PLASTIC LUMP DEFECT REDUCTION IN RECYCLED PLASTIC PELLETS MANUFACTURING

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การลดของเสียประเภทก้อนหน้าตะแกรงในกระบวนการผลิตเม็ดพลาสติกรีไซเคิล

นางสาวรรูปทิพย์ ไพบูลย์เกษมสุทธิ์

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รรูปทิพย์ ไพบูลย์เกษมสุทธิ์ : การลดของเสียประเภทก้อนหน้าตะแกรงในกระบวนการผลิตเม็ดพลาสติกรีไซเคิล (PLASTIC LUMP DEFECT REDUCTION IN RECYCLED PLASTIC PELLETS MANUFACTURING) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร. ณัฐชา ทวีแสงสกุลไทย, 130 หน้า.

งานวิจัยนี้มีวัตถุประสงค์เพื่อปรับปรุงกระบวนการผลิตและลดปริมาณของเสียที่เกิดจากข้อบกพร่องประเภทก้อนหน้าตะแกรงของกระบวนการผลิตเม็ดพลาสติกรีไซเคิล โดยการหาค่าปรับตั้งปัจจัยนำเข้าที่เหมาะสมเพื่อให้ได้จำนวนของก้อนหน้าตะแกรงที่ต่ำที่สุด ผู้วิจัยได้ดำเนินการปรับปรุงตามแนวทางของ ซิกซ์ ซิกมา ร่วมกับเครื่องมือควบคุมคุณภาพ โดยเริ่มจากระยะการนิยามปัญหาในโรงงานกรณีศึกษา โดยมีการจัดตั้งทีมงาน กำหนดวัตถุประสงค์ และขอบเขตในการปรับปรุง จากนั้นได้ทำการระดมความคิดในการวิเคราะห์แผนผังสาเหตุและผลเพื่อหาสาเหตุของข้อบกพร่อง และประเมินความสัมพันธ์ระหว่างเหตุและผล จากนั้นจึงทำการประยุกต์ใช้การวิเคราะห์ลักษณะของข้อบกพร่องและผลกระทบ ร่วมกับหลักการพาเรโตเพื่อหาปัจจัยนำเข้าที่สำคัญ จากการดำเนินระยะที่สอง ทำให้สรุปได้ว่า สาเหตุหลักของก้อนพลาสติกหน้าตะแกรง คือ ขนาดตะแกรงไม่ถูกต้อง อุณหภูมิที่ไม่เหมาะสม ความเร็วในการสกรูไม่ถูกต้อง เครื่องจักรขาดการบำรุงรักษาและการขาดการฝึกอบรม ในระยะที่สามจึงได้มีการระดมความคิดเพื่อหาวิธีการแก้ไขสาเหตุของปัญหา โดยได้ทำการออกแบบการทดลองแบบเชิงแฟคทอเรียล 2k แบบ 3 เรพลิเคต เพื่อหาระดับของปัจจัยที่เหมาะสม และจัดทำคู่มือปฏิบัติงานร่วมกับแผนการบำรุงรักษาเชิงป้องกัน เพื่อแก้ไขปัญหาของการขาดบำรุงรักษาของเครื่องจักรและการฝึกอบรม จากการออกแบบทดลองทำให้ได้ระดับของปัจจัยที่เหมาะสมคือ อุณหภูมิที่ 205 องศาเซลเซียส ความเร็วรอบสกรูที่ 80 รอบต่อนาทีและ ไซส์ตะแกรงที่ 100 หลังจากนั้นระยะการปรับปรุงกระบวนการ ทางผู้วิจัยได้นำระดับปัจจัยใหม่ที่ได้จากการออกแบบการทดลองมาใช้ในกระบวนการผลิตจริง เพื่อยืนยันผลการทดลอง และสุดท้ายระยะการควบคุมกระบวนการทางผู้วิจัยได้จัดทำแผนภูมิควบคุมกระบวนการผลิตเพื่อดูความเปลี่ยนแปลงของกระบวนการ ผลหลังจากการปรับปรุงพบว่า ข้อบกพร่องประเภทก้อนหน้าตะแกรงมีสัดส่วนของเสียก่อนปรับปรุงที่ร้อยละ 4.85 และมีค่าลดลงเหลือเพียงร้อยละ 2.30 ภายหลังจากทำการปรับปรุง

ภาควิชา	ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต	ลายมือชื่อนิสิต ....
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Based on the current situation, the case study company has been confronted with a large number of plastic lump defects within the process resulting in a higher production cost. Therefore, the purpose of carrying out this research project is to minimise the percentage defect rate of plastic lumps in the pelletising process by implementing Six Sigma DMAIC methodology along with quality control tools and Design of Experiment. In define phase, the process improvement team are formed and the purpose and scope of the research are set. For measure phase, Cause and Effect Diagram, Cause and Effect Matrix, Failure Mode Effects Analysis and Pareto chart are conducted through brainstorming technique in order to find the root causes of plastic lumps. In analyse phase, the quality tool and statistical technique such as affinity diagram and Design of Experiment will be applied in order to solve the root causes of plastic lumps. The root causes found in the previous phase are wrong screen pack, incorrect temperature, inadequate screw speed, lack of maintenance and lack of training. By using the Design of Experiment, the optimal parameters were found. Moreover, the work instruction which consists of operational procedure and preventive maintenance schedule are created in order to solve the problem of lack of training and lack of maintenance. For improve phase, the new parameters are implemented together with work instruction within the prescribed time. Then, control chart is created in the control phase in order to see change in the process. The result shows the percentage defect rate of plastic lump is reduced from 4.85% to just only 2.30%.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	....
		Advisor's Signature	....
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CHAPTER 1 INTRODUCTION

This chapter provides the overview of this research project which consists of the current state of Thailand's plastic industry followed by a brief background of the studied company used as a case study. Moreover, the problem statement, research objective, scope of research, expected benefits and research methodology will be presented in this chapter.

1.1 The Current State of Thailand's Plastic Industry

Nowadays, it is generally acknowledged that plastic has played a particularly important role in everyday lives since plastic can be found in miscellaneous products on a daily basis. Plastic is used as a core component and raw material in various manufacturing industries such as packaging, auto-parts, housewares, agriculture and construction as shown in Table 1. As a result of this widespread demand for plastics, Thailand's economic growth rate has benefitted tremendously.

Recently, Thailand has been regarded as one of Asia's leading plastic manufacturers (Leclaire, 2015). There are more than 3,000 plastic companies throughout Thailand, especially in the form of small and medium enterprises (SMEs). The Plastic industry not only brings a large source of income to the country, but also contributes to an increase in Thailand's employment rate. In 2013, the plastic industry employed a considerable portion of Thailand's total workforce with more than 380,000 workers (BOI, 2013).

Table 1. Number of Production and Values Classified by Market Segment Year 2016

Source: Adapted from PTIT (2016) and PITH (2016)

Market segment	Production (Ktons)	Values (Million Baht)
Packaging	2,277	182,794
E&E Appliances	800	150,264
Construction	766	108,766
Auto-part	342	88,513
Medical Devices	50	52,012
Safety and Security	111	34,753
Housewares	209	24,729
Recreation	84	16,752
Footwear	98	15,019
Filament (Non-textile)	274	14,436
Agriculture	113	12,841
Others	49	8,884

In Thailand’s plastic industry, a particularly interesting segment is the manufacturing of plastic pellets, in which plastics are transformed into pellets before being released into the market. Currently, plastic pellet manufacturers in Thailand have a production capacity of over 7 million tonnes per year, of which 55% is distributed for domestic use and 45% is exported to foreign countries (Kasikorn Research Center, 2017). During 2017, plastic pellets contributed to 3.7% of Thailand’s total export value, and was listed as one of Thailand’s Top-Five exported products (MOC, 2018). Accordingly, improvements in Thailand’s production capacity of plastic pellets will greatly benefit the country’s economy.

As stated by Kasikorn Research Center (2017), the total export value of plastic pellets in the first-four months of 2017 has remarkably increased by 8.3% when compared to the same period of the previous year. Referring to Figure 1, the graph illustrates Thailand's amount of plastic pellet exported in Ktons between the year of 2009 and 2017f. It is apparent that there was a gradual rise in number of plastic pellet exported from Thailand. Consequently, this can imply that the demand of Thailand's plastic pellet exports has tends to increase at a significant rate.

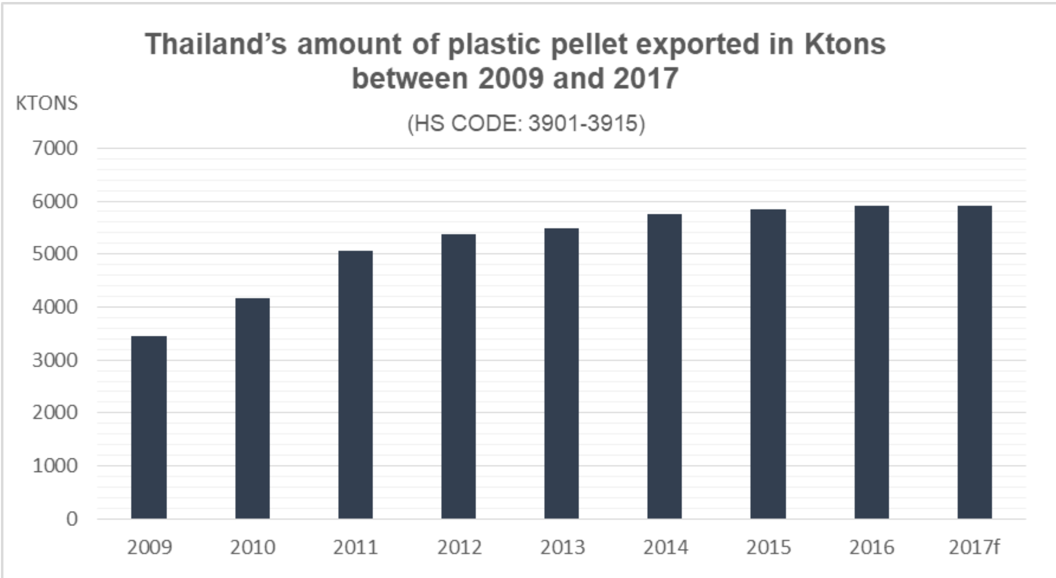

Figure 1. Thailand's Amount of Plastic Pellet Exported During Year 2009-2017f

Source: Adapted from MOC (2018) and Kasikorn Research Center (2017)

With reference to Krungsri Research (2017) and Kasikorn Research Center (2017), it is estimated that the demand for plastic pellets will increase enormously in the year 2017-2019 due to the CLMV market, which is composed of Cambodia, Laos, Myanmar, and Vietnam. During 2016, more than $750 million worth of plastic pellets were exported from Thailand to the CLMV market, which accounted for 9.7% of Thailand's export value of plastic pellets as shown in Table 2.

Table 2. Market Share of Thailand's Plastic Exports (By value)

Source: Adapted from MOC (2018) and Kasikorn Research Center (2017)

Year	China	Indonesia	CLMV	Others
2013	32.10%	9.30%	7.60%	51.00%
2014	31.40%	9.00%	7.80%	51.80%
2015	32.90%	8.30%	8.90%	49.90%
2016	31.60%	8.90%	9.70%	49.80%

As technology continuously advances, there are an increasingly amount of plastic products for consumers to choose from, each with distinctive properties and in various forms. As a result of this, the applications in which plastic can be used is endless. However, a consequence of the rapid consumption of plastics is the excessive plastic waste which has risen tremendously over the years. According to ACFS (2018), in 2015, the amount of plastic and foam waste being generated in Thailand was approximately 2.7 million tonnes or equivalent to 7,000 tonnes per day. Therefore, plastic recycling has become an important process which is an eco-friendly method of converting plastic wastes or scraps into beneficial products. Kasikorn Research Center (2017) also mentioned that plastic recycling helps reduce environmental issues and can also add value to plastic wastes up to 127-147% (DIP, 2015)

Referring to Bangkokbiznews (2017), the value of the Global Plastic Recycling market is now continuously increasing, and is forecasted by Statista, 2017 to be valued at $43 billion by 2020 due to an increase in global recycling rate and demand for environmentally friendly products. Furthermore, Bangkokbiznews (2017) also mentioned that the key plastic product in Thailand's recycling industry is recycled plastic pellets since recycled pellets can be moulded into a wide range of products which are used in numerous applications with lower prices.

As methods to decrease plastic wastes, the European Union has set a requirement for the export of new plastic products in which plastic products must be composed of at least 30% of recycled plastic pellets. Additionally, other incentives offered by the Board of the Investment of Thailand and government of Thailand to promote plastic recycling domestically include income tax exemptions for 8 years and zero import duty on plastic recycling machinery (Bangkokbiznews, 2017). Consequently, the incentive has led to a large number of entrepreneurs who have invested in the plastic recycling industry in Thailand. However, as a result of the increasing applications for recycled plastic pellets in various market segments, the intensity of competition in this industry has been rising rapidly. Therefore, major organisations in this industry tend to use pricing strategies in order to increase their sales meaning that the firm which can minimise their production cost will be able to become a successful company.

Today, one of the methods that is widely used to control production cost is to reduce non-value adding activities which include waste from transportation, waste from waiting, and waste from motion or specifically waste from defects since defects lead to a higher production cost and time consumption required for rework. By minimizing defects in production processes, the company will not only be able to handle and adapt to future market trends but also increase profit margins. Thus, this research will concentrate on the reduction of defects in recycled plastic pellets manufacturers in order to enhance company productivity.

1.2 Company Background

Due to an expanding plastic market and rapid development of the industrial estate in Thailand, especially in the eastern part such as Rayong and Chonburi province, many big-named petrochemical industries have made a huge investment in order to raise their productivity as well as acquiring a higher market share. For example, PTT Public Company Limited, Siam Cement Group Public Company Limited, and IRPC Public Company Limited, which are the leading petrochemical companies in Thailand, have increased their production lines for producing premium-grade plastic pellets. However, this increase in production has also resulted in a substantial increase of plastic wastes, which can be called as plastic scraps. As a business opportunity, many local and foreign entrepreneurs have capitalised on the increasing amount of plastic waste by establishing SMEs dealing with recycling plastic in the eastern part of Thailand.

As previously mentioned, due to the high competitiveness in the plastic recycling industry, JJ Inter Engineering Plastic Company is one of the many firms that have been affected from increasing SME competitors, and has led to a large negative effect on firm value. Therefore, JJ Company has been chosen as the business case study. JJ Company is located in Rayong, Thailand and was established in 2006 with a registered capital of $480,000. Due to the various types of recycled plastic pellets, JJ Company has exported over 175,000 kilograms to international clients in countries such as India, Taiwan, British Virgin Islands, Malaysia and China, and nearly 7,500 kilograms is distributed to Thai clients. In addition, JJ Company utilises a made-to-order business model which means that customers have to pay 50% deposit on every order, and pay the remaining debt after the product is delivered. Table 3 indicates the types of recycled plastic pellets that are produced by JJ Company.

Table 3. JJ Company's Product

Type of Recycled Plastic Pellet	Characteristic
Polycarbonate (PC)	Transparent plastic with high solidity and high heat resistance. PC also has good acid resistance but it is not good for alkaline.
Polyethylene (PE)	Transparent to opaque, good insulator and lightweight.
High Density Polyethylene (HDPE)	White plastic with high density and good resistant to chemical substances.
Low Density Polyethylene (LDPE)	Low density plastic but has a good resistance with both acid and alkaline. It is very flexible and it can also be used as an insulator. LDPE has good elasticity as well
Polypropylene (PP)	Polypropylene has similar properties like PE, but is harder than PE and it also resists to lipids and heat.
Ethylene Vinyl Acetate (EVA)	Lightweight, flexible and also has high temperature resistance.
Acrylonitrile Butadiene Styrene (ABS)	Excellent chemical and heat resistance, good machinability as well as high tensile strength.

1.3 Statement of the Problem

As mentioned earlier, JJ Company is confronted with the intensity of the rivalry among the recycling industry. Therefore, the company's historical performance data is needed in order to prioritize the area for improvement. Figure 2 illustrates all data of the studied firm's production was gathered for 10 months between the periods of January 1st, 2017 to October 31st, 2017. The data gathered included the number of outputs, number of defects, and defect rate. In order to calculate the percentage defect rate, this research will utilize the following equation:

$$\text{Defects per Unit (DPU)} = \frac{\textbf{Amount of Defect (kg)}}{\textbf{The total output (kg)}} \qquad (1.1)$$

$$\text{Percentage defect rate} = (1.1) \times 100\% \qquad (1.2)$$

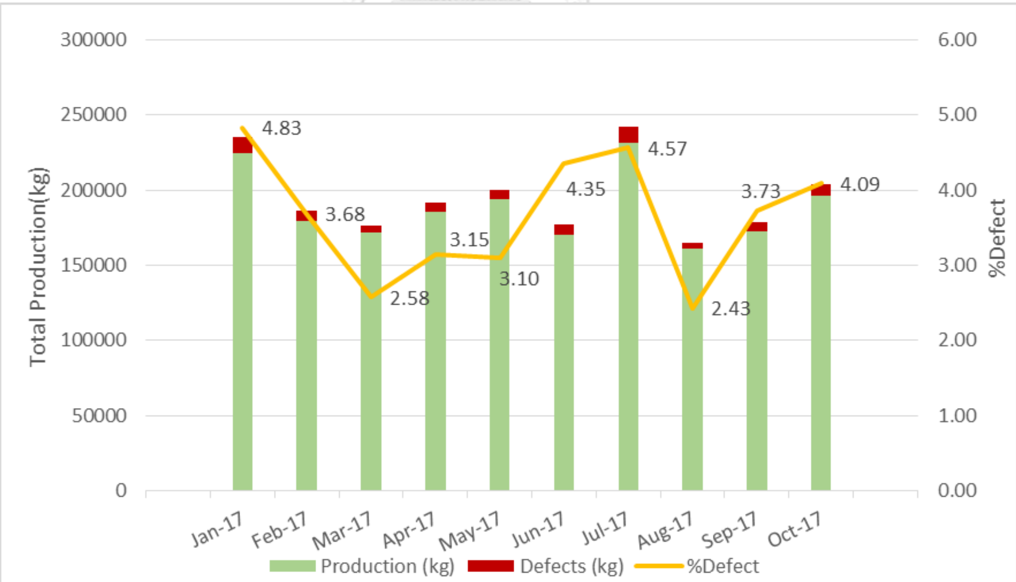

Figure 2. JJ Company's Productivity

Figure 2 demonstrates the current production situation, where JJ Company is facing the problem of higher defect level occurred within the process. It can be seen that there was approximately an average defect rate of 3.65% relative to the overall production occurring between January 1st, 2017 and October 31st, 2017, whereas the maximum percentage of defect is estimated to be 4.83%. The defects that occurred signify not merely an increase in production cost such as labour cost, machinery cost, and utility cost but also an increase in time consumed for rework. Thus, at the time of research, the studied company paid an average of 60,739 baht per month to cover all these costs. To improve the company's profit, this research will focus on minimising costs through defect reduction in JJ Company's plastic pelletising process.

According to the variety of recycled plastic pellet types, the types of pellets were chosen by firstly considering the amount of outputs, then the defect rate, and finally the cost of rework in each type by using the Pareto principle. From Figure 3, the results indicate that PP pellets have the highest volume of production, which was roughly 832,551 kilograms and accounted for 44.1% of the total production. By combining the data of PP pellets and PC pellets, it shows that these two categories represent a whopping cumulative percentage of 72.3%. Thus, from the 80/20 rule, PP and PC should be focused.

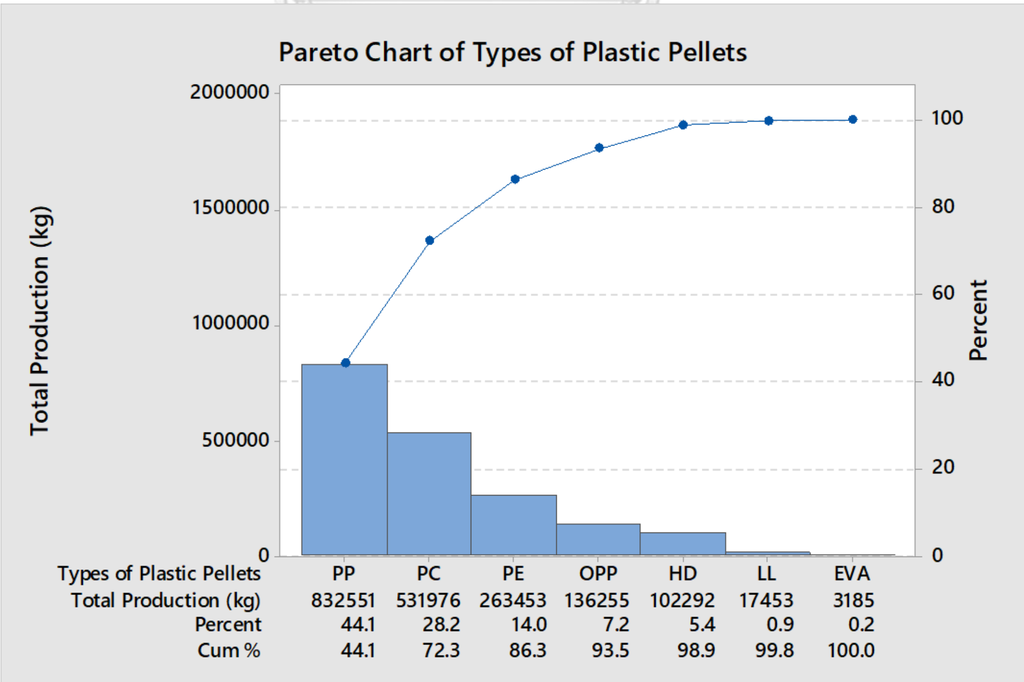

Figure 3. Pareto Chart of Total Production

Then, by comparing the amount of defects from all production lines, it was found that 78.9% of percentage defect rate are from the first five categories, which are PP, EVA, LL, PE, and OPP pellets whereas over 90% of percentage defect rate are from the first six categories as shown in Figure 4.Therefore, from the Pareto principle, PP, EVA, LL, PE, and OPP need to be considered.

Finally, the last consideration is the cost of rework of each type of pellet. Between January 1st, 2017 and October 31st, 2017, it was revealed that 62.3% of rework cost belonged to PP products and 16.7% belonged to PC products. The cumulative percentage of rework cost from PP and PC products is 79.0% as shown in Figure 5. Following the 80/20 principle, PP and PC should be tackled. However, from the three considerations mentioned above, the PP product is the only one product that passed three criteria; therefore, the PP production line will be studied in this research project.

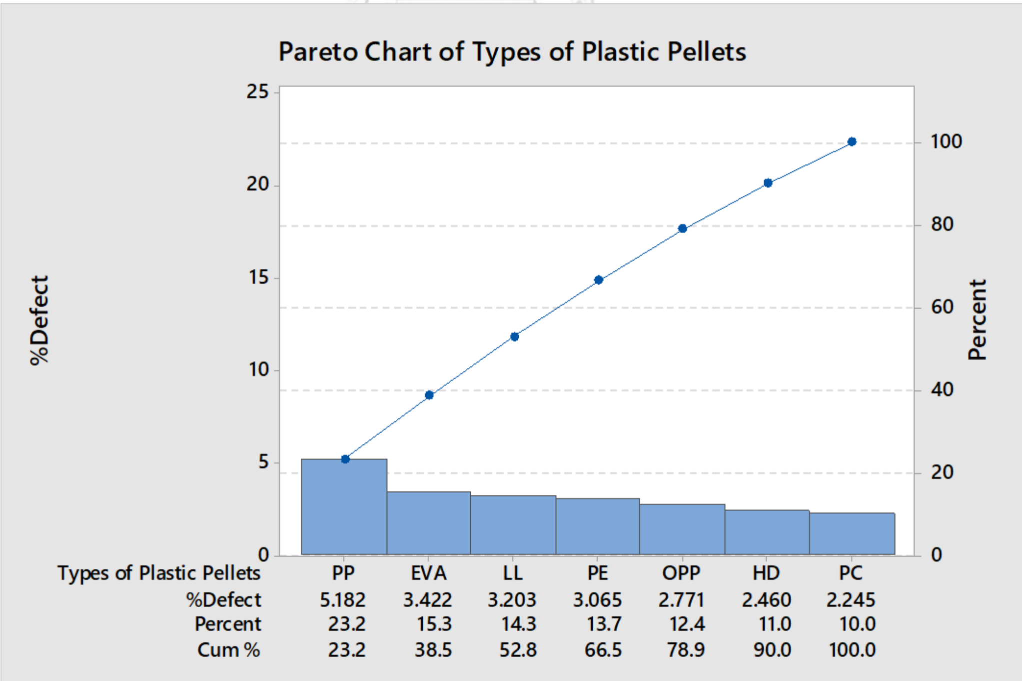

Figure 4. Pareto Chart of %Defect

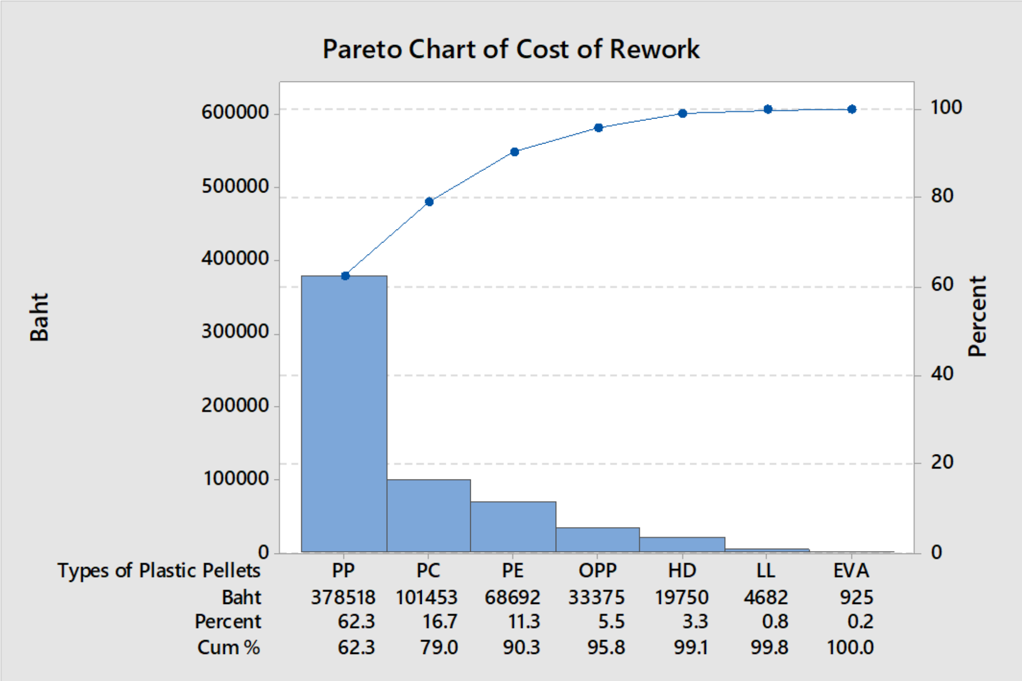

Figure 5. Pareto Chart of Cost of Rework in Each Type of Pellet

Upon choosing PP as the studied plastic pellet, the types of all defects which occurred during the research can be classified into six types, which are plastic lumps, black dots, doubles, tails, burnts, and moisture content. By analysing the historical data considering the amount of defects and their rework cost from January 1st to October 31st, 2017, it is shown that plastic lumps have resulted in the largest defect rate which is 3.35% and it represents an immense cumulative percentage of 90.2% as show in Figure 6. Thus, from the Pareto principle, the company should focus on solving the problem of plastic lumps in order to improve the business back up.

Furthermore, after gathering the cost of rework in each defect characteristics, it was clear that 93.8% of rework cost were caused by plastic lumps as shown in Figure 7. Therefore, from the 80/20 rule, plastic lumps was selected as the studied defect type. In addition, Figure 8 indicates 68.0% of percentage defect rate of plastic lumps are from the first four categories which are PP. EVA, PE, and LL production line. Thereby, from the 80/20 principle, PP, EVA, PE, and LL should be focused on. However, as mentioned earlier, PP products are the only type of pellet that passed the selection criteria; therefore, this research will focus on optimising the percentage defect rate of plastic lumps in the PP production line.

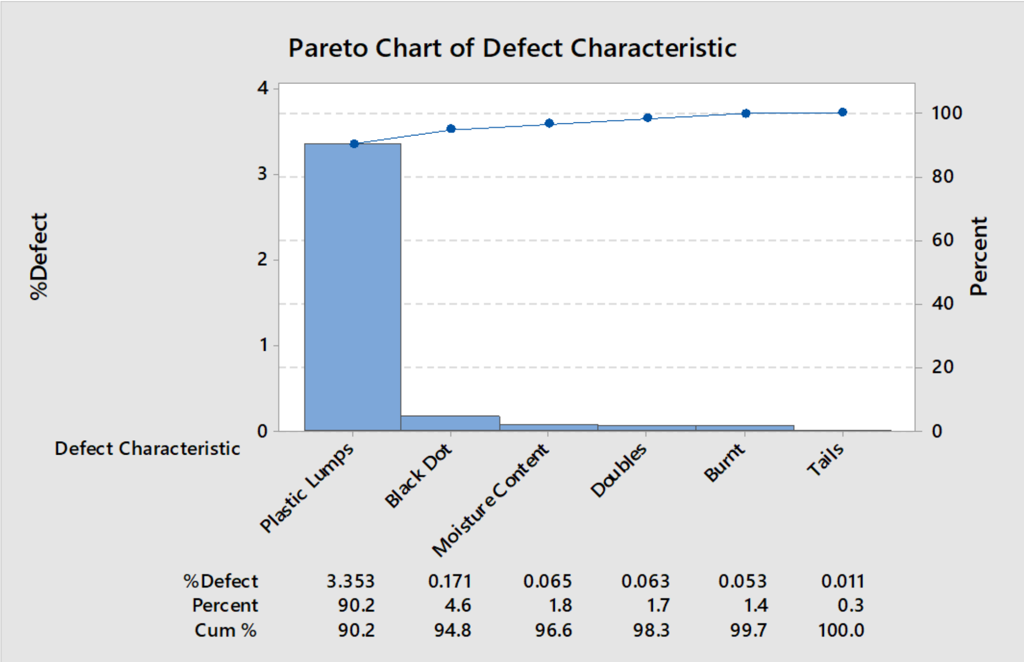

Figure 6. Pareto Chart of %Defect of Each Defect Characteristic

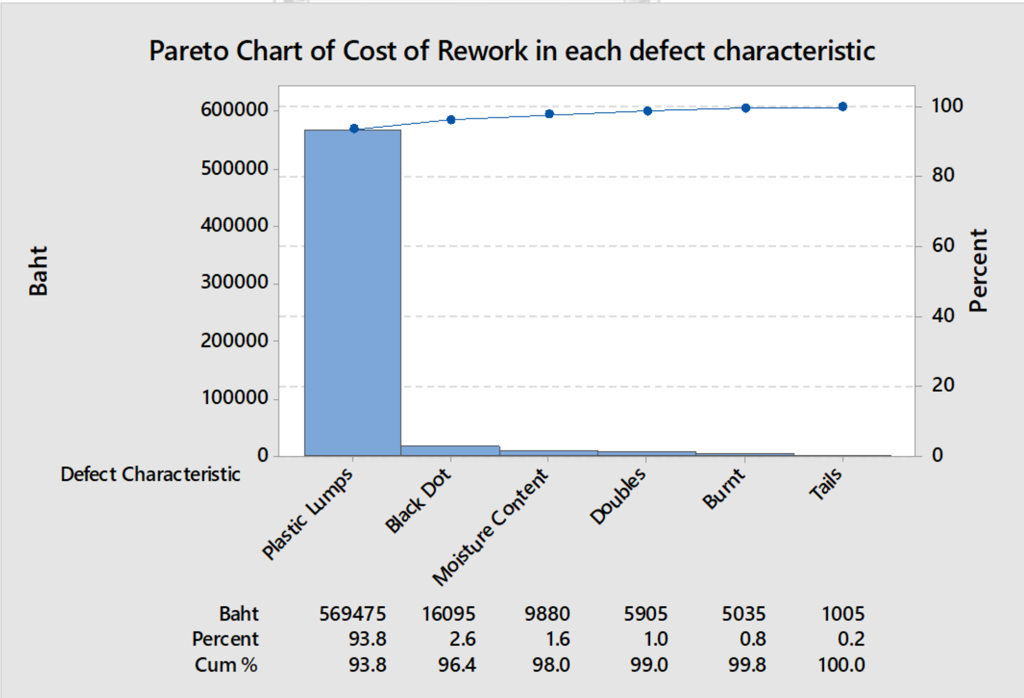

Figure 7. Pareto Chart of Cost of Rework in Each Defect Characteristic

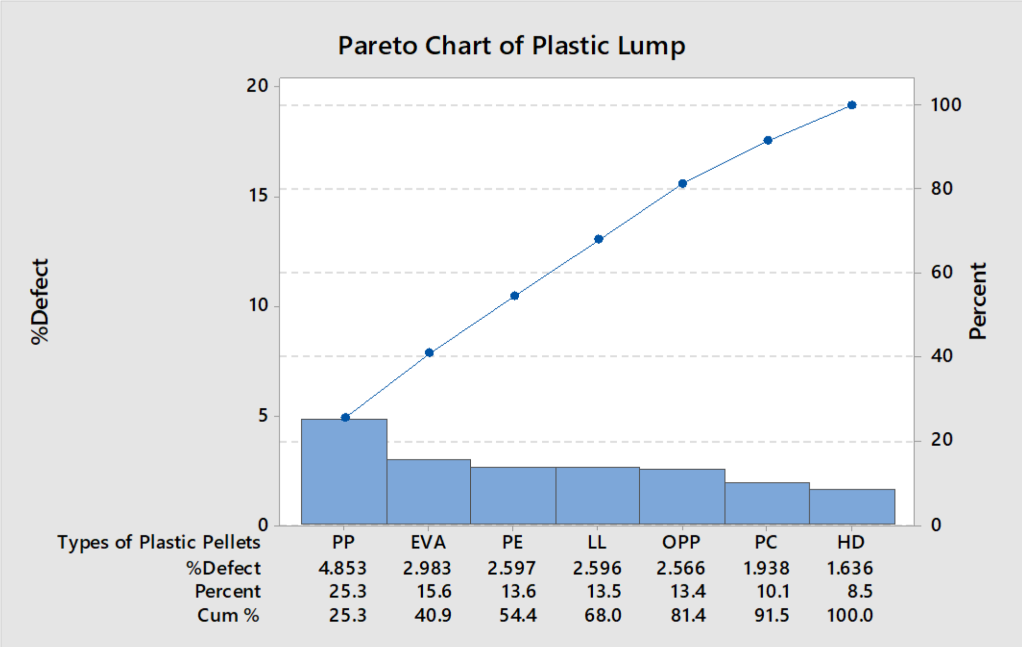

Figure 8. Pareto Chart of %Defect of Plastic Lump in Each Type of Pellet

From the previously analysed data, plastic lumps in the PP production line must be improved immediately in order to reduce costs since it has the highest defect rate and also caused the largest cost of rework. It is also projected that the amount of PP produced by JJ Company increases every year due to the rising trend. Referring to a report created by the Association of Plastic Recycler, the demand of recycled polypropylene resin has dramatically surged. It is forecasted that the need of recycled pellet from the well-known consumer company will be up to 1.36 hundred thousand tonnes per year (Plasticsinpackaging, 2016). Therefore, an appropriate method must be applied to solve this problem. By having an inappropriate solution, the amount of plastic lumps will tend to increase, ultimately leading the company to have negative financial performance and lose credibility for late delivering.

The sample of plastic lumps from PP production line is represented in Figure 9, 10 and 11. Plastic lumps in this research are defined as unmelted plastic that contain contaminants and impurities and are stuck on the screen pack. If there are too many plastic lumps on the screen pack, the melted plastic is unable to flow through the die.

Figure 9. The Sample of Plastic Lumps (1)

Figure 10. The Sample of Plastic Lumps (2)

Figure 11. The Sample of Plastic Lumps (3)

1.4 Research Objective

The aim of carrying out this research project is to reduce the percentage defect rate of plastic lumps by implementing Six Sigma DMAIC approach, quality control tools and Design of Experiment.

1.5 Scope of the Research

This dissertation focuses on minimising the percentage defect rate of plastic lumps by applying Six Sigma DMAIC approach together with quality control tools and Design of Experiment. Since there are a wide variety of plastic types, the work was scoped in PP production line, which plastic lumps generated the highest defect rate and cost of rework.

1.6 Expected Outcomes

The summary of expected benefits is shown as follows;

(1) To optimise the amount of plastic lumps and its defect rate

(2) To decrease losses and costs in the PP production process

(3) To enhance the studied company's competitiveness

(4) To improve product quality

(5) To reduce rework process

(6) To enhance customer satisfaction

1.7 Research Methodology

After acquiring the necessary knowledge from literature reviews, the Six Sigma DMAIC framework is constructed with several quality control tools and statistical techniques in order to accomplish the best results for this project. The conceptual framework in this research is composed of five phases which are I) Define, II) Measure, III) Analyse, IV) Improve, and finally V) Control phase as shown below;

(I) Define Phase

- ❖ Studying theories and literature reviews associated with Six Sigma, quality control tools, Design of Experiment, and production processes in order to apply for this particular case study.
- ❖ Setting up a quality improvement team that includes production manager, process engineer, supervisor, two machine operators, quality control operator and researcher. For this research project, the researcher is responsible for helping disseminate information, suggesting ideas, and then summarising all data gathered from all members in the team.

- Studying the production process, especially the plastic pellet extrusion process. Also, interviewing all staff involved in the production line in order to create a process flowchart to visualize and reveal the hidden problems of the overall processes involved in recycling plastic.
- Identifying the current problems, research boundaries, and propose a method(s) for improving quality in the studied company.

(II) Measure phase

- Gathering the data including the quality problem, types of defects and amount of defects that occur in the plastic pellet extrusion process.
- Holding a brainstorming-session within the team in order to find all possible causes of defective product by conducting Cause and Effect diagram and Cause and Effect Matrix.
- Performing Failure Effect Mode Analysis in order to prioritize risk within a process based on its severity, occurrence, and detection.
- Selecting the main factors by using the Pareto chart of FMEA.

(III) Analyse phase

- Conducting affinity diagram in order to group the similar solutions together.
- Conducting the Design of Experiment in order to find the optimal parameters for each factor in order to reduce the number of defective products by using MINITAB 18 programme.
- Creating work instruction.

(IV) Improve phase

- Developing action plan.
- Implementing plan within the prescribed time.
- Follow up the progression by arranging a meeting periodically.

(V) Control phase

- Measuring the defect rate and then comparing with the initial data before improvement.
- Summarizing overall results and suggest any recommendations.
- Writing the research thesis

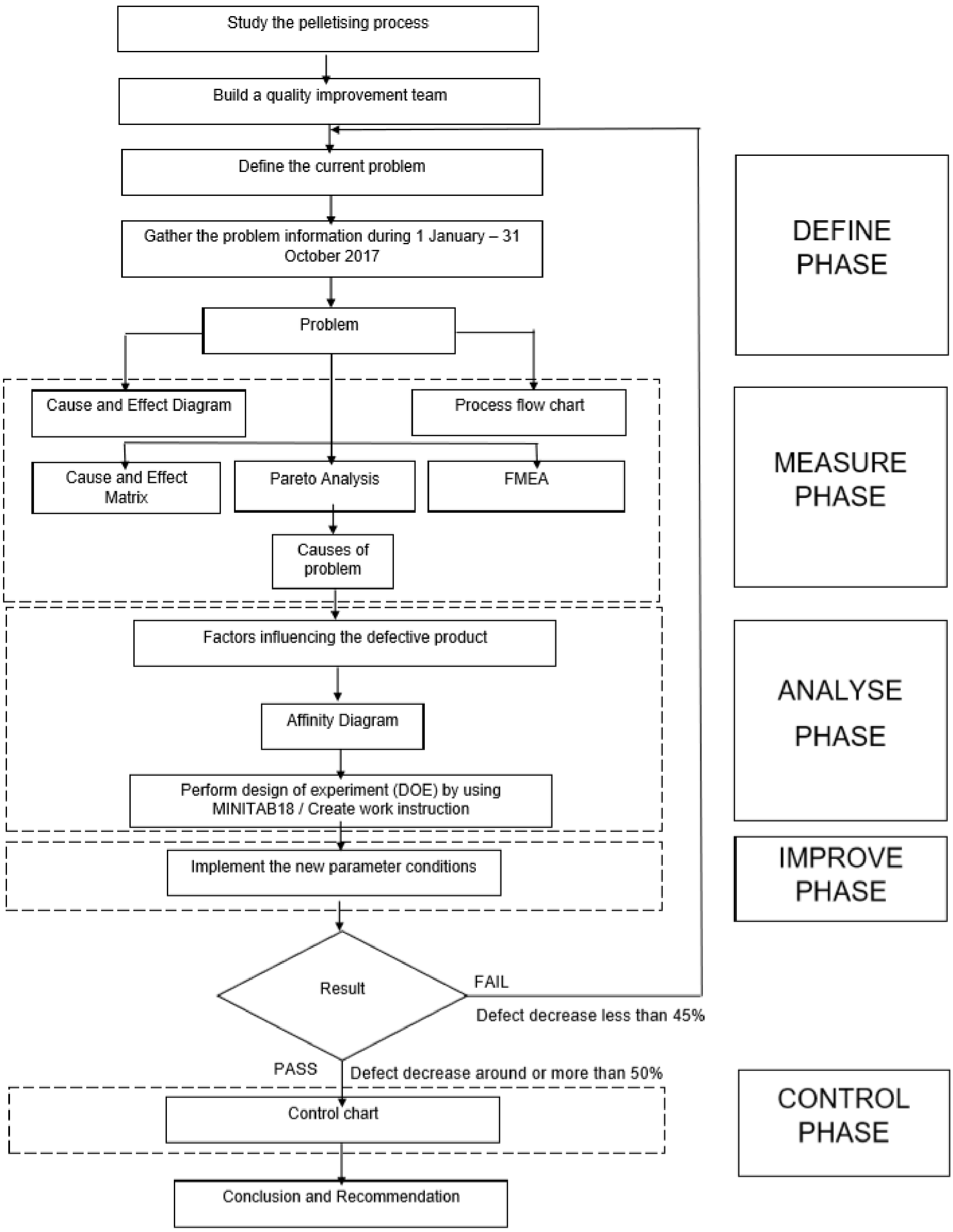

Figure 12. Roadmap of Research Project

CHAPTER 2 LITERATURE REVIEW

This literary analysis is undertaken to present academic journals and sources that provide an in-depth outlook on the topic of discussion. Using critical evaluation, the researcher plans on discussing the viability of various tools available in improving the position of JJ Company. Moreover, this analysis would help to further validate the importance of Six Sigma as a tool to reduce areas of defects in the process of plastic pelletising.

The literature review is divided into various sections, starting with Six Sigma approach, followed by a review of the DMAIC approach and related tools. Under the related tools section, the study aims at demonstrating the implications of company process flowchart, Pareto Chart, cause and effect diagram, and cause and effect matrix. Following this, the literary analysis moves on to Failure Mode and Effect Analysis, Design of Experiment, Affinity diagram, brainstorming technique, and lastly on control chart. A conclusion of the research findings is provided whereby the study also demonstrates a practical viability of using Six Sigma as a means to achieve the objectives of the study.

2.1 Six Sigma

In today’s world, many organisations have adopted various strategies in order to enhance their bottom line, boost customer satisfaction, increase productivity and so forth. One of the most commonly used methodologies for process improvement at this present time is Six Sigma methodology (Thawesaengskulthai & Tannock, 2008; Pavlíčková & Bogdanovská, 2016) Thereby, briefly the historical of Six Sigma and its definition will be elucidated in this section.

2.1.1 Historical Inference and Definition

Watson & DeYong (2010) indicated that the first reference to the process called Six- Sigma started from Motorola University Design for Manufacturing Training Programme in early 1988. Ever since, the concept of Six Sigma has been continuously modified, and now is considered to be far more sophisticated than its original creation and part of the Total Quality Management (Green, 2006). Kwak & Anbari (2006) mentioned that due to the extensive research undertaken in the concept of Six Sigma, there has been wide-scale upgrade in the applications of this tool, especially within the context of a project-driven management approach. Kwak & Anbari (2006) further indicates that with the added increase in demand for reduction in defects in the organisation's processes, Six Sigma has also taken initiatives in better understanding the requirements of the customers, the requirement for improved financial performance and also business productivity. All of it is linked in a linear manner, and therefore a problem in one area is likely to extend on to others. As the need for improving the processes within the organisation has increased over the course of time, Six Sigma tool has been apparent not only in the manufacturing industries, especially within Electronics industry, but has extended itself into areas of service industry as well, as indicated in the studies of Sehwail & DeYong (2003) and Wei, et al., (2010). Kumar & Bauer (2010) and Furterer & Elshennawy (2005) have also demonstrated its wide scale application in the public sectors and local governments as well.

Defining Six Sigma is a complicated process due to various authors having extended or limited the definition in one way or another. However, as stated by Antony & Banuelas (2002), Six Sigma can be viewed from two major different aspects, which are the statistical and business point of view. From a statistical viewpoint, Six Sigma can be described as *"having less than 3.4 defects per million opportunities or a success rate of 99.9997%"* whereas in a business viewpoint Six Sigma is described as *"a business strategy that is applied to enhance the company's profitability, increase the efficiency and the effectiveness of all operations in order to not only meet client's needs but also exceed the client's expectations"*

Six Sigma therefore does not have to be only limited to just a statistical tool, but should also take into account its problem-solving nature, thereby being a tool that utilising statistical methods to solve problems on the processes of an organisation, or improves it. Therefore, Six Sigma considers the requirements of the customer based on a review of the needs of the customer, and then it must specifically achieve an overall organisational process that has less than 3.4 defective parts per million as mentioned above (Coleman, 2008). The following figure has been indicates the achievement of Six Sigma based on the measurement factor of defects per million:

Process Capability σ_{st}	Defects per Million Opportunities (DPMO)	Long Term Yield
2	308,537	69.15% $z_{LT} = 0.5$
3	66,807	93.32%
4	6,210	99.38%
5	233	99.98%
6	3.4	99.99966%

Figure 13. Six Sigma Attainment Based on Yield, DPMO and Process Capability

Source: http://www.six-sigma-material.com/Six-Sigma.html

The implementation of Six Sigma is mainly performed via two different yet simple models. The models are the DMAIC (define-measure-analyse-improve-control) model and the DMADV (define-measure-analyse-design-verify) model. Selecting which one to utilise will depend whether an organisation requires an improvement of current PPSs (processes, products, and services; DMAIC) or if a new set of PPSs are required (DMADV) (Wessel, 2003).

DMAIC has been extensively proven to solve various problems in any service or manufacturing industry. Several literatures have used Six Sigma DMAIC methodology to eliminate defect or waste within the production, drive customer satisfaction, improve process performance, reduce the downtime and minimise process variability (Vivitchanont & Thawesaengskulthai, 2011; Rittichai & Chutima, 2016; Pimsakul, et al., 2013; Ruamchat, et al., 2017).

To further understand the definition of Six Sigma, the following table has been created in chronological order, from the oldest to newest definitions of Six Sigma.

Table 4. Chronological Definitional Changes for Six Sigma

Definition	Authors
With Sigma Six, companies can be more organized in such a parallel-meso structure that could help them reduce variations in important cooperation processes by implementing improvement specialists, structured methodology, and performance metrics that aim to accomplish planned objectives	(Schroeder, et al., 2008)
In order to minimize waste and resources while improving consumer satisfaction, companies should enable processes that allow its organisation to improve their bottom-line by created and checking everyday business activities.	(Harry & Schroeder , 2006)
As defined by ASQ, Sigma Six is an initiative that helps produce high-level results, change cultures, expand all employees and their skills while also improving work processes.	(ASQ, 2002)
A tool like no other that has been utilized in many companies that strive for near perfection. It helps them eliminate defects in whatever processes that they are having problems with.	(Jadhav, et al., 2015)

2.2 DMAIC Methodology

Six Sigma can be broken down into five phases which called DMAIC approach. DMAIC is an abbreviation for define, measure, analyse, improve, and control. DMAIC is known as an effective technique for solving problem. The definition of DMAIC and baseline measurement will be provided in this section as follows;

2.2.1 Definition of DMAIC and Baseline Measurement

DMAIC process is noted as a tool used by businesses as a means to improve profitability and efficiency of the business by meeting the expectations of the customers and their needs. It includes improving the processes of the businesses, inclusive of their services and products (Sehgal & Kaushish, 2013). Several authors have argued it to be a powerful tool that uses basic statistical methodology to improve their efficiency and therefore profitability (Srisungsuk & Thawesaengsakulthai, 2010; Anthony & Banualas, 2002; Bendall & Marra, 2005; Suwannarit & Thawesaengskulthai, 2010). The DMAIC process goes through five phases as indicated in the Figure 14. The following table represents what each of the stages are:

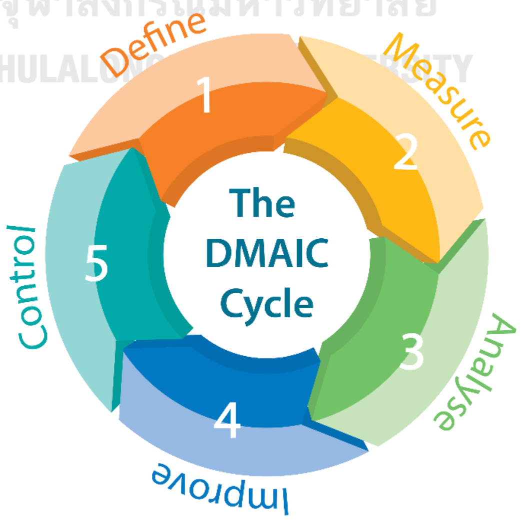

Figure 14. DMAIC Phase

Source: https://bringleacademy.com/course/lean-6-sigma-gb/

Table 5. The Definition of Each Phase and Suggest Tools.

DMAIC Stage	Definitions and suggest tools
Define	This is the stage where the problem is identified. This is a crucial stage as it is important to specifically target the problem, and therefore allowing easier implementation of the remaining processes of DMAIC (Sehgal & Kaushish, 2013). Tools such as company process flow-chart, Pareto, Scatter Diagram, Brainstorming and/or Graphs can be used to identify and define problems (Thaprasop & Thawesaengskulthai, 2008). Moreover, Hambleton (2007) states that other tools such as SMART, As-Is Project Charter Form, RACI matrix analysis can be used as well.
Measure	This is the stage where the defects are identified, such as the project stakeholders undertake data collection to identify the baseline measurement information and based on this the goals and objectives are established. Using the right measuring tool is vital in ensuring that the improvement that is required is attained, as with the wrong forms of measuring tool (Sehgal & Kaushish, 2013). In this stage, the tools used are such as Cause and Effect Diagram, Cause and Effect matrix, FMEA, and/or Brainstorming (Thaprasop & Thawesaengskulthai, 2008; (Snee & Hoerl, 2003). Hambleton (2007) further suggests other tools such as QFD (quality function deployment), Data Gathering Plan template, Gage R&R analysis, Statistical sampling and other can also be used.

DMAIC Stage	Definitions and suggest tools
Analyse	In this stage the data collected from measuring stage is evaluated and analysed. The purpose of doing so is to create a list of aspects that has to be improved (Sehgal & Kaushish, 2013). The tools used are such as Brainstorming technique, Correlation and regression and/or Design of Experiment (Hambleton, 2007).
Improve	In the improve stage, the improvement strategy is implemented, at an attempt to reduce defective processes (Sehgal & Kaushish, 2013). In this particular stage, the need to use strategies such as process optimisation, screening, brainstorming technique and standard operating procedure, implementation and transition plan can be used (Hambleton, 2007).
Control	This is the last stage and involves monitoring and controlling the implemented improvement process and ensure that the past defects do not re-occur as the processes run (Sehgal & Kaushish, 2013).A good way to control and monitor is via the use of control chart, control design and training (Hambleton, 2007)

Furthermore, Hambleton (2007) argues that DMAIC flow-chart consists of the following processes:

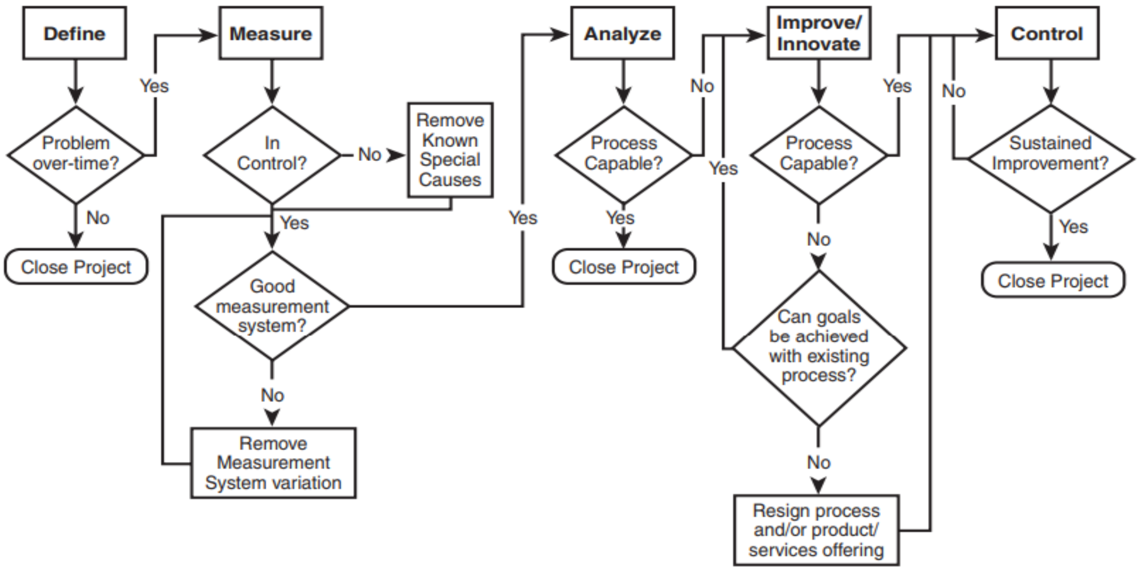

Figure 15. DMAIC Process Flow Chart

Source: Hambleton (2007)

When applying the Six Sigma strategy, it is important to evaluate the baseline measurement for more accurate understanding of the improvements made in the organisation's processes. Baseline measurement, therefore means the precise point of start for each project based on both secondary metrics (y's) and primary contract (Y). Baseline measurement is also referred to as the before measurement, whereas once the measurements are completed, then it is called the "after" measurement (SixSixmaMaterial, 2018). In this context, the objective of implementing Six Sigma is to ensure that the primary contract or Y is improved. Therefore, it is vital at this point to gather the most recent data as possible to determine where the initial origination is.

This process is vital because in the original project contract the value and the value determined via determination of the primary metric (Y), may or may not be the same. If there is extensive difference, then the project contract might have to be redone to ensure that the financials such as the budgets are amended to meet the "new" added requirements (Kosovo, 2015; Wilson & Wiltsie, 2009).

As this process of baseline measurement is being conducted, the need to distinguish and non-defective is vital. A defect is considered an attribute of the process that is non-conforming which does not meet customer's expectation. However, a defective cannot be viewed as a singular defect, as an individual defect in the process may have multiple levels of "Secondary" defects as well. Therefore, at this point, it is vital for the researcher to be able to distinguish between singular or multiple defects to ensure optimisation of the processes. In most cases a part or a process is likely have only two outcomes, that is either not defective or defective.

However, at a case where the chances of becoming defective and non-defective is equal, then a binomial distribution strategy has to be used. Therefore, a common means to demonstrate binomial distribution that the researcher can use is by having two possible outcomes registered, such as pass-fail, in-out, go-no-go, and others. Once that is determined, then methods such as Z-Score, DPMO, DPU or PPM can be used to attain numerical statistics to determine the baseline measurements (McCarthy & Stauffer, 2001; SixSixmaMaterial, 2018; Mitra, 2004). All of this becomes part of the DMAIC process which is later discussed in the following sections.

2.3 Related Tools

There are many tools and techniques that can be applied in Six Sigma projects as stated by Pyzdek & Keller (2014). For the basic tools and techniques that usually used are Pareto chart, flow chart, cause and effect diagram and check sheets (Ferrin, et al., 2005). And, for the advanced tools are hypothesis testing, Design of Experiment, regression analysis and control chart. Therefore, the explanation of tools and techniques that used in this research project will be elucidated in this section.

2.3.1 Company Process Flow Chart

The company process flow chart is the process that a company takes in order to utilise raw materials till the final product is produced. This company process flow chart is where the researcher is capable of identifying the problems that are being incurred in the process, or defects that are reducing operational efficiency. A company flow chart is often made up of three elements: input, actions and outputs. When these elements are graphically presented, then they become a process flow chart and termed a company process flow chart when it is associated to a company. The inputs in the chart are noted as the elements of production, that are any elements or items that is required in the production process, such as staff/labour, land, management, materials and etc. Action on the other hand, is the process where inputs are combined as a means to add value to the process. Actions can involve processes such as moulding, storage, handling, processing and even transportation (logistics). Lastly, the outputs, this is the outcome of the input and action. Output should not only represent the final product but it should also represent the by-products that are made in the process of producing this particular product such as pollution, scrap and other (Pyzdek & Keller,2014; Kumar & Bauer, 2010).

2.3.2 Pareto Chart

According to Neyestani (2017), Pareto chart is an analysis technique that involves the implementation of the 80/20 rule. This rule involves the selection of only a handful of elements or tasks that is responsible for a large impact on the organisation. The concept behind this is that 80% of the benefit is accountable from the 20% of the work that has been done. For instance, many of the major issues in waste production is caused by 20% of the processes that are involved. That is why the 80/20 rule is applied. The following is an example of a Pareto diagram based on cause of errors on website (Haughey, 2015).

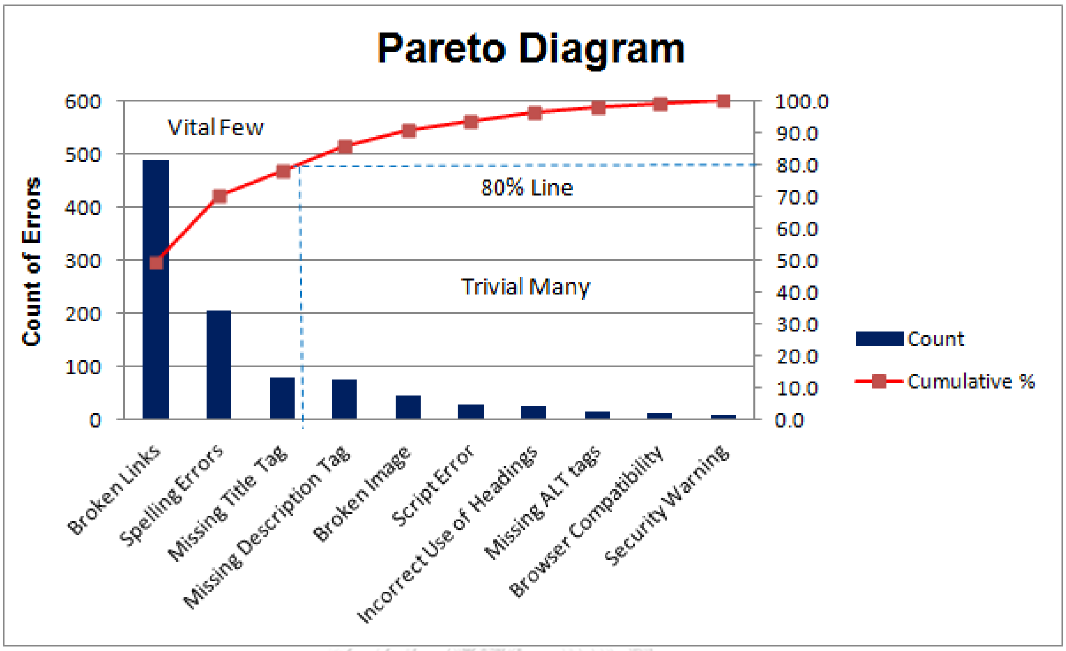

Figure 16. Pareto Diagram

Source: https://www.projectsmart.co.uk/pareto-analysis-step-by-step.php

As noted from this figure, that the bar-graphs are organised from frequency of errors to the least, which then would allow the organisation to identify the most prominent parts to be tackled first to the least prominent. It is vital that in ensuring process improvement, all problems and defects be removed at an attempt to attain perfection. If noted carefully, the chart is not only a combination of bar graphs, but also the involvement of a line graph.

2.3.3 Cause and Effect Diagram (Fishbone/Ishikawa Diagram)

The cause and effect diagram is more commonly known as the Ishikawa diagram or fishbone diagram. The name given to this particular diagram is directly from the founder, and it is believed to study the results of each impact. The purpose of studying the impacts and its result is to be capable of identifying potential causes and root-causes that result in a single effect. The diagram enables organisations to solve issues by gathering and organising causes routes which includes providing knowledge regarding organisation gaps. Understanding and comprehending the problem at a common level of understanding, assigning ranks for each causes, and studying to learn more about each of the causes. The fishbone diagram can be split up in to mainly six categories. These categories are environment, material, machine, measurement, man and method. The following figure is an example of cause and effect diagram.

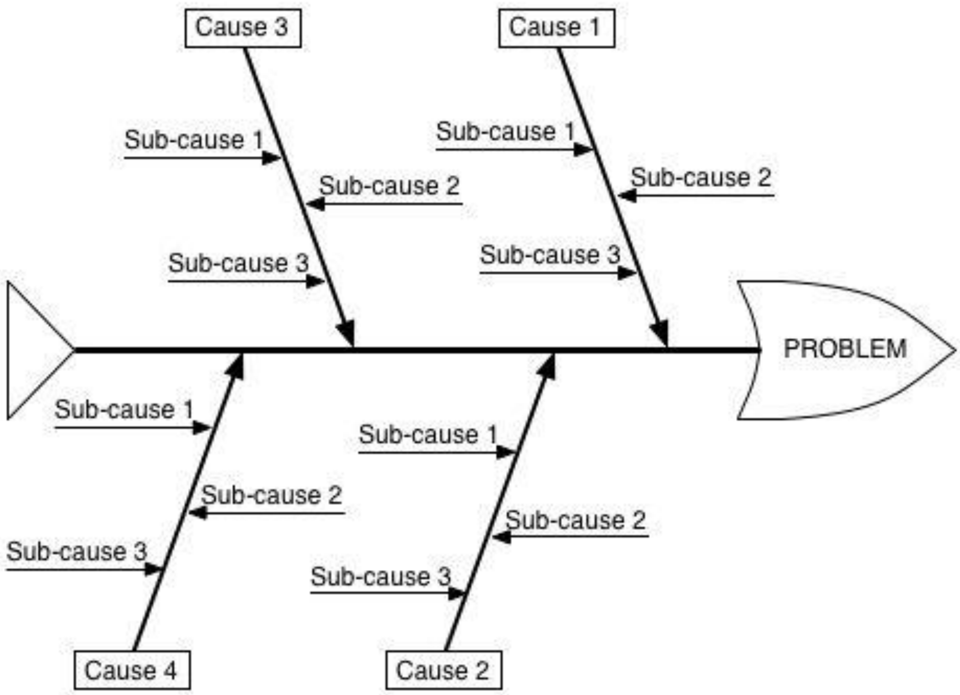

Figure 17. Fishbone Diagram

Source: http://www.becreate.ch/en/methods/fishbone-diagram.aspx

2.3.4 Cause and Effect Matrix

Cause and Effect Matrix is a tool that allows the researcher to identify which factors are playing a role in the outcome of the Six Sigma initiative. Therefore, it plays a role in realising the relationship between output and input variables. The following figure demonstrates an example of the Cause and Effect Matrix. Note that the process input variables are organised based on the level of priority. The more priority that is given, the higher the variables (input) position in the matrix, and often the priority level is also known as the priority number which is used to multiply. Moreover, based on this, output variables are placed on the horizontal area of the matrix (Pyzdek & Keller, 2014). Based on the priority level, the output variable is multiplied to achieve the result. The following are steps undertaken to create a C&E matrix:

Create a table with estimated number of rows and columns based on the number of input variable, output variable, while leaving extra columns for results and percentage.

On the vertical column on the far left side, list down all the input variables. These input variables can be numbered based on its impact on the output variable. Step 2 and Step 3 can be done alternatively or together. (blue highlight)

On the horizontal column input all horizontal variables that were previously brought to awareness after going through a series of tests. The output variables are placed based on what the client believes to be the most vital to the efficiency of the process. (orange highlight)

After horizontal column is created, place prioritization levels for the output variables. The prioritization level is the amount of importance placed on the output variable and it can be placed on any numerical value ranging from 1 to 10. Here 1 stands for least priority and 10 for most priority or it can be consider a scale level of 0, 1, 3, 5 or 0, 1, 3 and 9. This is used as a multiplier. The placement of these number can be random. (red highlight)

Now calculate the result column (purple highlight) by multiplying the prioritization number with the “Agreed” impact of input variable on the output variable (green highlight).

Once the result column is calculated then can be prioritised based on the results or from least to highest percentage.

As displayed in the figures below, the C&E matrix is finalized based on the impact of each input variable and output variable on the results, from least to most. (Pyzdek & Keller, 2014; Chulajata, 2011)

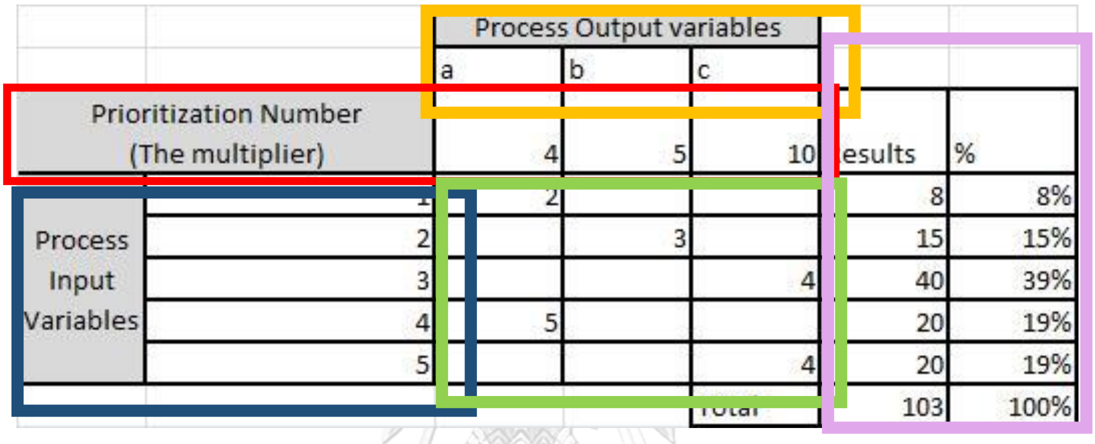

Figure 18. Cause and Effect Diagram

Source: https://sixsigmastudyguide.com/cause-and-effect-matrix/

2.3.5 Failure Mode and Effect Analysis

Failure modes and Effects Analysis or FMEA is a strategic tool that can be used to rank events that are categorized as "fail" and are effecting the operation process. As stated by Damanab et al., (2015), FMEA can be a useful tool in developing preventive measures and improve process flow by avoiding potential risks associated with event failure. The ranks are created based on the RPN, or the Risk Priority Number. The RPN demonstrates how each failure event is likely to impact the process. Therefore, higher up in the rank would demonstrate more impact from the failure event compared to a lower- ranked failure event (Jafari, 2009). In calculating the RPN the following calculation can be used based on having three attributes.

$$RPN = O \times D \times S$$

Where O represents the probability of incident occurrence

D represents the probability of detecting an incident

S represents the severity of the incident

It must be noted that the risk priority numbers are usually within 1 to 1000. Once the RPN is calculated, then the risks are rated based on what acceptability of the risk impact, which ranges from unacceptable to negligible. The following figures demonstrate samples of O, D and S tables:

Criteria to evaluate the Incident Occurrence Probability in the FMEA method

Description	Scale
Incident or failure occurrence is very likely (once or more per day)	10
Incident or failure occurrence is likely (every 3 to 4 days)	9
Incident or failure occurrence possibility is very high (once a week)	8
Incident or failure occurrence possibility is high (once per month)	7
Incident or failure occurrence possibility is medium (every three months)	6
Incident or failure occurrence possibility is low (every six months to a year)	5
Incident or failure occurrence possibility is very low (once per year)	4
Incident or failure occurrence possibility is rare (once every 1 to 3 years)	3
Incident or failure occurrence possibility is very rare (once every 3 to 5 years)	2
Incident or failure occurrence is unlikely	1

Figure 19. The Probability of Incident Occurrence

Source: Damanab et al., 2015, p. 4

Criteria to evaluate the Incident Consequent Severity in the FMEA method.

Description	Scale
Complete failure (stop) of the system	10
Severe damage to the system	9
Damage to the system is too high	8
Damage to the system is high	7
Damage to the system is medium	6
Damage to the system is low	5
Damage to the system is very low	4
Minor damage to the system	3
Very minor damage to the system	2
No damage	1

Figure 20. The Severity of The Incident

Source: Damanab et al., 2015, p. 4

Criteria to estimate the failure or Incident Detection Probability in the FMEA method.

Description	Detection probability	Scale
No device control devices	No detection	10
Existing fault detection by control devices is unlikely	Negligible	9
Existing fault detection by control devices is very low	Very low	8
Existing fault detection by control devices is low	Low	7
Existing fault detection by control devices is modest	Modest	6
Existing fault detection by control devices is average	Average	5
Existing fault detection by control devices is more likely than average	More likely than average	4
Existing fault detection by control devices is high	High	3
Existing fault detection by control devices is very high	Very high	2
Existing fault detection by control devices is extremely high	Extremely high	1

Figure 21. The Probability of Detecting an Incident

Source: Damanab et al., 2015, p. 4

2.3.6 Design of Experiment

According to (Pyzdek & Keller, 2014; Pimsakul, et al., 2013), the use of DOE or Design of Experiment, is a vital aspect of ensuring improved operational efficiency, especially in improving qualities. A DOE is involves creating an experiment where the project has more than one factor or in other words more than one independent variable, which can play a role in affecting the overall outcome of the project. The data collected from this stage allows the evaluation of how effective each independent variable or a combination of more than one independent variable can impact the outcome of the experiment. There are many forms of variables that an experiment should take into consideration, such as background variables, response variables, and primary variables. In addition to these, the experiment should take into account possible experimental error and interaction error. The following table demonstrates the definition of each of these variables and attributes that a DOE should take careful consideration:

Table 6. Attributes to Consider in DOE

Source: Pyzdek & Keller (2014)

Attributes to consider	Discussion
Background variables	These are variables that the DOE user or designer comes up on his/her own, but should not be placed as a constant aspect, as background variables are often constantly changing.
Response Variable	These are the main DEPENDENT variables that are taken into consideration, as because they are the ones that respond to a certain independent variable.
Primary Variable	These are the main INDEPENDENT variables that are considered to play a role in creating an effect. These variables are usually numerical, and can have elements such as speed, pressure or temperature. They can also be non-numerical, such as the method of production or the person producing.
Interaction	This is a condition when a factor is responsible for affecting another factor, for instance, if Factor A is affecting Factor B, then there is interaction and both these factors should be carefully considered.
Experimental Error	In an experimental situation, there are too many variables that create a source of variation. No experiment can explicitly deal with every single source of variation. These variables that are not considered explicitly are the common causes of variation. Randomisation is used to prevent the primary variable from being altered.

For this thesis project a 2k Factorial method is used; therefore, the following is the description of what 2k factorial is and how it is used. The 2k factorial comes in two types, a 2k Fractional-factorial and a 2k Full-factorial. The 2k fractional factorial Design of experiment, is when the experiment has to focus on the use of fractions. Fractions mean numbers that are not whole, such as ¼, ½, and so on. Here the 2k fractional factorial DOE utilises all of the combinations that are potentially possible for the settings of factors. This fractional factorial also utilises lower number of runs compared to the next 2k full factorial (Hicks, 1973; Hicks, 1993). 2k full factorial is a DOE type that involves the utilisation of all combinations of the factor setting. In such a scenario, where 3 factors are there, then 8 runs are made, and if there are 4 factors than 16 runs, and if there are 5 factors then 32 runs.

This is similarly applied on all cases of the factorial experiment, and the number of runs are based on the concept explained earlier. The purpose of using a full 2k factorial is to evaluate the combined impact on the process, while constantly running till an optimum setting can be identified (Pyzdek & Keller, 2014).

2.3.7 Affinity Diagram

Affinity diagram allows the user to organize the ideas presented in the analysis process and place them together based on the similarity that each of the ideas have. The purpose of this diagram is to create a form in which the data that is collected, and to reduce the complexity of these numerals, large themes or categories are formed, allowing a rather more specific approach to the problem at hand (Pyzdek & Keller, 2014). For example, if the company was facing a problem with the manufacturing line, then each of the data collected revolving around the manufacturing line would then be categorized under this specific theme, allowing easier identification and evaluation of the collected data. In order to create an affinity, diagram a few simple steps can be followed:

Place ideas on a cut card. The number of card is equivalent to the number of ideas; therefore, each card should have only one idea.

Then common themes are formed based on the collected data, from which each of the card are placed under each category. The team then reviews these categories and their resultant ideas, and then finalises if all the placed ideas below are within the same thematic requirement.

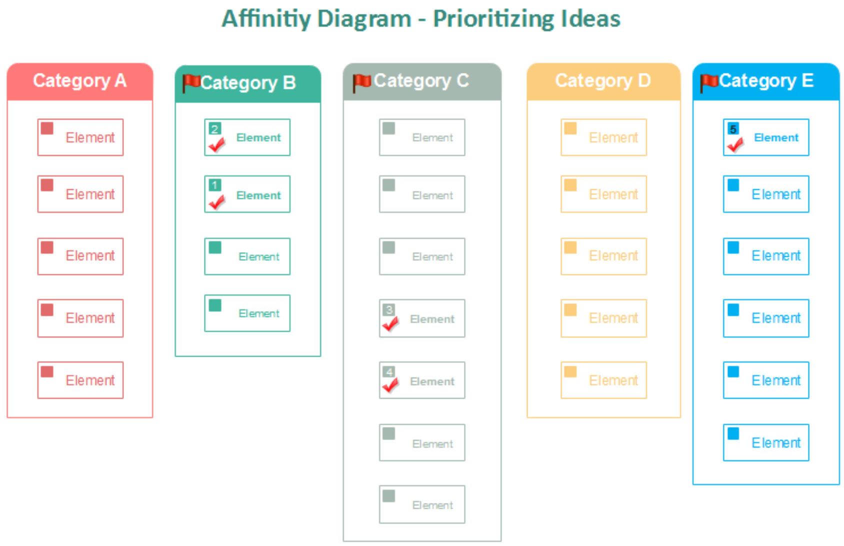

Figure 22. Affinity Diagram

Source: https://www.edrawsoft.com/affinity-diagram-sixsigma.php

2.3.8 Brainstorming Technique

Brainstorming process can be used in the areas of measure and even improve stages of the DMAIC process. As argued by SixSigmaInstitute (2018), brainstorming is a process where ideas are generated. In doing brain-storming, there are 5 methods that can be used. Firstly, brain-writing, which is a process where members of the group are insisted to write ideas within a constricted timeframe. This is also called as the 6-3-5 brain-writing process. The second method is benchmarking, which is a process of idea generation that is continuous, meaning they do not stop after a solution is found, in fact they continue on going till improvement is also noted. Benchmarking works under the concept that a process that is functional, does not mean it cannot be improved. The third method is assumption busting, a process that involves placing assumptions to why a problem is occurring and then implementing the cause-effect diagram or the Ishikawa diagram to trace the root cause of the problem.

This helps in seeing if the pre-determined assumption is the reason for the problem. The fourth method is creative brainstorming using the Nominal group technique. This is a technique where people who are not aware of one another are placed within a group setting. Therefore, the group would not engage with one another as a usual team would, which would resultantly push towards focusing on idea generation, and where the idea is false, the disagreement can help to reach further improvement. Lastly, modified brainstorming, a process that involves using either the anti-solution technique or the analogy technique. This form of brain storming is similar to creative brainstorming; however, it is extended due to the various techniques that can be used. Analogy technique as stated by (SixsigmaInstitute, 2018), “The ideas generated on the “analogy” then get translated to the real situation (the problem at hand)”. Whereas, the anti-solution technique is a method where problems are identified by not going to the root-cause of it but by making more problems (BC, 2009). For the purpose of brainstorming in this study, the researcher, as an individual researcher would focus on only assumption busting, benchmarking, and brain-writing.

2.3.9 Control Chart

One of the most effective tool that widely used in the control phase is the control chart. This tool is effective in monitoring the improvement levels and processes. There are many types of such charts and all depends on the overall data that have been collected or have to be collected. When applying the statistical approach, the control chart can be different for binominal distribution and poisson distribution For Binominal distribution, the collected data is based on two possible outcomes: existence of defect and non-existence of defect. However, for Poisson distribution has multiple outcomes, as there is one margin where the defect in the production unit is stated. In addition, Poisson distribution based control chart also includes errors (Montgomery, 2009).

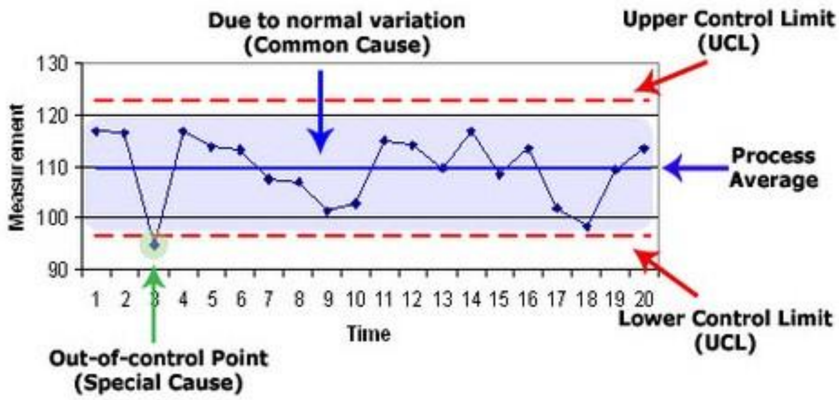

Figure 23. Control Chart

Source: https://www.clearpointstrategy.com/control-charts-everything-you-need-to-know/

2.4 Past Studies

Six Sigma has been utilised in various cases where the use of DMAIC methodology have proven to provide some improved performance. For example, in the study by Ganguly (2012), Six Sigma DMAIC method was used in improving the process of a rolling mill. In his practical study, he used DMAIC as a means to reduce coil slippage. The tools used in the study were cause and effect matrix, process flow chart, cause and effect diagram (Ishikawa fishbone), and DOE with 2k Factorial. The application of cause and effect matrix has been proven useful in the study Ganguly (2012). By utilising Six Sigma DMAIC methodology and tools the rolling mill operational processes were improved. It was concluded that the study was able to attain 5000+ alloys, followed by a reduction in cycle time from 47 days to 20 days, smooth operational process was achieved and also the problem of slippage was eliminated completely. Resultantly, other companies can adapt to similar approach to improve their efficiency by duplicating their Six Sigma DMAIC approach and relevant tools.

Another study by Hung & Sung (2011), they utilised DMAIC strategy in the food industry within the Taiwanese market. With this methodology the study was able to reduce various problems such as the problem of process variation was reduced, whereby now the company was able to bring down the number of defected processes. The conclusion of this study indicated that the overall defect rate of the production process of wheat buns were reduced by 70%; therefore, promoting improved processes within the company case study in Taiwan. The tools used in this study were Pareto Chart, project selection, tree diagram, process flow-chart, fishbone diagram, DOE with five factors, two levels, ½ fraction design with two replicates, and also FMEA. This is another example where the use of Six Sigma DMAIC methodology and tools have proven to be quite effective in the reduction of defects and improvement of efficiency. Once again, small and big companies can implement similar DMAIC approach to attain similar improvements. Although, it must be noted that the variables are subjective from company to company.

Besides, Jirasukprasert (2012) implemented DMAIC and Six Sigma principles to achieve an improved problem-solving situation in company A that deals with the production and manufacturing of rubber gloves. The findings indicated a massive reduction in defects from 195,095 DPMO to 83,750 DPMO. Therefore, this demonstrates an improvement in Six Sigma level to 2.9 from 2.4. The paper was able to identify on-going process-crisis in the manufacturing industries in Thailand, and suggested how the implementation of DMAIC and Six Sigma principles is indeed effective. However, all these studies have clearly suggested that the need to implement accurate baseline measurement is important to ensure that the improvement findings are accurate. The more recent the data, the better, as indicated in the baseline measurement section earlier. The baseline measurement used in this study were DPU, DPMO and Six Sigma level. Moreover, Pareto Chart, flow chart, fishbone, DOE, and control chart were also used. This demonstrates that in the use of DMAIC, such tools are proven to be effective in evaluating the problem, providing solutions and then considering possible improvements to increase efficiency, quality, and reduce rejection and defects. Similarly, this can be applied to other studies.

Additionally, in the study of Alshammari et al., (2018), lean and Six Sigma procedure was implemented to tackle the problem of consistent rejection of the plastic moulds that were noted to be defected or not meeting the requirement. These defects were usually revolving around the presence of bubbles, flash, internal surface masks and others resultantly causing company to have a lot of money on wasted defects that were placing a serious burden on the company's revenue and its eventual competitiveness. Therefore, DMAIC was implemented in this study on XYZ Company. The tools of DMAIC used in this study were cause and effect matrix, DOE, flowchart, Pareto Chart, fishbone diagram, action plan, DPU, and control chart. The study concludes that the use of several tools have been proven effective in the improvement of operational efficiency. DMAIC was therefore capable of effectively handling the problem of plastic mould rejections, which resultantly helped the company to regain its company image, which was constantly damaged due to consistent rejection of its plastic moulds. This is another example where the use of DMAIC have been proven highly effective and can be applied on other companies in the same industry or even different.

Another case study conducted by Mishra et al., (2015). This study focused on the company named Vimal Plastics, where they were facing the problem of quality control. The rejection data concluded that the company was having increased costs, reduced revenue and lack of proper brand image due to their high rejection volumes. It was noted that from the 2284 units of moulding produced, there were 33% rejection for model RJ-3004 and worst case was with the model RB-503, where the rejection was close to 92%. Nonetheless, the company attempted to continue with the procedure of DMAIC and Six Sigma to ensure improved operational efficiency and quality control. Via the use of this methodology, it was concluded that the quality was improved and the amount of rejection rates reduced. The tools used in this study were: basic Pareto diagram, affinity diagram, DOE, and fishbone diagram. Therefore, these tools have been proven to be effective in the reduction of rejected plastic moulds for Vimal Plastics, which therefore can be used in other industries as it has been proven to be effective by various studies inclusive of the one conducted by Mishra et al., (2015).

2.5 Limitation of DMAIC

Arguably, many authors have indicated a problem or a series of limitations in the DMAIC process, such as that in the study of Demast & Lokkerbol (2011) where their findings from their literature review suggested that the overall reason for using Six Sigma or DMAIC is to identify that the method itself is not applicable on all circumstances. Therefore, there is a problem within the method itself as it is not all solving or applicable in certain areas. As cited by Ganesh et al., (2015) that plausibility is not always available such that strong methods can be applied without restrictions in any situation, but in those circumstances identification for practical values of limitations is that they provide a standard for suggesting users when the DMAIC method is appropriate. Similarly, Fursule et al., (2012) stated that the most important aspect of DMAIC model that limits its effectiveness is the stakeholders involved in the process. This aspect was supported by Ganesh et al., (2015) as well. They believe that when the people are unable to implement the process effectively, the likelihood that the process would not bring about any benefit is also apparent. As stated in Ganesh et al., (2015) nothing would work well if cooperation from top managing officers/managers and that Six Sigma changes a company's thought process not by only educating working level staff with fact based decisions, but by providing this necessary knowledge for decision making to all levels of an organization. Therefore, the attribute of "people" might be a major factor in many studies were improvement has not been noticed, as the process itself involves identifying defects and removing them, which on a general level is supposed to improve process. This is supported by Goh (2002) in his early studies that demonstrated that the failure to implement proper Six Sigma strategy is due to the lack of knowledge in the area.

2.6 Conclusion of Case Study Review

A majority of the studies reviewed have indicated that application of DMAIC and Six Sigma is bound to bring about improvement in the organisation, only if the applicant or the person involved in the DMAIC process ensures it is done correctly and has sufficient knowledge. Therefore, when applying this to JJ Company, it is likely that defect within the processes would be identified and then eliminated, which would resultantly improve the overall process. The defect in this case is plastic lumps. At the end, the researcher aims to get the appropriate temperature, screw speed and size of screen pack which will produce fewer amount of defects. As further argued by Senapati (2004) that Six Sigma DMAIC method is one of the most effective approaches in reducing defects and improving process.

2.7 Extrusion Working Principle

As stated by Sukoptfe (2016), extrusion is a manufacturing process in which plastic is melted and then forced into a die using a rotating screw. The extruded end-product will be in the shape of the die. In the extruding process, firstly plastic, typically in the form of pellets, is fed into the barrel. During the initial feed, additives can be mixed to provide colour or additional characteristics (e.g. ultraviolet inhibitors). Following this, the rotating screw pushes the plastic pellets into the barrel where it is melted. To minimize overheating of the plastic, a thermostat and cooling system are used to control the temperature. Upon leaving the barrel, the molten plastic is screened to remove contaminants before entering the die of desired shape. The flow of the molten plastic must be carefully monitored as an inconstant flow rate will cause stresses in the plastic product. Finally, the plastic product is sent through cooling rolls to solidify the product and maintain the desired shape.

There are five main parameters that need to be concerned before extrusion process which are screw speed, melting temperature of plastic, cooling medium, extrusion pressure required, and types of die. The following figure shows the composition of extruder machine.

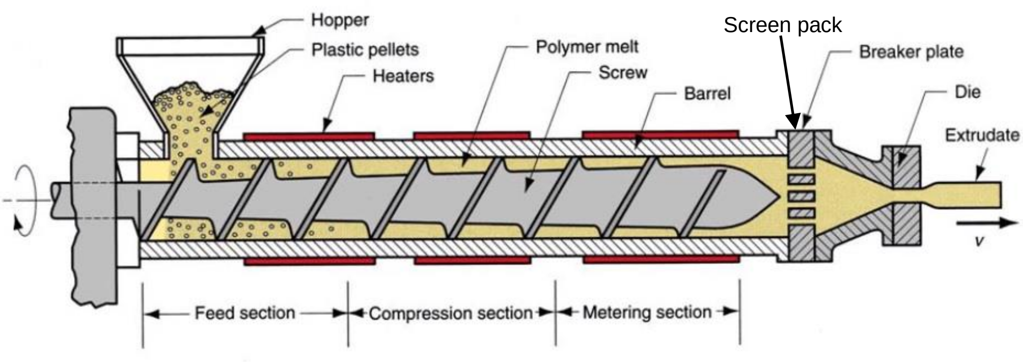

Figure 24. The Composition of Extruder Machine

Source: Adapted from http://slideplayer.com/slide/2452584/

CHAPTER 3 DEFINE PHASE

This chapter is the first step of the Six Sigma DMAIC approach called the define phase. In this phase, the problem and desired targets are defined in order to establish the boundaries for this research project. The define phase starts with assembling a process improvement team in order to brainstorm and share ideas regarding the problem. Then, a diagram is needed to help support in order to visually communicate ideas and help team members conceptualize the big picture; therefore, process flowchart will be applied in this step. A Process Flowchart is used in order to have a better understanding of the production process of JJ Company. Through using a process flowchart, the causes of inefficiency and frustration from the pelletising process can be realized, and then appropriate methods for improvements can be applied. Additionally, Pareto chart can be utilised to clearly understand the current problem. Finally, the project charter will be developed to conclude the essential components of this project research.

3.1 Process Improvement Team Formation

Team formation is essential in this research project since brainstorming is one of the most effective tools used to help generate innovative solutions to problems promptly (SixsigmaInstitute, 2018). Therefore, the process improvement team in this case study was assembled. The team consists of seven members who are highly experienced and specialised in the pelletizing process and plastic lump defects. Table 7 shows a list of positions for JJ Company's improvement team.

Table 7. JJ Company's Improvement Team

Number	Position	Experience
1	Production Manager	8 Years' experience
2	Supervisor	8 Years' experience
3	Machine Operator	5 Years' experience
4	Machine Operator	2 Years' experience
5	Process Engineer	4 Years' experience
5	Process Engineer	4 Years' experience
6	Quality Control Operator	4 Years' experience
7	Researcher (Raroopthip Paiboonkasemsut)	

The team will use the same members until this research project is completed, especially the machine operators who are responsible for controlling machine and the quality control operator in order to achieve the aim of this research. In this project, the researcher will be the project leader who is responsible for setting up the working plan, collaborating within the team, conducting Design of Experiment, analysing and summarising the results, and also executing the plan within the prescribed time.

3.2 Production Process

The flow of the plastic pelletising process can be separated into nine significant processes as shown in Figure 40. The plastic pelletising process starts from material classification and finishes at packaging. Apart from the company process diagram, there is an explanation of each step as follows:

3.2.1 Material Classification

In the first step of material classification, plastic scraps are categorised into five groups which are pellets, lumps, films, bags and powders. The workers in JJ Company is responsible for separating the incoming raw materials. In case of pellets, films, bags and powders, company will sell directly. Plastic scraps in this company are obtained from trading companies through bidding from large plastic manufacturers. In case of the large plastic manufacturers, the production manager is able to see the raw material first before joining an auction. And for the trading companies, if the raw materials does not meet the quality standards, the production engineer will be notified in order to inform the suppliers. (See Figure 25 and Figure 26). The example of lumps from well-known manufacturers will be shown in Figure 27 and Figure 28.

Figure 25. Material Classification (1)

Figure 26. Material Classification (2)

Figure 27. Lumps from Large Manufacturers (1)

Figure 28. Lumps from Large Manufacturers (2)

3.2.2 Shredding Process

The second process is used to cut large size lumps into smaller pieces by using a mechanical shredder. This step is called the size reduction process (See Figure 29 and Figure 30).

Figure 29. Shredding Process (1)

Figure 30. Shredding Process (2)

3.2.3 Grinding Process

In the third step, the product from the shredding process passes through a grinder in order to produce plastic flakes which allows them to be processed, packaged, and distributed easier. (See Figure 31)

Figure 31. Grinding Process

Figure 32. Output from Grinding Process

3.2.4 Washing Process

Once regrinding has been completed, plastic lumps needs to be washed in order to remove any contamination such as glue, sand, label, dust and other small impurities, which can be achieved by using water (See Figure 33).

Figure 33. Washing Process

3.2.5 Drying Process

After the washing process, the plastic flakes are sent through a dryer in order to remove moisture within the plastic flakes (See Figure 34).

Figure 34. Drying Process

3.2.6 Preparing Material

Next, the production engineer creates a checklist of raw materials and the amount required, and provides it to workers. Using this checklist, the workers prepare and send the raw materials to the supervisor and the machine operators. Figure 35 represents the raw materials is already prepared in jumbo bag before extrusion.

Figure 35. Preparing Material

3.2.7 Plastic Pellet Extrusion Process

In this step, the machine operators is responsible for prepare the extruder machine. The temperature for all zones and also die temperature are increased to their pre-set points by the process called "Heat soak", which takes approximately 60-120 minutes. Then the plastic flakes are fed into the hopper. After that, plastic flakes are melted through forcing the flakes through a pipe with rotating screw and into a heated barrel. Impurities are screened out by screen pack and then go through die and transported to water bath. The melted plastic is then cooled and then go to the pelletizer for transforming into pellets. Plastic flakes are physically converted into pellets so they can be distributed and remanufactured easier which consequently improves both the effectiveness and speed of reintroducing recycled plastic. In this pelletising stage, single or double screw extruders are generally used (See Figure 36 and Figure 37).

Figure 36. Plastic Pellet Extrusion Process

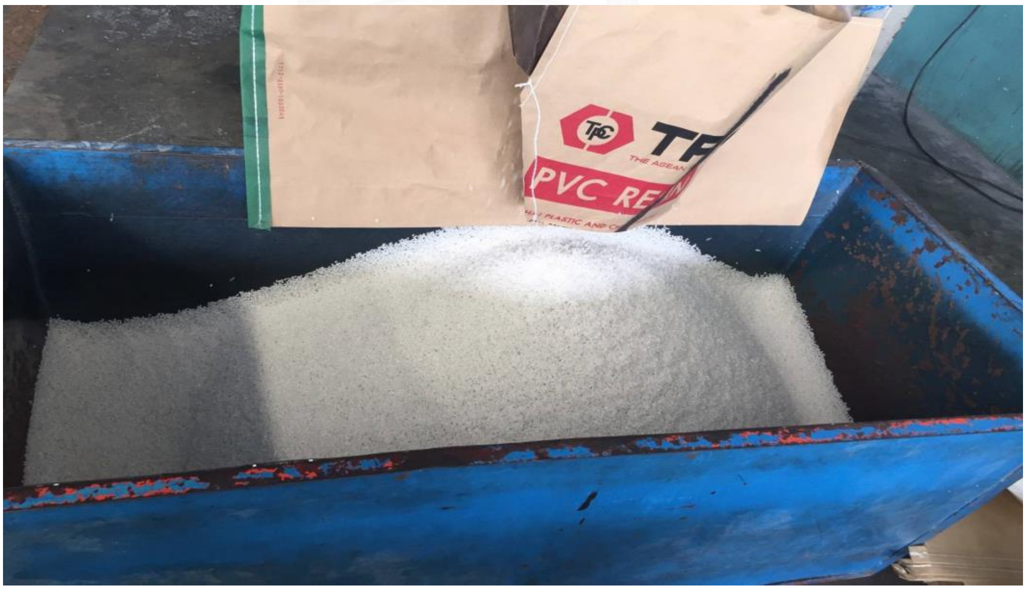

Figure 37. Output of Plastic Pellet Extrusion Process

3.2.8 Pellet Inspection

The supervisor chooses a sample of plastic pellets to be sent to the quality control operator. The quality control operator checks the quality of plastic pellets including melt flow rate, colour, and any impurities. If the quality of the plastic pellets meets the requirements, the workers packs the plastic pellets into the bag; otherwise, the quality control operator needs to report the issue to the supervisor for rework. (See Figure 38).

Figure 38. Laboratory

3.2.9 Packaging Process

Finally, the last step of the production process is packaging. The plastic pellets are packed into 25-kg bags. Then, the plastic pellets are relocated to the warehouse before being delivered to customers (See Figure 39).

Figure 39. Warehouse

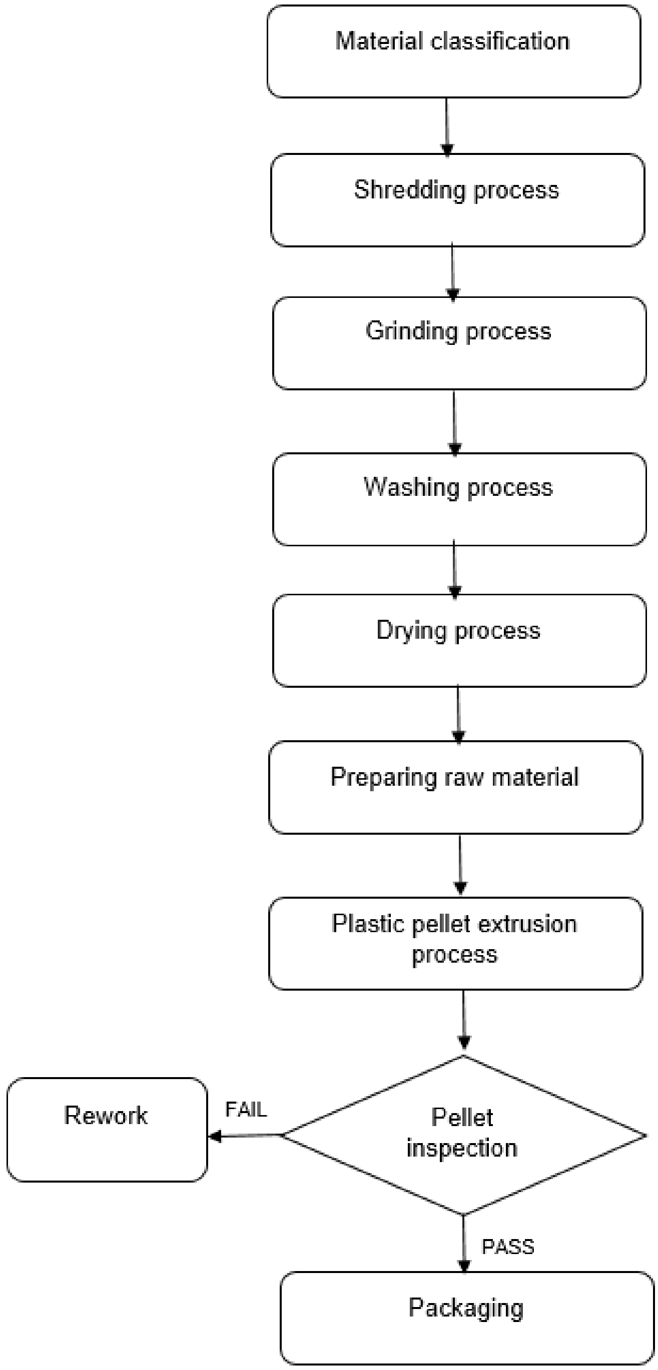

Figure 40. JJ Company process flow chart

3.3 Current Problem

Currently, a lot of defects occur from the plastic pelletising process resulting in a higher manufacturing cost from raw material, labour, machine operator, and also time consumption. In this research project, plastic lumps are the source of the highest defects in the plastic pelletising process.

Plastic Version and Defect Characteristic Selection

As mentioned in the Introduction chapter, it can be seen that between the studied period from January 1st 2017 to October 31st 2017, there were a large quantity of PP pellets produced, specifically 832,551 kilograms which accounted for 44.1% of total products as shown in Figure 41. And, PP pellets also had the highest percentage defect rate, which accounted for 5.18% as shown in Figure 42. Furthermore, Figure 43 also represents the highest rework cost caused by PP product. As previously mentioned, PP is the only one product that pass three selection criteria; therefore, PP pellets were chosen to be studied in this research.

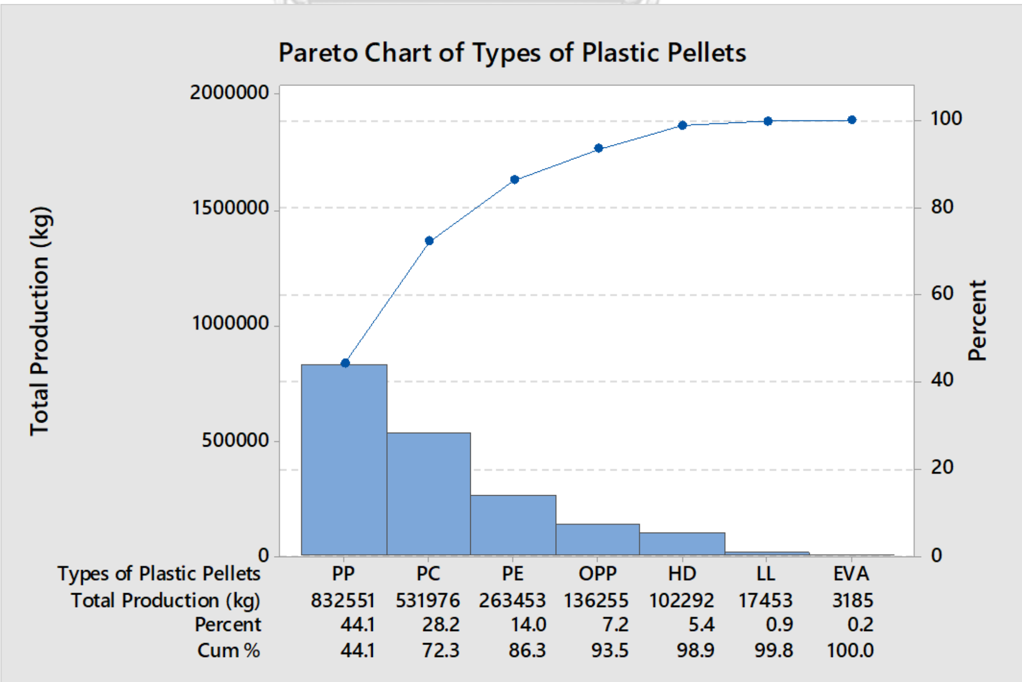

Figure 41. Pareto Chart of Total Production

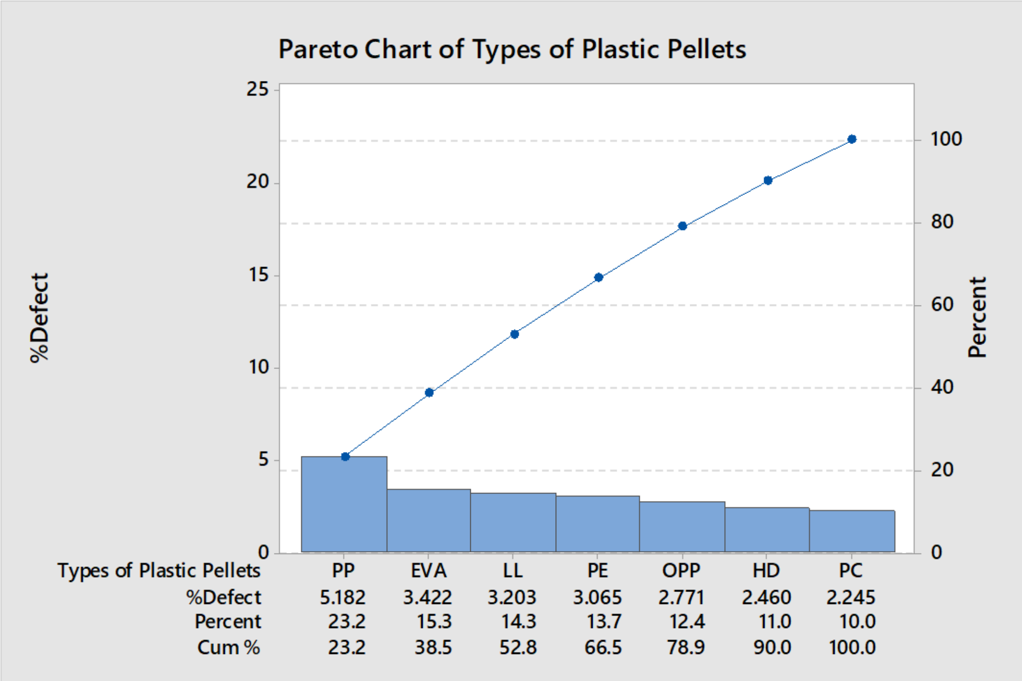

Figure 42. Pareto Chart of %Defect

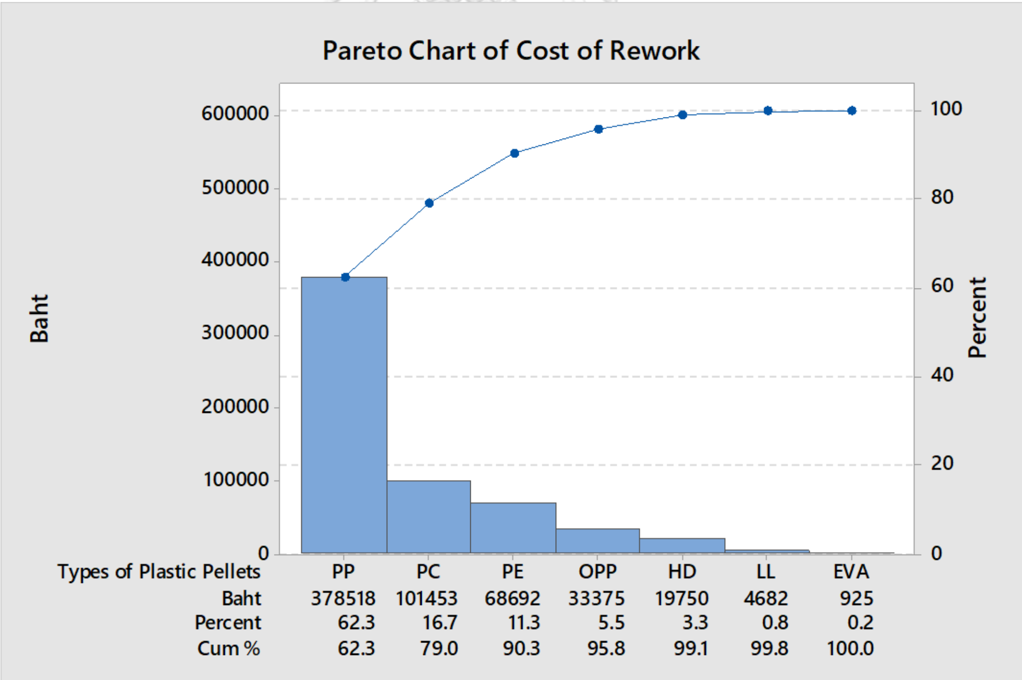

Figure 43. Pareto Chart of Cost of Rework in Each Type of Pellet

3.3.1 Defect Characteristic Selection

In order to select the defect characteristic for studying, this research considers from the defect rate and its rework cost. From Table 8, Figure 44 and Figure 45, it shows that during the period of January 1st 2017 to October 31st 2017, the plastic lump had the highest defect rate of 3.35% and also had the highest rework cost which was about 569475 baht Thereby, this research will focus on plastic lumps.

Table 8. Defect Characteristics

No.	Defect Characteristic	Total Defect (kg)	
		Amount of Defect (kg)	%Defect
1	Plastic Lumps	63,275	3.35%
2	Black Dots	3,219	0.17%
3	Burnts	1,007	0.05%
4	Moisture Content	1,235	0.07%
5	Doubles	1,181	0.06%
6	Tails	201	0.01%
Total Production (kg) (January 1st 2017 – October 31st 2017)		1,887,165	

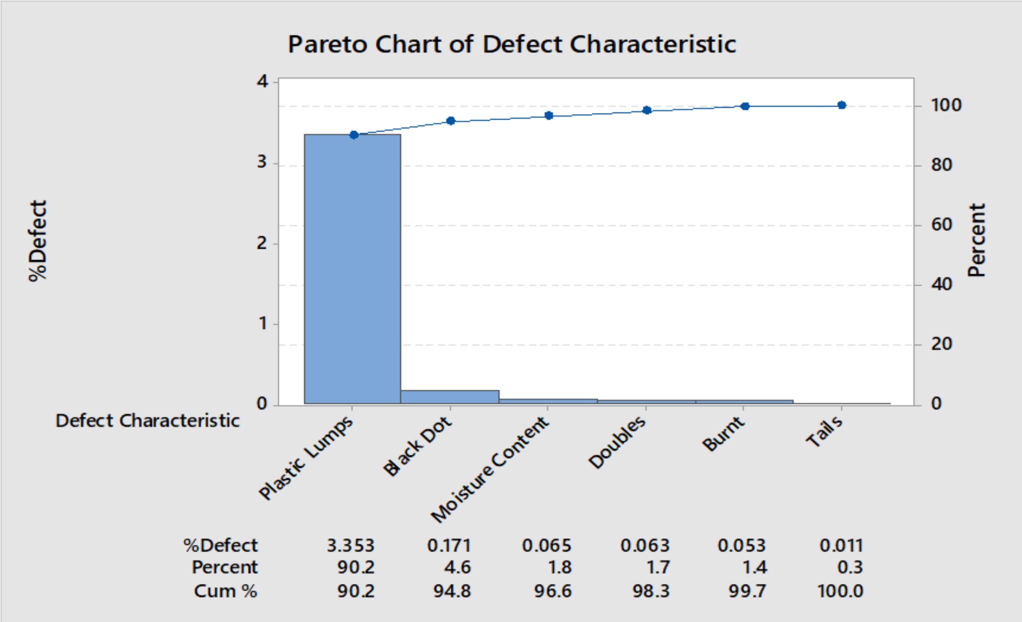

Figure 44. Pareto Chart of %Defect in Each Defect Characteristic

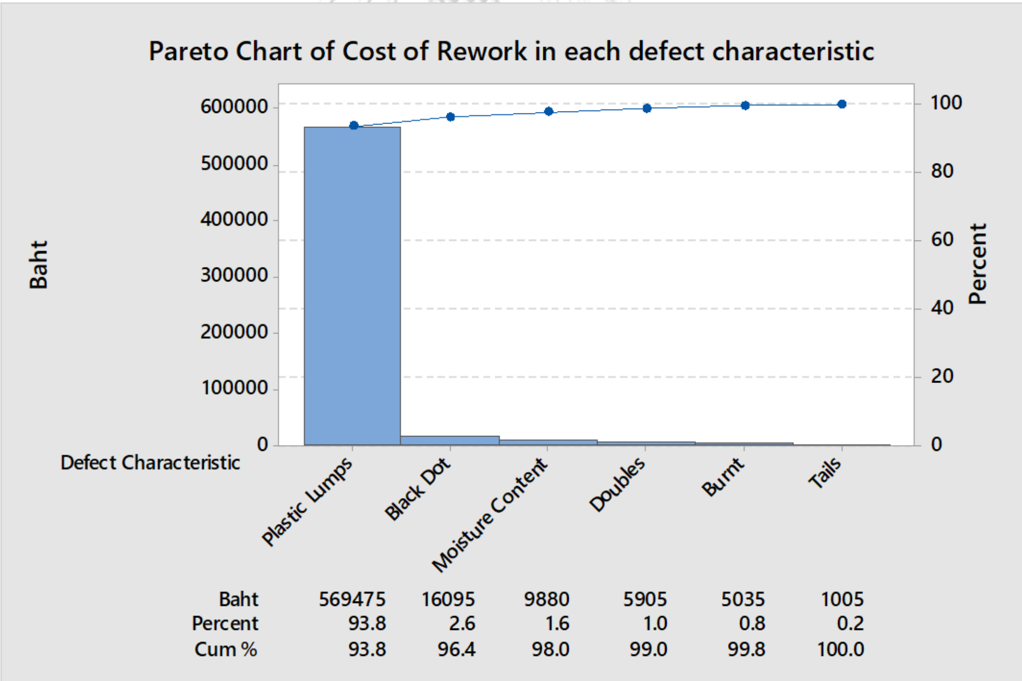

Figure 45. Pareto Chart of Cost of Rework in Each Defect Characteristic

Figure 46 also indicates there was the highest defect rate of plastic lumps from the PP production line, which amounted to roughly 4.85%. Hence, plastic lumps in the PP production line is studied in this research.

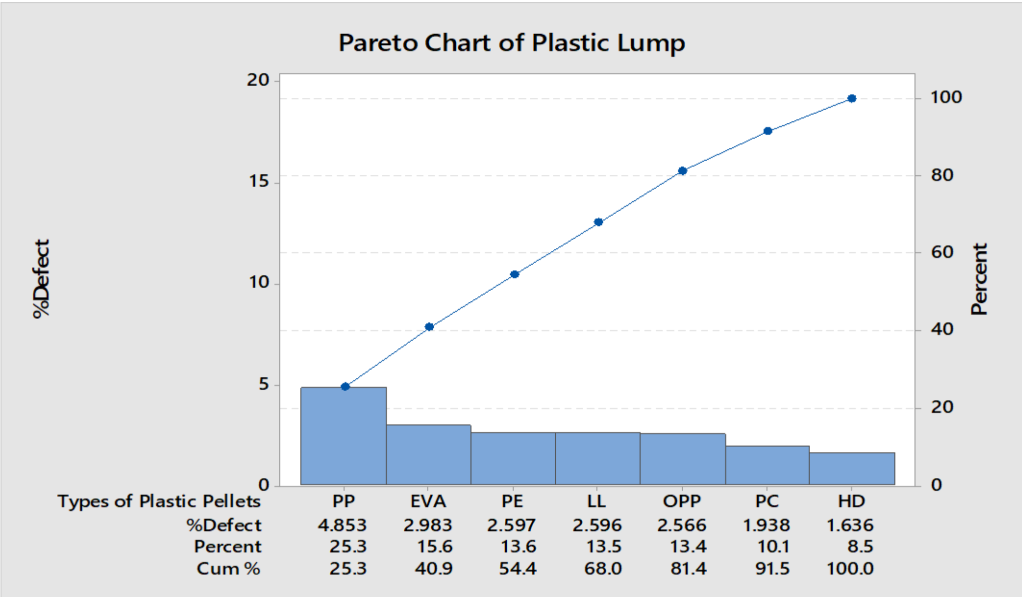

Figure 46. Pareto Chart of %Defect of Plastic Lump

3.3.2 Machine Selection

In the plastic pellet extrusion process, there are seven pelletising extruders which consists of five single-screw extruders and two twin-screw extruders. In Table 9, the specifications of the seven extruders in JJ Company is shown. However, since this project will focus on PP pellets, Extruder Six was chosen as it is the only extruder that produces PP pellets. The reason behind using one type of plastic per extruder is to reduce machine setup time, temperature switching and cleaning material.

Table 9. Machine Specification

Extruder Type	No	L (mm)	D (mm)	L//d	Motor (KW)	Rate (tonnes/day)
Twin screw	1	3186	79.65	40	120	8
Single screw	2	3100	145	21.38	60	5
Twin Screw	3	2226	57.4	40	100	3
Single screw	4	2600	125	20.80	60	3
Single screw	5	2800	145	19.31	60	5
Single screw	6	3000	160	18.75	60	8
Single screw	7	2700	145	18.62	60	5

3.3.3 Baseline Measurement

This research project will use the percentage defect rate as a baseline by converting Defect per Unit (DPU) to the percentage.

3.4 Summary of Define Phase Chapter

In summary, after the data gathering process between January 1st, 2017 and October 31st, 2017, the team found that a lot of defects occurred in the pelletising process. Plastic lumps were observed to be the largest defect characteristic within the process. Interestingly, it was also found that there were a large amount of plastic lumps produced in the PP production line which accounted for 4.85%. In addition, this research will focus on only Extruder Six since it is the only extruder that produces PP pellets. Therefore, the problem of plastic lumps occurring in the PP production line from Extruder Six must be improved immediately as the sales volume of PP pellets tends to increase every year. If the problem is not solved permanently, it will result in

JJ Company having negative financial performance in the future and also loss of due to delayed deliveries.

Project Charter

Project Name : Plastic Lump Defect Reduction In Recycled Plastic Pellets Manufacturing

Business case :
There are continuous wastes in pelletising process leading to a higher production cost.

Problem Statement :
After collecting the data between 1st January 2017 and 31st October 2017, it was clear that there are a high level of defects occurring in pelletising process especially plastic lumps. Plastic lump defect is mainly found on PP production line and have the highest percentage defect rate of 4.85%. It is also forecasted that plastic lumps have continuously increased.

Objective Statement :
To reduce the percentage defect rate of plastic lump in the PP production line

Project Scope :
This research project studies only on plastic lumps on PP production line by using extruder no. six

Project Metrics :
Business metrics: Cost of wastes
Primary metrics: Percentage defect rate
Secondary metrics: Storage area
Consequential metrics: Productivity and Production cost
Financial metrics: Cost of wastes

Project Assumption :

- Arrange the meeting with chief executive once a month. The chief executive will provide the useful advices and financial support.
- Team members are allowed to express their opinions fully and freely. And, all team members have a very good corporation.

Project Constraints :
The team members are able to spend 10 hours per week on the project. A meeting will also be held every week.

Team members :

Mr Sampan	B.	Production Manager
Mr Pitch	J.	Supervisor
Mr Kasidit	B.	Process Engineer
Mr Thongchai	C.	Machine Operator
Mr Khanthong	K.	Machine Operator
Mrs Pimolsiri	T.	Quality Control
Ms Raroopthip	P.	Researcher

Timeline :

Phase	Plan	Actual
Define	17 May 2017	20 May 2017
Measure	1 July 2017	1 July 2017
Analyse	6 Sep 2017	9 Sep 2017
Improve	28 Oct 2017	1 Nov 2017
Control	30 Nov 2017	1 Dec 2017

Figure 47. Project Charter

CHAPTER 4 MEASURE PHASE

In the measure phase of the Six Sigma DMAIC approach, the objective is to gather data and identify the causes of quality issues. The process starts with the brainstorming session. Brainstorming was performed within the established team to identify the causes of problems, and then summarized using a cause and effect diagram. Using the cause and effect diagram, a cause and effect matrix can be designed to prioritise sub-root causes of problems. Next, those causes were screened out using Failure Mode and Effects Analysis (FMEA) to identify the possible causes of failures. The scores obtained from the FMEA were prioritised using Pareto chart before experimenting and solving the problems arising from the plastic lump.

4.1 Cause and Effect Diagram

Cause and effect diagram is one of the most helpful tools that is widely used in the measure phase. The Cause and Effect Diagram is a product of the brainstorming session, and is used to visualize the potential causes of problems in the pelletising process. In this research, there were six main categories of problems referred as 6M and corresponds to man, material, machine, method, measurement, and mother-nature. As Figure 48 indicates, under each main cause there were also various sub-root causes. Each sub-root cause was accumulated depending on the defective product as mentioned in the earlier section.

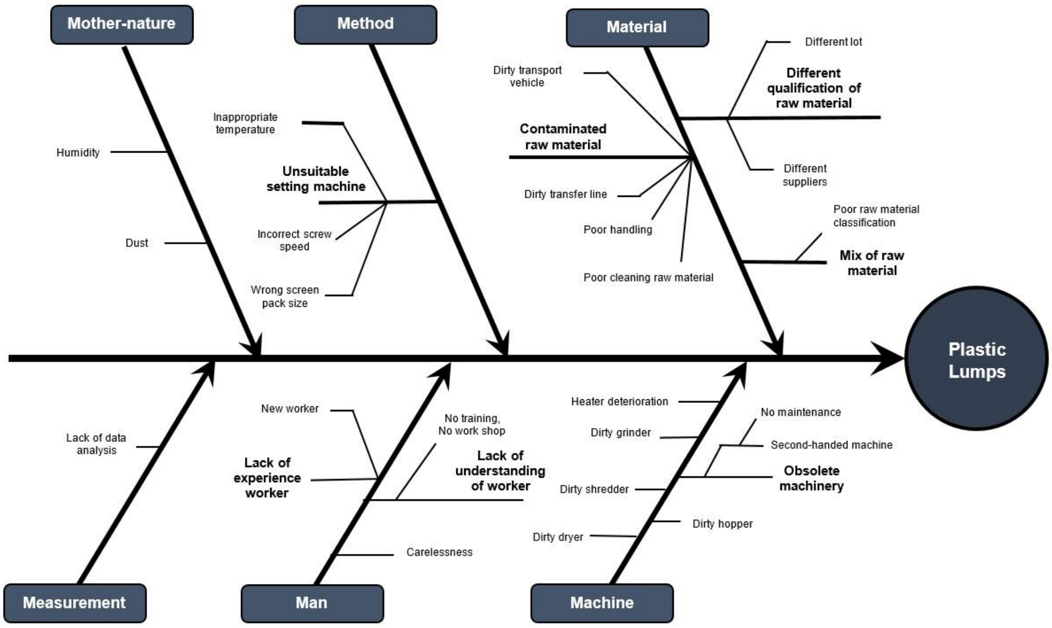

Figure 48. Cause and Effect Diagram of Plastic Lumps

4.2 Cause and Effect Matrix

Results from the cause and effect diagram of plastic lumps in the pelletising process shows that there are sub-root causes to the problem. Therefore, the cause and effect relationship is scored to be utilised to help detect the main factors in the problem (C-E Matrix). By utilising the C-E Matrix, this will enable us to select certain factors that are mainly related to the response variable that effects the plastic lumps. The steps for designing the C-E Matrix is labelled as follows:

(1) Use data that was obtained in the cause and effect diagram by brainstorming to fill in the cause and effect matrix table with defining the importance as can be seen in Table 10.

Table 10. Cause and Effect Relation Level

Cause and Effect Relation Level	Score
High: The key process input variable directly affects the generation of plastic lumps	9

Cause and Effect Relation Level	Score
Mid: The key process input variable moderately affects the generation of plastic lumps	3
Low: The key process input variable slightly affects the generation of plastic lumps	1
No Relation: The key process input variable does not affects the generation of plastic lumps	0

(2) Assign scores (importance point) from a range of 0-9 based on criterion to each factor. Define the ratios from effects to the factors that are related to the problems. All factors must be filled out in the form.

(3) Summarize the score result in the C-E matrix table, by collecting all the points from each factor and followed by determining the importance of each factor.

Table 11. C-E Matrix of Plastic Lump Defects

Factor	Code	Key Process Input Variables	Total Score
Material	A1	Raw material different lot	12
	A2	Raw material different supplier	12
	A3	Poor raw material classification	28
	A4	Dirty transport vehicle	16
	A5	Dirty transfer line	16

	A6	Poor cleaning raw material	36
	A7	Poor handling	28
Method	A8	Inappropriate Temperature	48
	A9	Incorrect screw speed	48
	A10	Wrong screen pack size	48
Machine	A11	Heater deterioration	8
	A12	Dirty grinder	34
	A13	Dirty shredder	34
	A14	Dirty dryer	28
	A15	No maintenance	42
	A16	Dirty hopper	34
Man	A17	New worker	14
	A18	No training, No work shop	42
	A19	Carelessness	8

Factor	Code	Key Process Input Variables	Total Score
Measurement	A20	Lack of Data Analysis	14
Mother-nature	A21	Dust	18
	A22	Humidity	6

From the above table, it was found out that there were twenty-two potential causes of plastic lump defects. In order to select the most likely causes, the criteria agreed by the team was to select causes which had a total score of more than thirty as shown below in Table 12.

Table 12. Potential Causes

No.	Code	Potential Causes	Total Score
1	A10	Wrong screen pack size	48
2	A8	Incorrect screw speed	48
3	A9	Inappropriate temperature	48
4	A15	No maintenance	42

No.	Code	Potential Causes	Total Score
5	A19	No training	42
6	A6	Poor cleaning raw material	36
7	A17	Dirty hopper	34
8	A12	Dirty grinder	34
9	A13	Dirty shredder	34

The explanation of these nine most significant causes will be clarified as follows;

(1) Wrong screen pack size

Using unsuitable screen pack size would create several problems such as inadequate back pressure, poor filtration and poor mixing, which leads to poor quality products such as tails, burnt, plastic lumps and black dots.

(2) Inappropriate temperature

Temperature is a major factor that can affect productivity rate and also product quality. Since the melting temperature of plastic depends on the proper extruder temperature, screw speed and back pressure (SCG Chemicals, 2011). For example, if the temperature within the extruder is set too high, it can cause yellow and burnt pellet. On the other hand, raw materials may not be melted entirely, if low temperature is set.

(3) Incorrect screw speed

Screw speed is also a major impact on the quality of plastic pellets produced by extruders. If screw speed is set too low, extrudate will be burnt by heat because it is in the extruder for too long period of time. Whereas, exceeding screw speed may create friction inside extruders, which leads to plastic degradation and plastic lump formation.

(4) No maintenance

In order to have good machine maintenance, the company should have a monthly and yearly maintenance schedule in order to prevent unexpected events which may lead to machine breakdown. With poor machine maintenance, it not only creates high maintenance costs but may also result in injuries or accidents. Furthermore, it will result in poor quality products. For example, if the extruder is dirty, the dirt particles from the extruder will contaminate raw material leading to plastic lump formation.

(5) No training

Without the proper training, workers will not truly understand the requirements of their role. Unskilled workers will spend their time to seek help or if they perform the work with misunderstandings, it may lead to errors. In contrast, experienced workers will have to spend their time monitoring and teaching inexperienced workers, and therefore will result in lower production efficiency. For example, if the worker does not know how to operate the extruder correctly, they might set up the wrong temperature, the screw speed or use the incorrect screen pack leading to the poor quality products such as black dot, burnt and plastic lumps.

(6) Poor cleaning raw material

With the high level of contaminants in raw materials, the screen pack will become clogged leading to an opportunity for producing lumps and leakage around the breaker plate.

(7) Dirty hopper

A dirty hopper can impact raw material quality. Therefore, impurities in raw material will lead to clogging of the screen and causing plastic lumps to be formed.

(8) Dirty grinder

Oil and grease from machinery and equipment will contaminate raw material with impurities and cause plastic lumps.

(9) Dirty shredder

Oil and grease from machinery and equipment will contaminate raw material with impurities and cause plastic lumps.

4.3 Failure Mode Effects Analysis

After analysing the potential causes by using the C-E Matrix in the previous section, it can be observed that there are nine high priority and most frequently occurring causes of plastic lumps. Therefore, Failure Mode Effects Analysis (FMEA) is used for ranking the impact of these nine main potential causes based on their severity (S), occurrence (O), and Detection (D). The multiple of these three criteria is equal to the risk priority number (RPN). The RPN indicates the risk associated with each potential cause, in which a higher RPN represents high risk priority and a lower RPN represents low risk priority. The characteristics of these factors are vital due to necessary understanding of the underlying problems caused by them and their effects. In the process, thorough guidelines and instructions regarding the FMEA procedure and the scoring process was clearly emphasized upon to team members which include the production manager, the process engineer, the supervisor, the machine operators, and the quality control operator. This is done in order to provide them with a true understanding of each score level, so that accurate results can be guaranteed, and scores can be assigned efficiently. The instructions were as follows:

Failure Mode and Effects Analysis Procedure

(1) Identify the key process input variables

(2) Determine the potential failure mode

(3) Determine the effects of the failure mode that tends to happen

(4) Determine the severity of the effects to the problems (See Table 13)

(5) Determine the potential causes of the problems

(6) Determine the frequency of occurrence (See Table 14)

(7) Determine the current process method to prevent the failure modes that are possible to happen

(8) Determine the capability of detection (See Table 15)

(9) Calculate the risk priority number (RPN) by utilising the following equation;

$$RPN = O * S * D$$

The failure mode and effects analysis of JJ Company will be provided in Table 16 as follows;

S = Severity (Hazards that occur if the problem happens. The criterion of scoring is shown in Table 13)

Table 13. Severity Table

Severity Level	Severity	Score
Very High	The key process input variable influences on a very large amount of defect	9-10
High	The key process input variable influences on a large amount of defect	7-8
Moderate	The key process input variable influences on a medium amount of defect	5-6
Low	The key process input variable influences on some amount of defect	3-4
Very Low	The key process input variable influences on a little amount of defect	1-2

O = Occurrence (The frequency of the occurrences, failures, or erroneousness of the problems. The criterion of scoring is shown in Table 14)

Table 14. Occurrence Table

Occurrence	Rate of Occurrence	Score
Very High	More than once per day	9-10
High	Once every 3-4 days	7-8
Moderate	Once a week	5-6
Low	Once per month	3-4
Very Low	Once per year	1-2

D = Detecting (The capability to detect problems before delivering the workings or products to the customers. The criterion of scoring is shown in Table 15)

Table 15. Detection Table

Detecting Level	Detecting	Score
Very Low	Very low possibility that control method will detect the defects	9-10
Low	Low possibility that control method will detect the defects	7-8
Moderate	Moderate possibility that control method will detect the defects	5-6
High	High possibility that control method will detect the defects	3-4
Very High	Very high possibility that control method will detect the defects	1-2

Table 16. FMEA of JJ Company

Process Title : Plastic Lump Defect Reduction In Recycled Plastic Pellets Manufacturing								
Project Team : Production manager, Supervisor, 2 Machine Operators, Process engineer, Quality control operator and Researcher								
Potential Failure Mode	Potential Effect of Failure	S	Potential Cause	O	Current Process Control	D	RPN	Recommend Action
Inadequate screen pack	Plastic Lumps	9	Unstandardized screen pack	10	No	8	720	Perform design and experiment to find the appropriate screen pack size
Incorrect screw speed	Plastic Lumps	9	Unstandardized screw speed	10	No	8	720	Perform design and experiment to find the right screw speed
Inappropriate temperature	Plastic Lumps	9	Unstandardized temperature	10	No	8	720	Perform design and experiment to find the proper temperature
No maintenance	Plastic Lumps	9	Unsuitable maintenance schedule	9	Random check twice a month	8	648	Create a preventive maintenance schedule
No training	Plastic Lumps	9	Improper training technique	9	Annual Training	7	567	Provide suitable training programme

Process Title : Plastic Lump Defect Reduction In Recycled Plastic Pellets Manufacturing								
Project Team : Production manager, Supervisor, 2 Machine Operators, Process engineer, Quality control operator and Researcher								
Potential Failure Mode	Potential Effect of Failure	S	Potential Cause	O	Current Process Control	D	RPN	Recommend Action
Poor cleaning raw material	Plastic Lumps	8	Cleaning Process	7	Random testing 3 times per week	6	336	Daily random testing/ Quality process control for cleaning
Dirty hopper	Plastic Lumps	8	Lack of awareness	6	Cleaning once a week	5	240	Cleaning equipment for every batch
Dirty grinder	Plastic Lumps	8	Grinding Process	5	Cleaning once a week	4	160	Quality process control for grinding/ Cleaning equipment for every batch
Dirty shredder	Plastic Lumps	8	Shredding Process	5	Cleaning once a week	4	160	Quality process control for shredding/ Cleaning equipment for every batch

After the cause of failure is identified by FMEA, the Pareto chart was used to identify the most significant causes contributing to the formation of plastic lumps. From Figure 49, the designed Pareto chart illustrates that the top-five highest RPN are inadequate screen pack, incorrect screw speed, inappropriate temperature, no maintenance, and no training. The result from Pareto chart shows the total score of the five main causes which is equivalent to 3,375 out of 4,271 or accounts for 79.0% of the total RPN score. Therefore, in the next phase this research will investigate more deeply into these five main causes in order to provide appropriate solutions for each cause (See Table 17).

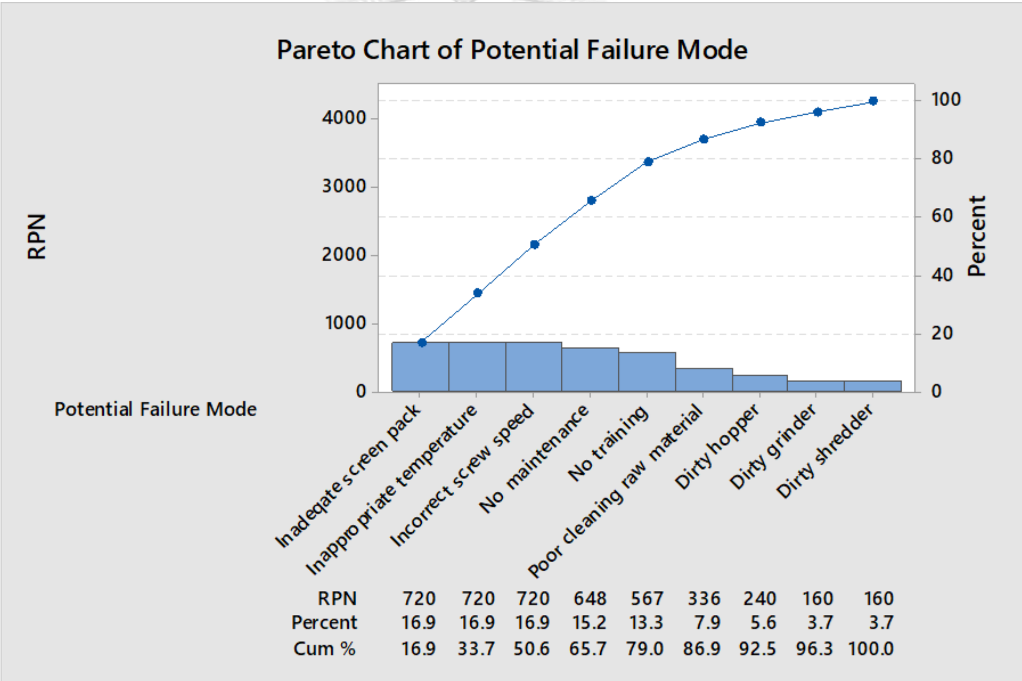

Figure 49. Pareto Chart of FMEA

Table 17. The Most Significant Causes of Plastic Lump

No.	Cause	RPN
1	Inadequate screen pack	720
2	Inappropriate temperature	720
3	Incorrect screw speed	720

No.	Cause	RPN
4	No maintenance	648
5	No training	567

4.4 Summary of Measure Phase Chapter

In the measure phase, four functional tools were used which are Cause and Effect diagram, Cause and Effect matrix, Failure Mode and Effect Analysis, and Pareto chart. Firstly, the Cause and Effect diagram was designed using gathered data from the brainstorming session in order to reveal all possible causes to the problem. Secondly, the possible causes identified were analysed through Cause and Effect matrix in order to find the most likely causes. Then, FMEA was used to prioritize which causes are to be focused on for improvement. Finally, a Pareto chart was applied to numerically evaluate using RPN score. From the Pareto chart, it was found that there are five prominent causes that have significant impact to the production process which are inadequate screen pack, incorrect screw speed, inappropriate temperature, lack of maintenance, and lack of training. Thus, the team concluded that these five main causes need to be focused on and improved in the next phase.

CHAPTER 5 ANALYSE PHASE

The analyse phase is the third stage of the DMAIC methodology, and is a vital part of this research. After the prominent causes were identified in the previous chapter, this chapter will show the manner in which the identified causes affects the pelletising process by using analytical tools and statistical tools, such as Affinity Diagram and Design of Experiment. The prominent causes of plastic lumps in the PP production line identified previously are incorrect temperature, wrong screen pack, improper screw speed, lack of maintenance, and lack of training.

5.1 Solution for Each Cause

5.1.1 Wrong Screen Pack

Wrong screen pack size will not only cause insufficient mixing and pressure, but also cause poor filtration leading to defects occurring and machine breakdowns. Hence, this problem can be solved by using DOE in order to find the proper screen pack for Extruder Six that produces the least amount of plastic lump defects.

5.1.2 Incorrect Temperature

In JJ Company, seven second-hand extruders are used in their production process. Currently, temperature settings for all extruders have a flat temperature profile where all zones are set at the same temperature. The wrong temperature will cause not only plastic lumps, burnt pellets, and yellow pellets but also create non-recyclable items. Therefore, the suitable temperature for Extruder Six must be examined in order to reduce the occurrence of defects as much as possible by using DOE.

5.1.3 Improper Screw Speed

Apart from the temperature, screw speed also has a major influence on product quality. By using a non-optimal screw speed, this will result in non-homogeneous plastic, plastic lumps, and yellow pellets. Therefore, the optimum screw speed of Extruder Six will be identified by using DOE to prevent and eliminate any defective items.

5.1.4 Lack of Maintenance

In JJ Company's current operation, Extruder Six and the other extruders do not have a maintenance schedule. The company will only repair and replace the machine and its parts when it has a problem or breaks down. This results in inefficient machinery, and thus inefficient operations during production. In order to solve this problem, the researcher will create the preventive maintenance schedule for the company. By creating this preventive maintenance schedule, it will not only eliminate the machine downtime but also improve both of on-time delivery performance and product quality, leading to a high level of customer satisfaction.

5.1.5 Lack of Training

Permanent machine operators of Extruder Six and also other extruders do not truly understand the proper working procedure. The workers operate the machinery based on what they are used to whether it's the correct or incorrect action. By creating the work instruction and proper training programme, the working efficiency of machine operators will improve and also lead to higher accuracy for better results. For a training programme, the operators will be trained before and during work.

The solutions as mentioned above can be categorised into two groups by using affinity diagram as shown in Figure 50. The first solution is using DOE. By conducting DOE, it helps the company identify proper parameter values such as the optimum temperature, screw speed, and screen pack for Extruder Six. By identifying the optimum parameter values, the assumption is that the defect rate and amount of plastic lumps in the PP production line will be reduced. Another solution is creating work instruction. The work instruction will be used for training the workers in order to enhance process efficiency, and will include the operational procedure for extruder and preventive maintenance schedule.

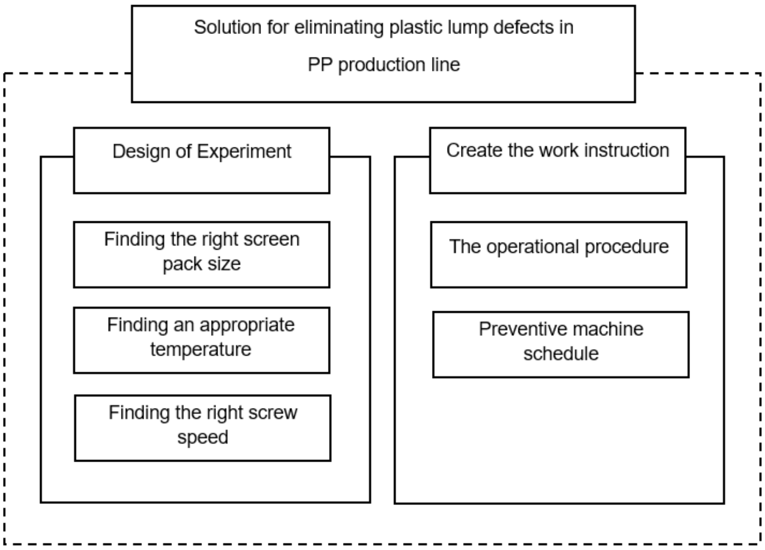

Figure 50. Affinity Diagram of JJ Company

5.2 Design of Experiment

Due to time limitations of the research, the 2k full-factorial design is selected for this project since only a limited amount of experimental runs are needed for this design. The 2k implies the design whilst k implies the factor, where each factor has only two levels. Referring to this research, there are three significant factors, and therefore it can be named as 2^3 design. The 2^3 design means that there are 8 different runs in the experiment.

5.2.1 Factor Level Selection

From the previous section, there are three significant factors that affect a response which are screen pack, temperature, and screw speed. Therefore, these factors will be used as variables as can be seen in Table 18. In this research, there are two levels of each factor which is low level and high level.

Table 18. Factor Level Selection

Factor	Level		Unit	Remark
	Low (-1)	High (+1)		
Screen pack	80	100	mesh	From the historical manufacturing data and the team discussion, the screen pack size of JJ company normally uses two sizes, which are 80 and 100 mesh. A lower screen pack mesh will result in unacceptable products while a higher screen pack will cause more resistance plastic to flow out.
Temperature	205	215	°C	From the historical manufacturing data and the team discussion, the temperature of PP is set between 205-215 °C. Temperatures under 205°C will lead to unmelt plastic, whereas temperatures over 215°C will cause the plastic to burn.

Factor	Level		Unit	Remark
	Low (-1)	High (+1)		
Screw speed	80	100	rpm	From the historical manufacturing data and the team discussion, the screw speed in JJ company is set at 80 and 100 rpm due to the limitation of machinery. However, unsuitable screw speed will impact the quality of the finished product.

5.2.2 Response Variable

In this experiment, the number of plastic lumps is considered as the response variable since this research is focused on defect reduction in the pelletising process.

5.2.3 Controlled Factor

The controlled variable is one of the variables that could have an effect on the result of the experiment, and thus must be kept at a constant value during the experiment. There are four controlled variables in this research which are:

(1) Using the same machine operators throughout the experiment,

(2) Using the same extrusion machinery and equipment through the experiment (Extruder Six is focused),

(3) Using the same raw materials that are supplied from the same lot and supplier during the experiment (PP is used as raw material). After

discussion with JJ Company, 100 kg of raw materials will be used for each experimental condition,

(4) And finally, using the same quality control operator throughout the experiment.

This research will use a randomisation technique on a MINITAB programme in order to generate a random order for the experiment. By using the randomize design, this eliminates uncontrollable conditions, selection bias, and also helps to verify that the model meets assumptions. In order to increase the data accuracy, this project will conduct 2^3 design with three replicate, which means that there are a total of 24 different experimental conditions. The design matrix of this project is provided in Table 19 and Table 20 as follows;

Table 19. Design Matrix for 2k Full-Factorial Design

StdOrder	RunOrder	Temp (°C)	Screw speed (rpm)	Screen pack size (mesh)
11	1	205	100	80
23	2	205	100	100
10	3	215	80	80
24	4	215	100	100
1	5	205	80	80
18	6	215	80	80
2	7	215	80	80
8	8	215	100	100
6	9	215	80	100
16	10	215	100	100
5	11	205	80	100
21	12	205	80	100
15	13	205	100	100
20	14	215	100	80
4	15	215	100	80
12	16	215	100	80
19	17	205	100	80
3	18	205	100	80
17	19	205	80	80
13	20	205	80	100
14	21	215	80	100
7	22	205	100	100
22	23	215	80	100

Table 20. Results of Experiment

StdOrder	RunOrder	Temp (°C)	Screw speed (rpm)	Screen pack size (mesh)	Defect (kg)
11	1	205	100	80	4.12
23	2	205	100	100	2.96
10	3	215	80	80	3.43
24	4	215	100	100	3.44
1	5	205	80	80	2.37
18	6	215	80	80	3.73
2	7	215	80	80	4.05
8	8	215	100	100	3.25
6	9	215	80	100	2.81
16	10	215	100	100	3.12
5	11	205	80	100	2.03
21	12	205	80	100	1.83
15	13	205	100	100	2.71
20	14	215	100	80	3.95
4	15	215	100	80	4.12
12	16	215	100	80	3.79
19	17	205	100	80	3.19
3	18	205	100	80	3.62
17	19	205	80	80	3.04
13	20	205	80	100	2.62
14	21	215	80	100	2.74
7	22	205	100	100	2.60
22	23	215	80	100	2.93
9	24	205	80	80	3.27

5.2.4 Model Adequacy Checking

Before analysing the experimental data, it is necessary to check a model adequacy first in order to guarantee that the experimental data is adequate for interpreting the results. The experiment data must meet the three key assumptions according to $\varepsilon_{ij} \sim NID(0, \sigma^2)$ principle (Thaprasop and Thawesaengskulthai, 2008). The three assumptions are normality, independence, and constant variance of residuals. If the experimental data does not meet the assumptions, it means that the results are invalid. Therefore, the research must firstly ensure that the assumptions are satisfied before moving to the next stage.

(1) The normality of residuals

The normality of the residuals can be examined from the normal probability plot of the residual. If the residuals are normality distributed, the points should fall along a straight line. On the other hand, the normality of residuals can also be checked from P-value by using Anderson-Darling Normality test. The normal distribution should have a P-Value of greater than 0.05. From Figure 51, it can be observed that the residual points are approximately close to the straight line and also have a P-value of 0.916 which is greater than 0.05. Thus, it can be concluded that the residuals are normally distributed.

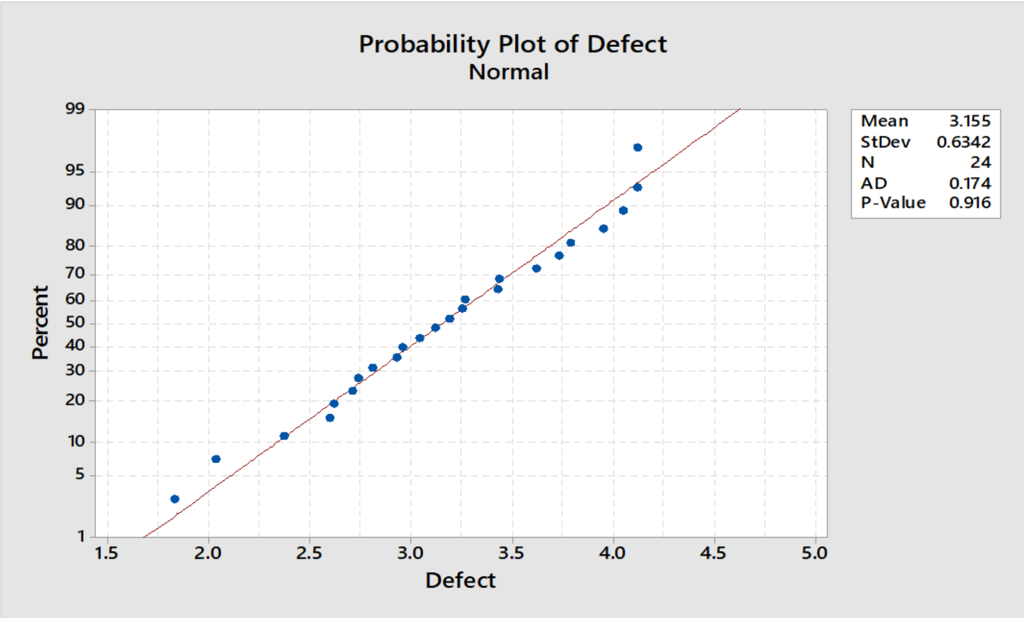

Figure 51. The Normality of Residuals

(2) The independence of the residuals

The independence of the residuals can be examined from the scatter plot of the residual versus the observation order. An independent residual should show randomly scattered points around the center line with no pattern in the plot. Figure 52 indicates the residual points are fall randomly around the center line with no specific trends. Therefore, it can be concluded that the residuals are independent.

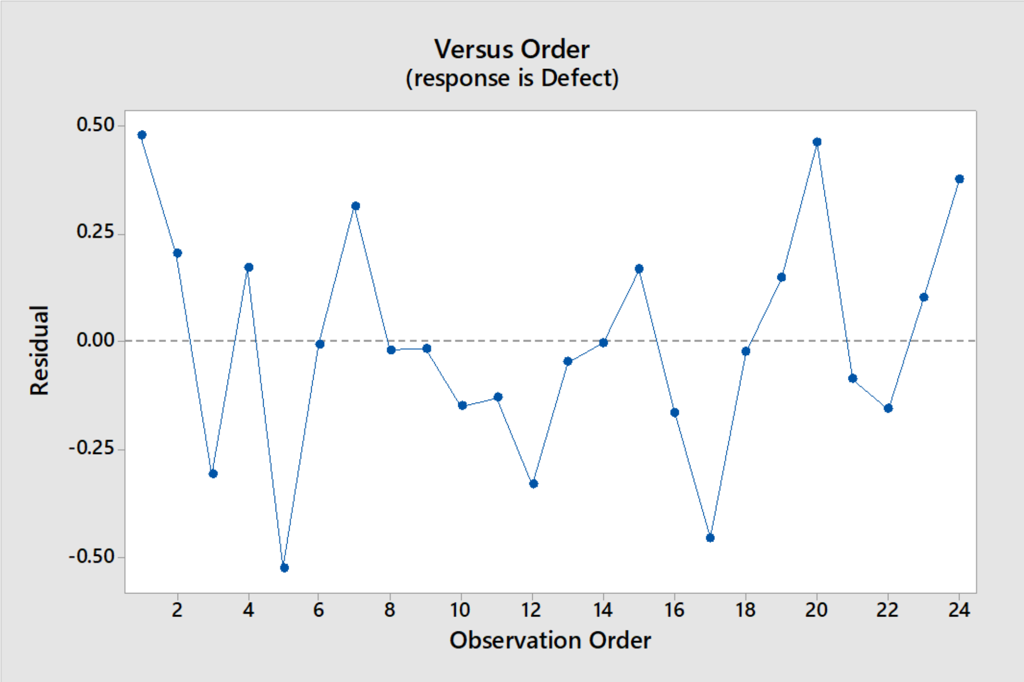

Figure 52. The Independence of the Residuals

(3) The constant variance of the residuals

For the constant variance of residual, the plot should show a random pattern of residuals on both sides of the 0 but should not be displaying any recognizable pattern. Referring to Figure 53, it can be seen that the residual points displays no pattern. Therefore, it can be concluded that the residuals have constant variance.

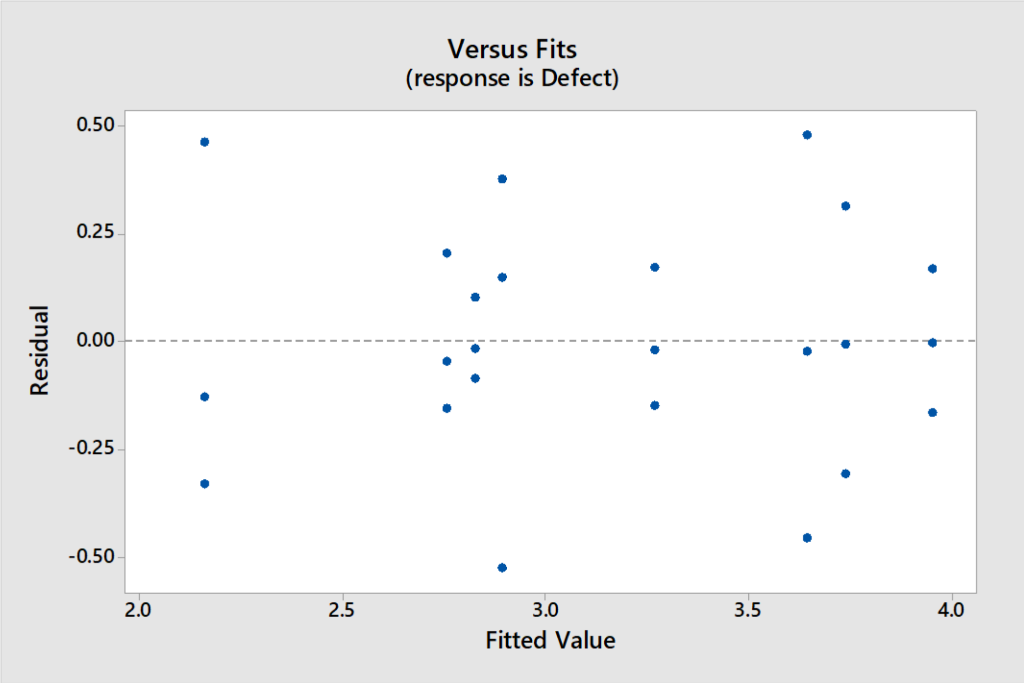

Figure 53. The Constant Variance of the Residuals

From three figures shown above, it represents that the experiment data meet the three key assumptions of linear regression model meaning that the experiment data is valid and it can be interpreted.

5.3 Experiment Analysis

The following figures display the data analysed provided by MINITAB programme, which includes the analysis of variance (ANOVA) table, the normal plot, Pareto chart, main effects plot, and interaction plots.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	7.65700	1.09386	10.99	0.000
Linear	3	7.42375	2.47458	24.85	0.000
Temperature	1	2.04167	2.04167	20.51	0.000
Screw speed	1	1.51002	1.51002	15.17	0.001
Screen pack	1	3.87207	3.87207	38.89	0.000
2-Way Interactions	3	0.17910	0.05970	0.60	0.625
Temperature*Screw speed	1	0.17682	0.17682	1.78	0.201
Temperature*Screen pack	1	0.00027	0.00027	0.00	0.959
Screw speed*Screen pack	1	0.00202	0.00202	0.02	0.889
3-Way Interactions	1	0.05415	0.05415	0.54	0.472
Temperature*Screw speed*Screen pack	1	0.05415	0.05415	0.54	0.472
Error	16	1.59300	0.09956		
Total	23	9.25000			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.315535	82.78%	75.24%	61.25%

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		3.1550	0.0644	48.98	0.000	
Temperature	0.5833	0.2917	0.0644	4.53	0.000	1.00
Screw speed	0.5017	0.2508	0.0644	3.89	0.001	1.00
Screen pack	-0.8033	-0.4017	0.0644	-6.24	0.000	1.00
Temperature*Screw speed	-0.1717	-0.0858	0.0644	-1.33	0.201	1.00
Temperature*Screen pack	0.0067	0.0033	0.0644	0.05	0.959	1.00
Screw speed*Screen pack	0.0183	0.0092	0.0644	0.14	0.889	1.00
Temperature*Screw speed*Screen pack	0.0950	0.0475	0.0644	0.74	0.472	1.00

Regression Equation in Uncoded Units

Defect = -200 + 0.98 Temperature + 2.17 Screw speed + 1.73 Screen pack
- 0.0103 Temperature*Screw speed - 0.0085 Temperature*Screen pack
- 0.0199 Screw speed*Screen pack
+ 0.000095 Temperature*Screw speed*Screen pack

Figure 54. ANOVA Table

From Figure 54, it indicates the analysis of variance for 2k full factorial design experiment with three replicates by using a MINITAB programme. The ANOVA table shows there are three main factors that greatly influence the defects which are temperature, screw speed, and screen pack by considering the P-value. The P-value from these three main factors are less than 0.05 meaning that all main factors are statistically significant. However, for 2 and 3 way interactions, there is no significantly different. The ANOVA results also show that R-squared and adjusted R-squared value are 82.78% and 75.24% respectively, meaning that the model provides a good fit to the data.

Moreover, Figure 55 reveals the main effects for factor A, B, and C are statistically significant at the 0.05 level. In addition, from Figure 56, the Pareto chart of the standardized effects reveals that the bar of factor A, B and C cross the reference line at 2.12, meaning that factor A, B and C are statistically significant. Therefore, the three main factors are Temperature (A), Screw speed (B), and Screen pack (C).

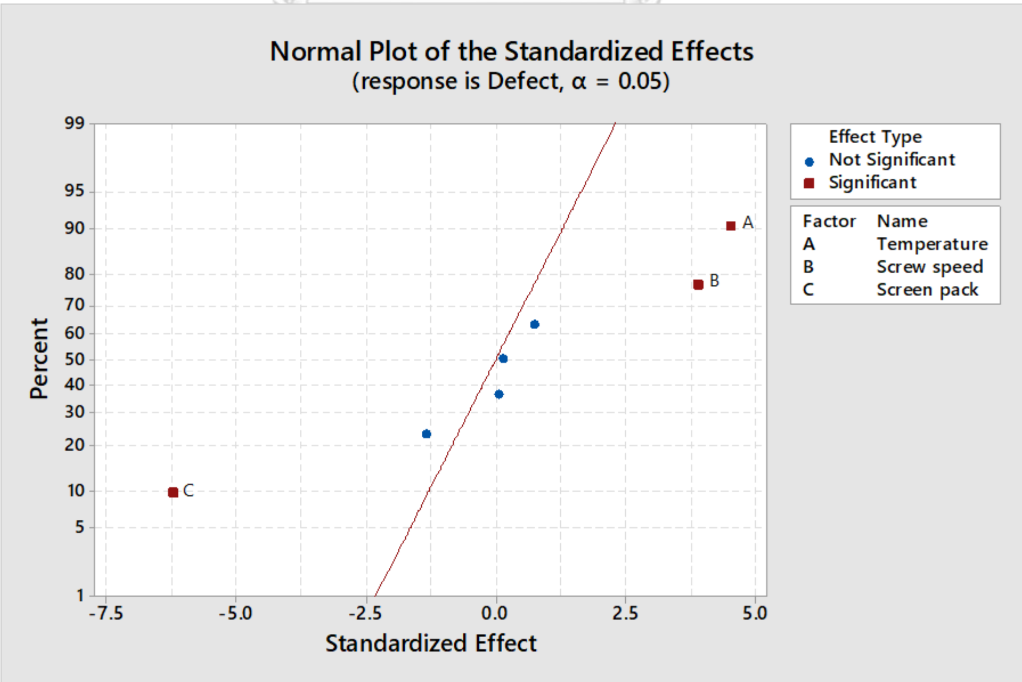

Figure 55. Normal Plot of Standardized Effects

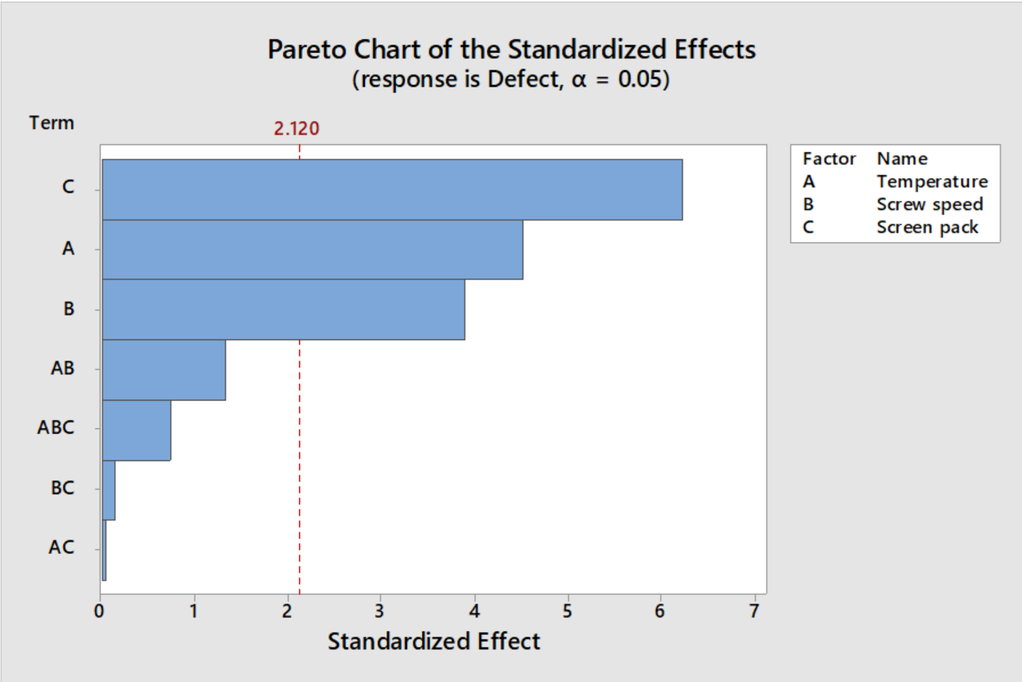

Figure 56. Pareto Chart of Standardized Effects

The main effects plot from Figure 57 illustrates the optimal conditions for each three main factors in order to have minor defects. By using a temperature of 205°C, screw speed at 80 rpm, and screen pack size of 100 mesh, it was found that these value settings generated the least amount of plastic lump defects in the PP production line. Furthermore, the interaction plot from Figure 58 represents the lines of temperature, screw speed, and screen pack, which can be seem that they are parallel to one another and implies that there is no interaction

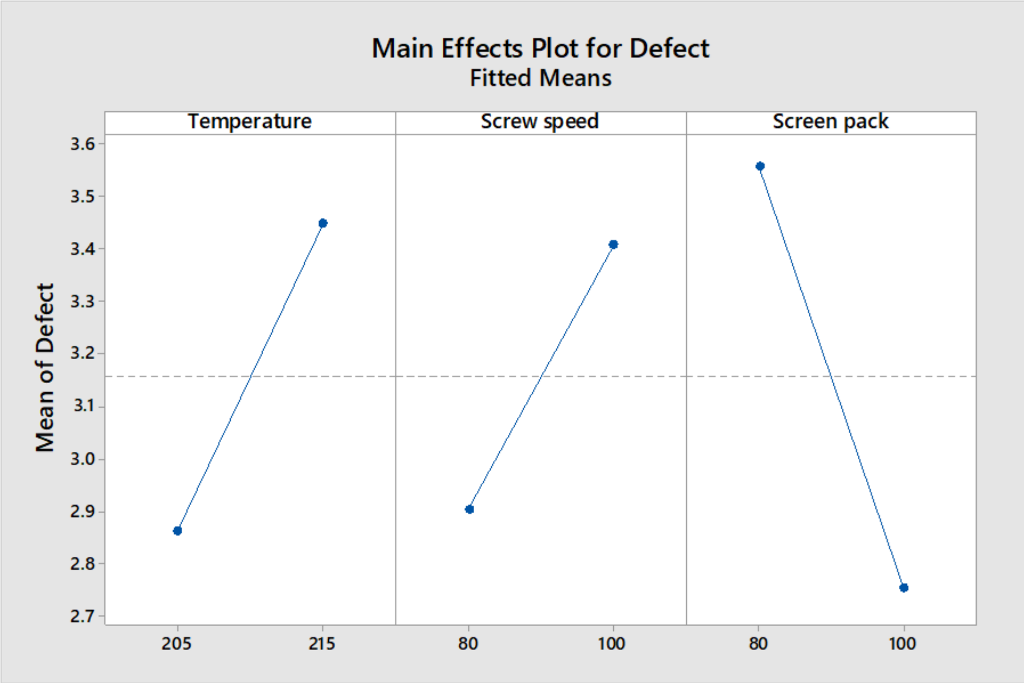

Figure 57. Main Effects Plot for Defect

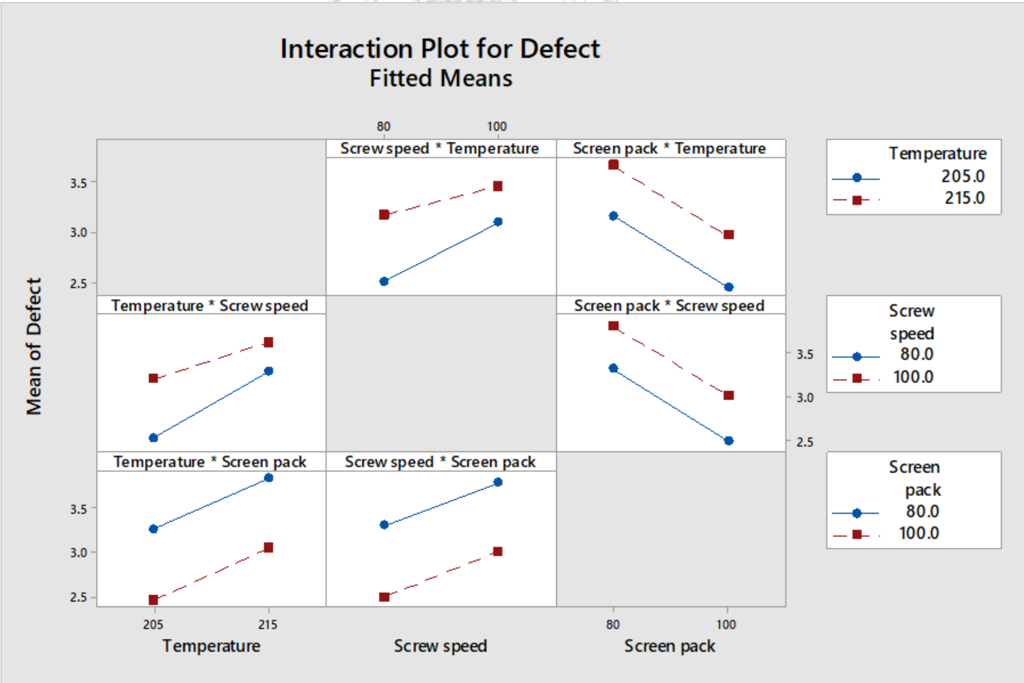

Figure 58. Interaction Plot for Defect

With respect to the reasons mentioned above, the optimal condition for temperature, screw speed, and screen pack of Extruder Six are shown in Table 21.

Table 21. The Optimal Conditions for Producing the Lowest Plastic Lumps

Factor	Condition	Unit
A= Temperature	205	℃
B= Screw speed	80	rpm
C= Screen pack	100	mesh

5.4 Work Instruction of Pellet Extrusion Process

According to the present pellet extrusion process of JJ Company, employees do not follow the proper procedure leading to wrong actions taken. As a result, these wrong actions cause defective products, inefficiency of machinery, and also machine breakdowns. Therefore, a proper work instruction must be created for operating the extruder to prevent these problems from occurring. By performing the work instruction of the extruder, the workers can operate the extruder properly, and thus increase the productivity. This research will create the work instruction for only Extruder Six since different extruders require different settings. The work instruction includes the operational procedure and the preventive maintenance schedule.

5.4.1 The Process of Creating the Operational Procedure

Firstly, the supervisor and the operation operators must develop the operational procedure for operating the extruder machine. Secondly, the process engineer will check the correctness of the procedure. Then, a secondary review is completed by the production manager in order to ensure that the operational procedure is ready for use. Finally, if the operational procedure is confirmed by the production manager then the procedure will be implemented in the real work.

5.4.2 Preventive Maintenance Schedule of Extruder

At the moment, the company does not have any maintenance schedule which leads to unexpected machinery breakdowns, poor quality products and consequently a delay of deliveries. Thus, it is important to create the preventive maintenance schedule for preventing unexpected machine failures. The preventive maintenance schedule will be created specifically for Extruder Six which is a single-screw extruder.

5.5 Summary of Analyse Phase Chapter

In summary, this phase starts with identifying solutions for the significant causes which are analysed from FMEA in the previous phase. Then, those causes were categorised into two groups by using Affinity diagram. It was found that there are two main solutions to solve this problem which are performing DOE, and creating work instruction. The DOE will be used to discover the optimal parameters for temperature, screw speed, and screen pack specifically for Extruder Six and it was found that by using a temperature of 205°C, screw speed at 80 rpm, and screen pack size of 100 mesh, the extruder was able to generate the smallest amount of plastic lumps in the PP production line. For the second solution, this research will create the work instruction including the operational procedure and preventive maintenance schedule for Extruder Six.

CHAPTER 6 IMPROVE PHASE

In the improve phase, the solutions found in the analyse phase are applied to the production process in order to decrease the defect rate of plastic lumps in the PP production line. In this stage, the team also developed an action plan through a brain storming session. The action plan is shown in Table 22 below:

Table 22. Action Plan for Solving the Plastic Lump Defects in PP Line

No.	Action step	Person responsible	Start date	Finish date
1	Employee training	Process engineer	01/11/17	15/11/17
2	Revise the process steps before working	Supervisor	11/11/17	31/03/18
3	Following the work instruction of pellet extrusion process precisely	Supervisor	11/17/17	31/03/18
4	Create the control chart	Researcher	10/04/18	11/04/18
5	Performance evaluation	Process Improvement Team	11/04/18	11/04/18

6.1 Employee Training

Employee training is important as it’s required to increase efficiency in the production process. Through training, the workers will understand the process and their role correctly. The steps of employee training are illustrated as follows:

(1) Process engineer have to understand the whole process before assigning tasks to supervisor and machine operators,

(2) Process engineer must explain the whole process in detail to the supervisor and machine operators,

(3) Process engineer assign the tasks to the supervisor and machine operators,

(4) Supervisor and machine operators have to understand their responsibilities in order to perform their job correctly. When faced with problems, they must promptly inform the process engineer to develop a first-hand solution.

6.2 Revise the Process Steps before Working

Before starting to work, each staff is to review their own working procedure with help from a supervisor in order to improve and work more efficiently. The following steps are taken:

(1) The supervisor summarizes the process steps in plastic pellet extrusion process,

(2) The supervisor inquires about the duty and responsibility in each step during the operation from each person to ensure that the machine operators will be able to deliver their assigned work correctly. If there are any parts which are incorrect, the supervisor will amend the issue and explain the correct scenarios to the machine operators,

(3) The supervisor and machine operators prepare to operate the extruder machine

6.3 Following the Work Instruction

The next step in the action plan is to accurately review the work instructions as the instructions will be used in the real working situation of pellet extrusion. The supervisor and machine operators must follow this work instruction carefully.

6.4 Create the Control Chart

The control chart is used for determining the changes of the amount of plastic lump defects in the PP product process during the five months implementation. The researcher will be responsible for creating the control chart, and the supervisor will collect the plastic lumps data.

6.5 Performance Evaluation

After implementing the solutions to the process, the supervisor will collect and summarize the number of plastic lump defects in the PP production line produced by Extruder Six. The researcher will align the plastic lumps data in order to create the control chart and use this information to evaluate the performance of the process, and also summarize the outcome to be shared through a meeting.

6.6 Summary of Improve Phase Chapter

In this chapter, the new parameter conditions are applied with the action plan. The action plan includes the following steps: employee training, reviewing operational procedures of staff before commencing work, performing work according to the work instructions, and creating a control chart. Finally, this information will be used for performance evaluation.

CHAPTER 7 CONTROL PHASE

In the previous phases, solutions were firstly developed in the analyse phase, and then applied as an action plan in the improve phase. This phase will evaluate the performance of the process after implementation of the solutions.

7.1 Result

The amount of plastic lumps in the PP product produced by Extruder Six was collected during a five months period between November 1st, 2017 and March 31th, 2018. Using this data, a control chart was plotted by using the percentage defect rate collected every day as shown in Figure 59.

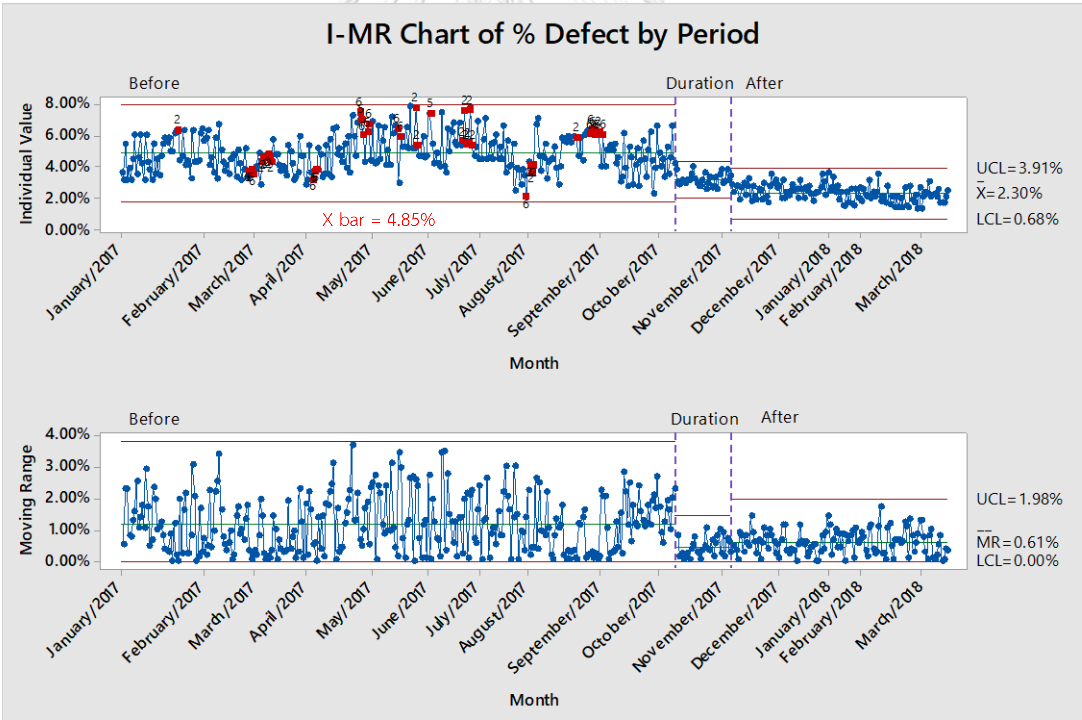

Figure 59. I-MR Chart of %Defect

It can be observed from the I-MR chart that it consists of two charts which are Individual chart and Moving Range chart. In order to interpret the I-MR chart, it is necessary to determine the moving range chart first because the control limits of the individual chart will be imprecise if the moving range chart is out of control. From Figure 59, it is shown that there is no point out of the moving range chart meaning that the process variation is in control. And, the moving range chart also displays that the variation of process has decreased after improvement. Thereby, the individual chart can be examined. For the individual chart, it represents that the trend of percentage defect rate of plastic lumps has decreased over time. The percentage defect rate was decreased from 4.85% to just only 2.30%. Furthermore, the outgrowth of doing this is cost savings. Referring to Table 23, it can be seen that the rework cost of plastic lump defects from Extruder Six was reduced from 36,364 Baht per month to 18,325 Baht per month.

Table 23. Before and After Improvement Data

	Before improvement	After improvement
Screen pack (mesh)	80 , 100	100
Temperature (°C)	205-215	205
Screw speed (rpm)	80 , 100	80
%Defect	4.85%	2.30%
Rework cost (per month)	36,364	18,325

7.2 Summary of Control Phase Chapter

In the control phase, the team concluded that the results are very satisfactory since the case study company has previously failed to solve this problem several times. By implementing new parameter conditions for five months, the percentage defect rate was reduced from 4.85% to 2.30%. However, by using the screw speed at 80 rpm, it results in a lower speed but does not affect delivery performance since the plastic lumps was decreased leading to more high quality output. Thereby, the owner of JJ Company is extremely satisfied with these results.

CHAPTER 8 CONCLUSION AND RECOMMENDATION

This research applied Six Sigma DMAIC approach along with the several quality control tools and statistical techniques for each phase in order to solve the problem of plastic lump defects in polypropylene production line from Extruder no. Six. The Six Sigma DMAIC methodology contains five steps starting with the define phase, followed by the measure phase, analyse phase, improve phase, and control phase, respectively. Plastic lump defects not only result in the higher cost of production but also the time that will be consumed when they have to be reworked on. Moreover, the process improvement team was able to decrease the percentage defect rate of plastic lumps from 4.85% to just only 2.30%. The summary of each steps are described in sections 8.1 – 8.5, which are listed below.

8.1 Define Phase

Based on the current situation, the team found that there is a higher defect rate of plastic lumps in polypropylene product. These defects impacted JJ Company in many aspects. The aspects include machinery cost, wage cost, and also reworking cost. Therefore, it is necessary to remove the plastic lump defects in order to improve the pelletising process.

8.2 Measure Phase

In the measure phase, four different types of functional tools were used, which are the cause and effect diagram, cause and effect matrix, failure mode and effect analysis, and Pareto chart. From the cause and effect diagram, it was designed using data gathered from the brainstorming session in order to reveal all possible causes to the problem. The team found twenty-two possible causes for the plastic lump defects. The possible causes identified were then analysed through cause and effect matrix in order to find the highest possible causes by scoring the factors. After that, FMEA was used to prioritize the causes to focus on for improvement. Finally, a Pareto chart was applied to numerically evaluate using RPN score. From the Pareto chart, it was found that there were five prominent causes that have significant impact to the production process. These causes include inadequate screen packing, incorrect screw speed, inappropriate temperature, no maintenance, and no training. Thus, the team concluded that these five main causes need to be focused on and improved in the next phase.

8.3 Analyse Phase

This phase starts with identifying solutions for the significant causes which are analysed from Pareto chart of FMEA in the previous phase. Then, those causes will be categorised into two groups by using the Affinity diagram. It was found that there are two main solutions to solve this problem which are performing DOE and creating work instructions. For the first solution, the DOE will be used to discover the optimal parameters for temperature, screw speed, and screen pack specifically for Extruder Six. The team have chosen the 2k full factorial design for this DOE which is the most effective experiment with three input factors and two levels for each factor, where the experiment was then repeated for three times. From the experiment results, it was found that by using a temperature of 205°C, screw speed at 80 rpm, and screen pack size of 100 mesh, the extruder generated the smallest number of plastic lumps in the PP production line. For the second solution, this research will create the work instruction which includes the operational procedure and preventive maintenance schedule for Extruder Six.

8.4 Improve Phase

In this chapter, the new parameter conditions are applied with the action plan. The action plan includes the following steps: employee training, reviewing operational procedures of staff before commencing work, performing work according to the work instructions, and creating a control chart.

8.5 Control Phase

In the control phase, the team recorded the value obtained from the experiment and performed check-ups on the workers to keep track on their implementation of the operational procedure and preventive maintenance. After that, a control chart was created to study how the process changed over time. The team was satisfied with the results observed, since the case study company have previously failed to resolve this problem several times in the past. Furthermore, the percentage defect rate of plastic lump defects in the PP production line from Extruder Six was decreased from 4.85% to 2.30%, leading to improved cost savings. The owner of JJ Company is extremely satisfied with these results.

8.6 The Limitations of the Research

The following is a list of limitations present in the research:

(1) The research is aimed at solving the plastic lump problem only at the studied factory.

(2) The only production line selected for the study is polypropylene line.

(3) The data obtained from the machines was only from one single machine, which was Extruder Six.

(4) The raw material obtained for the experimentation was from the same supplier and lot.

(5) There are only two sizes of screen pack, which are 80 and 100 mesh

(6) There are two levels of screw speed, which are 80 and 100 rpm due to limitation of the extruder machine.

8.7 Problems and Obstacles in the Research

The problems and obstacles present in the research are as follows:

(1) There was a difficulty in setting up meetings between employees and staff due to an overloaded workload from factory customers. Therefore, there was not much available time to convene and discuss the issues.

(2) Staff not trying to cooperate with the new workflow. This is because some of the staff are used to what they usually do, which led to them ignoring new instructions, resulting in communication difficulties between team members and staff.

(3) Varying a single variable during the experimentation was not possible due to the workload at the factory. Without being able to vary each factor individually, we were unable to assess the initial problems related to each factor efficiently.

8.8 Recommendations

In order to implement the Six Sigma DMAIC methodology, improvements of knowledge and skills are a necessity in an organization’s hierarchy to create a much smoother workflow when tackling problems. Corporate managers must ensure that all work personnel acquire the necessary understanding of the Six Sigma DMAIC approach, which will then lead to the organization’s goals. Management must also make sure that there is enough stimuli to induce work personnel to cooperate and support the improvements in placed based on the guidelines, or it might result in a backfire and damage the organization instead.

8.9 Suggestions for Further Research

There are three suggestions for the further research of studied company as follows;

(1) The company should start solving the quality problems of raw material. Since a higher quality of raw material will result in a better product quality.

(2) The company should vary the temperature levels besides the two levels that are currently being used in order to approach to a zero defect.

(3) The company should applied the Design of Experiment to the others types of plastics in order to find the optimal solution for each plastic type.

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APPENDICES

Appendix A: Work Instruction (Operational Procedure)

WORK INSTRUCTION JJ company	Page 1	
	JJ-WI-001	
Single Screw Extruder Operation and Control (ED 6)	No : A	Edited : 1.0
	Start date : 1/11/2017	

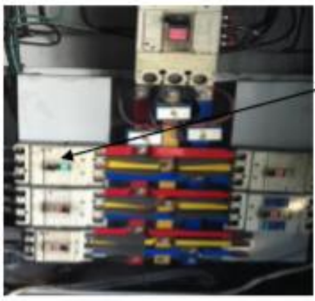
Operational procedure

WORK INSTRUCTION JJ company	Page **2**	
	JJ-WI-001	
Single Screw Extruder Operation and Control (ED 6)	No : A	Edited : 1.0
	Start date : 1/11/2017	

1. **Objective**
   1.1 To operate the machine correctly and safely
2. **Scope of work instruction**
   2.1 For extruder number six only
3. **Abbreviation**
   3.1 ED 6 Stands for Extruder number six

WORK INSTRUCTION JJ company	Page **3**	
	JJ-WI-001	
Single Screw Extruder Operation and Control (ED 6)	No : A	Edited : 1.0
	Start date : 1/11/2017	

4. Process steps



4.1 Turn on Main Breaker to "On" position

4.2 Turn on all Sub Breakers to "On" Position

4.3 Set the desired temperatures by using instruction provided in attachment 1

WORK INSTRUCTION JJ company	Page **4**	
	JJ-WI-001	
Single Screw Extruder Operation and Control (ED 6)	No : A	Edited : 1.0
	Start date : 1/11/2017	

4.4 Open water valve to fill up water in water bath

4.5 Wait until temperature reach the target, then turn on equipment on the following process

4.6 Push "start" button to start motor of main screw and mixing propeller

WORK INSTRUCTION JJ company	Page **5**	
	JJ-WI-001	
Single Screw Extruder Operation and Control (ED 6)	No : A	Edited : 1.0
	Start date : 1/11/2017	

4.7 Push "start" button to start motor of sub screw

4.8 Feed the raw material to Hopper

4.9 Adjust the speed of pelletizer machine at suitable level

<table>
<tr><td rowspan="2">WORK INSTRUCTION
JJ company</td><td colspan="2">Page 6</td></tr>
<tr><td colspan="2">JJ-WI-001</td></tr>
<tr><td rowspan="2">Single Screw Extruder Operation and Control (ED 6)</td><td>No : A</td><td>Edited : 1.0</td></tr>
<tr><td colspan="2">Start date : 1/11/2017</td></tr>
</table>

4.10 Extruder machine extrudes plastic to water bath and convey to pelletizer machine

4.11 Plastic pellets go through storage tank and ready to pack into 25 kg bag.

WORK INSTRUCTION JJ company	Page **7** JJ-WI-001	
Single Screw Extruder Operation and Control (ED 6)	No : A	Edited : 1.0
	Start date : 1/11/2017	

5. Packaging process

5.1 Start the Weighing Machine and wait until number show 0.00

5.2 Fill up the recycled plastic pellets into bag until reach the target weight

5.3 Enclose the bag

WORK INSTRUCTION JJ company	Page **8**	
	JJ-WI-001	
Single Screw Extruder Operation and Control (ED 6)	No : A	Edited : 1.0
	Start date : 1/11/2017	

6 How to stop the machine

6.1 Let the plastic flow out of the extruder machine

6.2 Stop main screw by press red buttons (See Figure 4.6)

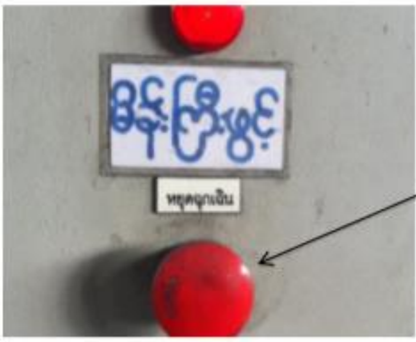
6.3 Stop sub screw by press red buttons on (See Figure 4.7)

6.4 Reduce cutting speed to 0 by using down arrow (See Figure 4.9)

6.5 Stop motor by reduce speed to 0 (See Figure 4.6)

6.6 Clean the machine and work area

7 For the emergency case



7.1 Press emergency stop button

WORK INSTRUCTION JJ company		Page **9**
		JJ-WI-001
Single Screw Extruder Operation and Control (ED 6)	No : A	Edited : 1.0
	Start date : 1/11/2017	

8 Attachment

8.1 Instruction for adjust temoerature

1. Press + button to increase temperature

2. Press - button to reduce temperature

Appendix B: Work Instruction (Preventive Maintenance Schedule)

Extruder No: ______________________

Responsible: ______________________ Date: _____________________

Work Activities	Daily	Monthly	Yearly	Remark
Cleaning (C)				
C1: Spray cleaning agent on surface of the magnetic				
C2: Clean dust filter inside electrical control box				
C3: Clean water bath				
C4: Clean die head				
C5: Clean the surrounding of the single screw machine				
C6: Clean screen pack				
C7: Clean the breaker plate				
Inspection (I)				
I1: Electrical wires of the heater, thermocouple, and the velocity measurement wire around the motor				
I2: Oil level inside the gear box				
I3: Tightness of conveyor belt				
I4: Oil lines, oil pipe junctions				
I5: Pulley				
I6: Sharpness of the cutter				
Lubrication (L)				
L1: Add grease in motor				
Adjustment (A)				
A1: Tighten the connections of the electrical equipment inside the electrical control box				
A2: Tighten the screws inside between the electrical wire heater and heater				
A3: Tighten any parts with oil leakages				
A4: Tighten the screws in between the heater and the screw cylinder				
A5: Tighten the oil pipe connections				
Testing (T)				
T1: The temperature control and solenoid valve				
T2: The water and oil pump				
T3: The gear and motor				
T4: The vacuum system				

REFERENCES

APPENDIX

VITA

Rarooptthip Paiboonkasemsut was born on September 6, 1992. She completed a Bachelor's Degree in Chemical Engineering, Thammasat University. After graduating, she continued to study a dual degree program to pursue for a Master of Science in Engineering Business Management from Warwick Manufacturing Group, the University of Warwick and a Master of Engineering in Engineering Management from Faculty of Engineering, Chulalongkorn University.