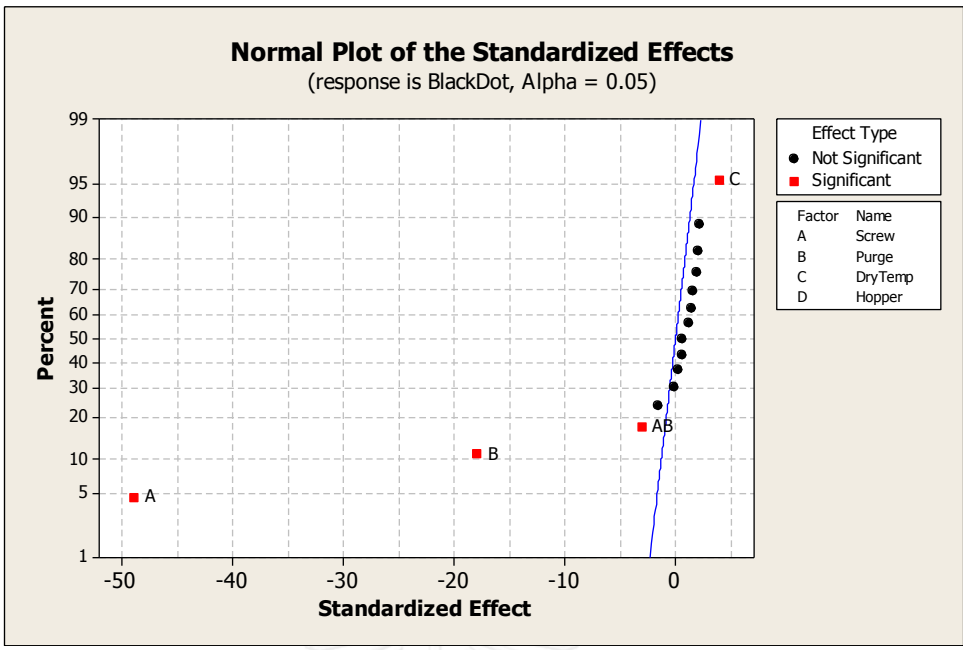


Figure 6-5: Normal plot of the standardised effects

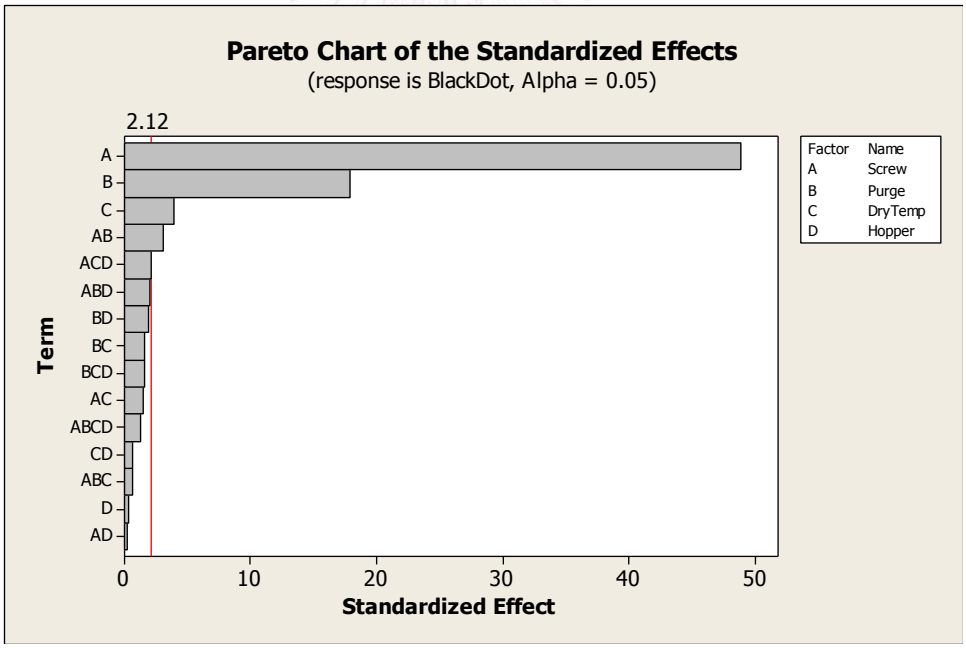


Figure 6-6: Pareto chart of the Standardised effects

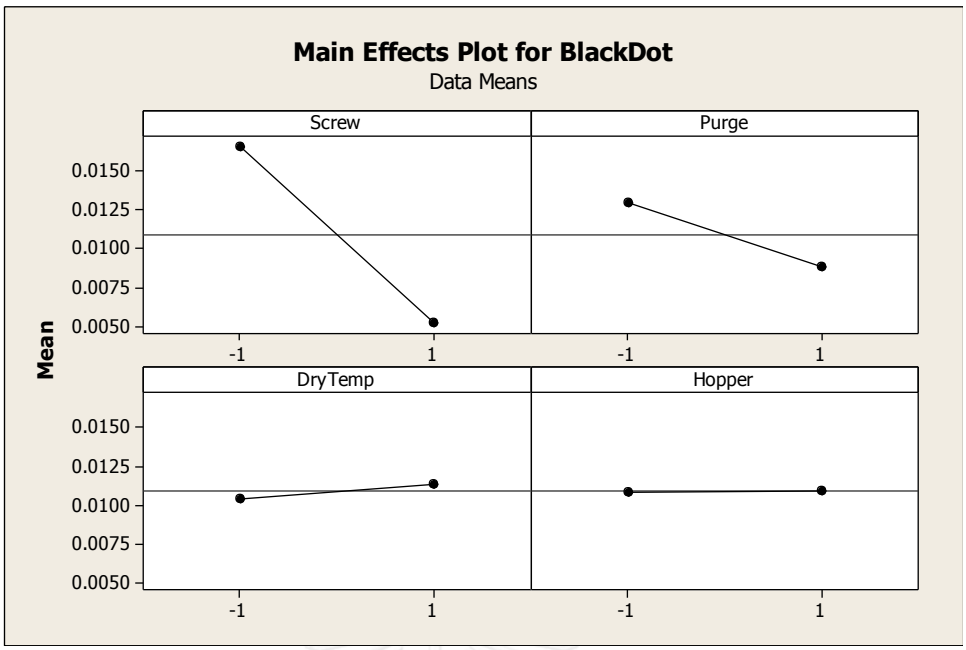


Figure 6-7: Main effects plot for BlackDot

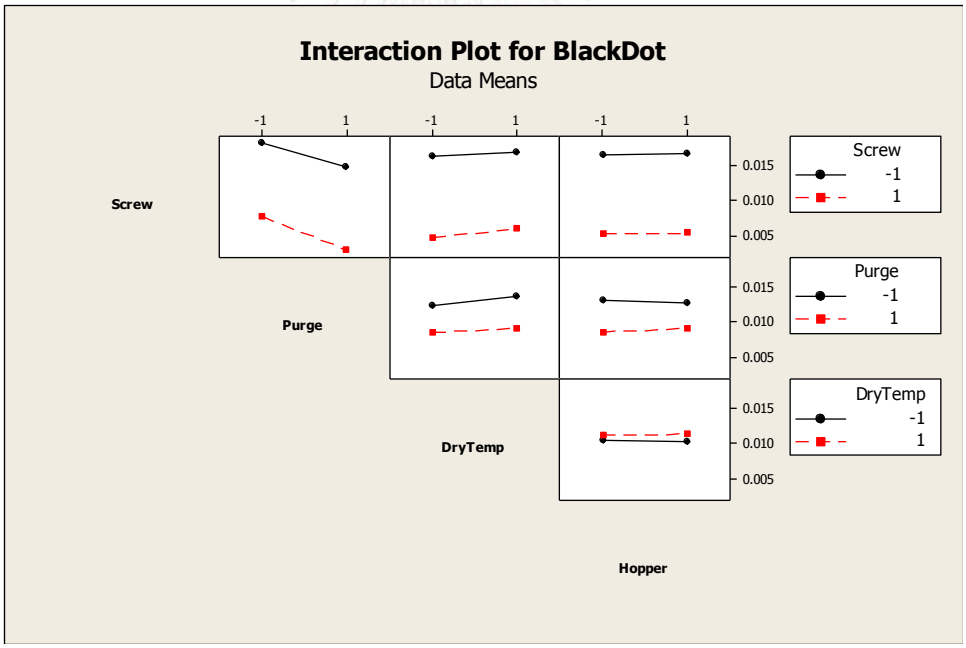


Figure 6-8: Interaction plot for BlackDot

6.1.7 Optimisation of Process Conditions

The optimum condition of levels for each factor in this experiment can be achieved by using Response Optimisation command in Minitab Release 16. The results of Response Optimisation analysis is reveals in response optimisation session window output (see figure6-9) and optimisation plot (see figure 6-10). According to optimisation plot, the optimum level condition of Screw, Purge, DryTemp, and Hopper factors are 1, 1, -1, and 1, respectively that should be implemented to the plastic injection moulding process of the company to reduce the black dot defect; moreover, the composite desirability (D=0.98750) and individual desirability (d=0.98750) are close to 1, which indicates the settings seem to achieve favourable results of the response. The optimum levels of each factor for reduce black dot defect is summarise in table 6-3.

Response Optimization

Parameters

	Goal	Lower	Target	Upper	Weight	Import
BlackDot	Minimum	0.002	0.002	0.01	1	1

Global Solution

Screw	=	1
Purge	=	1
DryTemp	=	-1
Hopper	=	1

Predicted Responses

BlackDot = 0.0021 , desirability = 0.987500

Composite Desirability = 0.987500

Figure 6-9: Response optimisation

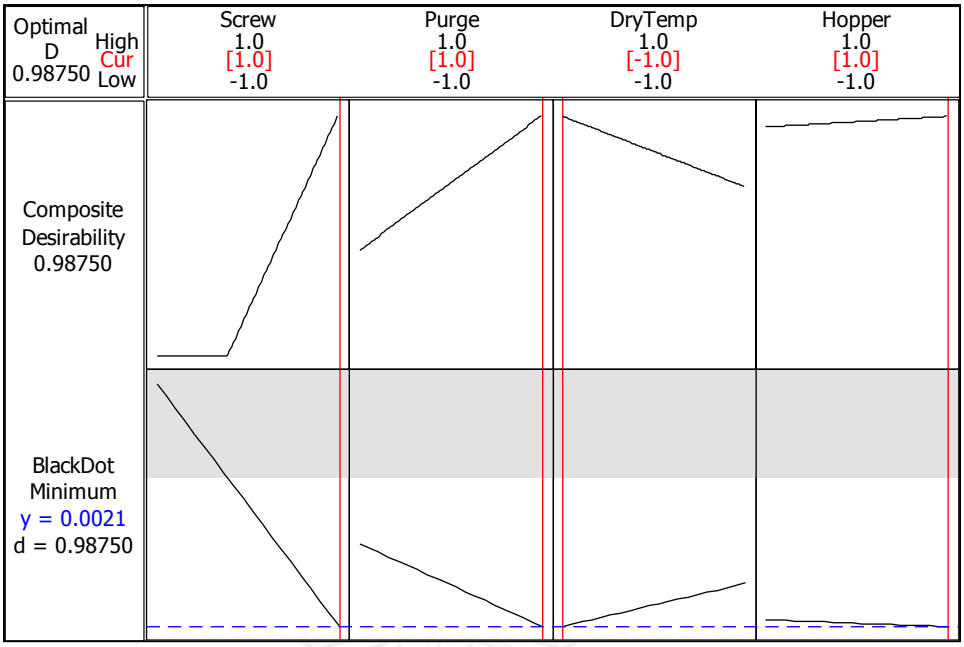


Figure 6-10: Optimisation plot

Table 6-3: Optimum factors levels

Factors	Acronym	Levels	Definition
1.Barrel/screw cleaning method	Screw	1	Do clean the screw and barrel
2.Purging materials	Purge	1	Purging compound
3.Resin drying temperature	DryTemp	-1	120°C
4.Hopper filter system	Hopper	1	With magnetic separator

6.1.8 Confirmation Test

The intention of the section is to perform the production test to confirm that the suggested optimum process condition setting can be reduce the proportion of black dot defective parts in the manufacturing process.

Testing Procedures

1. Prepare two identical injection moulding machine with same model, specification, and life (Machine number P24 and P25)
2. Both machine are having the same size, type, and life of reciprocating screw
3. Prepare two identical moulds with same life that produce same product (Mould number M04A and M04B)
4. Assemble Mould number M04A to Machine number P24, and Assemble Mould number M04B to Machine number P25
5. Load the same batch of raw material (Polycarbonate, PC) into both machine's hopper
6. Setting both machine with same conditions as shows in table 6-3, and same injection parameter
7. Run the production for 28 days
8. Perform visual inspection to check for black dot defect on the moulded parts from both machine and record the data
9. Compare the result with the previous process working conditions

Test Result

Table 6-4 shows the summary of the before and after improvement condition for black dot defect. According to table 6-4, the black dot defective proportion of machine number P24 after improvement is 0.34% comparing with 0.72% before improvement. A similar trend can be observed in machine number P25, where the black dot defective proportion of machine number P25 after improvement is 0.33% comparing with 0.59% before improvement. Overall, the average percentage of black dot defective parts for both machines is reduced from 0.65% to 0.34% (47.69% reduction).

Table 6-4: Percentage of black dot defect of before and after improvement

Machine No.	%Black dot defect before improvement	%Black dot defect after improvement	Percentage improvement
P24	0.72%	0.34%	52.78%
P25	0.59%	0.33%	44.07%
Total (P24,P25)	0.65%	0.34%	47.69%

6.2 Summary of Improve Phase

In improve phase, Design of Experiment (DOE) technique is implemented to determine instantaneously the individual and interactive effects of selected four factors that could affect the black dot defect in plastic injection moulding process. The 4 factors including barrel/screw cleaning method, purging materials, resin drying temperature, and hopper filter system. DOE command in Minitab Release 16 is the tool that assists the team performed the experiment. The full 2^k factorial design with 2 replicates is implemented. Thus, 2^4 which are 16 runs, with 2 replicates, so 32 full runs are requisite to conduct the experiment. In addition, each factor consists of two levels (low and high).

The outcome of the experiment explained that the main effect of barrel/screw cleaning method, purging material, and resin drying temperature, and interaction effect of barrel/screw cleaning method with purging materials, and barrel/screw cleaning with resin drying temperature with hopper filter system all together are significant. The optimum conditions were calculated by Response Optimisation command provided that clean the barrel and screw, using purging compound, set 120°C for resin drying temperature, with magnetic separator in hopper are the optimum manufacturing process conditions. Furthermore, the result of the production test that runs for two selected machine with suggested optimum condition is confirmed that the total proportion of black dot defective parts of both machines is reduced from 0.65% to 0.34%, or 47.69% reduction.

CHAPTER 7
CONTROL PHASE

The root causes of the problem and the optimum solutions to reduce the black dot defect of the process were determined in the previous chapter. This chapter, control phase, is to sustain the proposed improvement plan by ensure that the new process conditions continue to work well and stays fixed on long term, confirmed that the process is produce a desired output results, and maintain quality level. The control chart is implemented to monitor a process for black dot defect and remove them so they don't occur again, and maintain injection moulding process in desired operating conditions.

7.1 Control Plan for Black Dot Defect

The control plan is established and implemented in the company to reduce black dot defect in the process are describe as following:

7.1.1 Barrel/Screw cleaning method

In the past, the company does not have any cleaning schedule or maintenance plan for cleaning barrel and screw of injection moulding machine, but the company will clean the barrel and screw when the amount of black dot defect is high or run to failure maintenance due to the company does not want to interrupt the daily production time. However, this run to failure maintenance plan can cause a high level of defect rate and sometime it is necessary to stop in the middle of the production which cost a lot of changeover time. For this reason, the team have constructed the cleaning procedures and control plan for barrel and screw as reveals in appendix E1 and F, respectively.

7.1.2 Purging Materials

Purging process is the method to remove the residual materials left in the barrel and screw of the injection machine when changing colour and raw materials. Purging materials and types is the factor that determine how well is the purging is performed. Previously, the company using Polypropylene (PP) material to purge barrel and screw of the machine when changeover the product. Nevertheless, the result from previous chapter confirm that purging compound is much more effective than Polypropylene. Therefore, from now, the company will use purging compound instead of Polypropylene to purge barrel and screw. The procedures to purge barrel and screw and control plan are reveals in appendix E2 and F, respectively.

7.1.3 Resin Drying Temperature

High resin dying temperature can cause excessive melt temperature inside the barrel that might cause material degradation in the melt stream which causes black dot defect. Therefore, it is essential to determine the right drying temperature for different type of resin. In this cause, the team deal with Polycarbonate (PC) where the optimum drying temperature for this type of plastic resins is 120°C. Consequently, the operators have to ensure that the drying temperature for Polycarbonate is 120°C all the time. The procedures to setting resin drying temperature and control plan are reveals in appendix E5 and F, respectively.

7.1.4 Hopper Filter System

The results from the Design of Experiment in the previous chapter claims that there is no different between the hopper filter system that have magnetic separator and the hopper filter system without magnetic separator. However, there is still a chance that foreign materials from many possible sources can be trapped inside hopper and mixed with raw materials. To avoid this occurrence, the company will always clean the hopper and use magnetic separator to screen foreign materials. The procedures to cleaning hopper and control plan are reveals in appendix E3 and F, respectively.

7.2 Control Chart

The process will be check by applying the control charts. Black dot defect is an attribute data, thus p-chats (faction non-conforming) are suitable type of control chart to be applied to monitor the proportion of black dot defective parts in the process. The sample size of 28 days with unequal subgroup from previous chapter in Confirmation Test section was collected. Figure 7-1 and figure 7-2 shows the control chart for black dot defect of machine number P24 and P25, respectively. Figure 7-3 shows the control chart for black dot defect of combine machine number P24 and P25. It can be seen that the proportion of black dot defect of individual machine and combine machine are not fall out upper control limit (UCL) and lower control limit (LCL). Thus, it can be concluded that the process are in control.

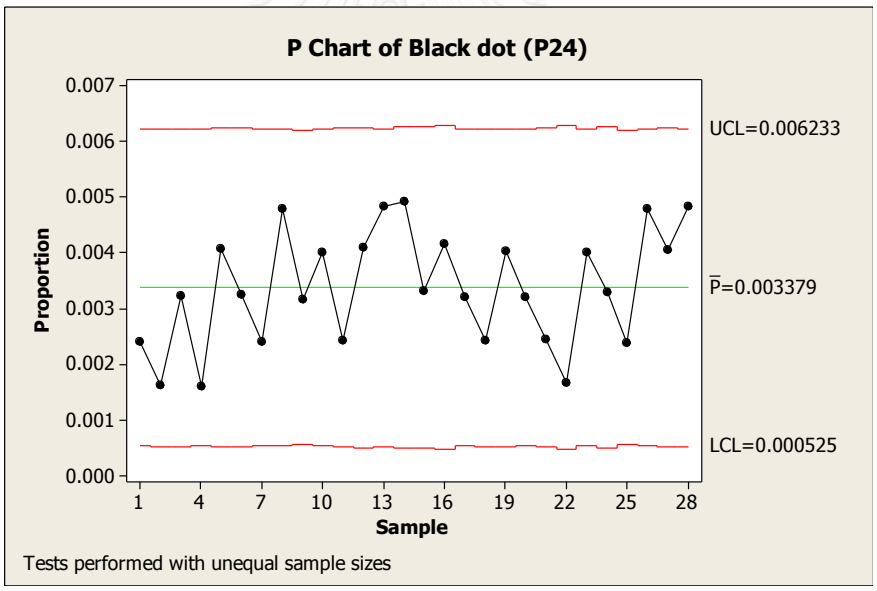


Figure 7-1. P Chart of Black dot (P24)

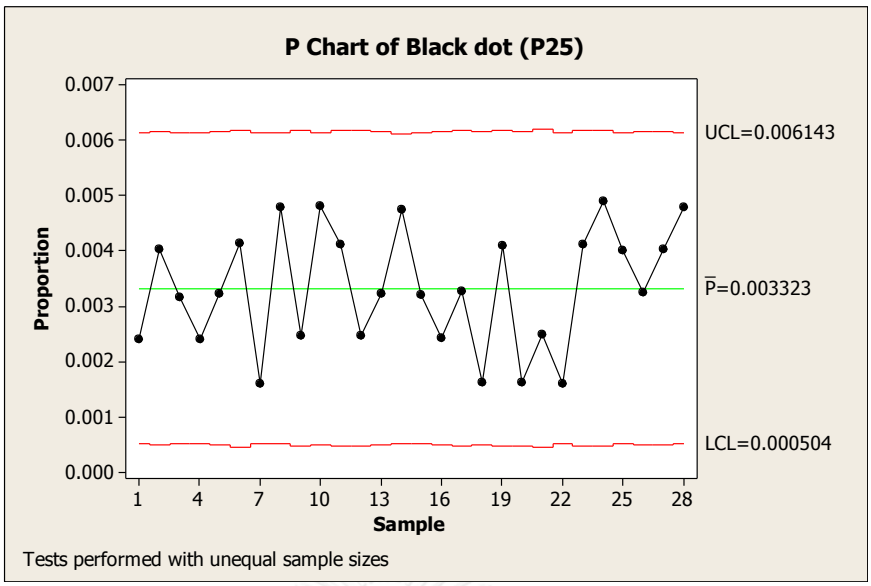


Figure 7-2. P Chart of Black dot (P25)

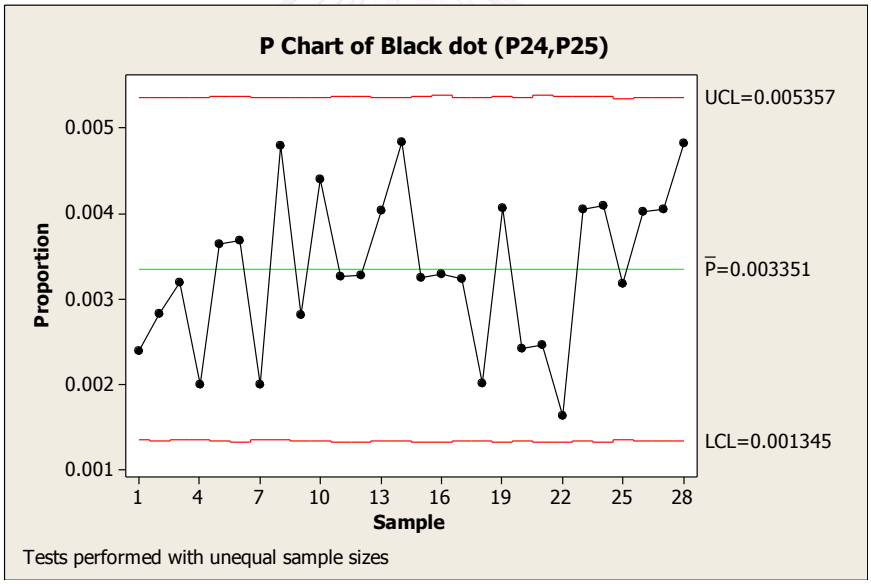


Figure 7-3. P Chart of Black dot (P24, P25)

7.3 Summary of Control Phase

In control phase, the control plan for each factors are constructed and implemented in the company to sustain the optimum condition in the process and make it as a standard. The control plan mainly focus on barrel and screw cleaning method, purging materials, resin drying temperature, and hopper filter system. To support the control plan, controls charts are apply to monitor a process for black dot defect. In this case, the p-chart is applied because the black dot defect is attribute data. In addition, after implemented the optimum solution, the process is in control since the proportion of black dot defect of individual machine and combine machine are not fall out upper control limit (UCL) and lower control limit (LCL).

CHAPTER 8
CONCLUSION AND RECOMMENDATIONS

This research applies Six Sigma DMAIC Methodology to reduce black dot defect in plastic injection moulding process. The Six Sigma DMAIC Methodology consists of five phases, which are define, measure, analyse, improve, and control phases. In define phase, the problem was identified. In measure phase, the problem was measure and determines the problem causes. In analyse phase, the problem was analysed to determine the root causes. In improve phase, the optimum condition was recognised and implemented in the production process. Lastly, in control phase, the standard procedures were constructed and monitor the process. All in all, the approach was implemented to reduce process variation and defectives in the process.

8.1 Conclusion

In define phase, after understanding the manufacturing process, process mapping, and current situation of the company, it is found out that the major problem in the process are defect that appeared on the moulded part. The most frequently type of defect that is occurs in the process is black dot type which it lead to defective moulded parts and it have to go to regrind. In addition, the operation of the company is based on made-to-order fashion, thus selecting particular product to perform the research is not appropriate. Consequently, the identification of which machine is produce the highest black dot defect rate is implemented here. All in all, the objective of this research is to reduce the moulded defect parts from the black dot type in plastic injection moulding process, and use selected injection moulding machines as a pilot (machine No. 24 and 25). To achieve this objective, an effective cross-functional project team is then formed to support and brainstorm to identify the potential cause of the black dot issue.

In measure phase, the cause of the problem were determine by focusing on possible cause of the problem and selection of main factors is most influence to the

problem which consists of measurement system analysis, cause-and-effect diagram, cause-and-effect matrix, and failure mode and effect analysis. In measurement system analysis, the measurement system that is implemented in this company to inspect the defect of moulded parts in plastic injection moulding process is complete by using direct visual inspection to check the appearance of the moulded parts. From the result, %Repeatability of Appraisers, %Reproducibility of Appraisers, %Effectiveness of Repeatability of Verification, and %Effectiveness of Reproducibility of Verification are all 100% which mean that the result from the inspection is dependable. To identify the causes of the defect, the brainstorming session is conducted in the company by the team members from different functional department in the company that are knowledgeable and have experience in plastic injection moulding process to obtain the cause of the black dot defect which the team have identify 33 factors, and summarise in cause-and-effect diagram (fishbone diagram). Then, cause-and-effect matrix is used to prioritise the main factor that results in the problem by scoring the cause-and-effect relationship of the problem and prioritise the score in Pareto chart that minimise the factors to 20 main factors that will input to explore the factors in Failure Mode and Effect Analysis (FMEA). The outcome from FMEA indicated that 5 factors are the most critical to the process including: barrel/screw carbonised and dirty, previous material trapped, raw material degradation, regrind contamination, and contamination in hopper.

In analyse phase, statistical analysis is done by implementing hypothesis testing of those selected factors from FMEA in measure phase and each factor consists of two level to confirm the statistically significant of the causes of the black dot defect. The statistical analysis of these factors is completed by the aids of Minitab Release 16 in 2 Proportions command that is based on two proportion z-test. As a result, it can be confirmed that the proportion of black dot defective parts of injection moulding machines no. P24 is not significantly different from the proportion of black dot defective parts of injection moulding machine no. P25. Moreover, the results of the tested five factors by statistical analysis reveals in Table 5-7. Hence, it can be concluded that 4 factors including:

barrel/screw cleaning method, purging materials, resin drying temperature, and hopper filter system are have an effect of the black dot defect and differs at the 0.05 level of significant.

In improve phase, Design of Experiment (DOE) technique is implemented to determine instantaneously the individual and interactive effects of selected four factors that could affect the black dot defect in plastic injection moulding process. The 4 factors including barrel/screw cleaning method, purging materials, resin drying temperature, and hopper filter system. DOE command in Minitab Release 16 is the tool that assists the team performed the experiment. The full 2^k factorial design with 2 replicates is implemented. Thus, 2^4 which are 16 runs, with 2 replicates, so 32 full runs are requisite to conduct the experiment. In addition, each factor consists of two levels (low and high). The outcome of the experiment explained that the main effect of barrel/screw cleaning method, purging material, and resin drying temperature, and interaction effect of barrel/screw cleaning method with purging materials, and barrel/screw cleaning with resin drying temperature with hopper filter system all together are significant. The optimum conditions were calculated by Response Optimisation command provided that clean the barrel and screw, using purging compound, set 120°C for resin drying temperature, with magnetic separator in hopper are the optimum manufacturing process conditions (see table 8-1). Furthermore, the result of the production test that runs for two selected machine with suggested optimum condition is confirmed that the total proportion of black dot defective parts of both machines is reduced from 0.65% to 0.34%, or 47.69% reduction (see figure 8-1).

Table 8-1: Optimum solution for each factor

Factors	Optimum Solution
1.Barrel/screw cleaning method	Do clean the screw and barrel
2.Purging materials	Purging compound
3.Resin drying temperature	120°C
4.Hopper filter system	With magnetic separator

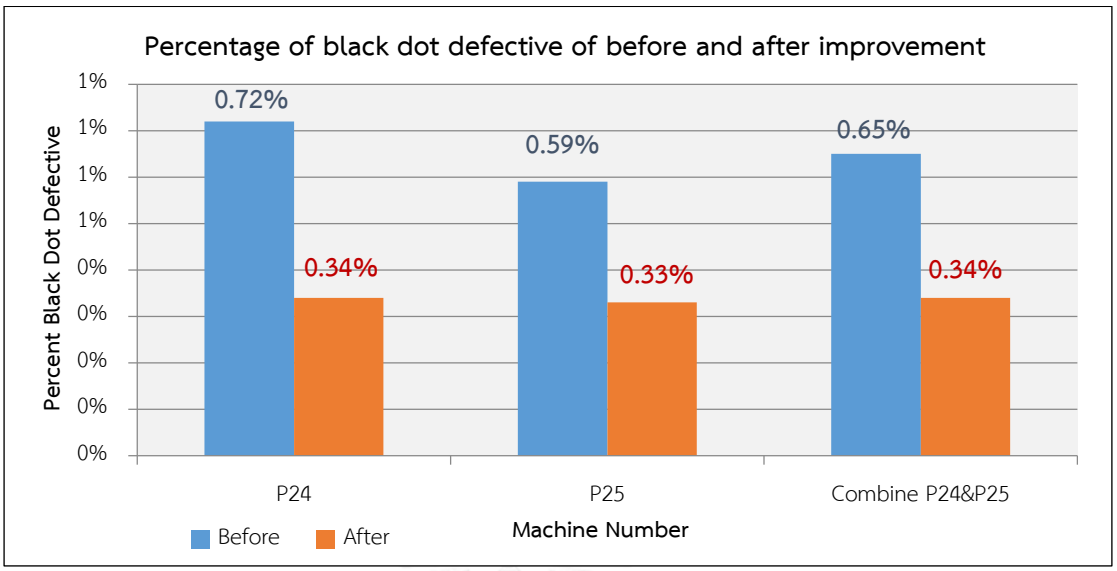


Figure 8-1: Percentage of black dot defective of before and after improvement for machine number P24 and P25

In control phase, the control plan for each factors are constructed and implemented in the company to sustain the optimum condition in the process and make it as a standard. The control plan mainly focus on barrel and screw cleaning method, purging materials, resin drying temperature, and hopper filter system. To support the control plan, controls charts are apply to monitor a process for black dot defect. In this case, the p-chart is applied because the black dot defect is attribute data. In addition, after implemented the optimum solution, the process is in control since the proportion of black dot defect of individual machine and combine machine are not fall out upper control limit (UCL) and lower control limit (LCL).

8.2 Limitations of Research

This research is concentrating only the reduction of the black dot defect in plastic injection moulding process that occurs in the company.

There are only two same model and specification of plastic injection moulding machine that is use to perform the experiment throughout this research which is machine number P24 and P25. Subsequently, the optimum condition might be differing with other model and specification of plastic injection moulding machine.

There is only one type of raw materials or plastic resins that is use to perform the experiment throughout this research which is Polycarbonate (PC). Consequently, the optimum condition might be varying with other kind of raw materials.

The response in this research is attribute data which is the proportion of black dot defective parts. The attribute data have limit number of statistical tools and technique to apply in the analysis comparing with variable data.

8.3 Recommendations

Six Sigma DMAIC Methodology is a combination of tools and techniques that involves statistics concept; therefore, it is essential that the team should have fundamental knowledge about statistics to understanding the results of process improvement. In addition, the manual statistical calculation in various phases of Six Sigma seem to be a very difficult to perform. Consequently, the use of statistical software can be done to calculate and analyse data in Six Sigma quality and process improvement projects.

During the team formation, it is essential that every member of the team should come from different department with expertise of the interested process improvement in order to collect variety of aspects or ideas within the process.

There are other numerous minor factors that contribute to black dot defect in the process which listed in the Failure Mode and Effect Analysis (FMEA) that have not been considered in this research. Thus, it is recommended that some of those minor factors should be future explored in order to increase the chance of reducing higher black dot defect in the process.

The procedure to cleaning screw of the injection moulding machine is very critical. If the operators clean the screw with incorrect method and clean the screw too often, the screw can be worn down and damage the surface coating of the screw. Hence, it is recommended that the operators should strictly follow the work instruction and control plan of screw cleaning and the company should train the operators on screw cleaning skills.

There are various brand and grade of purging material. Thus, it is recommended that to test with different brand and grade of purging material which might offers a better screw purging results and might reduce the frequency of disassembly screw cleaning process.

There are standard sheet for resin drying temperature setting. However, it is recommended that to fine-tune the resin drying temperature to obtain optimum performance and higher productivity with acceptable black dot defects rate.

Since Six Sigma is the method to reduction of defects in the process. Accordingly, it is recommended that to use this research as guideline and method to reduce black dot defect for other injection moulding machine subsequently. In addition, there are other types of defects that occur in the injection moulding process. So, this process improvement approach can be used to future reduce other types of defect in the process.

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APPENDIX

Appendix A: QC Reminder

QC. REMINDER		INJECTION MOULDING CO.,LTD.	
CUSTOMER	ABC CO., LTD.	DIE NO.	M019
PART NAME	Cover (Top)	MODEL	190
PART CODE	LV1TB-00100000M10	MATERIAL	PC

TITLE: DEFECT : BLACK DOT

❶ GOOD PARTS (G)

Plastic moulding cover(top) without black dot defect

❷ NO GOOD PARTS (NG)

Plastic moulding cover(top) with black dot defect

Mam P.	14-Jul-2014	15-Jul-2014	Nanthiya A.
PREPARED BY	ISSUED DATE	EFFECTIVE DATE	APPROVED BY

Appendix B: Visual Inspection Record

Measurement System Analysis

Visual Inspection Record

Sample	Standard Reference	Inspector A		Inspector B		Inspector C	
		1	2	1	2	1	2
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Appendix C: Cause-and-Effect Matrix Query Form

Cause-and-Effect Matrix

Query form of rating factors that affect the black dot defect in the plastic injection molding process

Respondent: _____ **Date:** _____

Instructions: Please mark "X" in the box that contains number 0 to 10 that based on your exact opinion

0 = Not impact to the black dot defect
5 = Moderate impact to the black dot defect
10 = Very high impact to the black do defect

Item	Code	Key Process Input Variable (KPIV)	Score										
		MACHINE											
1	MAC1	Uncontrolled heater bands	0	1	2	3	4	5	6	7	8	9	10
2	MAC2	Damage barrel/screw	0	1	2	3	4	5	6	7	8	9	10
3	MAC3	Contamination in hopper	0	1	2	3	4	5	6	7	8	9	10
4	MAC4	Previous material trapped in barrel	0	1	2	3	4	5	6	7	8	9	10
5	MAC5	Barrel/screw carbonised and dirty	0	1	2	3	4	5	6	7	8	9	10
6	MAC6	Sprue bushing in not seating properly	0	1	2	3	4	5	6	7	8	9	10
7	MAC7	Dirty mould from lubricants	0	1	2	3	4	5	6	7	8	9	10
8	MAC8	Dirty mould from fiction	0	1	2	3	4	5	6	7	8	9	10
9	MAC9	Dirty machine from grease leaks	0	1	2	3	4	5	6	7	8	9	10
10	MAC10	Dirty machine from oil leaks	0	1	2	3	4	5	6	7	8	9	10
11	MAC11	Rusty mould	0	1	2	3	4	5	6	7	8	9	10
		MAN											
1	MAN1	Operator not sort out the dirty runner	0	1	2	3	4	5	6	7	8	9	10
2	MAN2	Inconsistent process cycle	0	1	2	3	4	5	6	7	8	9	10
3	MAN3	Set wrong parameters	0	1	2	3	4	5	6	7	8	9	10
4	MAN4	Lack of screw cleaning skills	0	1	2	3	4	5	6	7	8	9	10
5	MAN5	Fill wrong type of material	0	1	2	3	4	5	6	7	8	9	10
6	MAN6	Change the material filling operator	0	1	2	3	4	5	6	7	8	9	10
		MATERIALS											
1	MAT1	Dusty raw material	0	1	2	3	4	5	6	7	8	9	10
2	MAT2	Deteriorated raw material	0	1	2	3	4	5	6	7	8	9	10
3	MAT3	Raw material contamination	0	1	2	3	4	5	6	7	8	9	10
4	MAT4	Incorrect raw material grade	0	1	2	3	4	5	6	7	8	9	10
5	MAT5	Regrind contemination	0	1	2	3	4	5	6	7	8	9	10
		METHOD											
1	MET1	Improper machine cleaning	0	1	2	3	4	5	6	7	8	9	10
2	MET2	Improper mould cleaning	0	1	2	3	4	5	6	7	8	9	10
3	MET3	Improper mould setup	0	1	2	3	4	5	6	7	8	9	10
4	MET4	Improper injection cycle time	0	1	2	3	4	5	6	7	8	9	10
5	MET5	Improper injection temperature	0	1	2	3	4	5	6	7	8	9	10
6	MET6	Improper injection screw turning speed	0	1	2	3	4	5	6	7	8	9	10
7	MET7	Not completely purge all previous material in the barrel	0	1	2	3	4	5	6	7	8	9	10
8	MET8	Change mould (product) regulary	0	1	2	3	4	5	6	7	8	9	10
9	MET9	Improper screw cleaning	0	1	2	3	4	5	6	7	8	9	10
10	MET10	Material bag dusty due to handling	0	1	2	3	4	5	6	7	8	9	10
		MEASUREMENT											
1	MEA1	Poor visual inspection	0	1	2	3	4	5	6	7	8	9	10
		ENVIRONMENT											
1	ENV1	Power Surge	0	1	2	3	4	5	6	7	8	9	10
2	ENV2	Power Failure	0	1	2	3	4	5	6	7	8	9	10
3	ENV3	Unclean material storage area	0	1	2	3	4	5	6	7	8	9	10
4	ENV4	Dust around the machine	0	1	2	3	4	5	6	7	8	9	10

Appendix D1: FMEA – Severity Query Form

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA

Query form of ranking *SEVERITY* for black dot defect in the plastic injection molding process

Core Team: Factory Manager,Production Manager,Production Engineer, Production Supervisor,QA Engineer, Maintenance Engineer,Researcher

Instructions: Please mark "X" in the box that contains number 1 to 10 that based on your exact opinion on serverity effect
Provide each effect its own severity rating from 1 to 10, with 10 being the most severe

Item	Key Process Input Variable (KPIV)	Ranking									
1	Uncontrolled heater bands	1	2	3	4	5	6	7	8	9	10
2	Damage barrel/screw	1	2	3	4	5	6	7	8	9	10
3	Contamination in hopper	1	2	3	4	5	6	7	8	9	10
4	Previous material trapped in barrel	1	2	3	4	5	6	7	8	9	10
5	Barrel/screw carbonised and dirty	1	2	3	4	5	6	7	8	9	10
6	Sprue bushing in not seating properly	1	2	3	4	5	6	7	8	9	10
7	Dirty mould from lubricants	1	2	3	4	5	6	7	8	9	10
8	Dirty mould from fiction	1	2	3	4	5	6	7	8	9	10
9	Dirty machine from grease leaks	1	2	3	4	5	6	7	8	9	10
10	Dirty machine from oil leaks	1	2	3	4	5	6	7	8	9	10
11	Rusty mould	1	2	3	4	5	6	7	8	9	10
12	Operator not sort out the dirty runner	1	2	3	4	5	6	7	8	9	10
13	Inconsistent process cycle	1	2	3	4	5	6	7	8	9	10
14	Set wrong parameters	1	2	3	4	5	6	7	8	9	10
15	Lack of screw cleaning skills	1	2	3	4	5	6	7	8	9	10
16	Fill wrong type of material	1	2	3	4	5	6	7	8	9	10
17	Change the material filling operator	1	2	3	4	5	6	7	8	9	10
18	Dusty raw material	1	2	3	4	5	6	7	8	9	10
19	Deteriorated raw material	1	2	3	4	5	6	7	8	9	10
20	Raw material contamination	1	2	3	4	5	6	7	8	9	10

Appendix D2: FMEA - Occurrence Query Form

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA

Query form of ranking *OCCURRENCE* for black dot defect in the plastic injection molding process

Core Team: Factory Manager,Production Manager,Production Engineer, Production Supervisor,QA Engineer, Maintenance Engineer,Researcher

Instructions: Please mark "X" in the box that contains number 1 to 10 that based on your exact opinion on serverity effect
Provide how likely for a failure to occur by rating from 1 to 10, with 10 being the most likely

Item	Key Process Input Variable (KPIV)	Ranking									
1	Uncontrolled heater bands	1	2	3	4	5	6	7	8	9	10
2	Damage barrel/screw	1	2	3	4	5	6	7	8	9	10
3	Contamination in hopper	1	2	3	4	5	6	7	8	9	10
4	Previous material trapped in barrel	1	2	3	4	5	6	7	8	9	10
5	Barrel/screw carbonised and dirty	1	2	3	4	5	6	7	8	9	10
6	Sprue bushing in not seating properly	1	2	3	4	5	6	7	8	9	10
7	Dirty mould from lubricants	1	2	3	4	5	6	7	8	9	10
8	Dirty mould from fiction	1	2	3	4	5	6	7	8	9	10
9	Dirty machine from grease leaks	1	2	3	4	5	6	7	8	9	10
10	Dirty machine from oil leaks	1	2	3	4	5	6	7	8	9	10
11	Rusty mould	1	2	3	4	5	6	7	8	9	10
12	Operator not sort out the dirty runner	1	2	3	4	5	6	7	8	9	10
13	Inconsistent process cycle	1	2	3	4	5	6	7	8	9	10
14	Set wrong parameters	1	2	3	4	5	6	7	8	9	10
15	Lack of screw cleaning skills	1	2	3	4	5	6	7	8	9	10
16	Fill wrong type of material	1	2	3	4	5	6	7	8	9	10
17	Change the material filling operator	1	2	3	4	5	6	7	8	9	10
18	Dusty raw material	1	2	3	4	5	6	7	8	9	10
19	Deteriorated raw material	1	2	3	4	5	6	7	8	9	10
20	Raw material contamination	1	2	3	4	5	6	7	8	9	10

Appendix D3: FMEA - Detection Query Form

FAILURE MODE AND EFFECTS ANALYSIS: PROCESS FMEA

Query form of ranking *DETECTION* for black dot defect in the plastic injection molding process

Core Team: Factory Manager,Production Manager,Production Engineer, Production Supervisor,QA Engineer, Maintenance Engineer,Researcher

Instructions: Please mark "X" in the box that contains number 1 to 10 that based on your exact opinion on serverity effect
Provideeffect of a failure from occurring rating from 1 to 10, with 10 being the lowest likelihood of detection

Item	Key Process Input Variable (KPIV)	Ranking									
1	Uncontrolled heater bands	1	2	3	4	5	6	7	8	9	10
2	Damage barrel/screw	1	2	3	4	5	6	7	8	9	10
3	Contamination in hopper	1	2	3	4	5	6	7	8	9	10
4	Previous material trapped in barrel	1	2	3	4	5	6	7	8	9	10
5	Barrel/screw carbonised and dirty	1	2	3	4	5	6	7	8	9	10
6	Sprue bushing in not seating properly	1	2	3	4	5	6	7	8	9	10
7	Dirty mould from lubricants	1	2	3	4	5	6	7	8	9	10
8	Dirty mould from fiction	1	2	3	4	5	6	7	8	9	10
9	Dirty machine from grease leaks	1	2	3	4	5	6	7	8	9	10
10	Dirty machine from oil leaks	1	2	3	4	5	6	7	8	9	10
11	Rusty mould	1	2	3	4	5	6	7	8	9	10
12	Operator not sort out the dirty runner	1	2	3	4	5	6	7	8	9	10
13	Inconsistent process cycle	1	2	3	4	5	6	7	8	9	10
14	Set wrong parameters	1	2	3	4	5	6	7	8	9	10
15	Lack of screw cleaning skills	1	2	3	4	5	6	7	8	9	10
16	Fill wrong type of material	1	2	3	4	5	6	7	8	9	10
17	Change the material filling operator	1	2	3	4	5	6	7	8	9	10
18	Dusty raw material	1	2	3	4	5	6	7	8	9	10
19	Deteriorated raw material	1	2	3	4	5	6	7	8	9	10
20	Raw material contamination	1	2	3	4	5	6	7	8	9	10

INJECTION MOULDING CO., LTD.		WORK INSTRUCTION		Document no. : WI-SCREW-001 Rev. no. : Effective date : 14-JULY-2014
Process Description:	Screw and barrel cleaning	**Purpose:**	To assure screw and barrel are properly cleaned and ready prior to the start of new run	
Equipment Description:	Toshiba EC230S I/J Machine	**Responsible:**	Maintenance Department	
Materials/tools require: Safety glasses, Hot gloves, Brass brushes, Brass gauze, Round wire brush, Electric drill, cotton rags				

Illustration	Step	Instructions
	1.	Remove panels surrounding injection unit
	2.	Move injection unit back to maximum retracted position, when at maximum retracted position disconnect injection unit from nozzle touch cylinder by removing a pin
	3.	Remove injection unit guide on operator side of machine, and swivel machine outward to gain access to nozzle assembly
	4.	Remove nozzle heater, thermocouple, nozzle tip, nozzle, and nozzle body
	5.	Remove screw by removing split collar attaching screw to machine
	6.	Move screw foreword towards nozzle end of barrel and remove through the front of barrel
	7.	Detach screw tip, remove check ring and shoulder ring from screw tip
	8.	Clean screw by polishing the screw with round copper wire brush clean thoroughly until all traces of previous materials are removed
	9.	Clean barrel by using brass brushes threaded onto a rod and hand drill clean inside of barrel thoroughly until all traces of previous materials are removed
	10.	Reassemble screw tip and attach to screw, replace screw in barrel
	11.	Reassemble nozzle component, reattach thermocouple and nozzle heater
	12.	Swivel injection unit back into place, reinstall injection unit guide
	13.	Reattach injection unit to nozzle touch cylinder
	14	Reattach panels to injection unit

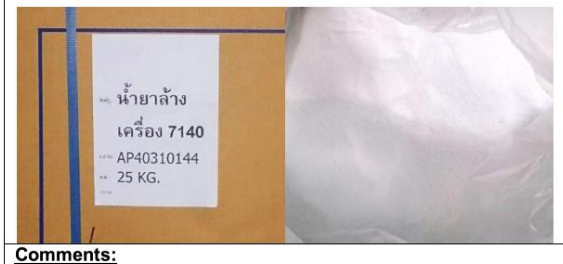
Comments:

- Use precaution when cleaning to try and avoid scarring inside surfaces with hardened materials
- Verify check ring and shoulder ring are installed correctly

Issued by	Approved by
Date:	Date:

INJECTION MOULDING CO., LTD.		WORK INSTRUCTION		Document no. : WI-SCREW-002 Rev. no. : Effective date : 14-JULY-2014
Process Description:	Screw Purging	**Purpose:**	To assure screw and barrel are properly cleaned and ready prior to the start of new run	
Equipment Description:	Toshiba EC230S I/J Machine	**Responsible:**	Maintenance Department	

Materials/tools require: Safety glasses, Hot gloves, Copper rod, Purging compound

Illustration	Step	Instructions
  	1.	Check that all zones are in the proper temperature range for the grade of purging compound being used
	2.	Retract the injection unit. Run the barrel empty using maximum back pressure. Wipe the hopper and feed throat
	3.	Feed the required amount of purging compound into the hopper. About one to two barrel capacities of purging compound is required for purging a typical injection molding machine
	4.	With the screw completely forward, increase the back pressure to the maximum level.
	5.	After purging compound begins coming out from the nozzle, increase the screw speed to the maximum safe level.
	6.	Drop the back pressure after the purging compound coming out from the nozzle is almost clean.
	7.	Retract the screw and perform short, high-velocity injection shots.
	8.	Repeat steps 1 through 7 if contaminants are still visible.
	9.	The machine is clean and purging is complete when purging compound coming out from the machine is visibly free of contamination.
	10.	Displace the purging compound remaining in the machine with the next resin, again, at the maximum back pressure and maximum safe screw speed with the screw completely forward.

Comments:

- The actual amount of purging compound required depends on the difficulty of the application and the condition of the equipment.

Issued by	Approved by
Date:	Date:

INJECTION MOULDING CO., LTD.	WORK INSTRUCTION	Document no. : WI-HOPPER-001 Rev. no. : Effective date : 14-JULY-2014

Process Description:	Hopper cleaning	**Purpose:**	To assure hopper is properly cleaned and ready prior to the start of new run
Equipment Description:	MSC-300 Hopper Dryer	**Responsible:**	Maintenance Department

Materials/tools require: Safety glasses, safety gloves, Ladder, Alcohol cleaner, Air blower gun

Illustration	Step	Instructions
	1.	Use Ladder to be safe and pull hopper to front of the machine where the drain is located
	2.	Get a clean bucket and put it where the material will drain
	3.	Under the hopper there is a lever, one side says open and the other side says closed. Push it open so material goes in the bucket.
	4.	Close the bucket and attach the material tag. Forward to the warehouse for storage.
	5.	Unclip the latches, on the top lid.
	6.	In the center, there two knobs which hold the hopper to the machine. Unscrew them so the bracket comes out, and unlatch the last two latches at the bottom of the hopper. Gently push the hopper so is at a 45 degree angle.
	7.	Inside the hopper there are four components that have to be removed for cleaning. These components consist of - Lining - Rubber - Magnetic separator - Conical strainer
	8.	Clean inside of the hopper to remove any loose material. Then use alcohol to wipe the hopper clean.
	9.	Clean the four components with air and alcohol and reassemble.
	10.	Reassemble hopper to machine.

Comments:	**Issued by**	**Approved by**
	Date:	Date:

INJECTION MOULDING CO., LTD.		WORK INSTRUCTION		Document no. : WI-CRUSHER-001 Rev. no. : Effective date : 14-JULY-2014
Process Description:	Plastic crusher machine cleaning	**Purpose:**	To assure plastic crusher is properly cleaned and ready prior to the start of new run	
Equipment Description:	SG-230F Crusher	**Responsible:**	Maintenance Department	

Materials/tools require: Safety glasses, safety gloves, Air blower gun, cotton rags

Illustration	Step	Instructions
	1.	Check the protective device is good, if found unsafe guards phenomenon, should be immediately removed
	2.	Use the time to check bearing lubrication condition is good
	3.	Check the hydraulic machine from the top or from the top of the screw head is returned, adjusting pads are installed correctly and pressed
	4.	Check all fasteners are tightened flour machine , should be timely secure all loose
	5.	Check whether the timber mill cavity materials or other debris, if it should be cleaned.
	6.	Check the vents are blocked, and clean up the dust.
	7.	Check all drive belts are installed correctly and in good condition, if found damaged belt should be replaced when there is oil on the belt or sheave applications promptly wipe with clean cotton rags
	8.	After finished using the machine, clean the surface of dust by air blower gun to keep the body clean.

Comments:

- Beware of saws blade when cleaning
- Do not cleaning when machine is in operation

Issued by		Approved by
Date:		Date:

Appendix E5: Work Instruction – Plastic Resin Drying temperature setting

INJECTION MOULDING CO., LTD.		WORK INSTRUCTION		Document no. : WI-HOPPER-002 Rev. no. : Effective date : 14-JULY-2014	
Process Description:	Plastic resins drying temp. setting	**Purpose:**	To assure plastic resins are properly dried and ready prior to the start of new run		
Equipment Description:	MSC-300 Hopper Dryer	**Responsible:**	Maintenance Department		
Materials/tools require: Safety glasses, safety gloves					
Illustration		**Step**	**Instructions**		
		1.	Load the require plastic resins into the hopper dryer		
		2.	On the control panel, turn on the main power, turn the switch to on position for both fan motor and heater		
		3.	The green light indicated that the fan motor and heater are on.		
		4.	Turn on the timer and set the time to suite with specific material		
		5.	Set the temperature to specific plastic resins		
		6.	After heating for a period of time, check if the temperature meter shoes the same as the set temperature		
		7.	When the heating time completed, the green light will off which indicate that plastic resins is dry completely and ready to be use		
Comments: - The drying temperature and time resins must be referred to the reference drying temperature for different specific plastic - Contract the plastic resins supplier if there is no reference drying temperature for specific plastic resins				**Issued by**	**Approved by**
				Date:	Date:

Appendix F: Control Plan

Control Plan

Prototype	Pre-launch	X	Production	Key Contact/Phone	Date (Orig.)	Date (Rev.)
Control Plan Number						
Part Number/Latest Change Level				Core Team Seat Heater team	Customer Engineering Approval/Date (If Req'd)	
Part Name/Description				Supplier/Plant Approval/Date	Customer Quality Approval/Date (If Req'd)	
Supplier/Plant		Supplier Code		Other Approval/Date (If Req'd)	Other Approval/Date (If Req'd)	

Part / Process Number	Process Name / Operation Description	Machine, Device, Jig, Tools For Mfg.	Characteristics			Special Char. Class.	Methods				Reaction Plan
			No.	Product	Process		Product / Process Specification/Tolerance	Evaluation Measurement Technique	Sample Size	Sample Freq.	Control Method	
1	Receiving raw materials a) plastic resins	–	1	Appearance	–	–	No contamination or any foreign materials	Visual inspection	100%	All batch	QA. Mat'l Std.	Make claims to supplier
		–	2	Spec. Mat'l	–	–	Ref. QA. Std.	Mat'l cert.	100%	All batch	Supplier cert.	Make claims to supplier
2	Mat'l preparation a.) Runner	–	3	Appearance	–	–	No oil contamination or any foreign materials	Visual inspection	100%	All batch	Screen contamination before running	Clean plastic injection machine
3	Machine Preparation a.) Screw	Toshiba EC230S	4	Appearance	–	–	No carbonised or dirty on the surface of screw	P-Chart	100%	All batch	Clean the screw (refer to WI-SCREW-001)	Sent screw for hard chrome applications
	b.) Hopper	MSC-300 Hopper	5	Appearance	–	–	No contamination or any foreign materials inside hopper	Visual inspection	100%	Every day	Clean the hopper (refer to WI-HOPPER-001)	Pay more attention on cleaning hopper
	c.) Plastic Crusher Machine	SG-230F Crusher	6	Appearance	–	–	No contamination or any foreign materials inside crusher machine	Visual inspection	100%	Every day	Clean the crusher (refer to WI-CRUSHER-001)	Pay more attention on cleaning crusher machine
	d.) Plastic resins dry temperature	MSC-300 Hopper	7	Resins dry temp. guideline	pre-dry resins	–	Set dry temperature to suite with specific raw materials	Temperature meter	100%	Every day	Set resins dry temp. (refer to WI-HOPPER-002)	Contract supplier for resins dry temp. guideline
4	Mould Assembly and Set up a.) Mould Assy. On Injection machine	–	8	Appearance	–	–	Assemble the mould on the mould unit of the injection moulding machine	Visual inspection, Checklist	100%	Every changeover	Mould Set-up Checklist	Re-assemble if the mould are not fit properly

Control Plan

[ ] Prototype [ ] Pre-launch [X] Production Control Plan Number	Key Contact/Phone	Date (Orig.)	Date (Rev.)	
Part Number/Latest Change Level	Core Team Seat Heater team	Customer Engineering Approval/Date (If Req'd)		
Part Name/Description	Supplier/Plant Approval/Date	Customer Quality Approval/Date (If Req'd)		
Supplier/Plant / Supplier Code	Other Approval/Date (If Req'd)	Other Approval/Date (If Req'd)		

Part / Process Number	Process Name / Operation Description	Machine, Device, Jig, Tools For Mfg.	Characteristics			Special Char. Class.	Methods						Reaction Plan
			No.	Product	Process		Product / Process Specification/Tolerance	Evaluation Measurement Technique	Sample Size	Sample Freq.	Control Method		
5	Injection	Toshiba EC230S	9	–	Injection Temperature	–	Customer Inject. Parameter Std.	Temperature monitor	100%	Every 2 hrs.	Check Sheet		Contact customer
			10	–	Injection Time	–	Customer Inject. Parameter Std.	Cycle time monitor	100%	Every 2 hrs.	Check Sheet		Contact customer
			11	–	Injection Pressure	–	Customer Inject. Parameter Std.	Pressure monitor	100%	Every 2 hrs.	Check Sheet		Contact customer
6	Inspection	–	12	Black Dot Defect	–	–	QA. Std.	Visual Inspection	100%	Every unit	Inspection Check sheet		Report to customer
			13	–	–	Inspection Process	Inspector competency	Approve Inspector list	–	Every Inspector	Inspector name list		Train and evaluate the inspector
7	Packing	Corrugated box	14	Appearance, Quantity	–	–	Packing the moulded parts as specify by the customers	Quantity counting worksheets	100%	Every unit	Customer Packing Std.		Train and evaluate the packing staff
		Plastic container	15	Appearance, Quantity	–	–	Packing the moulded parts as specify by the customers	Quantity counting worksheets	100%	Every unit	Customer Packing Std.		Train and evaluate the packing staff
8	Storage	Pallet	16	Location, Quantity	–	–	Store the finished product at specific storage area	Inventory tags	100%	Every unit	Storage Plan		Train and evaluate the inventory staff
9	Delivery	Truck	17	Appearance, Quantity	–	–	Load the require amount of finish goods onto the truck and deliver to customer	Shipping marks, tags	100%	Every unit	Packing list		Train and evaluate the delivery staff

VITA

Mr. Itthiwat Rattanabunditsakun was born on February 26th, 1990 in Bangkok, Thailand. He completed his undergraduate degree in Automotive Design and Manufacturing Engineering in 2012 at International School of Engineering, Chulalongkorn University. In 2012, he undertook his postgraduate dual-degree programme in Engineering Management, and Engineering Business Management jointly offered by Regional Centre for Manufacturing System Engineering, Chulalongkorn University, and Warwick Manufacturing Group, University of Warwick, respectively.