DEFECT REDUCTION BY DMAIC METHOD: A CASE STUDY OF A JEWELRY MANUFACTURER

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ABSTRACT

This research is a case study of a jewelry manufacturer with the purposes to solve a problem of the defect rate of resins in the modeling department. DMAIC methodology (Define, Measure, Analyze, Improve, and Control) was applied in the research to analyze and identify root causes of the defective resins, improve modeling processes, and reduce a defect rate of resins. Data were collected by using the data collection forms, observations, interviews, and historical data. As a result, there are eight root causes of the defects divided into four categories of the causes and effects diagram. The research was scoped down to focus on only two categories, which are methods and manpower. Researcher proposed five solutions to solve the problem of defects as well as few control strategies to measure and maintain the improvements. Company has gained many benefits from this research. The results clearly indicate that the defect rate of resins decreased significantly.

Keywords: *Lean Six Sigma, DMAIC Methodology, Defect rate, Cause and Effect Diagram*

บทคัดย่อ

งานวิจัยนี้เป็นกรณีศึกษาของโรงงานผลิตเครื่องประดับ มีวัตถุประสงค์เพื่อแก้ปัญหาเกี่ยวกับจำนวนชิ้นงานเรซิ่นที่เสียจากการผลิตของแผนกพิมพ์ โดยการใช้ DMAIC (การกำหนดประเด็นปัญหา การประเมินปัญหา การวิเคราะห์ปัญหา การเสนอวิธีการแก้ไข และ วิธีการควบคุม) เป็นเครื่องมือในงานวิจัยนี้ เพื่อวิเคราะห์และวินิจฉัยต้นเหตุของชิ้นงานเรซิ่นที่เสีย รวมถึงปรับปรุงขั้นตอนการผลิตแบบพิมพ์ให้ดีขึ้น และลดจำนวนชิ้นงานเรซิ่นที่ผลิตเสีย ข้อมูลถูกจัดเก็บจากการใช้แบบฟอร์ม การสังเกต การสัมภาษณ์ และจากฐานข้อมูลเก่าของบริษัท ผลจากการสำรวจพบว่า มี 8 ปัจจัยที่ทำให้ชิ้นงานเรซิ่นเกิดข้อผิดพลาด โดยการแสดงผลแบบ แผนผังการแสดงต้นเหตุและผลกระทบ ซึ่งสามารถแบ่งออกได้เป็น 4 กลุ่มใหญ่ จากนั้นจึงเลือกเจาะจงเพื่อศึกษาและปรับปรุงแค่เพียง 2 กลุ่ม คือ ความผิดพลาดที่เกิดระหว่างกระบวนการการผลิตแบบพิมพ์ และการทำงานของบุคลากร นักวิจัยได้เสนอ 5 วิธี เพื่อแก้ไขปัญหา รวมถึงการสร้างกลยุทธ์สำหรับการควบคุมเสถียรภาพ ผลจากการปรับปรุงขั้นตอนการการทำงานของแผนกพิมพ์ทำให้เห็นว่า บริษัทได้รับประโยชน์จากงานวิจัยชิ้นนี้อย่างมาก เพราะจำนวนชิ้นงานเรซิ่นที่เสียลดลงอย่างเห็นได้ชัด

คำสำคัญ: ลีนซิกส์ซิกมา ระเบียบวิธี DMAIC อัตราของเสีย แผนผังก้างปลา

Received October 2019

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INTRODUCTION

This research is a case study of JEMM Company, a jewelry manufacturer based in Bangkok, Thailand. The company's annual sales in 2017 and 2018 are USD 1,600,000 and USD 1,700,000 with an estimation of sales USD 2,300,000 in 2019. JEMM Company produces many types of jewelry products which are categorized into 5 items; Ring, Earrings, Bracelet and Bangle, Necklace and Pendant, and Brooch.

Figure 1: Modeling Processes

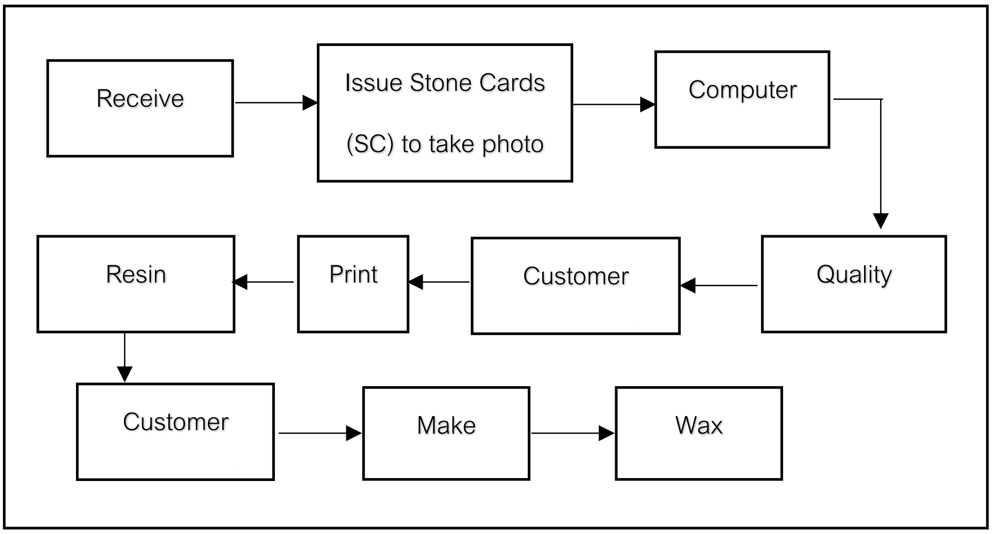


Figure 1 illustrates the process flow of modeling process of JEMM Company. First, the company receives the orders from the customers, the gem stones of the customers are inspected and photo is taken in order to issue Stone Card (SC) which acts as a bill of material. After that, order details, stone photos, and information are combined together and sent to computer modeler to create a 3D-model image and print out as a resin. Next, the resin is sent to the wax carving station to clean and check the quality by presetting the center stone. If the resin is perfect and passes quality control, it will be sent out to the station of silicone for silicone cutting. If not, the resin has to be sent back, to adjust the 3D-model and print out a new resin. Last stage is wax injection, hot wax is injected into the silicone mole and wait for it to cool, then the wax piece is sent to the wax carving station again to check quality before being sent out to cast into gold. The quality control of wax is considered the last process of modeling department, sending the wax to cast is the responsibility of the factory.

Defect is a cause that interrupts the production efficiency and effectiveness and also causes higher unnecessary costs to the company which are unable to avoid or eliminate the defection completely. It disrupts the company's income and revenue (Chatrattanawuth, 2014) and leads to rework which consumes more resources such as time, money, and materials. Quality defects increase service, inspection, warranty, rework, and scrap costs as well as inventory and processing time (Jirasukprasert et al., 2014).

According to the data as shown in the Table 1, 76% of total number of products were printed out as resin more than one time in 2016. That means that resins were rejected from the quality control. The percentage in 2017 and 2018 are 76.19% and 83% respectively. This mean that the defect rate of resin has been increasing every year without any awareness. Therefore, this research aims to improve modeling process of jewelry manufacturing, find out root causes of defects, and focus on the research question ***"How to reduce defect rate of the resin during the modeling process by using DMAIC model (Define, Measure, Analyze, Improve, and Control)?"***

Table 1: Records of Resin Printing (2016 - 2018)

	2016			2017			2018		
	Pieces	Percentage	Accumulate Percentage	Pieces	Percentage	Accumulate Percentage	Pieces	Percentage	Accumulate Percentage
Print 1 time	42	24.00%	24.00%	65	23.81%	23.81%	69	17.00%	17.00%
Print 2 times	37	21.14%	45.14%	53	19.41%	43.22%	88	21.67%	38.67%
Print 3 times	25	14.29%	59.43%	52	19.05%	62.27%	85	20.94%	59.61%
Print 4 times	19	10.86%	70.29%	32	11.72%	73.99%	60	14.78%	74.38%
Print 5 times	8	4.57%	74.86%	12	4.40%	78.39%	39	9.61%	83.99%
More than 5 times	44	25.14%	100%	59	21.61%	100%	65	16.01%	100%
Total	175	100%		273	100%		406	100%	

Source: JEMM Company

Research Objectives

The objectives of this research are as followed:

1. To identify and analyze the root causes of the defect resins.
2. To implement DMAIC model in order to improve modeling process and reduce defect rate of resin.

Scope of the Research

This research focuses mainly on the modeling department of only one jewelry manufacturing company. The aim is to reduce defect of resins that occur during the modeling process resulting in rework of computer modeling, resin printing, and resin cleaning process. The historical data is collected over a period of three years, from January 2016 until December 2018.

In this study, only related departments are interviewed in order to understand the process and gain detailed information such as; causes of the rejections, consequences of poor quality resins, nature of products, limitation of process. Lastly, the improvement plan is recommended to reduce the defect of resin from quality concerns.

LITERATURE REVIEW

Quality Management

George et al. (2004) stated that things that do not meet customer requirements or needs and demands are considered as defects which will create cost of poor quality and inefficiency. It is also said by Reid & Sanders (2013) that a good quality management of processes can contribute to a good quality of products or services. Therefore, companies should pay attention to the quality of each processes including paperwork requirements of each processes to ensure that it contains all information needed in order to finish the process correctly.

In the present research, the company is concerned about the resins that failed to pass quality control. These defects disturb workflow of modeling processes because rejected resins are returned to modeler to rework and make adjustments in the computer and reprint a new resin. It creates waste of resources and time which lead to delay in the modeling process and late delivery to customers as a consequence.

Lean Six Sigma

Lean is also referred as “Lean Production” or “Lean Manufacturing” widely uses to improve manufacturing process and production and the reduction of wastes (Chugani et al., 2017). Lean Manufacturing is defined as a management methodology that concerns with identifying components adding value to the product and reducing unnecessary components. It leads to the reduction of wastes or other unnecessary resources used in the production which is a main goal of Lean. Tools that are commonly used in Lean analysis are 5S and 7 wastes analysis. Lean Six Sigma 5S is used to analyze quality and efficiency of the workplace.

Six sigma is a business strategy that allows companies and organizations to drastically improve their performances by breaking through business processes to improve and monitor everyday activities in ways that minimize wastes and resources while increasing customer’s satisfaction (Kaushik et al., 2012). Other also considers Six sigma as a business strategy known as an imperative for operations and business excellence It is an approach to identify and eliminate defects and mistakes or failures that may affect processes or systems (Jirasukprasert et al., 2014). It is now used by numerous firms to improve business processes by applying six sigma DMAIC (define, measure, analyze, improve, control) methodology as a tool to improve quality and process (Garza-Reyes et al., 2010). In order to apply six sigma successfully, companies must to identify and understand the need of both internal and external customers. In general, can say that it is a method with analysis and adjustment of processes to reduce defects and to make the product or service suitable for customer’s needs. It gives importance in management of processes because process considered to be the fundamental element in organization functioning.

George (2002) defines lean six sigma as a methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed and invested capital. This integration of lean manufacturing and six sigma refer to the mean of getting things done faster, better quality, cheaper price, and safer as the benefits of the two are combining and filling the gaps for each other.

In order to get the best from the two methodologies, Lean Six Sigma uses tools from both toolboxes to increase speed of improvement while also increase accuracy in problem solving. The common tools are 5S, 7 wastes, brainstorming, process mapping, standardization, pareto analysis, 5-why and cause-and-effect diagram. The integration of two methodologies enhance capability which enables each limitation within individual concepts to be offset, therefore surpassing capabilities beyond any single methodology (Muraliraj et al., 2018). The top ten benefits of implementing Lean Six Sigma are 1) increase profits and financial saving, 2) increase customer satisfaction, 3) increase production capacity, 4) reduce production cycle time, 5) reduce costs, 6) reduce defects, 7) reduce inventory, 8) reduction in machine breakdown time, 9) improve quality, and 10) improve production capacity.

DMAIC Methodology

Garza-Reyes et al. (2010) state that DMAIC is one of the Six Sigma’s distinctive and essential approaches to quality and process improvement. It consists of the following stages; Define, Measure, Analyze, Improve, and Control. The DMAIC model aims to meet the customer’s requirements. It is also defined as a problem-solving structure. The structure of doing specific processes at specific times and sequences and obtaining the information from every process in order to guide decision making to ensure that the solutions proposed can eliminate the problem and reduce root causes (George et al., 2004). The model indicates how the problems should be addressed step by steps. It involves grouping the quality tools while establishing standardized routine practices to solve the problems (Bezerra et al., 2010). It is used to improve existing processes and has proven successful in improving cycle time, reducing defects and costs while raising customer's satisfaction and consequently increase company's profitability in every industry worldwide.

Cause-and-Effect Diagram

Root causes analysis is referred to a set of techniques that are used to find the reason for the occurrence of unexpected or unwanted situations or accidents. It has been successfully used to help identifying sources of the problems and also leading the way toward solutions. Cause is an input factor that defines the reason of the problem when it occurred (Sarkar et al., 2013).

Cause and effect analysis is one of the techniques to help analyzing and identifying potential root causes of the problems which is also called "Ishikawa or Fishbone diagram". It clearly shows relationships between all the factors and its consequence results by categorizing all the factors into its categories such as; Methods, Manpower, Machinery, Materials, and Measures.

Cause and effect is also considered as an important tool for problem-solving of quality management used to identify possible causes of problems or defects in the existing process by brainstorming, generating ideas, and gathering information from the team or associated people. Another benefit is that it also helps to narrow down the scope of problems.

METHODOLOGY

Data collection

In this research, data is collected by using two methods; Data collection forms and Interviews. Researcher uses the data from January 2016 to December 2018 to analyze the further stages. There are two main forms used to collect data and record information needed as indicated in Table 2 and 3.

Table 2: Time Card of Modeler

Date	Description	Name	JM-No.	Start Time	Finish Time	Notes
2 Jan 18	CAD	Modeler A	JM-2258	9.00	12.00	
2 Jan 18	CAD	Modeler A	JM-2258	13.00	15.00	Finish version 1
2 Jan 18	CAD	Modeler A	JM-2260	15.05	18.00	Stone drafting

Table 3: Records of Modeling Expenses

Date	Invoice No.	Supplier	Description	JM-No.	Price
15 Jan 18	INV-D15742	Supplier A	Print Resin	JM-4569	฿ 1,650
16 Jan 18	INV-180122	Supplier B	Silicone	JM-4465	฿ 250
30 Jan 18	RP-18/0041	Supplier C	Print Resin	JM-4581	฿ 1,200

Table 2 Modeler time card is a data collection form to record how much time modeler spend for each product by recording under JM number of products. Each modeler is required to fill in their own time card and submit to modeling coordinator at the end of the week. Then coordinator will input data into the system beginning of each week. On the other hand, Table 3 is a form to record all the expenses associate with modeling department such as; invoices of resin printing, invoices of silicone, and outsource computer modeling. Another method researcher uses to collect data and information is to interview people who are associated with resin. This is to gather information of defects and understand its consequences. Total 15 persons were interviewed individually consist of 4 computer modelers, 2 resin and wax

modelers, modeling coordinator, 2 resin supplier, head of setting department, head of goldsmith, QC of modeling department, QC of factory, factory manager, and sales person.

Data analysis

All data and information gathered will be used to analyze by implementing DMAIC methodology form Six Sigma concept. This approach helps to solve problem step by step by going through the five phases of Define, Measure, Analyze, Improve, and Control.

Define

From the observation, it was identified that the company has been facing the problem of late delivery. It is because of rejection of resin from quality control which lead to a delay start and cause late delivery as consequences. Another reason that causes the problem is customers' involvements that consume time and efforts and affect the production and cause delay. But this is considered as an external factor which the company cannot control. On the other hand, the internal factor that causes delay is a rejection of resin due to quality in terms of technical problems which can be controlled and managed. As they need to re-print and rework on the resins, the company should find a solution to reduce defects of resins and solve this problem.

Figure 2: Process Flow of JEMM Company

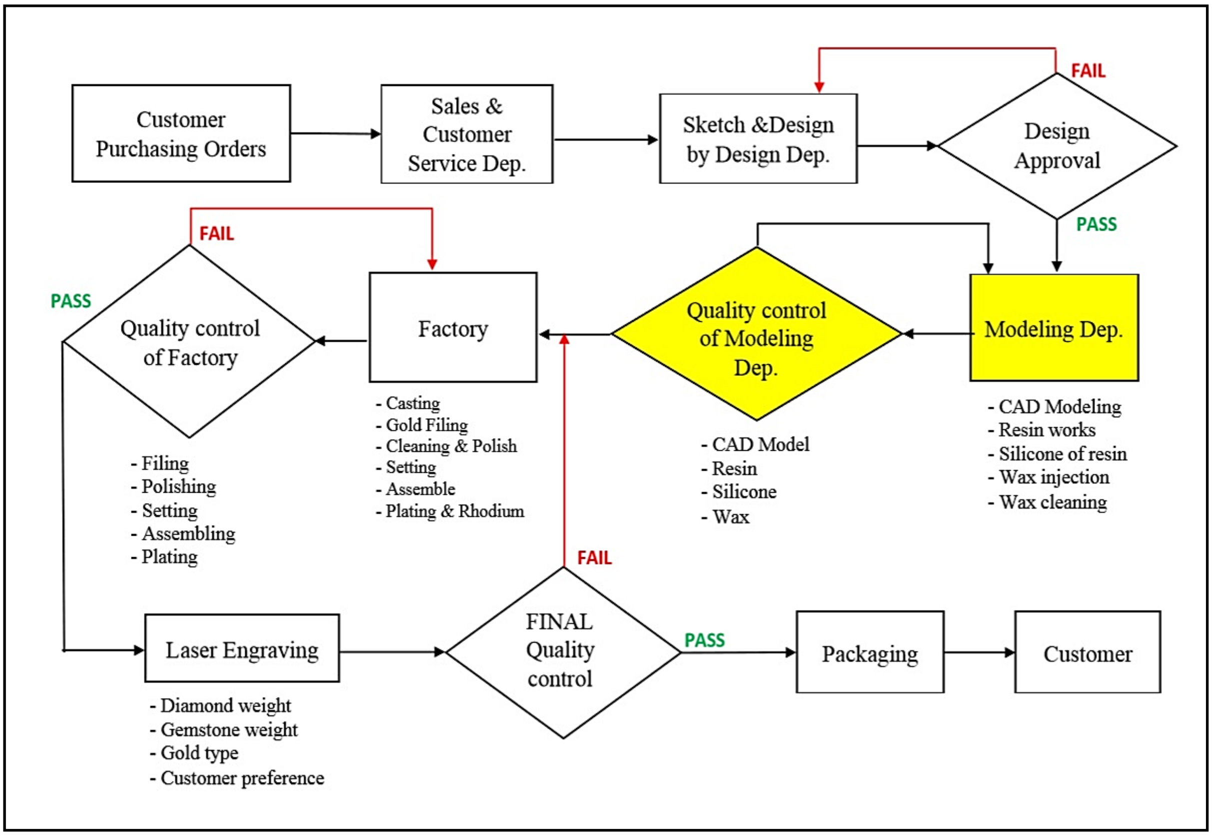
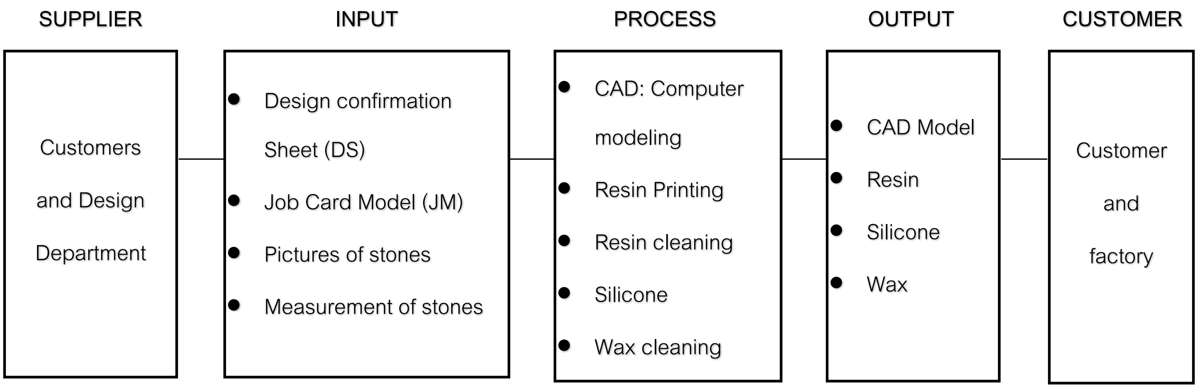


Figure 2 above shows the processes mapping of the company starting from receiving the order until it's delivered to customers. This is only an overall process to give a holistic view of production processes. As seen in the diagram, every process needs to pass the quality control in order to continue to the next process. Processes are highlighted yellow in figure above which helps to clarify specific scope of the research.

In Figure 3 below shows the SIPOC diagram of modeling department which is the focus area. For the supplier, customers are considered as a supplier because they supply center stones for modeling department to take pictures and create 3D-model in the computer while design department supplies the design and product information in the form of design sheet (DS). On the other hand, customers and factory are also considered as customer of modeling department. Factory is a direct internal customer because they are the ones who receive the wax from modeling department and sends out to cast into gold. The casting process is the responsibility of the factory. Even though the customers are classified as supplier, they're also considered as customer of modeling department itself because sometimes the company is required to send resin pieces to customer to review and approve the resin before proceeding with further stages.

Figure 3: SIPOC of Modeling Department



Measure

According to the historical data from January 2016 to December 2018, Table 1 shows number of resin printing times. Number of pieces produced increased 56 percent in 2017 and 49 percent in 2018, but percentage of pieces that print resin 1 time decreased gradually from 24 percent in 2016 to 17 percent in 2018. It means that defect rate of resins increased continually every year.

Table 4: Cost of Good and Defect Resin in 2016 (THB)

	2016					
	Pieces	**Percentage**	**Accumulate Percentage**	**Resin Cost (THB)**	**Cost of good resin (THB)**	**Cost of defect resin (THB)**
Print 1 time	42	24%	24%	83,782	83,782	0
Print 2 times	37	21%	45%	73,808	36,904	36,904
Print 3 times	25	14%	59%	49,870	16,623	33,247
Print 4 times	19	11%	70%	37,901	9,475	28,426
Print 5 times	8	5%	75%	15,958	3,192	12,767
More than 5 times	44	25%	100%	87,772	14,629	73,143
Total	175			349,092	164,605	184,487

Table 4 shows the calculation of cost of good and defect resins in 2016. Total annual printing cost of resin is 349,092 baht. As you can see 47 percent of total cost or 164,605 baht is a cost of goods or resins that passed the quality control while 184,487 baht equal to 53 percent of total cost are due to defect resin. More than half of the total resin costs in 2016 are allocated to the defect resins.

In table 5, number of pieces produced in 2017 increase 56 percent from 2016 with total resin printing cost of 593,832 baht while percentage of defect resins remain at 53 percent same as 2016. Total cost spent on the defect resins is 313,085 baht.

Table 5: Cost of Good and Defect Resin in 2017 (THB)

	2017					
	Pieces	Percentage	Accumulate Percentage	Resin Cost (THB)	Cost of good resin (THB)	Cost of defect resin (THB)
Print 1 time	65	24%	24%	141,389	141,389	0
Print 2 times	53	19%	43%	115,286	57,643	57,643
Print 3 times	52	19%	62%	113,111	37,704	75,407
Print 4 times	32	12%	74%	69,607	17,402	52,205
Print 5 times	12	4%	78%	26,103	5,221	20,882
More than 5 times	59	22%	100%	128,337	21,390	106,948
Total	273			593,832	280,747	313,085

Table 6: Cost of Good and Defect Resin in 2018 (THB)

	2018					
	Pieces	Percentage	Accumulate Percentage	Resin Cost (THB)	Cost of good resin (THB)	Cost of defect resin (THB)
Print 1 time	69	17%	17%	146,143	146,144	0
Print 2 times	88	22%	39%	186,386	93,193	93,193
Print 3 times	85	21%	60%	180,032	60,011	120,021
Print 4 times	60	15%	74%	127,081	31,770	95,311
Print 5 times	39	10%	84%	82,603	16,521	66,082
More than 5 times	65	16%	100%	137,672	22,945	114,726
Total	406			859,918	370,584	489,334

Table 6 shows that the number of pieces produced increased 49 percent from 2017 with total resin printing cost of 859,918 baht. But in 2018, approximately 57 percent of costs or 489,334 baht are allocated to the defect resins which increased 4 percent from previous year.

It can be concluded that JEMM Company has been growing quite fast in the past 3 years as can be seen from the number of pieces produced in 2016, 2017, and 2018. As the number of pieces produced increased, defect resins increased as well. In 2016 and 2017 total defect resin costs are 53 percent of total resin printing costs while in 2018 it increases to 57 percent. Therefore, JEMM Company should start paying attention to the problem of defect resins and try to find solutions to reduce eliminate defects.

Figure 4 shows as-is swim lane process mapping of modeling department which specify who is responsible for each process. After the sales received design confirmation from customer, design department prepares all the details information for CAD modeler which is called "Design Confirmation Sheet (DS)". Model department opens a job card for model called "JM-No" and attaches it with the DS to make sure that modelers can see all the information and important details.

Once they finished the CAD, they will send the file to supplier to print out a ceramic resin. The resin pieces then go into factory for quality check as to whether the specifications and proportion are correct or not. If it passed the quality control, factory will send it to another supplier for a silicone mole.

Next is wax injection and preparing for final wax to send out for casting. This is the last process of model department and the rest will be counted as a production process. But if the resin is rejected from the factory, it will be sent back to adjust the model in computer and re-print again. Therefore, this research will focus in the area of modeling and analyze the root cause of the resin that are rejected from the factory.

Figure 4: As-is Swim Lane Process Mapping of Modeling Department

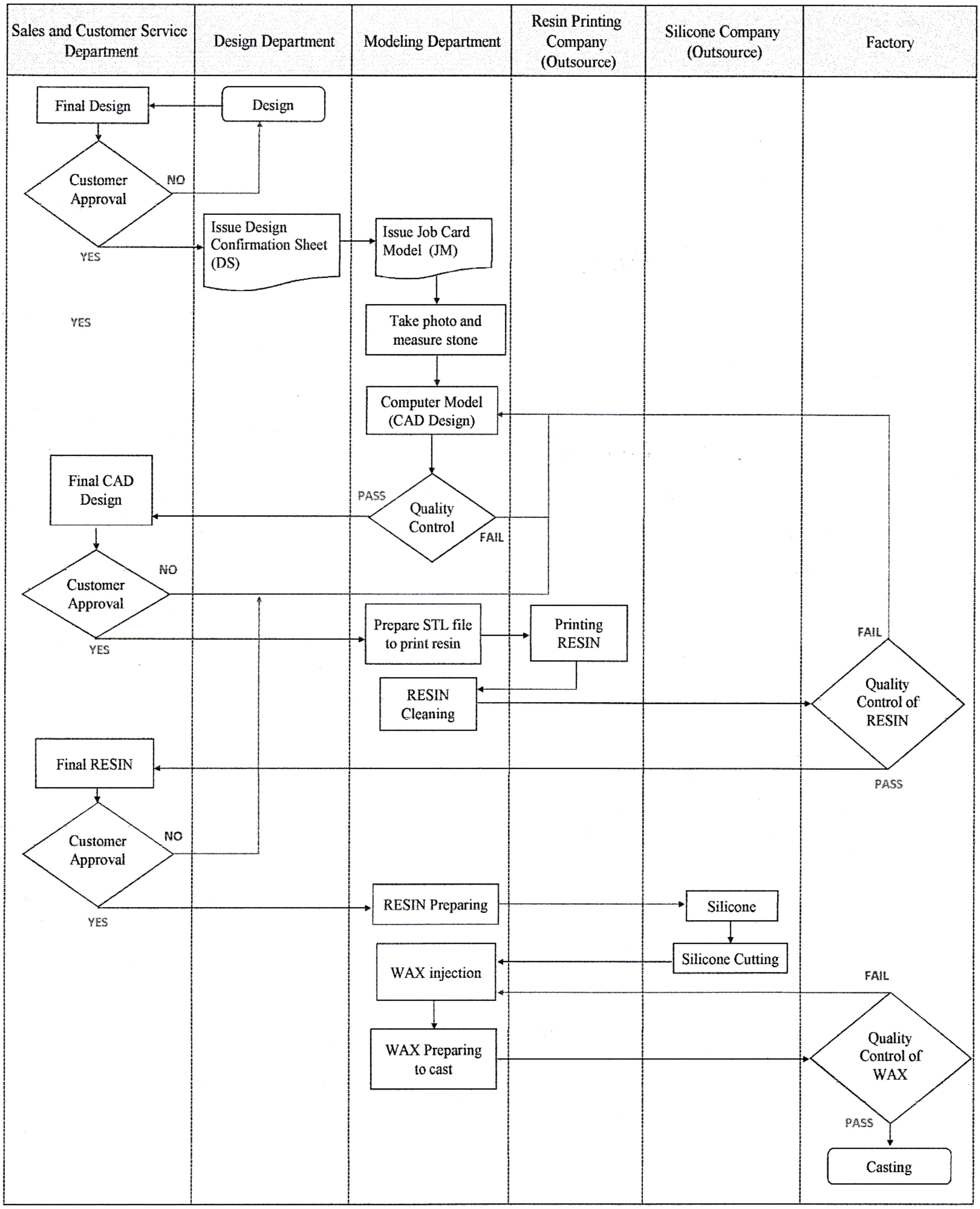


Table 7 illustrates a breakdown of processing time of each process in the modeling department with the total cycle time of 13 days to 29.5 days. The result of cycle time does not include designing process, design approval process, and the process of issuing design sheet because as mentioned earlier that modeling process started after receiving design sheet from the design department.

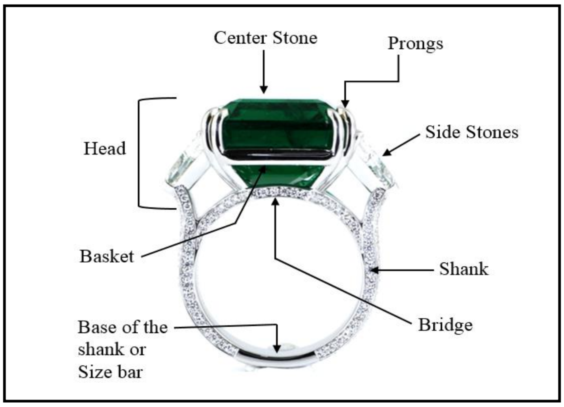
Table 7: Modeling Cycle Time

Process	Responsible Department	Processing time (Day)
Customer confirmed design	Sales and customer services	1 - 3 (not include)
Issue Design Sheet (DS)	Design Dep.	0.5 (not include)
Issue Job Card model (JM)	Modeling Dep.	0.5
Stone measuring and photo	Modeling Dep.	1 - 2
Computer Modeling	Modeling Dep.	3 - 14
Quality control of CAD	Modeling Dep.	1
Customer approval of CAD	Sales and customer services	1 - 2
Prepare STL file	Modeling Dep.	0.5
Printing Resin	Outsource	1.5 - 2
Resin cleaning	Modeling Dep.	0.5 - 1
Quality control of Resin	Factory	0.5 - 1
Customer Approval of Resin	Sales and customer services	1 - 2
Resin preparation to Silicone	Modeling Dep.	0.5
Silicone	Outsource	1
Silicone cutting	Outsource	0.25 - 0.5
Wax injection	Modeling Dep.	0.25 - 0.5
Wax preparation to cast	Modeling Dep.	0.25 - 0.5
Quality control of Wax	Factory	0.25 - 0.5
Total Modeling Cycle Time		**13 - 29.5**

Analyze

The goal of this phase is to identify and analyze the root causes of defect resins. During the analyzing phase, the researcher interviewed every member associated with modeling and resin, including factory manager and quality control staffs. The main objective was to gain more understanding of the problems and its consequences. From gathering the information, the reasons of defects were categorized into eight causes. Figure 5 below illustrates the ring structures which consists of center stone, side stones, prongs, head, basket of the stone, shank, bridge and size bar.

Figure 5: Ring Structure



As a result from analyzing all data and information that researcher had collected and gathered by observation and interview, there are eight causes of resin rejections as follows:

1) **Resins are in a wrong size:** The resin is printed in a wrong ring size.
2) **The ring is not proportion:** Head and Shank are not in a right proportion.
3) **Resins are failed of pre-setting:** The center stones cannot be set on the resin meaning the stone sizes in the computer are not correct.
4) **The prongs are too small:** The prongs of center stones are too small compared to the actual size of stone. It is not safe for the stone because there will be a chance that the

stone might pop out. For example; prongs with the width of 0.7 mm is only suitable for stone size 3.0 mm +/- 0.1mm. If the stone is bigger than 3.1mm, it is not safe to set the stone because there is a chance that the prongs can break and stone pop out.

5) **The shank is too thin:** If the shank is too thin, setter cannot set small diamonds on the shank because the bottom of diamonds will go through the gold and might scratch the skin. In the case of a plain shank, if the shank is too thin, the ring will become sharp and might make customer feeling hurt while wearing it. For example; plain shank should be minimum 1.2 mm thickness and for the shank to set diamonds, it depends on sizes of diamonds to set on the shank such as; diamonds size 1.0mm should have thickness of 1.7 mm.
6) **Resins are not designed for assemble:** Sometimes resins are printed into separate parts for a purpose of setting. Modeler didn't plan for goldsmith how to assemble the pieces. In the case that the goldsmith cannot assemble, resin will be sent back to the modeling department to adjust and re-print again.
7) **The bridge is too thin:** Bridge is acting as a base for ring sizing. If it is too thin, it will become very sharp and hurt the finger because the bridge is sitting on the finger. For example; a minimum thickness should not be less than 1.2 mm for CAD Model.
8) **Resins are poorly print:** The resin itself is defect from printer. The surface of the resin is unequal and not smooth.

All eight causes are further categorized into the four categories of cause and effect diagram to analyze relationship between the causes and effects which are defect resins. The four categories are Machinery, Methods, Manpower, and Others.

Figure 6: Cause and Effect Diagram of Defect Resin

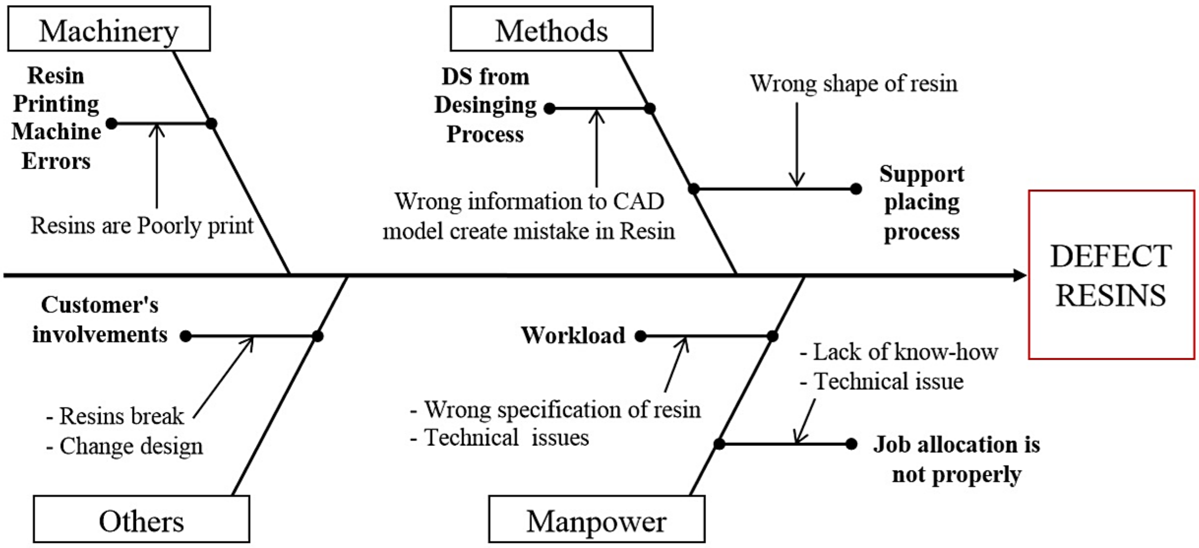


Table 8 is an explanation of the cause and effect diagram in figure 6 above.

As a result from analyzing all information, it shows that category Methods and Manpower are causes from internal which can be managed to reduce defects while category Machinery and Other are causes from external factors that cannot be controlled. Therefore, this research will only focus on the internal causes in Improve phase and Control phase.

Table 8: Cause and Effect of Defect Resin

Category	Cause	Effect
Machinery	Resin Printing Machine Error	Surface of the resin is unequal and not smooth. Can see different layers of printings.
Methods	Design Sheet (DS) from designing process	Wrong information in the DS passing to computer modeler could lead to a mistake in resin such as wrong ring size and wrong setting type.
Methods	Support placing process	Supports need to be placed correctly and properly if not, the resin will not come out as expected.
Manpower	Job allocation is not properly	Each modeler has their own way of thinking, different style, and different expertise. If the work is not allocated properly, it could lead to a technical issue when the resin is printed out because they're lacked know-how and experience with the style that they're not familiar with.
Manpower	Workload	When there is too much workload, modelers pay less attention to small details such as ring size and prong thickness because they want to work fast. This causes a mistake in resin in terms of technical issues which result reprint of resins.
Others	Customer's involvement	Sometimes the resin piece is sent to customer for approval before proceeding further stage, but customer sometimes breaks the resin because it is very fragile. On the other hand, some customers don't like the resin and request to change design.

Improve

The goal of Improve phase is to identify solutions to solve the problems, in this case to reduce defect resins and eliminate wastes. From the Analyze phase, there are eight causes of resin rejections:

1) Resins are in a wrong size.
2) The ring is not proportion.
3) Resins are failed of pre-setting.
4) The prongs are too small.
5) The shank is too thin.
6) Resins are not designed for assemble.
7) The bridge is too thin.
8) Resins are poorly print.

Seven out of eight causes of resin rejection are technical issues that occurred internally which can be grouped into 2 categories; **Methods** and **Manpower**.

Methods

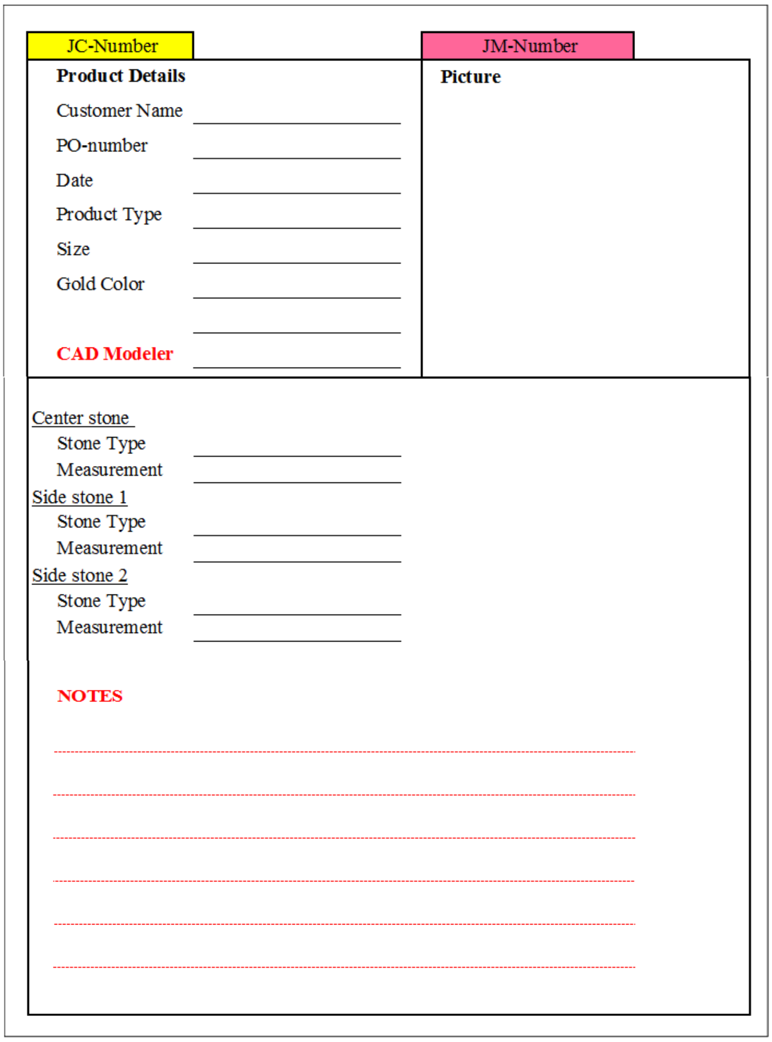
- Resins are in a wrong size

In this category the company is lacking a system to control information in terms of product's specifications such as; center stone, ring size, gold color, setting type, length of bracelet, and length of necklace. It is very important to collect as much information as possible because it is considered as customers' requirements. Therefore, company should create a checklist of all important criteria of product and attached with Design sheet (DS) and Job Card Model (JM) before assigning the works to each modeler. This is to ensure that there are all information needed in order to make the correct computer modelling. A sample of the job card model is shown in figure 7.

Manpower

- The ring is not proportion.
- Resins are failed of pre-setting.
- The prongs are too small.
- The shank is too thin.
- Resins are not designed for assemble.
- The bridge is too thin.

Figure 7: Job Card Model



In this category the causes of rejections are from human errors. Currently there are four modelers in charge of computer modeling. Each one has different expertise in different style of products. But sometimes they're given work that are not their style because of the workload. This is where mistakes occur and lead to defect resin because they lack. The know-how and their knowledge is limited to each one style. Therefore, there are three ways to solve the problem and eliminate defects.

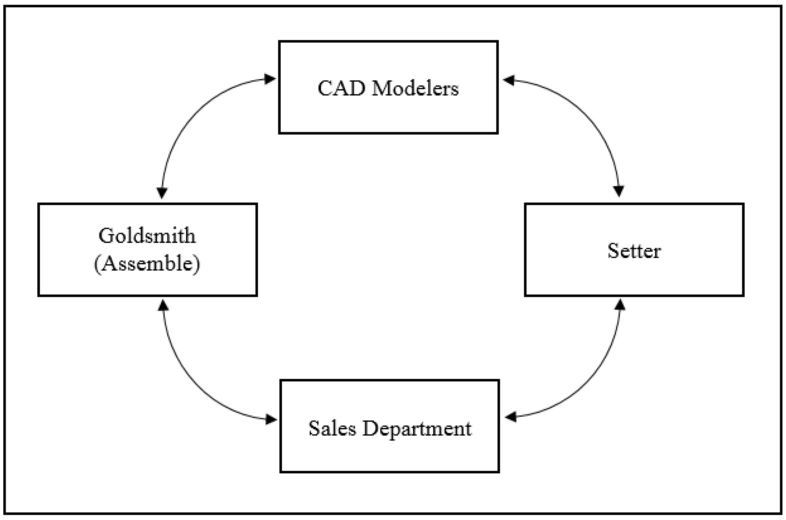
Professional Training

JEMM Company is using Rhino CAD as a main program for computer modeling. They should allocate budget to send their modelers to take more Rhino courses. It will also help encouraging them to learn new techniques, gather new ideas, and develop themselves so they can work more efficient and more effective.

Encourage Collaboration

According to the SIPOC analysis, factory is considered as customer of modeling department. As shown in Figure 8 below, company should encourages collaboration between CAD modelers, factory, and Sales department to smooth the process flow are reduce mistakes, especially the setters and goldsmith because they are the one that set all stones and assemble the piece.

Figure 8: Modeling Collaboration Cycle



For example; if the product is a ring and the modeler does not know what size of prongs is suitable for different sizes of center stone, he should go to the setter and ask for his opinion. Another example is for a bracelet, problems are usually about the hinge and connecting part. In this case, modeler should go to discuss with goldsmith to ask for his opinion because they are the ones who assemble pieces together. By promoting collaboration between modeling department and factory, it will help modeler foresee a potential problems and solve them before printing the resin.

CAD Reviews Form

In order to print out CAD model on a paper to review, CAD modelers must put a ruler zone on the left of the paper. This is to enable to check and measure that the print out pictures are of actual size. It is very important to always print out a correct actual size of model pictures on the paper so it's easier and more precise to see a potential problems.

Build up standards

First, modeling department should set up a meeting with the factory at least once a week. This will give a chance for modelers to observe the problems, learn from the mistakes, and discuss for solutions. Second, modeling department should collect data and information from the pieces that they had made and doesn't have any problems in order to build up a list of standard measurements for technical specification. For example; prong thickness for different sizes of stones, minimum thickness of the bridge, minimum thickness of the shank for different sizes of diamonds and types of setting, etc.

Machinery

- Resins are poorly printed.

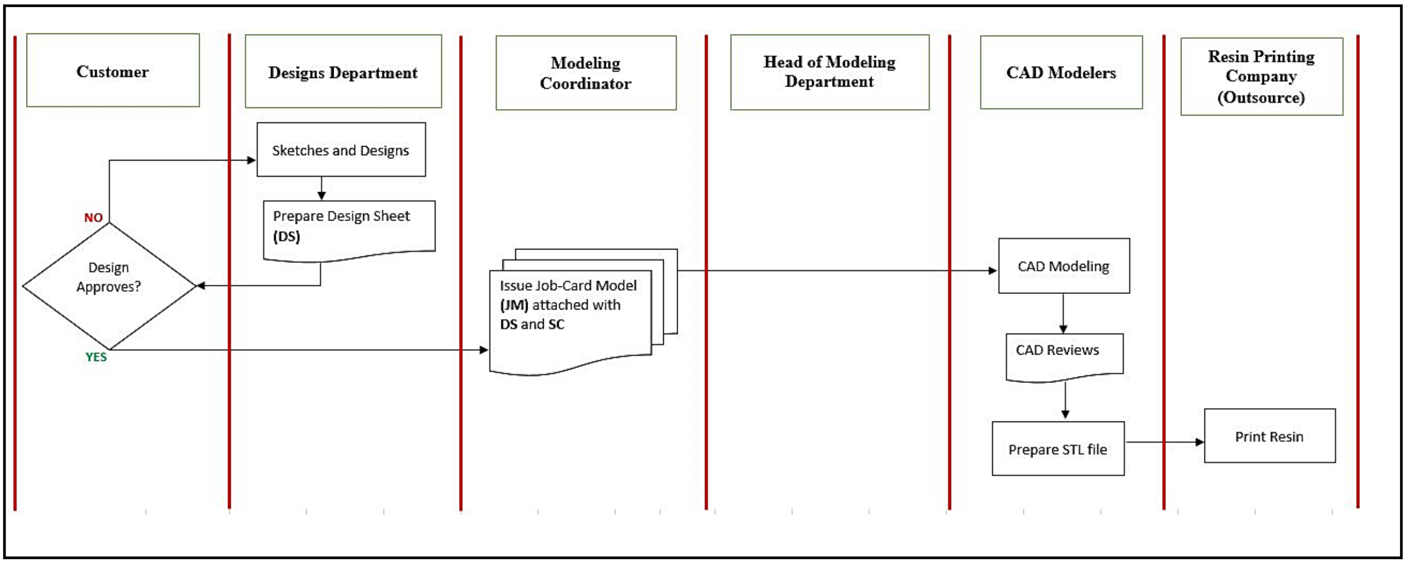
When the resin is poorly printed means surface of the resin is unequal and not smooth therefore you can notice different layers of the resin surface. It is listed as number eight on causes of resin rejections. It is the only cause that was grouped into category machinery because the root cause is from an error of the resin printing machine which is in charge of the outsource company. Currently, after researcher has discussed with few resin printing companies, they're still not be able to control this problem. The protocol is to re-boost machine and reprint the same tray again on a next schedule. Therefore, this research does not focus on this category for further information because it's an external cause that JEMM Company cannot control.

Control
The objective of six sigma DMAIC is not only to improve the process but it is also to control and make sure that the improvement of process of continuing for a long run.

Work Instruction - Control information of Job Card Model (JM)
First, the purpose of work instruction is to ensure that modelers will receive accurate and correct information from the designing department, modeling coordinator has to open Job Card Model (JM) then transfer all the information into JM paper and give to head of modeling department to approve before giving to CAD modelers to start the model. Another process is that every pieces must get approval from the head of modeling department before sending the file outside to print out as resin. These additional processed also help standardizing and simplifying the processes which reduce gaps in the process. A comparison between as-is work flow and a new work instruction is illustrated in figure 9 and figure 10.

Project Charter to build up standards
The second, create a project charter for a project to build up standards with a clear project objectives and milestone then assign to responsible team member.

Figure 9: As-is Work Flow of Modeling

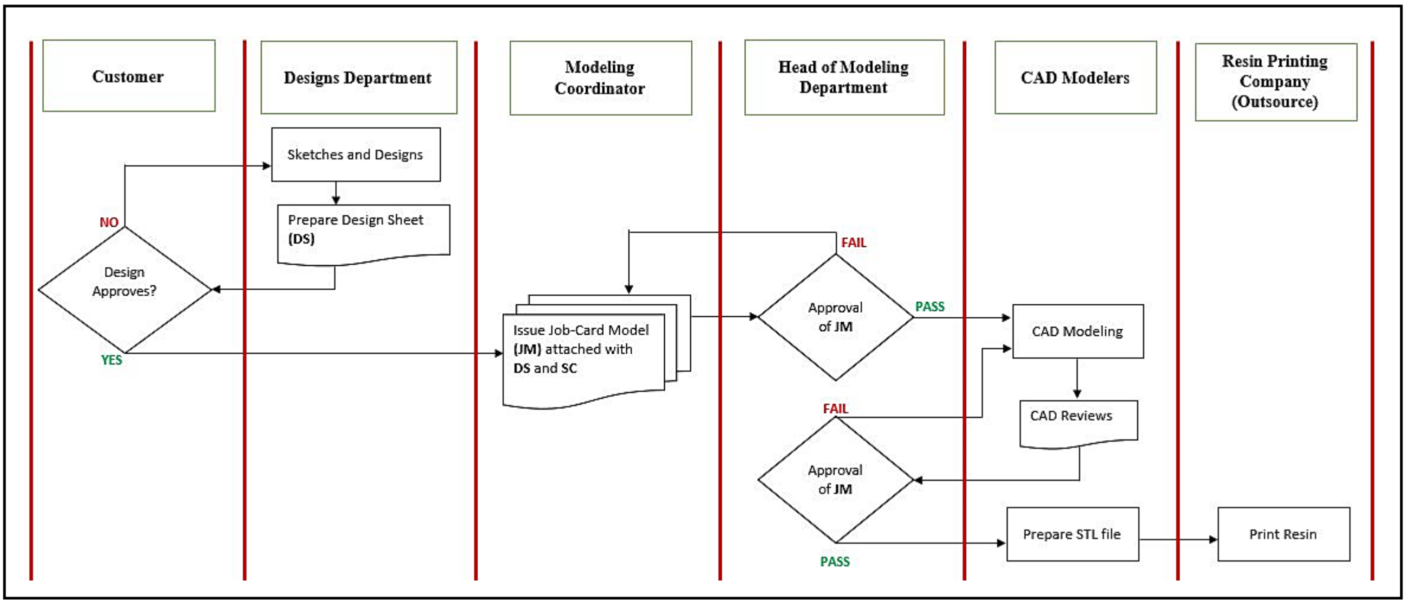


KPI from quality of resin
Every time CAD modelers want to send out the file to print resin, they need to get an approval from the head of modeling department. The third controlling activity is to set additional criteria for KPI relatively to quantity of resin printing and quality of the resin which refers to reject rate of defect resins from the factory.

Improvement of Defect Rate of Resins
The researcher re-designed the job card model and CAD review form. JEMM Company started using both of the new documents in January, 2019 together with a new work instruction to control information and ensure continuous improvement. After that, researcher has collected data and gathered all information and feedbacks by using the same data collection methods as before in order to compare the results. Then, the project of building up modeling standards of

specification was launched to start in April, 2019 which are controlled by using the project charter with specific time frame and a clear objectives.

Figure 10: To-Be Work Flow of Modeling



As a result, number of resins print one time has increased significantly from 17% in 2018 to 42% at the end of quarter 2 in 2019. Numbers are shown in Table 9 below. This means that company has been able to clearly reduce the defect rate of resins and also improve modeling processes.

Table 9: Improvement of Resins Printing (Q1 + Q2)

	2018							2019				
	Q1	Q2	Q3	Q4	Total	Percentage	Accumulate Percentage	Q1	Q2	Total Q1+Q2	Percentage	Accumulate Percentage
Print 1 time	23	19	12	15	69	17%	17%	44	56	100	42%	42%
Print 2 times	19	29	23	17	88	22%	39%	35	41	76	32%	74%
Print 3 times	16	28	19	22	85	21%	60%	12	21	33	14%	88%
Print 4 times	9	18	20	13	60	15%	74%	9	2	11	5%	93%
Print 5 times	7	11	9	12	39	10%	84%	0	7	7	3%	96%
More than 5 times	7	24	19	15	65	16%	100%	2	8	10	4%	100%
Total	81	129	102	94	406			102	135	237		

CONCLUSION

This research emphasizes mainly on the modeling department of JEMM Company as the annual resin cost has continually increased from 349,092 baht in 2016 to 593,832 baht in 2017, and 859,918 baht in 2018. It aims to solve the problem of defect rate of resins occur once in the modeling processes by following research objectives to identify and analyze the root causes of the defective resins and to implement DMAIC model in order to improve modeling process and reduce defect rate of resins.

As a result of the findings, it can be concluded that there are total eight root causes of defect resins that got rejected form the factory. The researcher therefore proposed the following changes. First, JEMM Company has implement a new design of Job Card Model and CAD

Reviews Form to eliminate gaps for mistakes and ensure that CAD modelers will be getting a correct and full information of the piece before they start working on the model. Second, they have encouraged collaboration among modeling department, factory, and sales and customer service department to smoothen the process and reduce technical issues of the resins. Third, modeling coordinator has been working the project to build up standard specifications of CAD models controlling by the project charter with clear objectives and deadline. Fourth, they have added a new work instruction to improve the modeling processes. By adding a process of approval from the head of modeling department before giving job card model (JM) to CAD modelers and before sending the file outside to print resins, this helps standardizing and simplifying processes which reduce gaps in the process. Last, in order to control and evaluate the improvement, the company has set additional criteria for KPI that related to the quantity of resin printing and quality of the resins which refers to the reject rate of defect resins from the factory.

Theoretical Implications

This research has applied DMAIC methodology which is one of the Six Sigma's distinctive and essential approaches to quality and process improvement consist of Define, Measure, Analyze, Improve, and Control (Garza-Reyes et al, 2010). Bezerra et al. (2010) also states that it is a model uses to analyze root causes of problem and to improve existing process which has been proven to be successful in eliminating resources and defects. The DMAIC model is also defined as a problem-solving structure that indicates how the problems should be addressed step by step with grouping of quality tools.

After the researcher has applied the DMAIC methodology to analyze and solve the problem of defect resins, it has become an effective tool to identify root causes of the problem and solutions to improve modeling process as well as quality of the resins. It has confirmed that this methodology is an approach to reduce cost of poor quality (COPQ) in order to generate profit margin as mentioned by Kumar and Sosnoski (2009) because quality defects increase scrap costs, inventory, and processing time as well as interrupt production efficiency and disturb the company income and revenue (Chatrattanawuth, 2014).

Managerial Implications

This research aims to reduce defect rate of resins by analyzing and identifying root causes of the defective resins. JEMM Company can improve modeling process by controlling information on the job card model to be accurate and complete. It's also reducing number of resins that are rejected from the factory due to quality issues because modeling department and factory collaborate more and work closer to each other. They discussed about the CAD model and foresee the technical issues while it's still a file in the computer so they can adjust and solve the problems before printing out as resins. In addition, this research has increased the understanding relationship between causes and its consequence defect of resins. As showed earlier in the table 5.1, the improvement of resins printing during quarter 1 and 2 in 2019, the result clearly shows that company has gained benefits from applying DMAIC methodology. JEMM Company can save more money due to a significant decrease in percentage of resin printing more than 3 times which has shifted to be printing only one and two times. They also reduce wastes in term of resources such as time, efforts and costs of re-printing the resins.

Limitations and Recommendations for Future Research

The research emphasizes on the modeling processes of JEMM Company, defects that occur during other processed were not included in the analysis. Therefore, the results and propose solutions may not be appropriate to apply to other companies due to a difference in business characteristics. Another limitation of the research is all transportation costs that associate with a rework of defects were not included in the analysis. This includes transportation costs such as; cost occurring from picking up the resin from outsource, sending resin to silicone, and picking up the resin and silicone back to factory.

For future research, the study could be investigate more into the production processes because jewelry products are very detailed and customized. There are many interesting areas in the production processes that could be improved. JEMM Company can gain more benefits such as; flexible capacity, elimination of wastes, continuous improvement of products and services, and increase in efficiency.

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