PRODUCT DESIGN PROCESS IMPROVEMENT FOR A JEWELLERY MANUFACTURER

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พันพร เลิศขจรสุข : การปรับปรุงกระบวนการออกแบบผลิตภัณฑ์สำหรับผู้ผลิตเครื่องประดับ (PRODUCT DESIGN PROCESS IMPROVEMENT FOR A JEWELLERY MANUFACTURER) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ. ดร. ปารเมศ ชุติมาPh.D., หน้า.

วัตถุประสงค์หลักของวิทยานิพนธ์ฉบับนี้คือ เพื่อปรับปรุงกระบวนการออกแบบผลิตภัณฑ์สำหรับผู้ผลิตเครื่องประดับโดย ใช้หลักการ Lean Six Sigma DMAIC โดยเลือกบริษัทผู้ผลิตเครื่องประดับในประเทศไทยแห่งหนึ่งเป็นกรณีศึกษา

ในขั้นตอน Define จะเริ่มจากการจัดตั้งกลุ่มเพื่อพัฒนากระบวนการออกแบบ และระบุปัญหาในปัจจุบันที่บริษัทเผชิญอยู่ ซึ่งก็คือการส่งมอบสินค้าให้แก่ลูกค้าล่าช้า และการที่รูปแบบของสินค้าที่ผลิตเสร็จนั้นไม่ตรงตามความต้องการของลูกค้า และต่อไปในขั้นตอน Measure มีการสร้าง Cause and Effect diagram เพื่อวิเคราะห์และระบุสาเหตุของปัญหา รวมถึงมีการกำหนดและจัดลำดับความสำคัญของ RPN โดยใช้วิธีการ FMEA และสรุปผลสาเหตุของปัญหาโดยใช้แผนภูมิ Pareto และในขั้นตอน Analyse มีการประชุมกลุ่มเพื่อพิจารณาหาแนวทางแก้ไขปัญหา และในขั้นตอน Improve มีการวางแผน Action Plan ซึ่งจะมีการใช้ระบบการวางแผนรายวันโดยนำ ERP software มาช่วย และยังมีการนำ CAD และการพัฒนาผลิตภัณฑ์ต้นแบบโดยใช้ 3D Printer รวมถึงหลักการ Concurrent Engineering มาช่วยพัฒนากระบวนการออกแบบ และในขั้นตอนสุดท้ายหรือขั้นตอน Control มีการใช้หลักการ APQP เพื่อติดตามและควบคุมการพัฒนากระบวนการออกแบบผลิตภัณฑ์

จากข้อมูลที่ได้หลังการปรับปรุงการบวนการออกแบบ บริษัทมีการปฏิเสธผลิตภัณฑ์จากลูกค้าโดยเฉลี่ยลดลง และมีเปอร์เซ็นต์ของคุณภาพการออกแบบเพิ่มขึ้น นอกจากนี้ยังพบว่า การพบข้อผิดพลาดด้านการออกแบบในช่วงที่ผลิตสินค้าเสร็จแล้วนั้นลดลง และสุดท้าย บริษัทสามารถปรับปรุงในเรื่องการปฏิบัติตามกำหนดการส่งมอบสินค้า รวมถึงการผลิตสินค้าให้ถูกต้องตามที่ลูกค้าต้องการ เนื่องจากระดับความพึงพอใจของลูกค้าที่มีต่อตารางการส่งมอบสินค้าตรงเวลาและผลิตภัณฑ์ที่เป็นไปตามข้อกำหนดนั้นเพิ่มขึ้น

ภาควิชา	ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต	ลายมือชื่อนิสิต	....
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PANPORN LERTKACHONSUK: PRODUCT DESIGN PROCESS IMPROVEMENT FOR A JEWELLERY MANUFACTURER. ADVISOR: PROF. PARAMES CHUTIMA, Ph.D., pp.

The major purpose of this thesis is to improve the product design process for a jewellery manufacturer by utilisation of Lean Six Sigma DMAIC Methodology. The case is the operations of a jewellery manufacturer in Thailand.

In Define phase, a product design process improvement team was formed and current problem which is delay in delivery and product not as per customer specifications were identified. During Measure phase, Cause and Effect Analysis was performed in order to determine root causes, RPNs were defined and prioritised by utilisation of FMEA, and the root causes were graphically summarised using Pareto Chart. In Analyse phase, the solutions for eliminating the problem were discussed. In Improve phase, action plan was created with an integration of the daily planning system using an ERP software, CAD programme and development of product prototype using 3D Printer, and Concurrent Engineering. Lastly, in Control phase, APQP system was integrated in order to monitor and control the product design process.

After the improvement, there is a reduction in the average percentage of the product rejection from the customers and the average percentage of design quality was also increased. Furthermore, there was a reduction of the design error items found at the launch phase. Lastly, it allowed the company in delivering product as per customer specifications as the results revealed that the degree of customer satisfaction with adherence to the delivery schedules and product as per specifications were increased.

Department:	Regional Centre for Manufacturing Systems Engineering	Student's Signature	....
		Advisor's Signature	....
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ABREVIATIONS

AM	Additive Manufacturing
AM	Advanced Manufacturing Technology
APQP	Advanced Product Quality Planning
CAD	Computer-Aided Design
CATME	Comprehensive Assessment of Team Member Effectiveness
CE	Concurrent Engineering
CEPD	Concurrent Engineering of Product Design
CTQ	Critical to Quality
2D	Two-dimensional
3D	Three-dimensional
DMAIC	Define, Measure, Analyse, Improve and Control
DQ	Design Quality
EBL	Electron Beam Lithography
ED	Engineering Design
EDI	Electronic Data Interchange
EnMS	Energy Management System
ERP	Enterprise Resource Planning
ESAs	Energy Saving Activities
ISM	Interpretive Structural Modelling
KPI	Key Performance Indicator
LSS	Lean Six Sigma
LSSEs	Lean Six Sigma Enablers
MPL	Multiple Patterning Lithography
QA	Quality Assurance
RAS	Remote Acceleration Sensor
SC	Supply Chain
SCM	Supply Chain Management

SCP	Supply Chain Performance
SIPOC	Suppliers, Inputs, Process, Outputs and Customers
SLA	Stereolithography
SLSSF	Strategic Lean Six Sigma Framework
SMEs	Small and Medium-Sized Enterprises
SOPs	Standard Operating Procedures
SWOT	Strength, Weakness, Opportunity and Threat
T&D	Training and Development

CHAPTER 1 – INTRODUCTION

This chapter presents the needs for conducting this research project consists of background of the study, background and analytical overview of the case study company, research overview emphasising statement of problem along with research question, hypothesis development, research objective, assumptions of the study, scope of the research, expected outcomes and overview of thesis structure.

1.1 Background of the Study

In the last few years, the gems and jewellery industry in Thailand has witnessed major growth which is mostly a result of a markedly increased trend in exports of the jewellery items in different parts of the world. Thailand was ranked in the world's top ten exporters in 2016 with the export value of over 14.2 billion US dollars. Moreover, Thai craftsmen top the charts all over the world regarding recognised skills and expertise in gemstone polishing and jewellery making (GITInformationCenter, 2018). Nevertheless, the growth of this sector would be limited because of high market competition in the midst of a global economic slowdown. Due to the fact that Thailand has skilled labour but production bases tend to shift to places where costs are lower such as Vietnam and Myanmar. Hence, Thailand should focus on product design to create market value to cope with increased competition and a global economic slowdown (Reuters, 2016).

Wuttipornpun and Yenradee* (2004) stated that the jewellery business is quite distinctive due to the fact that utilisation of precious materials like gold is required in the form of raw materials. Using these materials as a raw material, which is rare demands and also has specific characteristics, are required to be analysed in line with the production planning process. In another study conducted by Mula, Poler, and Garcia-Sabater (2007) was stated that the utilisation of the precious materials like gold possess a financial value. Harry and Schroeder (2006) stated that a number of models, as well as techniques, have been adopted by jewellery companies in order to resolve the issues linked with productivity, waste management, and competitiveness within the industry. A tool, which has been frequently utilised by the jewellery industry include

Lean Six Sigma, which is basically a hybrid methodology that consists of a combination of both Lean and Six Sigma (Atmaca & Girenes, 2011). These methodologies allow a company to adapt the data-driven and customer focused approach towards the overall production process improvement with the help of waste reduction. In addition, the Lean Six Sigma method composes of various aspects of a business which includes customer satisfaction, design, management, and finally production (Furterer, 2009).

Thus, this research contributes to the overall product design process through applying the model of the Lean Six Sigma DMAIC method to strategically address its encountering problems arising from the production management and also enhance the overall product design process in a jewellery manufacturer. The reason behind the selection of Lean Six Sigma DMAIC method for this study is that it could help a jewellery manufacturer in enhancing the product design process through adequate management, along with that, it could also help in the elimination of waste during the production process, which in turn would lead towards effective cost management, achieving the highest possible customer satisfaction and profitability, and finally increasing in market value of Thailand's jewellery manufacturing.

1.2 About the Case Study Company

The case study company offers high quality and well-crafted personal adornments equipped with exquisite gemstones. The company started as the first Jewellery shop that was established on the Yaowarat Road. Initially, the company employed around four to five skilled craftsmen in order to fulfil the demands of the consumers of both finished and burnished gemstones designed jewellery. Slowly and gradually the company grew and it turned into a partnership business in April 1971, even after four decades, the company still continues to serve its customer with extreme loyalty, and offering them finely crafted jewellery which serves as the cornerstone for the success of the company. Today, the company does not only maintain the highest standards which were set by the ancestors of the company, but at the same time the business has also made huge investments in equipping itself with the highly talented and proficient craftsmen and human resources to serve its customer in the most pleasurable manner possible. Major products of the case study company are shown in Figure 1.

Figure 1: Major Product of the Case Study Company

The company follows a hierarchical organisational structure which is given in Figure 2. In the structure, each level is one over the other, and at each stage within the chain, one individual has some employees working under them and comes within their span of control. For the production part, all craftsmen are controlled by the production department which collaborates with Operation Director on plans for production and also corporate growth and development.

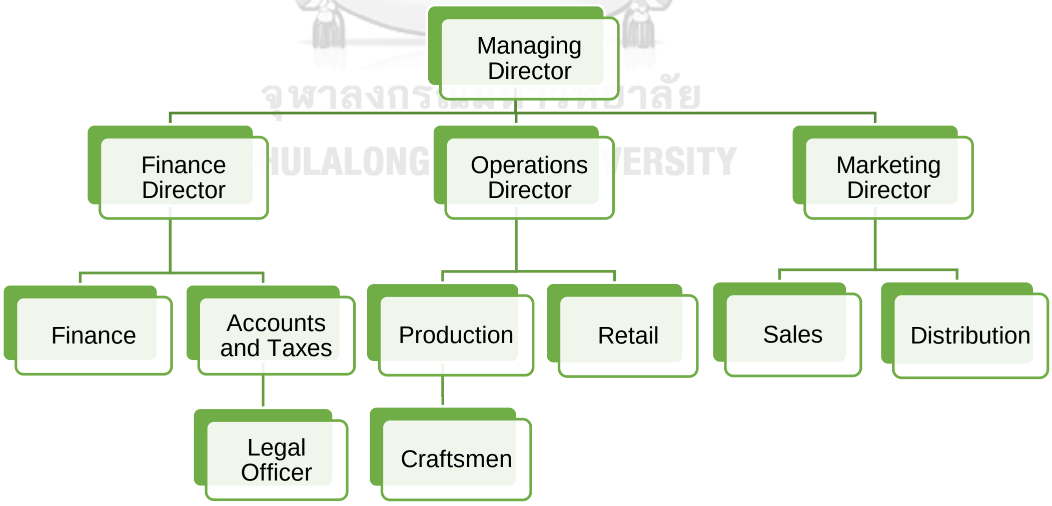

Figure 2: The Organisational Structure of the Case Study Company

Since the company has grown exponentially it has been facing some issues regarding the production flow process which has resulted in delay and decrease in a level of customer satisfaction. In addition, the amount of waste developed has grown and it has increased the overall cost of production for the company. Thus, the company aims to improve the production flow process continuously for the sustainability of business growth.

Furthermore, in today's rapidly evolving global environment, it has become crucial for the smaller firms like the case study company to ensure the management of the production flow process in a more appropriate manner. Consequently, it has become quite significant to keep all of these aspects under consideration and develop a system or model which could not only guarantee the efficient management of the production flow process, while at the same time a system that will help reduction of waste during the production process.

1.2.1 Competitive Business Position

Although the case study company's cash generated currently seems to be fairly low, the company is still able to continuously maintain a competitive position in the jewellery industry over the years. This position can be clarified using Porter's Five Forces Model (Porter, 2008) as demonstrated in Figure 3:

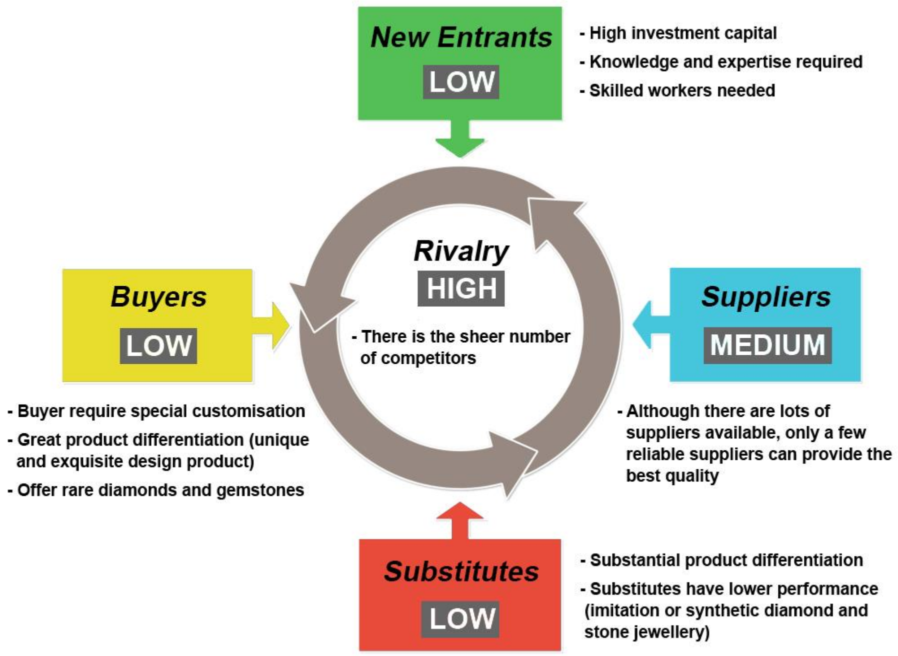

Figure 3: Porter's Five Forces Model for the Case Study Company (Adapted from Porter, 2008)

Regarding rivalry, it is fairly aggressive competition among the jewellery industry since there are numerous competitors while the demand keeps increasing. At present, new entry into the jewellery industry is relatively low due to high entry and investment costs. Besides, it is a prerequisite to have knowledge, expertise as well as skilled workers for new entrants. The company has been buying gold settings from suppliers whereas the company itself also has goldsmiths who have an ability to produce gold settings. However, there are only a few reliable suppliers that can provide the best quality of the gold settings, so it can be concluded that suppliers have medium bargaining power in the supply chain.

There is low threat of substitutes even though in these days there are lots of alternative jewellers or even artificial jewellery which are trying to gain the market share, but as a matter of fact, gold, diamond and gemstone jewellery have their own value and with each passing day as well-being of the country and its people is being enhanced, the social position, as well as the standard of living, are significant factors for people, the gold, diamond and gemstone jewellery are still high in demand than all substitute products, therefore most substitute products actually can't make a threat to this particular jewellery industry. Regarding buyers, the company's customers tend to have low bargaining power due to most of them require special customised products with the finest quality and the unique selling point of the company is an ability to offer a great product differentiation with unique and exquisite design as well as rare diamonds and gemstones.

1.2.2 Corporate Strategies

The case study company intends to be the premier jeweller serving the utmost loyalty service and finest pieces of jewellery to customers. This business was regarded as providing high quality and well-crafted personal adornments equipped with exquisite gemstones, most products are made-to-order or as per customer specifications. In addition, the case study company aims to be the leading jeweller with the goal of achieving the highest possible customer satisfaction and obtaining higher profitability. With all these reasons and the application of Porter's generic competitive strategies (Porter, 1980) which can be used in determining the best generic approach to compete with its competitors, it can be clarified that the competitive strategy for the case study company seems to fall in the differentiation focus quadrant. Porter's generic competitive strategy for the case study company is illustrated in Figure 4 below:

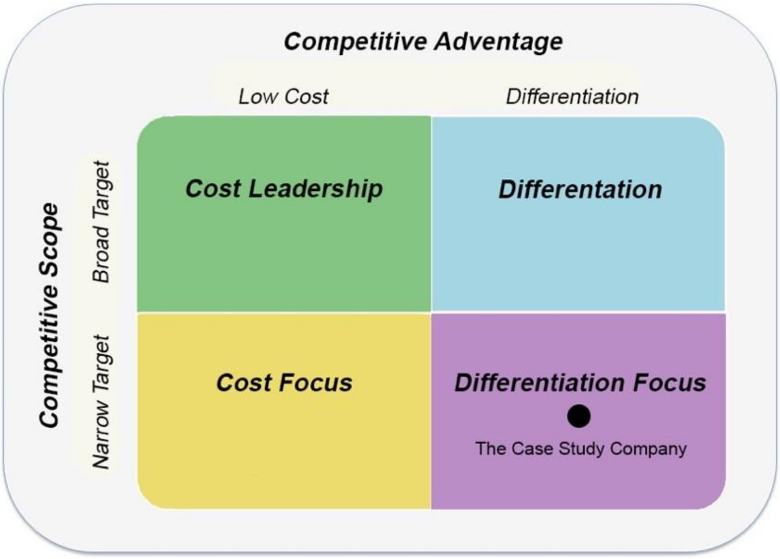

Figure 4: Porter's Generic Competitive Strategy for the Case Study Company (Adapted from Porter, 1980)

Considering business level under Miles and Snow's strategy typology (Miles R. E., Snow C. C., Meyer A. D., & J., 1978), it can be stated that the case study company follows a defender strategy in the jewellery market and subsequently moving towards becoming an analyser. This is because the case study company is obliged to defend its current position as a leading premier jeweller in the market, maintain its stable status and serve current customer expectations. In addition, as the jewellery market in Thailand is growing rapidly and more customers are attracted by the increases in competition among gold, diamond and gemstone industry, this will force the case study company to become more analytical as an analyser in holding on to its customer satisfaction and current markets while also prospecting to be relatively innovative through researching and developing new technology, which will allow the company to discover new growth opportunities.

As the case study company is in a highly competitive market, it is significant for the company to improve the corporate strategies over the years to maintain its profitability. In terms of building such corporate strategies, the applying of SWOT analysis helps in evaluating knowledge of internal and external factors involved in a decision-making process (Fallon, 2018) as well as helps in determining which market segments give the best opportunities for a company to achieve its goal (Newton & Newton, 2013). In addition, during a competitive situation, the analysis can also identify how the company could efficiently manage its resource utilisation in order to meet the demands. The SWOT analysis matrix of the case study company has been identified as showed in Figure 5. The strengths and opportunities indicate advantageous circumstances allowing the company to perform as an analyser. On the other hand, the weaknesses and threats indicate limitations and forewarning allowing the company to execute a defender strategy.

Figure 5: SWOT Analysis for the Case Study Company

From the SWOT analysis, the major weakness which is delayed delivery of the product to customers resulting from ineffective production planning and scheduling indicates a bad signal. Besides, there are various types of potential threat which are also not a positive sign although highly talented and proficient craftsmen and human resources have equipped to serve the company's customer in the most pleasurable manner and punctual to the delivery schedules possible. The company's vision and mission statement are shown in Figure 6.

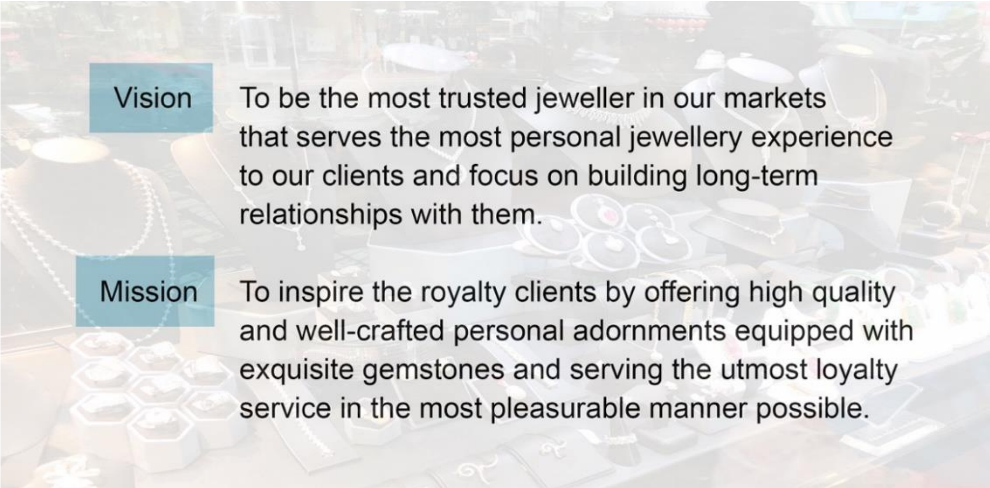

Figure 6: The Case Study Company Vision and Mission Statement

1.2.3 Production Process Overview

The production process has become a fundamental part of the company for a long time. Since most products of the company are made-to-order, so the product as per customer specifications and adherence to the delivery schedules are the key factors to strengthen and maintain customer relationships, which could help the company in terms of increasing market share of the total market for its products and services. Figure 7 provides an illustration of the current production flow process, which is being followed by the case study company.

Figure 7: Traditional Production Flow Process of the Case Study Company

1.3 Statement of Problem

Recently, the case study company has witnessed some serious issues within the production process, mostly due to an inadequate management and monitoring of the production process as well as inefficient time management of the production system. From Figure 1.7 which provides an illustration of the current production flow process of the case study company, therefore, it could be stated that the current production process is quite complex and long, moreover, a major issue with the current production flow process is that there is no step of management and monitoring for product design process due to the fact that the current production system being utilised by the company is outdated. These limitations are the reasons why there occurs product not according to customer requirements and also delays in the delivery of final product to the customers, which in most of the cases customers cancel the orders, and in turn leads to a generation of wastage.

Furthermore, quality control comes at the last phase of the project lifecycle, as it has happened in many cases where customers have rejected or returned the jewellery designed by the company as they stated that it was not as per their provided requirements. Besides, the company has to pay purchase new raw material and go through the whole production process again which leads towards increasing the overall costs of raw material for the company which makes the operations of the company quite expensive and also results cost of goods sold to rise which finally becoming detrimental to the performance of the company in the longer-run (Lukitaputri & Yadrifil, 2015). Table 1 and Figure 8 show the expenses of the case study company.

Table 1: Expenses of the Case Study Company

Expenses	Year		
	2015	2016	2017
Cost of Goods Sold	฿ 1,405,754.70	฿ 1,668,226.10	฿ 2,091,212.00
Operating Expenses	฿ 1,748,759.43	฿ 1,892,414.60	฿ 2,157,547.85
Total Expenses	฿ 3,154,514.13	฿ 3,560,640.70	฿ 4,248,759.85

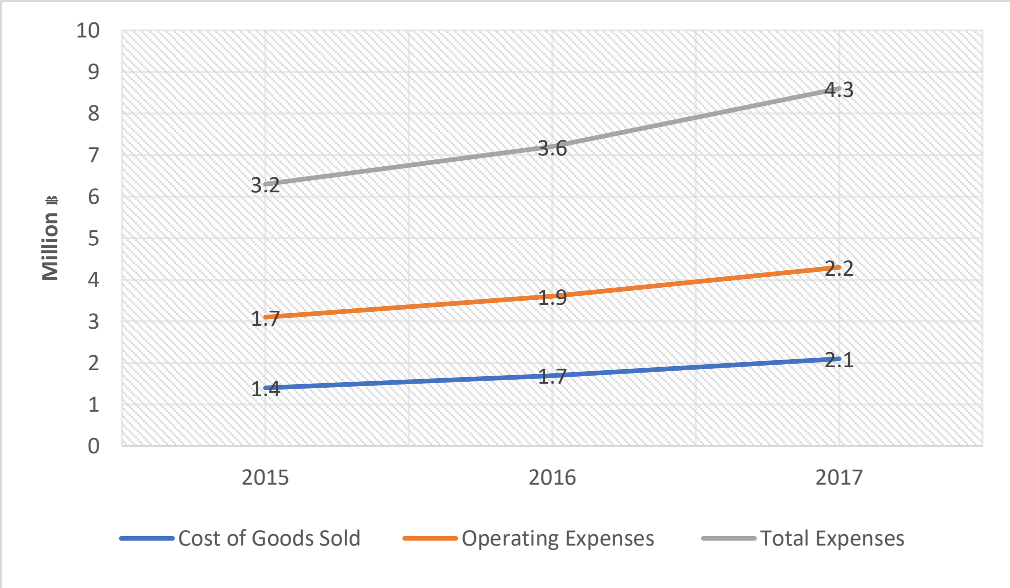

Figure 8: Expenses of the Case Study Company

Another essential aspect here is the company should add new process which is approval of customer before processing forward to the casting process due to the firm must ensure that the design meets the customer requirements in case it does not they must get back on the drawing board instead of proceeding forward with casting. This, in turn, will help in reducing the cost, while at the same time it will help the firms in ensuring that the final product is developed specifically as per the requirements of the customer. Therefore, it could be specified that there is a need to integrate methods which could identify an issue or problem during the design phase and rectify the issue in the same phase instead of proceeding to the next phase.

In summary, delayed delivery and product not according to customer requirements can have possible root causes. In order to capture different viewpoints on root causes, the Ishikawa diagram as known as the cause-and-effect diagram or the fishbone diagram depicted on the next page (Figure 9), provides an illustration of all potential main causes and their root causes of the delay in delivery and the product not according to customer requirement problems that the company have confronted for the last few years.

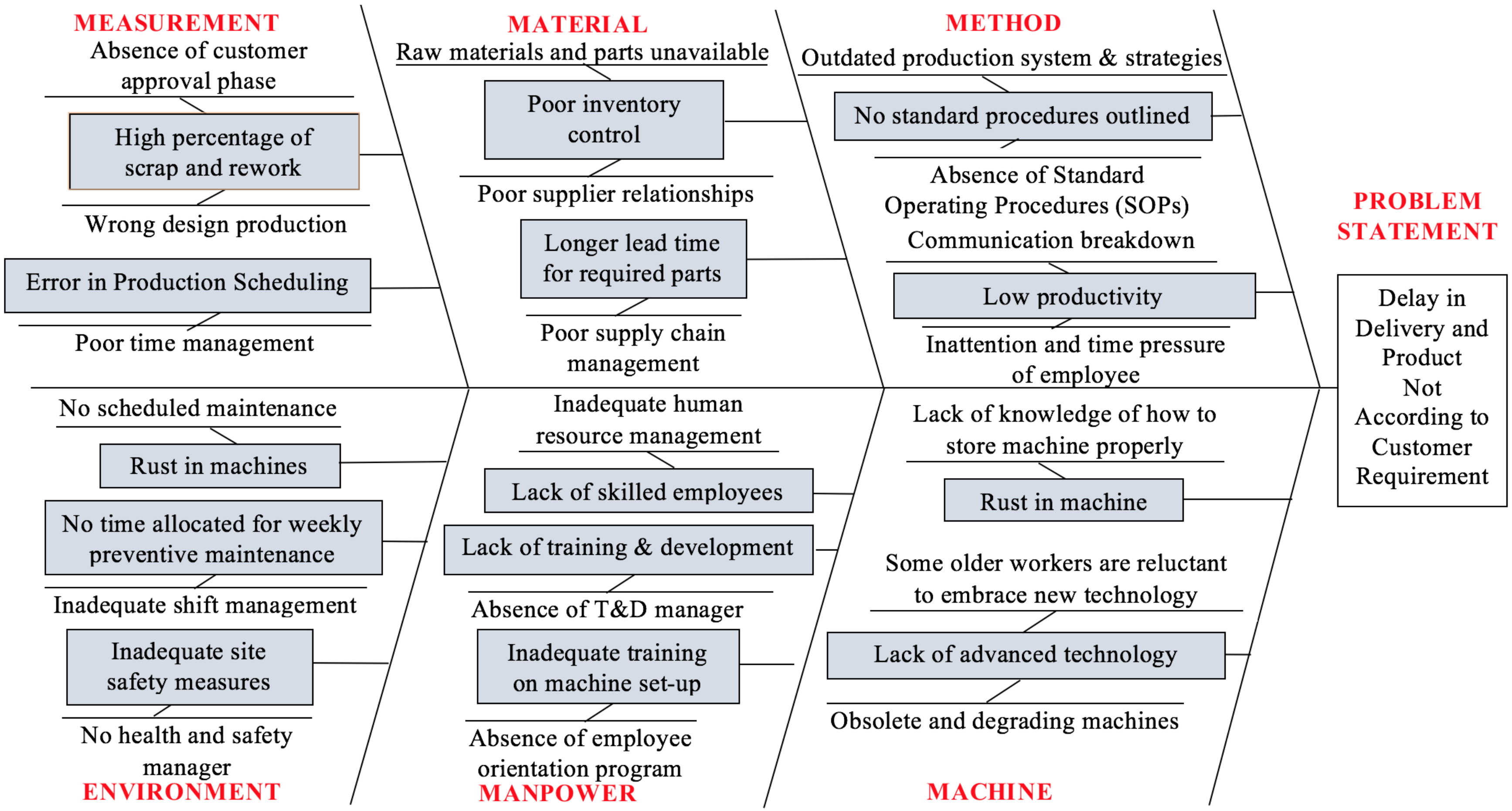

Figure 9: Summary of Possible Causes for the Delay in Delivery and Product Not According to Customer Requirements

1.4 Research Question

This research sets out to answer the following research question: "How can DMAIC approach in Lean Six Sigma helps improve the product design process within the jewellery manufacturing company to overcomes the issue through the elimination of overall waste produced due to wrong order delivery and also reduces in the percentage of delayed delivery that ultimately helps achieve highest possible customer satisfaction and obtain higher profitability?"

1.5 Hypothesis Development

To support the research question, it was hypothesised that "The jewellery manufacturing company improves the product design process in order to overcome the issue through the elimination of overall waste produced due to wrong order delivery and also reduces in the percentage of delayed delivery to ultimately achieve highest possible customer satisfaction and obtain higher profitability by implementing Six Sigma using the DMAIC methodology".

1.6 Research Objective

The objective of this research is to improve the product design process within the jewellery manufacturing company by implementing Lean Six Sigma using the DMAIC methodology.

1.7 Assumption of the Study

Keeping under consideration the fact that the researcher in this study intends to adopt Lean Six Sigma DMAIC model in order to reduce waste and improve the overall product design process, following are some of the assumptions which will be considered by the researcher with respect to the case study company:

- First, the researcher will assume that the company possess complete process knowledge as far as production of jewellery is concerned. Therefore, the researcher will also assume that the current gaps in the process knowledge at the firm are caused due to rejection from customer or manufacturing of defected products, which in turn leads towards increased waste for the company. According to the theorem of Six Sigma, the process outputs (Y) are caused by the environment, the process, and the system inputs:

$$Y = f\ (X_1 \ldots X_n)$$

- Second assumption associated with this study is that all the variations during the production process are caused due to gaps in the process knowledge. These variations usually occur when a system fails to perform in an exact manner for a set of statics process inputs, which leads towards the assumption that there are certainly additional factors that are not yet understood by the firm are basically affecting those processes. According to the theorem of Six Sigma, these variations in the process are a result of environment, the process, and the system inputs:

$$\partial Y / \partial X = f'\ (X_1 \ldots X_n)$$

- Third assumption for this study is that customers only pay for value; therefore, it could be stated that products such as diamond rings are the main vehicles to deliver value for the case study company. Thus, value is only created when a specific need of the customer is met, secondly quality is certainly not the measure of perfection but instead it is the measure of the effect. The case study company currently fails to understand the customer and more importantly their needs which is the major driver of cost for the business.
- Fourth and the final assumption for this study is that when it comes to selecting between short-term profit and long-term sustainable growth, it is the long-term growth which must always outperform the short-term profits for the case study company. This is one of the most essential assumptions of this study since it serves as the cornerstone of Lean Six Sigma methodology. Therefore, if the case study company follows an effective, sophisticated and sustainable manufacturing process it will certainly achieve long-term growth through the formation of sustainable relationship with the customers.

1.8 Scope of the Research

This thesis focuses on the improvement of the product design process of the case study company. Even though there are entirely 13 processes as shown in the current production flow process in Figure 7, the work was scoped to designing (process 1) until creating a wax (process 4) as presented in Figure 10.

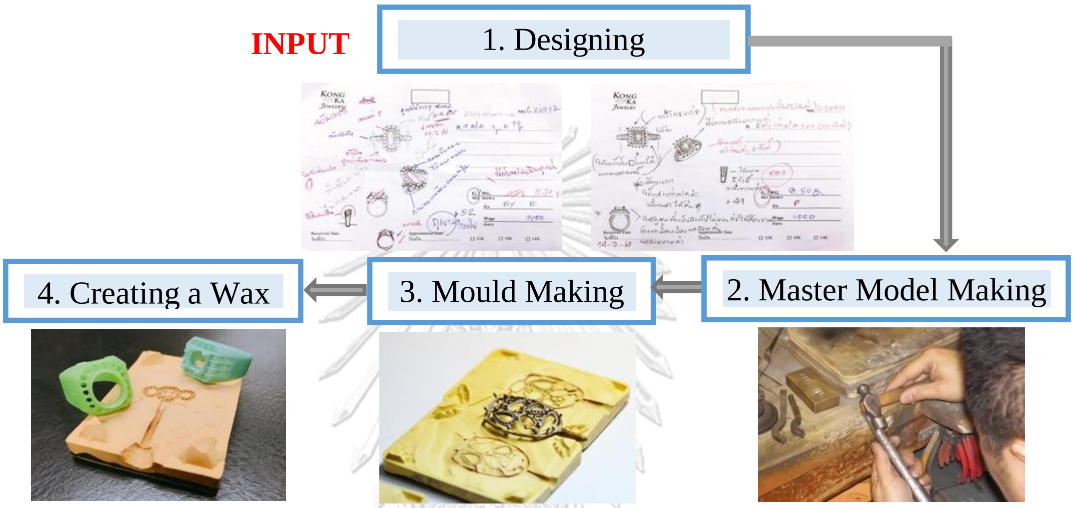

Figure 10: Scope of the Research

The reason for focusing only on these processes as the subject of the study is due to finished design of wax model should be approved by customers before going to the casting process with the aim of eliminating the problem that products have to be redesigned due to they are not according to customer requirements.

1.9 Expected Outcomes

Following are some of the expected benefits which the researcher plans to achieve through this study:

- Reduction in the product rejection rate currently resulted by delays in the delivery of final product to the customers and also product not according to customer requirements, which in most of the cases customers cancel the orders, and in turn, leads towards a generation of wastage.

- Integration of innovative and effective Lean Six Sigma practices within the production systems, resulting in enhancing the competitiveness of the company
- Ensuring adherence to the delivery schedules, which in turn will result in the reduction of the delays
- Reduction in the number of complaints by customers
- Improvement in the productivity and the design quality of the products
- Reduction in the overall operational costs, through ensuring world-class standards in scaling
- Improvement in the overall sales revenue, with lower investments
- Induction of good management practices for management of customer records and product categories and improvement in inventory management to be more efficient
- Promotion of a culture of continuous improvement within the organisation

1.10 Overview of Thesis Structure

The structure of this thesis is organised into five chapters. Contents of these chapters are concisely described as follows:

Chapter 1 provides an introduction and overview of the research which is comprised of background of the study, analytical company background, production process overview, statement of problem, research question, hypothesis development, research objective, scope of the project, expected outcomes and overview of the thesis structure.

Chapter 2 reviews existing literatures in various relevant topics such as Six Sigma DMAIC methodology, SIPOC Diagram, Concurrent Engineering, Computer Aided Design and Rapid Prototyping, Advanced Product Quality Planning and Failure Mode and Effect Analysis. All of which could aid the manufacturing process of jewellery of the case study company through ensuring low operational cost and waste reduction.

Chapter 3 of the study describes an overview of the research methodology, that will be utilised by the researcher in order to achieve the overall research outcomes. Each section will outline the research methods of how the research project was conducted, which will be utilised for achieving the research objectives.

Chapter 4 presents an illustration of method implementations and overall research findings which will be achieved by the researcher through the integration of the different set of methods and tools like Concurrent Engineering, Advanced Product Quality Planning and Failure Mode and Effect Analysis. Thus, this section will elaborate on how an integration of these tools helped in making the production process more effective for the case study company. Moreover, this section of the study will also include data collection, data analysis, and results analysis phase which will be utilised by the researcher to answer the research questions as well as to answer that the results are as expected or not.

Chapter 5 of the study concludes the overall research. The researcher will compare previous and new approach of performing things and also provide an overview of how the overall researcher objectives are achieved, along with that the researcher will also present a brief overview of the answer to the researcher questions.

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction

This chapter of the study will present an overview of existing literatures with respect to the product design process of a jewellery manufacturer including review of literatures published over utilisation of Lean Six Sigma DMAIC methodology and Concurrent Engineering (CE) model; as these methods can help in optimising the manufacturing functions, improving the manufacturing speed, while at the same time reducing the cost during the design process. Furthermore, this section will also include review of literatures in SIPOC Diagram, Failure Mode and Effect Analysis (FMEA), Computer Aided Design (CAD) and Rapid Prototyping and Advanced Product Quality Planning (APQP).

2.2 Review of Six Sigma DMAIC Methodology

Six Sigma DMAIC has been popularly used by a number of researchers for a long time as it provides achievement of continuous improvement with the help of understanding the needs of the customer, and it streamlines the process through the reduction of the operational costs and enhancing the overall production quality. Shokri, Bradley, and Nabhani (2016) defined Lean Six Sigma as the methodology which helps in the reduction of the variations, as well as the one which helps in the detection of defects through identifying and preventing them. In another study conducted by Antony, Setijono, and Dahlgaard (2016), they defined Six Sigma as the method which marries the lean management principles in order to improve the overall efficiency as well as the elimination of the waste through the adoption of a data-driven and statistical approach of Six Sigma, through detection of defects and enhancing the overall production flow process.

Furthermore, Snee (2010) stated that the improvement which occurs through the utilisation of Lean Six Sigma method helps in the reduction of the waste as well as service failure rates within the company at a much more negligible level. Whereas, Yadav and Desai (2017) stated that the main power of the Six Sigma remains within the ability of the tool of creation of repeatable method, which in turn helps in facilitation of the statistics and analysis for determining and defining the source of the issues.

In order to enhance the product design process of the company, the Lean Six Sigma model selected for this study is DMAIC method (De Mast & Lokkerbol, 2012), which is basically a data-driven quality strategy helps in improving the production process (Johansson, 2017), which is the integral aim of the Six Sigma Quality initiative. Every step in the DMAIC process works in a cyclical manner, which ensures that the best possible results are achieved (Callahan & Roberts, 2017). The followings are Six Sigma DMAIC steps involved in the process:

2.2.1 Define

Customers defined their requirements and spectators, the core business process, from the beginning and the ending of the process, and the issues critical to quality.

2.2.2 Measure

The core business process performance is measured through the development of a data collection plan of the process (Antony, Rodgers, & Gijo, 2016). The data is also collected from different sources in order to determine the defects in the current system, and the results are compared to determine the reasons behind the shortfall.

2.2.3 Analyse

The collect data is analysed and a process map is developed with the aim of determining the root causes behind the defects (Vashishth, Chakraborty, & Antony, 2017), along with that, opportunities are also explored for improving the process.

2.2.4 Improve

The target process is improved through the designing of creative solutions aimed towards fixing and preventing the issues, through utilisation of discipline and technology, the company develops and integrates implementation plan.

2.2.5 Control

The improvements are monitored and controlled in order to ensure that the new process stays on course (Thomas, Francis, Fisher, & Byard, 2016). This helps in the prevention of reverting back to the old ways, however, it needs development, documentation, as well as the implementation of the current monitoring plan (Adikorley, Rothenberg, & Guillory, 2017). The most important part of this phase is the institutionalisation of the improvement with the help of modification within the systems and the existing structures of the organisation.

In brief, the summary of the past researches about Six Sigma DMAIC is demonstrated in Table 2 below:

Table 2: Summary of Past Researches on Lean Six Sigma DMAIC

Authors	Year	Objective	Method
Shokri, Bradley & Nabhani	2016	Reduce the level of scrap rate in the production of a product known as the "Remote Acceleration Sensor (RAS)" that is used for Air Bags through Lean Six Sigma (LSS) methodology	Lean Six Sigma DMAIC
De Mast & Lokkerbol	2012	Compare critically the DMAIC method with insights from scientific theories in the field of problem solving	Lean Six Sigma DMAIC
Johansson	2017	Find the main problems that exist and causes mistakes when delivering items from warehouse to client's production department	Lean Six Sigma DMAIC
Callahan & Roberts	2017	Outline the core terms, concepts, and methods of Lean Six Sigma for improving quality, service, efficiency, and value in high-demand industries (manufacturing, military, nuclear safety, and now healthcare) and reflects the scientist-practitioner philosophy inherent in our training	Lean Six Sigma DMAIC
Antony, Setijono & Dahlgaard	2016	Explore the link between Lean Six Sigma (LSS) and Process/Product/Service Innovation	Lean Six Sigma
Snee	2010	Assess Lean Six Sigma to identify important advances over the last ten to fifteen years and discuss emerging trends that suggest how the methodology needs to evolve	Lean Six Sigma

Yadav & Desai	2017	Identify Lean Six Sigma enablers (LSSEs) and analyse the interaction among the enablers via a hierarchical model developed by employing interpretive structural modelling (ISM) and determine the driving and dependence power of enablers through fuzzy MICMAC analysis	Lean Six Sigma
Antony, Rodgers, & Gijo	2016	Demonstrate the widespread but fragmented application of Lean Six Sigma within the UK public sector, providing the context of some of the challenges faced within the sector as well as some of the successful applications of Lean Six Sigma	Lean Six Sigma
Vashishth, Chakraborty, & Antony	2017	Explore the trend and most common themes about Lean Six Sigma(LSS) implementation in the finance sector, and also to identify gaps in the themes that may be preventing organisations from identifying benefits from their LSS strategy and developing an agenda for future research on LSS themes.	Lean Six Sigma
Thomas, Francis, Fisher & Byard	2016	Propose a new Strategic Lean Six Sigma Framework (SLSSF) that attempts to create a more balanced and integrated approach between the Lean and Six Sigma elements and one that is capable of achieving greater efficiency of production whilst also ensuring variation reduction and CTQ issues are eradicated from the production process	Lean Six Sigma
Adikorley, Rothenberg & Guillory	2017	Explore Lean Six Sigma (LSS) project and program success in the textile and apparel industry	Lean Six Sigma

2.3 Review of SIPOC Diagram

Several research studies have used SIPIC diagram which is a tool that is used for the identification of some of the most relevant elements of a process improvement project before the work on the project begins (Simon, 2017). According to Mishra and Kumar Sharma (2014), SIPOC diagram is quite similar to that of process mapping, and some of the other in/out of scope tool, however, an aspect which differentiates this model from other is the ability of the model to provide additional details regarding the project. The name of the tool prompts the project management team to keep under consideration the suppliers involved in the production flow process, the inputs involved in the process, the process towards which the team intends to achieve a certain improvement, the output linked with the process, and the customers who receive the process outputs (Thawani, 2004). Besides, Jacobson and Johnson (2006) explained in their article that the SIPOC tool is quite beneficial under the circumstances where there is no clear information about the suppliers regarding the specifications related to the input, the waste management process who actually are the customers of the process, and the request and queries of the customers.

The summary of previous researches on SIPOC Diagram can be illustrated in Table 3 below:

Table 3: Summary of Past Researches on SIPOC Diagram

Authors	Year	Objective	Method
Mishra, & Kumar Sharma	2014	Introduce a hybrid framework (suppliers, inputs, process, output and customers + define, measure, analyze, improve and control (SIPOC+DMAIC)) aimed at improving supply chain management (SCM) process dimensions in a supply chain (SC) network	SIPOC and Lean Six Sigma DMAIC
Thawani	2004	Six Sigma has been deployed strategically to change the culture of organisation through inculcating process control discipline applied in manufacturing and non-manufacturing businesses	SIPOC and Lean Six Sigma
Jacobson & Johnson	2006	Conduct a comprehensive review and assessment of the extant Six Sigma healthcare literature, focusing on: application, process changes initiated and outcomes, including improvements in process metrics, cost and revenue	SIPOC and Lean Six Sigma

2.4 Review of Concurrent Engineering Model

Concurrent Engineering (CE) could simply be termed as the work methodology that specifically emphasises over the performance of tasks in a concurrent manner. Singhry, Rahman, and Imm (2016) stated that CE could be referred to as an approach that is utilised for product development where the function of manufacturing as well as design engineering are integrated which in turn helps in the reduction of the total amount of time required for development and then introducing a new product into the market. According to Anderson (2014), the basic premise of CE is dependent over a total of two concepts. First, it is dependent on the life cycle of the product which includes production, functionality, assemble, testing, and disposal, whereas, second aspect consists of design activities which must take place in a concurrent manner. Therefore, CE helps the engineers in running the design activities in a simultaneous manner alongside one another which does not only increase the overall productivity but at the same time, it also increases the quality of the final product developed.

Ball and Runge (2014) stated that CE can prove to be an extremely essential model for the manufacturing industry due to the fact that it can help the designers to determine the errors in an early design phase, therefore they can either resolve the error or redesign the product in that phase. Therefore, through identification of errors and fixing it during the design phase the team is able to reduce the cost of production which it might have incurred if the product has moved forward towards the completion phase.

Hence, it could be stated that major aim of the CE process is to ensure that the entire life cycle of the product is taken under consideration during the design of the product. Thus, using the CE model allows the designer to collect and understands the user requirements, propagation of conceptual design in the early phase, running computational models, and development of product prototypes, which in turn lead towards development of final product of supreme quality.

In a recent study conducted by Ball and Runge (2014) it was determined that CE has replaced the more conventional model of sequential design flow. CE as compared to sequential design flow model utilises a more iterative approach, whereas the sequential model, on the other hand, moves in linear manner. Therefore, the sequential model begins through collection of user requirements and then it sequentially moves towards the design and the implementation phase, in this model the team strictly follow the process that does not allow the team to move either backward or forward, moreover the team is not capable of anticipating any problem that might arise during the product development process, due to which in case some goes wrong the product has to be disposed which is extremely costly when it comes to Jewellery manufacturing.

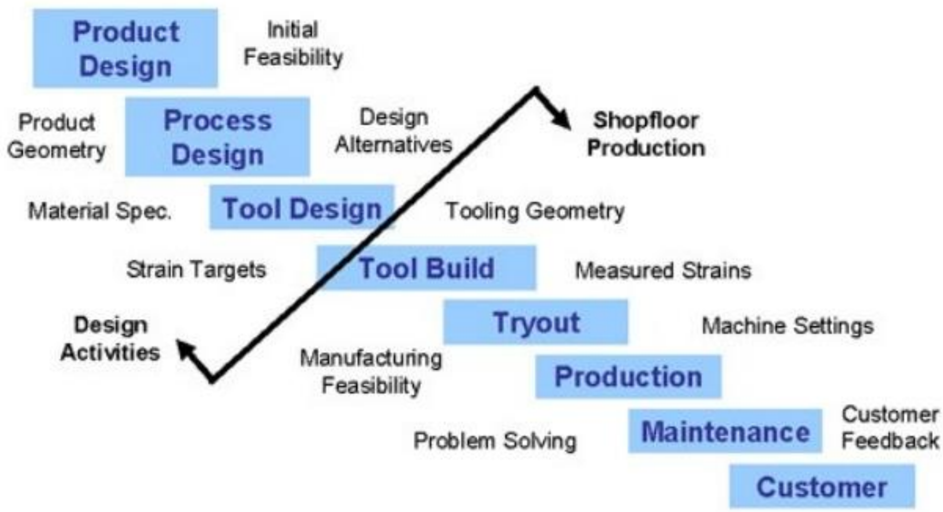

Figure 11: Concurrent Engineering Model
(Source: Ball, & Runge, 2014)

Hence, it is more effective to utilise the CE model, as the model allows the designers to change the tracks instead of following a strict hierarchy, this ensures that during the product development process all aspect of the product lifecycle as taken under consideration, which in turn lead towards development of a high-quality product, while at the same time reducing the overall product development cost through waste reduction. CE can prove to be a highly effective model to be implemented within the Jewellery industry due to the fact that it will provide the designer more authority and flexibility during the design phase, because of its collaborative nature.

In short, the summary of previous research studies regarding the Concurrent Engineering model can be demonstrated in Table 4 below:

Table 4: Summary of Past Researches on Concurrent Engineering Model

Authors	Year	Objective	Method
Singhry, Rahman & Imm	2016	Examine the mediating effect of concurrent engineering of product design (CEPD) on the relationship between advanced manufacturing technology (AMT) and supply chain performance (SCP)	Concurrent Engineering
Anderson	2014	Show how to use concurrent engineering teams to design products for all aspects of manufacturing with the lowest cost, the highest quality, and the quickest time to stable production	Concurrent Engineering
Ball & Runge	2014	Produce reusable engineered systems through ontology: implementing an information sciences approach to architecture-driven, model-based, concurrent engineering	Concurrent Engineering

2.5 Review of Computer Aided Design and Rapid Prototyping

The emergence of technology has almost changed the manner in which all the industries operate around the globe, a technology which has completely change the jewellery industry, is Computer Aided Design, which allows the designer to build rapid prototypes of extremely expensive jewellery, which is stored in the virtual database in order to be replicated in case similar sort of designs are needed in the future (Rajili, Olander, & Warell, 2015). Furthermore, with the passage of time the software has become more sophisticated which in turn has led towards incredibly accurate designed final product, which is rendered using 3-3 images.

Rajili, Liem, Olander, and Warell (2015) stated that CAD jewellery design process has not replaced processes such as casting, polishing, welding, and soldering during the jewellery design process, but it has allowed the designers to create prototype model which could be rendered using 3D designs, in order to collect customer feedback over the design of the jewellery. The jewellery designers simply have to use a mouse and keyboard in order to create a prototype, CAD has made the jewellery design process extremely efficient and innovative through utilisation of the state of the art software's and equipment's. Once, the designers metamorphose the design, the designs are sent in the form of digital files to the production plants or the 3D printers where after approval of the customer they are finally transformed into a resin form. The process works in quite a sophisticated manner, as the 3D form is embedded into a plaster investment that is placed within the furnace where the model is incinerated. In the next phase, the investment consisting of the negative impression is filled with the help of molten gold through vacuum casting over the precious metal that will be worked and tooled by the skilled bench jewellers. Lastly, the finished CAD jewellery design moves towards the polishing team where they prepare it for setting of the diamond, and the product is delivered to customer. Briefly, the summary of the recent publications about Computer Aided Design is illustrated in Table 5 below.

Table 5: Summary of Past Researches on Computer Aided Design and Rapid Prototyping

Authors	Year	Objective	Method
Rajili, Liem, Olander & Warell	2015	Examine the practice of jewellery design, i.e. how practitioners describe their work and how they create the knowledge needed for their practice	Computer Aided Design and Rapid Prototyping
Rajili, Olander & Warell	2015	Understand the nature of the practice, how designers reason about jewellery making, and how they create the knowledge they need in the design process	Computer Aided Design and Rapid Prototyping

2.6 Review of Advanced Product Quality Planning

Advanced Product Quality Planning (APQP) could simply be defined as a well-structured process and product design approach, it has emerged as a framework which allows the firm to design a product which meets the needs of the customer (Schneider, 2015). Under APQP the major aim of product quality planning is to facilitate both the collaboration as well as the communication process alongside the engineering activities. APQP process involves all manufacturing, marketing, procurement and the product design team in the process, which ensures that the customers' voice is heard, understood and then it is translated into the requirements which lead towards the development of ideal project which meets the needs of the customer. According to Deshpande, Siddhalingeshwar, and Ekabote (2016) APQP supports identification of change in a very early phase of production development, which leads towards development of innovative products which mostly exceeds customer expectations.

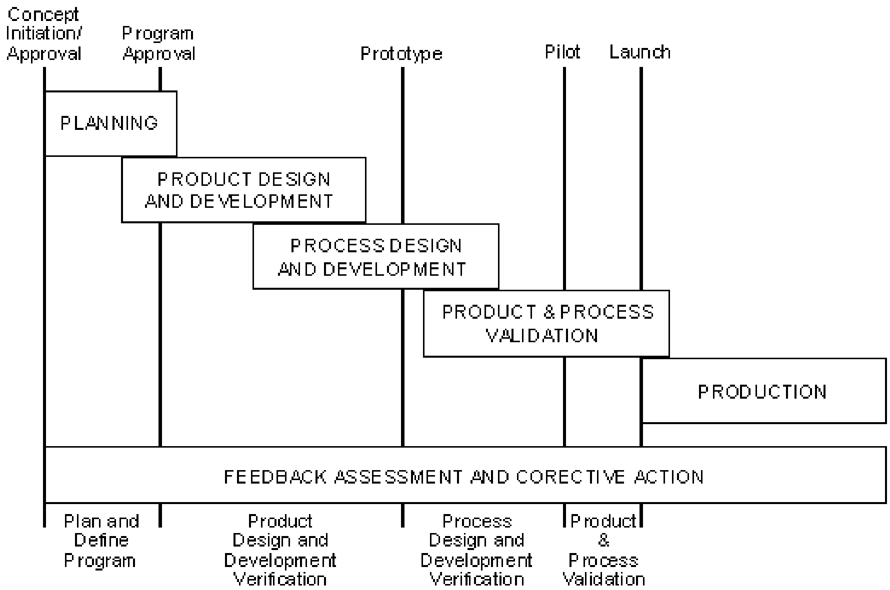

Figure 12: Advanced Product Quality Planning (NPDSolution, 2017)

The summary of part research studies regarding Advanced Product Quality Planning can be demonstrated in Table 6 below.

Table 6: Summary of Past Researches on Advanced Product Quality Planning

Authors	Year	Objective	Method
Schneider	2015	Identify which Advanced Product Quality Planning (APQP) tools are applicable in health care and aim to reach consensus on additional tools that if added, would make the APQP model more likely to meet the needs of the health care industry	Advanced Product Quality Planning
Deshpande, Siddhalingeshwar & Ekabote	2016	Define industrial methodology based on Engineering Design (ED), especially to address the needs of automobile engineering students	Advanced Product Quality Planning

2.7 Review of Failure Mode and Effect Analysis

Failure Mode and Effect Analysis (FMEA) is an approach which could be utilised for the identification of all the possible failures during the design or assembly phase. Using FMEA approach failures are prioritised as per the significance of their impact, and the frequency at which these failures could occur. Therefore, it could be stated that the major aim of FMEA is to take action in order to either reduce or eliminate the failure from the production process through prioritising them. Issar and Navon (2016) stated that FMEA also helps in the documentation of the existing actions and knowledge with respect to the risks of failure for use in the continuous improvement process.

Table 7: Summary of Part Research on Failure Mode and Effect Analysis

Authors	Year	Objective	Method
Issar and Navon	2016	Help managers and consulting academicians as a ready reference for cross-industry implementation of operational excellence	Failure Mode and Effect Analysis

2.8 Summary of the Literature Review Chapter

Hence, it could be concluded that integration of tools such as Six Sigma DMAIC, Concurrent Engineering, Advanced Product Quality Planning and Failure Mode and Effect Analysis can certainly aid the jewellery design process, as these models will allow the firms to identify the potential flaws during the design phase, and the errors could be rectified right there and then, which in turn would lead towards reduction of wastage and making the production process highly efficient. Moreover, it will also result in reducing the overall costs of production. Therefore, this will lead towards the development of a highly effective and efficient product development process for the jewellery industry.

CHAPTER 3 – RESEARCH METHODOLOGY

3.1 Introduction

This chapter of the study will provide a brief overview of the methodology which will be utilised in order to achieve the overall research objectives. The researcher will initially begin with the identification of the sources and impact of waste within the case study company. Then, the researcher will justify the research strategy of how the research project was conducted in order to implement the DMAIC Six Sigma model aimed towards the reduction of wastage and generation of quality jewellery products as per the customer specifications.

3.2 Sources of Waste During Jewellery Manufacturing

In this section, the researcher will provide a brief overview of the sources of waste generation at the case study company, which has led towards increasing the overall costs of operation for the company. The major sources of waste at the company include:

3.2.1 Rework Phase

A major source of wastage at the case study company is reworking, due to the fact that often customer specifications are either misunderstood or there is a difference in the design of the final products, which in turn lead towards increasing the reworking cost of the jewellery. This cost is extremely high for the case study company due to the fact that the company follows quite a long jewellery manufacturing process with zero checks or monitoring mechanisms in place. Since the company is at fault the costs are borne by the firm, however, it also leads towards delay in the deliveries, which leads towards further increasing the costs in terms of overtime, premium freight, along with other supply chain and administrative costs.

3.2.2 Total Rejection

This type of waste includes the pieces of jewellery which have become non-conforming to the customers, due to the manufacturing of the wrong product. This in turn leads towards wastage of precious raw material such as gold, which has to be melted and re-shaped in order to meet the customer specifications. Therefore, this is a whole non-value added process which does not increase the raw material purchasing cost for the firm, but more importantly, it also increases the operational costs as the whole process such as melting moulding, and casting has to be repeated once again.

3.2.3 Process Bottlenecks

Currently, the case study company lacks the manpower required to fulfil the number of orders which are being placed by the customer along with the machines which are manually used for polishing, grinding, and filling which takes a longer period of time. Therefore, as a result of this, in case there is a rejection from the end customers, the whole process has to be repeated again, which does not only lead towards exhaustion of the workforce, but more importantly it also increases the cost of operations in the form of overtime which has to be paid to the workers.

3.2.4 Inventory

Another major source of waste at the case study company is inadequate inventory management, due to more than often it has been seen that the firm has unnecessarily overproduced certain set of items like rings or bracelets, therefore, these inventories either in the form of gold settings or finished goods does lead towards increasing the amount of waste for the company. According to estimation, this unnecessary inventory every year increases the overall cost of the company by more than 25% to 30%, which is quite high keeping under consideration the size of the firm.

3.3 Improvements in the Design Process with Integration of DMAIC Model

The data for the study will be collected using primary data which will be collected from the case study company. It will be prepared and processes using the DMAIC model. The following is the research strategy which will be followed in this study:

3.3.1 Define Phase

The following research steps will be followed by the researcher in the define phase:

- SIPOC diagram will be created in order to provide a much clearer view of the business as well as the operational processes of the case study company
- A process improvement team will be formed
- A customer satisfaction survey was conducted
- Information will be gathered regarding the product design process during the jewellery production
- Studying the existing data available within the company database regarding product design, production and waste management
- The information that will be collected in this phase will include data related to waste management process during the jewellery production, and also customer requirement processing process
- Identification of the current problem that the case company was being faced
- Evaluation of the current production process and identification of the downfalls
- Design Quality (DQ) in the product design process for this study will be defined
- Identification of the key performance indicator

3.3.2 Measure Phase

In this phase, the team will brainstorm and as well as create a list and prioritise the current potential causes of the problem by using cause and effect analysis. After that, finding and prioritisation of root causes will take place by using Failure Mode and Effect Analysis (FMEA). Lastly, the team will summarise the root causes using Pareto Chart.

3.3.3 Analyse Phase

In this phase, the team will brainstorm and discuss for finding innovated solutions for eliminating delay in delivery product to customers and product not as per customer specifications.

3.3.4 Improve Phase

This phase will describe how the team implement the plan and tracked the progress. The action plan that the process improvement team has to follow will be created. The team will develop and integrate the daily planning system using an Enterprise Resource Planning (ERP) software. Furthermore, the methodology or approach which the team has selected to apply within the case study company is Computer Aided Design (CAD), which does not only possess the potential of improving the overall design efficiency but more importantly it will help the case study company in reducing the customer rejection and help in waste management, while at the same time it will allow the case study company to develop highly creative designs for its customer which in turn will provide the company with a competitive edge in the market.

The team will also utilise Rapid Prototyping which helps the company to fabricate a model using CAD data or to link the CAD with the design process, this will allow generating final design outputs from CAD through using a 3D printer that will be linked directly with the production line. In order to generate design prototypes, the team will utilise Additive Manufacturing Strategy, using which the planned tool movement will help in printing one layer of wax over another in order to create a final piece of product. Then, improvements will be made in the deployment process in case of redundancies using the Concurrent Engineering model which will allow the designer of the case study company to identify errors in the design of the jewellery during the design phase. This in turn will allow them to rectify the error there and then reducing the chances of customer rejection and returns.

3.3.5 Control Phase

In order to monitor and control the product development process, the team will sustain the new product design process and production flow process along with monitoring of improvements for ensuring sustainable and continued success. This will be done through integration of Advanced Product Quality Planning (APQP) method for controlling the design process as this model will allow the firm to monitor the up-front quality of the product being developed, while at the same time case study company will also be improve the product output through ensuring that the final products delivered by the firm comply with the customer requirements and supports the new continual. Lastly, and more importantly a control plan will be created and updating of the records will be made.

3.5 Summary of the Research Methodology Chapter

Hence, through the utilisation of Six Sigma tools such as DMAIC will help in ensuring that the amount of waste which is currently produced during the product development process is reduced. In order to overcome the issue of delayed delivery, the team will implement the Daily Planning system using ERP software. This in turn will allow the company to overcome the issue of changing consumer demands, and the fluctuation which it usually faces in the prices of the raw material that increases the overall production costs for the company. Moreover, in order to improve the overall product design process, the team will use the CAD 3D design model which will certainly help the case study company in improving the overall design process, while at the same time development of prototypes using the Rapid Prototyping will allow the case study company to ensure that the design of the jewellery is created as per the requirements given by the customer, since the company will show its customers the prototype of the design in order to avail their feedback, therefore, in case customer rejects the design the company can simply use non-parametric design approach in order to create a new design as per customer feedback, which in turn will not only save the cost of purchasing new equipment and manpower cost but at the same time it will make the whole product development process more efficient.

Furthermore, the team will utilise Concurrent Engineering model during the improvement phase. In this phase, customers, designers and craftsmen will work together in order to be involved with the product from the beginning, and also have an opportunity to brainstorm about the product design which will improve the overall product design process and ensure that the final product is designed as per the needs of the customers and more importantly reduce wastage and cost incurred by the firm currently due to customer returns. Lastly, in order to ensure a high control over the production process, the researcher implemented the APQP System. The system allowed the case study company to improve the overall communication process through creating a strong channel of collaborative channel between the customers and the designers.

CHAPTER 4 – IMPLEMENTATION AND RESULTS

4.1 Introduction

This section of the study will provide a brief illustration of the overall results of the study. The major objective of this section is to provide an overview of the changes which were experienced by the case study company, after the integration of the DMAIC model, in the product design process. The focus of this section of the study will be on the various Six Sigma DMAIC development models which have been identified in chapter two of the study, and how these models have led towards improving the overall design and product development process, while reducing waste and cost of production due to customer rejections at the case study company.

4.2 Define

Since this research study will be conducted at a jewellery manufacturing company located in Thailand, it is essential for the researcher to understand the business operations as well as the processes which are being followed by the jewellery company operating within the Thai industry. Therefore, keeping this aspect under consideration, the researcher will draw a SIPOC diagram for jewellery production process in order to provide a much clearer view of the business as well as the operational processes of the case study company as depicted in Figure 13:

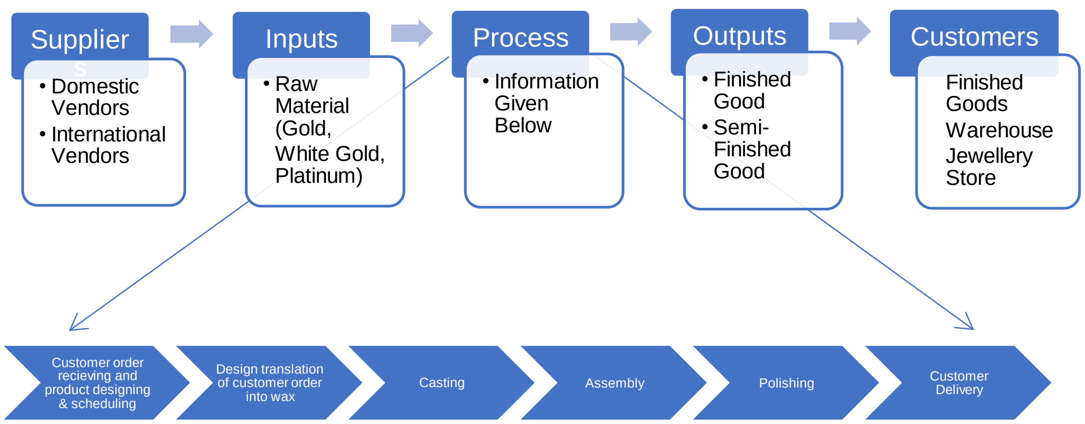

Figure 13: SIPOC Diagram for Jewellery Production Process

A team consists of 7 people was formed for process improvement. All team members are identified in the following table (Table 8).

Table 8: Process Improvement Team Formation

No.	Position	Experience
1	Production Manager	9 years' experience
2	Designer	10 years' experience
3	Craftsman	12 years' experience
4	Process Engineer	6 years' experience
5	Marketing Manager	5 years' experience
6	Quality Control Operator	5 years' experience
7	Researcher	

In order to measure degree of customer satisfaction with the production flow process and the overall service quality, a customer satisfaction survey was conducted in June 2017, the total number of participants involved in the survey was 100. An average degree of customer satisfaction with the production process from the case study company's customer satisfaction survey can be illustrated in Figure 14.

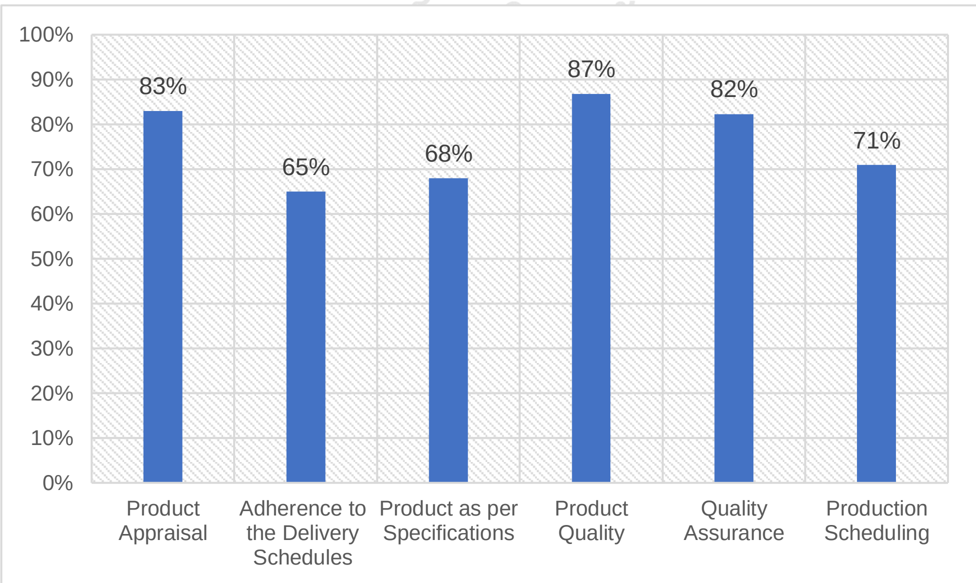

Figure 14: Degree of Customer Satisfaction with the Production Process

The result of the survey revealed that the customer satisfaction in the product appraisal process of the company was 83% of the total number of participants. However, the satisfaction in adherence to the delivery schedules was only 65% of all the participants which is quite inadequate. This statistic indicates that the company has inadequate management and monitoring of the current production process. Along with that, only 68% of all the participants filed satisfy regarding the final product delivered to them was as per their specifications which shows ineffective communication between customers and artisans and also lack of customer order management ability of the current system. The result also showed that 87% of the customers stated that they were satisfied with the quality of the products, whilst, 82% of the customers mentioned that they were satisfied with Quality Assurance (QA) process of the company. Lastly, 71% of the customers were satisfied with production scheduling of the company.

According to customer satisfaction with the service, the result of the survey revealed that 87% of the customers were satisfied with the overall services that the company provided to them and 86% of the customers were satisfied with the way that the company communicates with them. Finally, 76% of the customers were satisfied with customer relationship management. An average degree of customer satisfaction with the service from the case study company's customer satisfaction survey can be demonstrated in Figure 15.

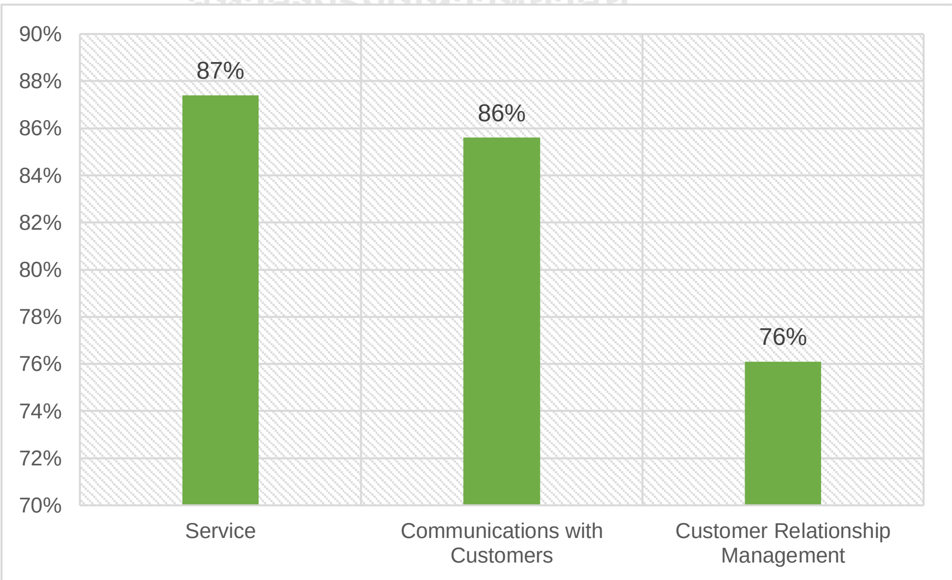

Figure 15: Degree of Customer Satisfaction with the Service

From the customer satisfaction survey on the production process and service presented in Figure 15 and 16, adherence to the delivery schedules and product as per customers' specifications are the significant factors that should be considered by the company, as they showed as the lowest level of satisfaction among all consideration issues, which are 65% and 68%, in the survey. This results indicated that the company should focus on improving the overall production process, especially in the product design process and the time management of the current production system, to help reduce the amount of product that not according to customer requirements and also decrease the percentage of delayed delivery in order to create better customer satisfaction.

After that, the process improvement team has evaluated the current production process and identification of the downfalls. The team has identified the current problem that the case company was being faced which is a high product rejection rate. The following table (Table 9) and figure (Figure 16) illustrated the product rejection rate of the company in June 2017 – December 2017.

Table 9: Product Rejection Rate

Item	Production Quantity	Quantity of Rejection	Percentage of Rejection
Ring	75	23	31%
Earrings	66	21	32%
Pendant	51	14	27%
Bangle	24	8	33%
Necklace	15	5	33%
Bracelet	10	3	30%
Brooch	7	3	43%
Total	248	77	Average 31%

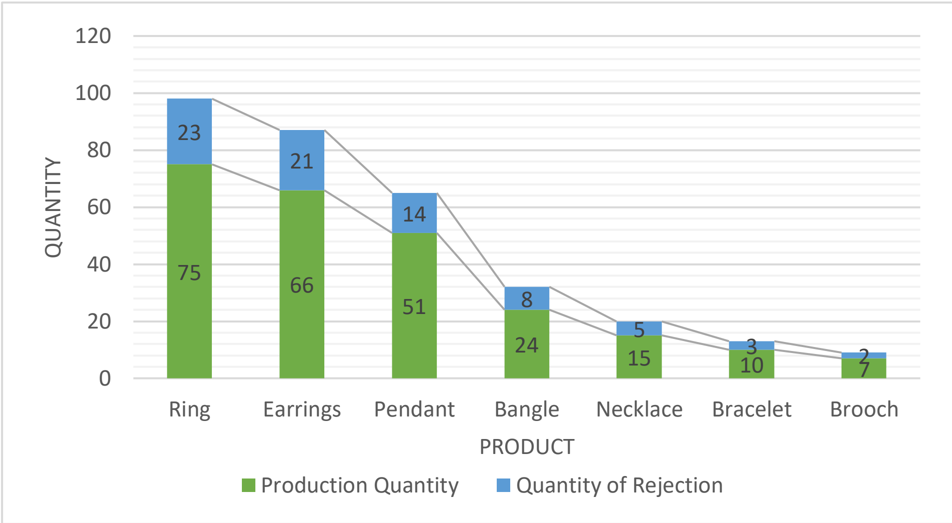

Figure 16: Product Rejection Rate

From June to December 2017, the company produced 248 products consist of ring, earrings, pendant, bangle, necklace, bracelet and brooch, whilst 77 products of all the production quantity had been rejected from the customers which can be calculated as 31% rejection rate. Hence, the process improvement team decided to calculated Design Quality (DQ) in the product design process of the company by using the following equation:

$$\mathbf{DQ} = \frac{\text{No. of design items} - \text{No. of design error items}}{\text{No. of design items}} \times 100\%$$

Thus, the following table and figure (Table 10 and Figure 17) show the percentage of Design Quality of the company in June – December 2017.

Table 10: Design Quality

Item	No. of Design Items	No. of Design Error Items	Design Quality
Ring	75	25	67%
Earrings	66	22	67%
Pendant	51	16	69%
Bangle	24	11	54%
Necklace	15	8	47%
Bracelet	10	4	60%
Brooch	7	4	43%
Total	248	90	Average 58%

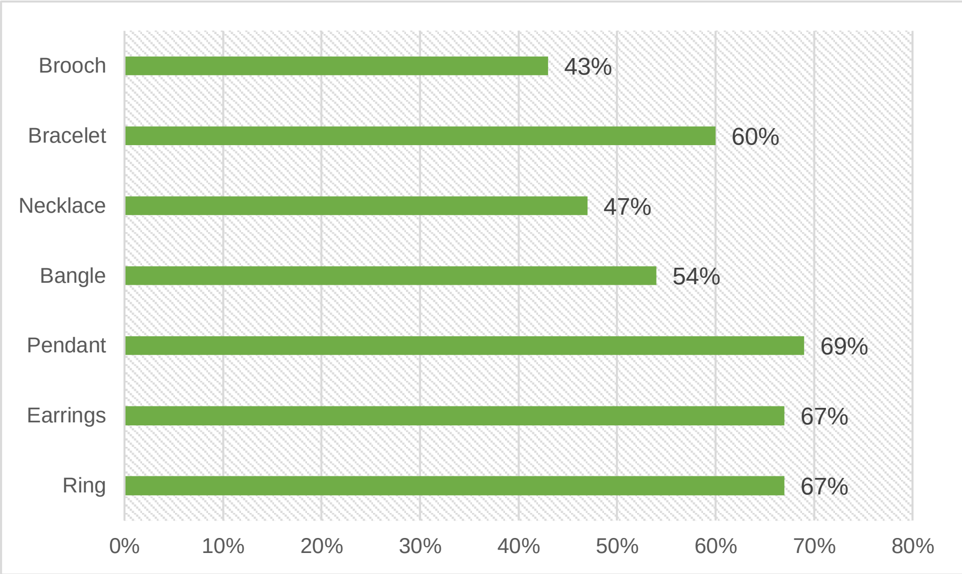

Figure 17: Design Quality

An average percentage of Design Quality of the company in June – December 2017 was 58%. Furthermore, the process improvement team has identified the number of design error items, the number of design error items found at product design phase, and the number of error items found at launch phase as shown in Table 11.

Table 11: Number of Design Error Items

Item	Production Quantity	No. of Design Error Item	% of Design Error Item	No. of Design Error Item Found at Design Phase	% of Design Error Item Found at Design Phase	No. of Design Error Item Found at Launch Phase	% of Design Error Item Found at Launch Phase
Ring	75	25	33.33%	4	16%	21	84%
Earrings	66	22	33.33%	4	18.18%	18	81.82%
Pendant	51	16	31.37%	3	18.75%	13	81.25%
Bangle	24	11	45.83%	2	18.18%	9	81.82%
Necklace	15	8	53.33%	2	25%	6	75%
Bracelet	10	4	40%	1	25%	3	75%
Brooch	7	4	57.14%	1	25%	3	75%
Total	248	90	Avg. 42.05%	17	Avg. 20.87%	71	Avg. 79.13%

Table 11 indicated that the production quantity of the company in June – December 2017 was 248 and the number of design error items were 90 which was calculated as 40.05% of the total products produced. Moreover, the number of design error items found at product design phase was 17 which was calculated as 20.87% while the number of design error items found at launch phase was 71 which was calculated as 79.13% of the number of design error items. Figure 18 illustrated the number of design error items found at design phase and launch phase.

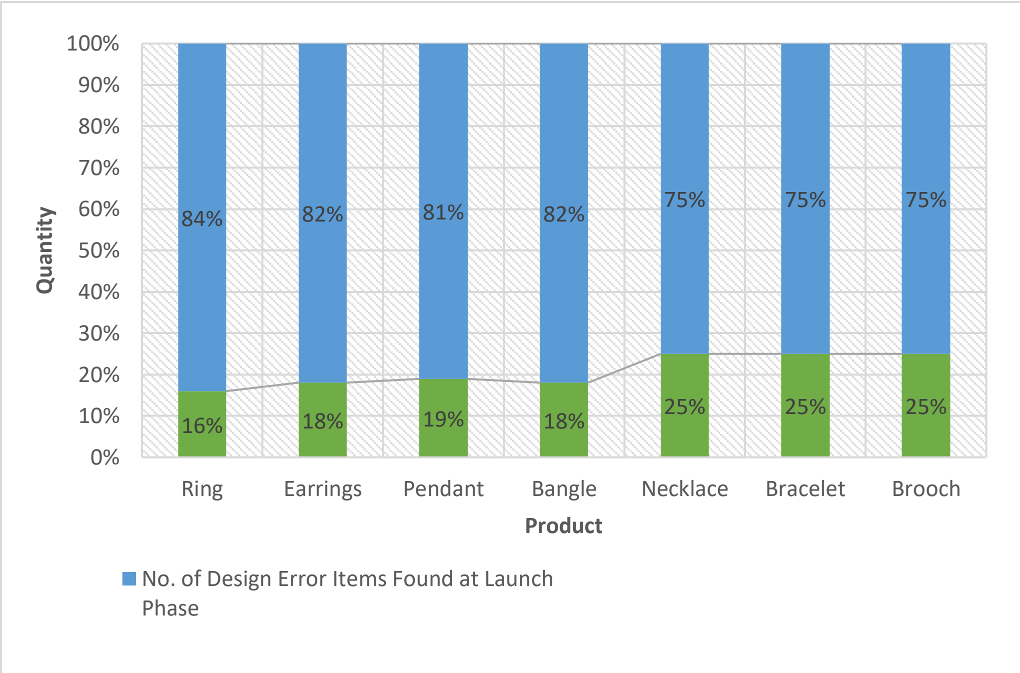

Figure 18: Number of Design Error Items Found at Design Phase and Launch Phase

Hence, this information revealed that the discovery of the design errors took a long period of time and mostly it was at the end of the production process where the company determined that the customer has rejected the product, which in turn led towards increasing the cost of developing counter-measures.

After that, the key performance indicators for DMAIC production process are identified as shown in Table 12:

Table 12: KPI's for DMAIC Production Process

Areas	KPI	Objectives
Financial Indicators	• Revenues generated per employee • Cash Flow • Revenues generated per customer • Profit Margin • Revenues generated per assets	✓ Grow revenues generated per employee ✓ Improve the current cash flow rate ✓ Grow revenues generated per customer ✓ Boost profit margin ✓ Grow revenues generated per asset
Customer Indicators	• Rate of rejection per customer • Sales per customer • Customer defection rate • Customer loyalty index	✓ Decrease rate of rejection per customer ✓ Boost sales per customer ✓ Decrease current customer defection rate ✓ Boost customer loyalty index ratio
Personnel Index	• Total employee turnover • Employee satisfaction index • Employee absenteeism rate	✓ Decrease current employee turnover rate ✓ Achieve positive employee satisfaction index ration ✓ Decrease employee absenteeism rate
Process Indicators	• Total inventory turnover • On time delivery • Lead time of jewellery production • Downtime of jewellery production • Productivity per employee	✓ Boost the turnover rate ✓ Improve product delivery time ✓ Reduce the current lead time ✓ Reduce the current downtime ✓ Increase productivity rate per employee

4.3 Measure

In this phase, the process improvement team started meeting and brainstorming to find all possible causes by considering the Cause and Effect Diagram in Figure 9 and created a list and prioritising the current potential causes of the problem using Cause and Effect Analysis shown in Table 12 and Table 13. Then the team brainstormed to find the root causes and identified the Risk Priority Number (RPN) by utilising Failure Mode and Effects Analysis shown in Table 14, while prioritisation of root causes will take place in Table 15 and were summarised in the Pareto Chart in Figure 20. The Cause and Effect Matrix is illustrated in Table 13.

Table 13: Cause and Effect Matrix

Factor	Code	Key Process Input Variables	Production Manager	Designer	Craftsman	Process Engineer	Marketing Manager	Quality Control Operator	Score
Method	A1	Outdated production systems and strategies	8	6	7	5	8	7	41
	A2	Absence of Standard Operating Procedures (SOPs)	6	4	4	4	5	6	29
	A3	Communication breakdown	9	10	10	10	8	9	56
	A4	Inattention and time pressure of employee	5	7	6	9	4	4	35
Materials	A5	Raw materials and parts unavailable	5	6	5	8	4	6	34
	A6	Poor supplier relationships	6	5	5	6	4	6	32
	A7	Poor supply chain management	2	3	2	4	4	5	20
Measurement	A8	Absence of customer approval phase	9	10	10	10	8	10	57
	A9	Wrong design production	9	10	10	10	9	9	57
	A10	Poor time management	8	9	7	8	5	5	42
Environment	A11	No scheduled maintenance for machines	3	2	4	5	2	5	21
	A12	Inadequate shift management	4	2	3	5	4	6	24
	A13	No health and safety manager	2	3	2	4	2	3	16
Manpower	A14	Inadequate human resource management	2	2	1	1	4	3	13
	A15	Absence of T&D manager	7	5	5	6	4	3	30
	A16	Absence of employee orientation program	7	4	3	5	2	3	24
Machines	A17	Lack of knowledge of how to store machine properly	2	1	2	5	1	3	14
	A18	Some older workers are reluctant to embrace new technology	5	6	6	5	5	6	33
	A19	Obsolete and degrading machines	8	7	9	9	8	6	47

The following table (Table 14) prioritised the potential causes of delay in delivery and product not as per customer specifications from the Cause and Effect Matrix.

Table 14: Potential Causes

No.	Code	Potential Causes	Total Score
1.	A8	Absence of customer approval phase	57
2.	A9	Wrong design production	57
3.	A3	Communication breakdown	56
4.	A19	Obsolete and degrading machines	47
5.	A10	Poor time management	42
6.	A1	Outdated production systems and strategies	41
7.	A4	Inattention and time pressure of employee	35
8.	A5	Raw materials and parts unavailable	34

The process improvement team used Failure Mode and Effect Analysis (FMEA) to analyse Risk Priority Number (RPN), potential cause and recommend action. The FMEA table for all possible failures is demonstrated in Table 15.

Table 15: FMEA Table for All Possible Failures

Process Title: Product design process improvement for a jewellery manufacturer

Project Team: Production Manager, Designer, Craftsman, Process Engineer, Marketing Manager, Quality Control Operator

Potential Failure	Potential Effect of Failure	S	Potential Cause	O	Current Process Control		D	RPN	Recommend Action	Responsible	Action Result				
					Prevention	Detection					Action Taken	S	O	D	RPN
Absence of customer approval phrase	Delayed delivery and product not as per customer specification	9	The current design process was monotonous and obsolete	10	No	Quality check	8	720	Add customer approval phrase before casting	Process improvement team	1/12/2017	9	3	2	54
Wrong design production	Delayed delivery and product not as per customer specification	9	Absence of customer approval phrase	10	No	No	8	720	Add customer approval phrase before casting	Process improvement team	1/12/2017	9	3	2	54
Communication breakdown	Delayed delivery and product not as per customer specification	9	Lack of involvement with product design process	10	No	No	8	720	Perform concurrent engineering to make customers, designers and craftsmen to be involve with the product from the beginning	Process improvement team	1/12/2017	9	3	2	54
Obsolete and degrading machines	Delayed delivery and product not as per customer specification	9	Lack of confidence in adopting new technology	9	No	No	8	648	Integrate CAD 3D modelling and development of product prototypes using 3D printer	Process improvement team	1/12/2017	9	2	1	18
Poor time management	Delayed delivery and product not as per customer specification	9	Failing to keep a to-do list and not prioritising	8	No	No	7	504	Implement daily planning system to set a number of priorities in the jewellery designing process	Process improvement team	1/12/2017	9	2	2	36
Outdated production system and strategies	Delayed delivery and product not as per customer specification	8	No improvement of production system and strategies	7	No	No	6	336	Perform concurrent engineering and adopt an ERP system	Process improvement team	1/12/2017	8	3	2	48
Inattention and time pressure of employee	Delayed delivery and product not as per customer specification	8	Lack of awareness	6	No	No	6	288	Daily random testing	Process improvement team	1/12/2017	8	3	2	48
Raw materials and parts unavailable	Delayed delivery and product not as per customer specification	8	Raw materials and parts unavailable	6	No	No	5	240	Adopt an ERP system	Process improvement team	1/12/2017	8	2	2	32

Lastly, the team summarised the root causes with the highest Risk Priority Number (RPN) in the FMEA. Table 16 shows the prioritisation of the potential failures and the Pareto chart of the potential failure mode is demonstrated in Figure 19.

Table 16: Summary of the Root Causes with the highest RPN in the FMEA

No.	Code	Potential Causes	RPN	Percent	Cum %
1.	A8	Absence of customer approval phase	720	17%	17%
2.	A9	Wrong design production	720	17%	34%
3.	A3	Communication breakdown	720	17%	51%
4.	A19	Obsolete and degrading machines	648	16%	67%
5.	A10	Poor time management	504	12%	79%
6.	A1	Outdated production system and strategies	336	8%	87%
7.	A4	Inattention and time pressure of employee	288	7%	94%
8.	A5	Raw materials and parts unavailable	240	6%	100%

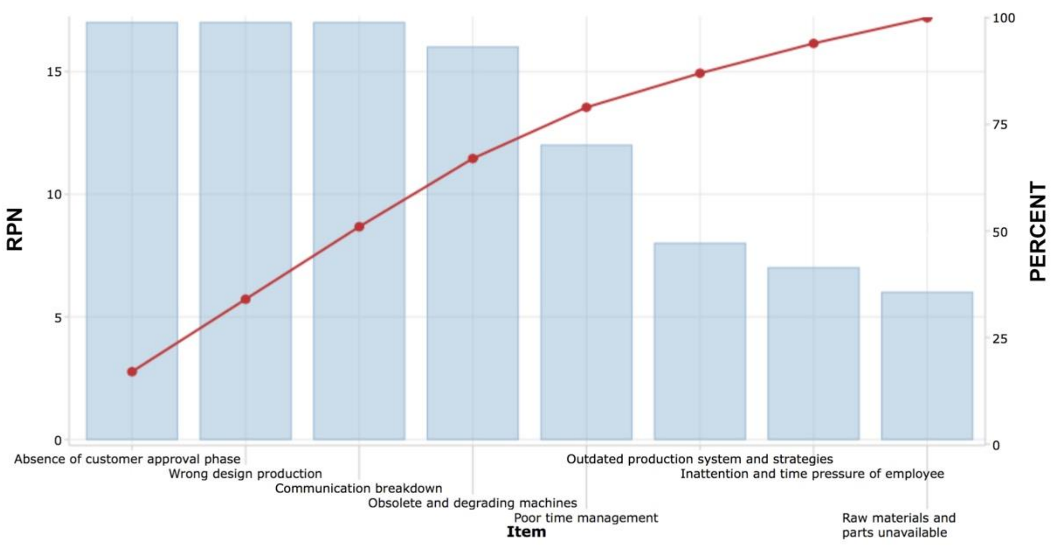

Figure 19: Pareto Chart of Potential Failure Mode

4.4 Analyse

In this phase, the process improvement team discussed for finding innovated solutions and the approaches which will be utilised in order to help in eliminating delay in delivery and product not as per customer specifications include:

- Daily Planning with the help of Enterprise Resource Planning (ERP) software
- Improving the design process by introducing Computer Aided Design 3D modelling such as JewelCAD, Rhinoceros and Gemvision Matrix and development of product prototypes using the 3D Printer.
- Controlling and monitoring of design process using Concurrent Engineering by making customers, designers and artisans to be involved with product from the beginning. Moreover, the Product Development phase with an integration of CAD and Customer Approval phase have been added to the design process.

An Affinity Diagram of the solutions for eliminating delay in delivery and product not as per customer specifications presented in Figure 20 below.

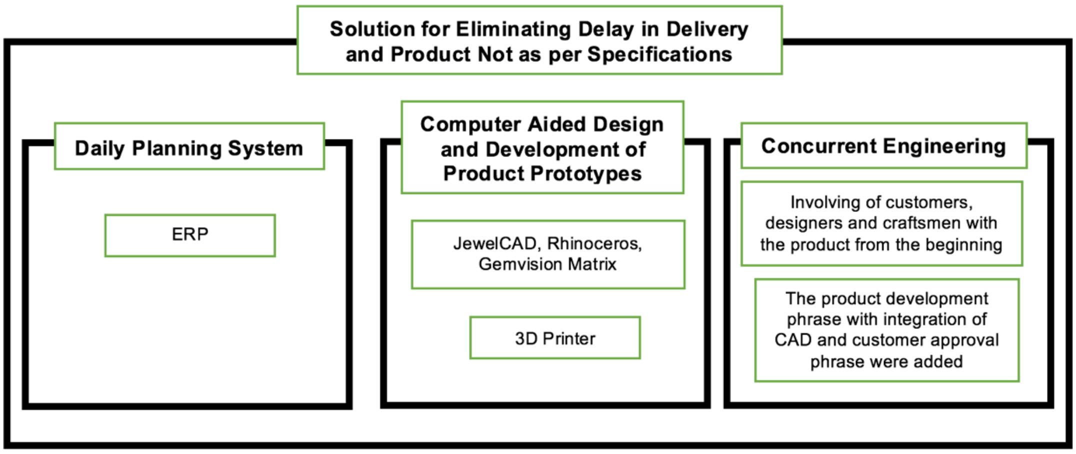

Figure 20: Affinity Diagram of Solutions for Eliminating Delay in Delivery and Product Not as per Customer Specifications

4.5 Improve

In this phase, the team has brainstormed for developing the action plan. The following sections explain how the team implemented the plan and also followed up the progress.

4.5.1 Daily Planning using an Enterprise Resource Planning Software

In order to overcome the issue of delayed delivery, the team implemented the Daily Planning System; using this system the team regulated the activities such as; designing, moulding and product development in a much better manner. The basic idea behind this daily planning system is to set a number of priorities in the jewellery designing process this includes:

- Time management
- Setting different set of activities
- Development of proper plan
- Organisation of different set of activities
- Prioritising of all the activities involved in the design process

The propose Daily Planning System will be supported using an Enterprise Resource Planning system. Therefore, the case study company will adopt an agile ERP software known as WinMan ERP, in order to address the dynamic market changes, following are the aspects which this new ERP software will allow the company to control:

Purchasing and Costing of Raw Materials: Using this software the case study company can simply log in the cost of purchasing of the raw materials at the point of sale, along, with that the price of metal fixing can also be managed by the system using the accurate cost calculation function.

Management of Waste: The ERP software will help in waste reduction through log pricing for the based materials, while at the same time it also provides the ability to track all the scrap and the by-products which are involved in the jewellery manufacturing process. Thus, this will allow the designers to achieve Lean as this system will help in the optimisation of the jewellery design process through the elimination of the waste at each and every level of the design process including from the purchasing of the raw material, to management of working hours, and time required to develop a final product.

Batch Production and Traceability: In order to reduce the large amount of waste, due to rejection from the customer the company using this new system will focus on batch production of the jewellery. Under which it will manufacture specific styles and sizes of jewellery in a methodological manner, and the design will be traced by the assigned design engineer who will be assigned with a unique ID, using which during the initial phase the 3D design will be shown to the customer, and feedback will be collected in order to ensure the design is as per customer needs, or even in case changes are required it will be performed during this phase, before the product finally goes into production. Along, with that the ERP software will provide the ability of traceability from the initial design phase to the final sale of the product, therefore using this procedure the material used within the final product can be directly matched with the purchase order in order to generate and manage the cost queries.

Electronic Data Interchange: This is the most important aspect of the ERP software, as the system will automate the whole data collection and payment process it will automate the process of issuing of invoices, purchasing orders, and even the shipping notes, which in turn will lead towards increased the overall accuracy of the final products developed and at the same time it will also eliminate the waste currently being generated due to mass product rejections from customers.

Inventory Management: The ERP software will allow the company to track all the small and valuable items such as gems, and even nuts and screws which are quite rare and hard to find. Along, with that the system is interconnected which provides a free flow of data with respect to stock to the different departments.

4.5.2 Computer Aided Design 3D Modelling and Development of Product Prototype using 3D Printer

With the implementation of the CAD program, the designers at the case study company were able to create and modify the design of the jewellery in an effective manner, before even they were sent for production. Figure 21 demonstrated creating and modifying design of the jewellery by using CAD.

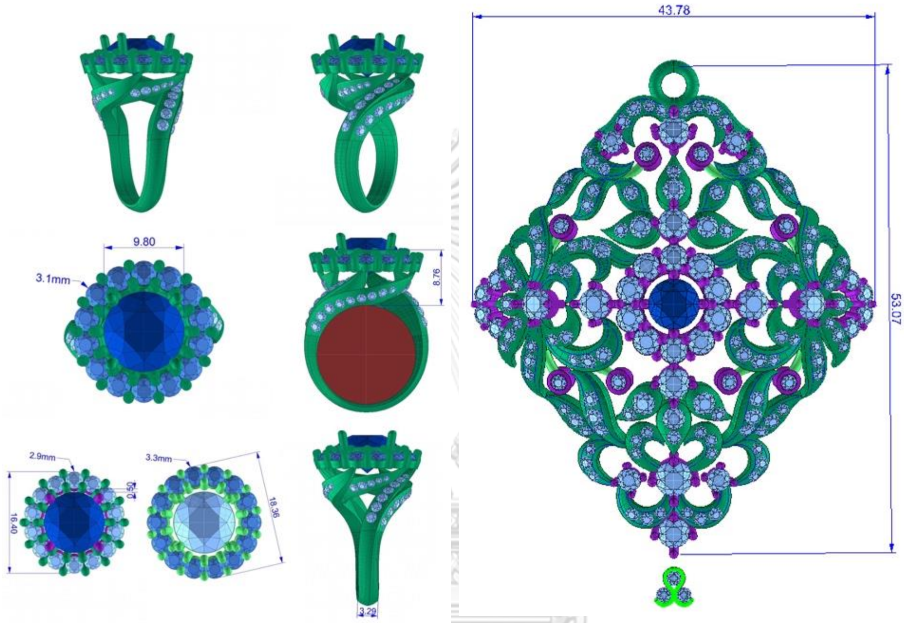

Figure 21: Creating and Modifying Design of the Jewellery using CAD

The integration of CAD does not only lead towards making the design process simple, but the use of 3D printers also allowed the case study company to print the wax model in a more efficient and quick manner, as compared to traditional methods. The 3D printing process utilised a wax like resin for printing of materials or using Stereolithography (SLA) technology, the printer simple prints one layer of wax over another in order to create a final piece of product. Once, these wax layers are printed, in the next phased the model is then utilised for building a mould and then casting process afterwards. The 3D printer was layering process can be illustrated in Figure 22.

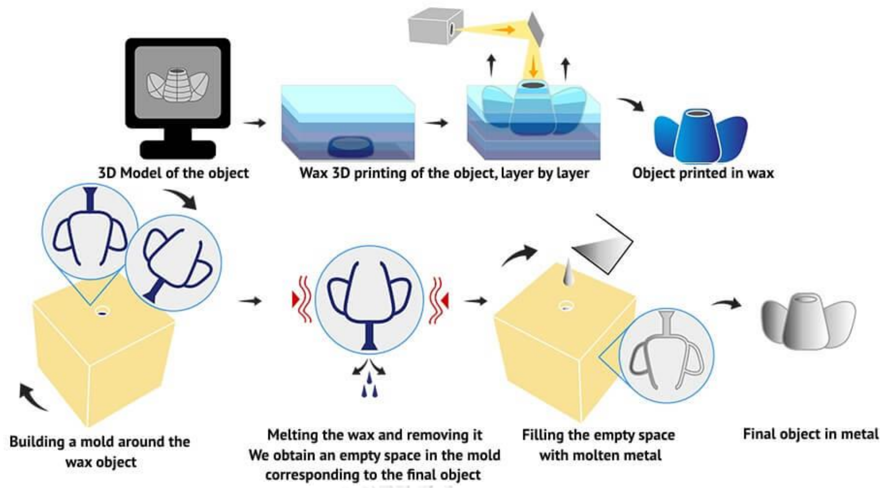

Figure 22: 3D Printer Wax Layering Process

Hence, through the integration of CAD program, the case study company did not have to worry about precise measurement while creation of pieces, since the program allowed the firm to automatically resize and readjust the different pieces of jewellery in an automatic manner, in case the customers rejected the design or have asked for certain set of changes in the design process. Therefore, this allowed the firm to work with some of the trickiest clients, who previously cancelled the product after they were delivered to them, since using the CAD program the steps involved in changing the design of a product did not take days and long working hours, instead it just took around 5 to 6 hours, to integrate the changes in the design and develop another prototype for the customer for feedback. An example of changing design using CAD presented in Figure 23.

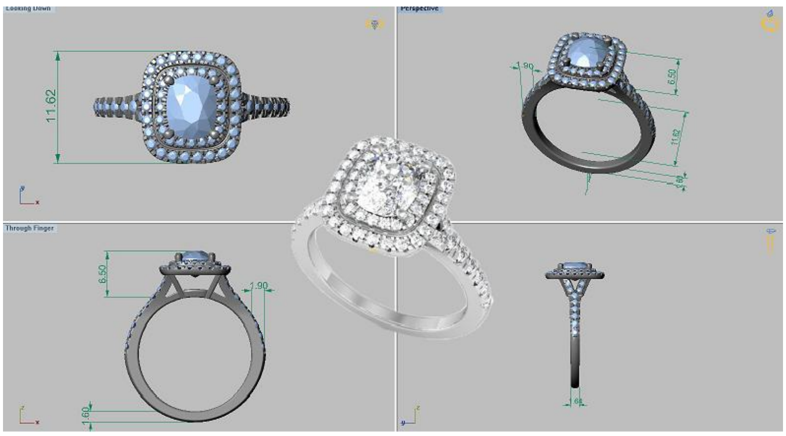

Figure 23: Changing Design Using CAD

Furthermore, it also allowed the case study company to save the design in the database, which made it easier for the company to create motifs as well as the design for the new customers through copying them from the old products, this led towards the development of a more cohesive line of jewellery for the company. Hence, despite developing the product from scratch, the firm was able to carve and redraw the design from the database and design a whole new model of jewellery. The CAD library is demonstrated in Figure 24.

Figure 24: CAD Library

Hence, one of the most significant features of the CAD program was that it allowed the case study company to create photorealistic images of the jewellery, along with the reflection and the shadows just like the final design, this provided both the customer as well as the designer with a much better and clear idea of how the finalised product will look like, hence, it allowed the case study company to avail essential feedback from the customer with respect to the design of the jewellery in case customer rejected the design or asked for changes in the design, the designers were simply able to make the changes using 3D rendering, to ensure that the final product is developed as per the customer specification which in turn led towards zero waste and reduction of overall cost of production of the case study company. Realistic 3D rendering to show customer design prototypes can be demonstrated in Figure 25.

Figure 25: Realistic 3D Rendering to Show Customer Design Prototypes

In order to improve the overall efficiency of the design process and reduce waste, the team utilised a set of three software programmes include:

4.5.2.1 JewelCAD

In order to improve the overall efficiency of the jewellery design process, the researcher will utilise JewelCAD, which is basically a 3D Free-Form Surface Based Compact Modeller. This will enable the case study company to design customised and stylish designs of jewellery, in a 3D format. Thus, before proceeding to the final product development phase, the design of the jewellery will be shown to the customer in order to collect their feedback, once the customer approves the design only then it proceeds to the product development phase. However, in case the customer rejects the design then, in that case, the design will be changed as per customer feedback, the flexible and intuitive nature of the tool will allow the firm to makes changes in the design of the jewellery during the initial phases, where they can develop different shapes and sizes to ensure that the product meets the customer needs, which in turn will automatically lead towards reduction of waste, which is a major source of concern for the firm in the current jewellery design process.

Therefore, this tool can prove to be highly effective for the case study company, since it will not only help in designing of customised jewellery, moreover, it will allow the company to collect and store essential customer data, which in turn will reduce the chances of error in the design process. One of the most innovative features of this tool is that it will enable the case study company to perform projection mapping over the surfaces and the curves; using which the designers will be able to perform the functions of deforming and transforming of the individual surfaces. Hence, in order to collect the customer data, and enhance the process of jewellery design at the company the researcher will implement the JewelCAD model designed, an illustration of the data collection and the design process is given in the Figures 26, 27, 28 and 29:

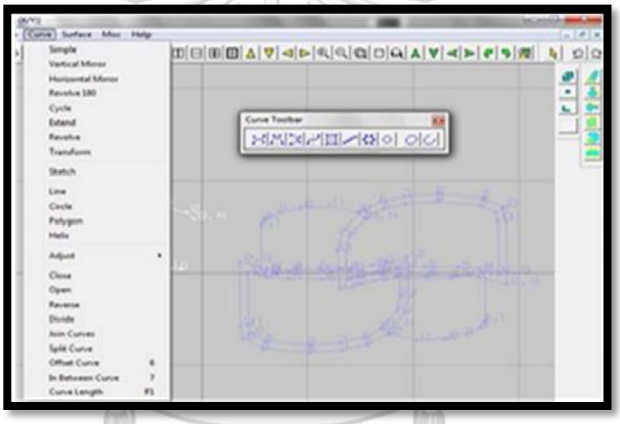

Figure 26: Using 2D, 3D for Development of User Extendable Database

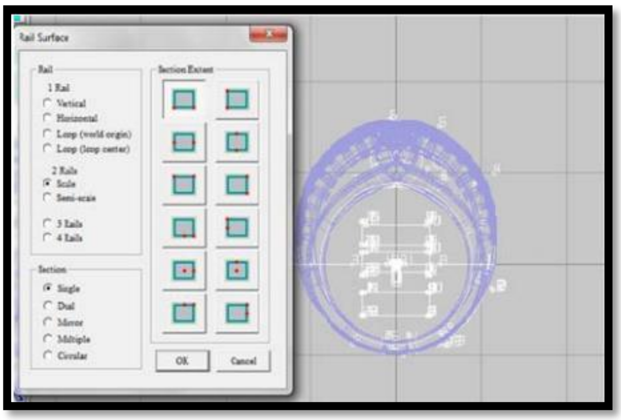

Figure 27: Conversion of 2D Sketch to 3D

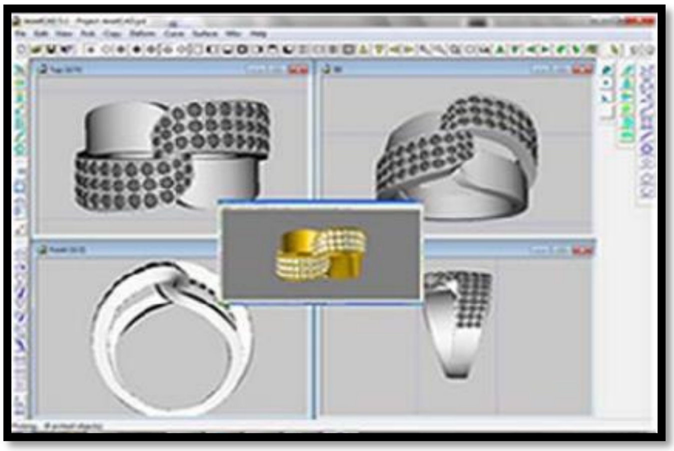

Figure 28: Jewellery Designing After Completion of Solid Modelling Phase

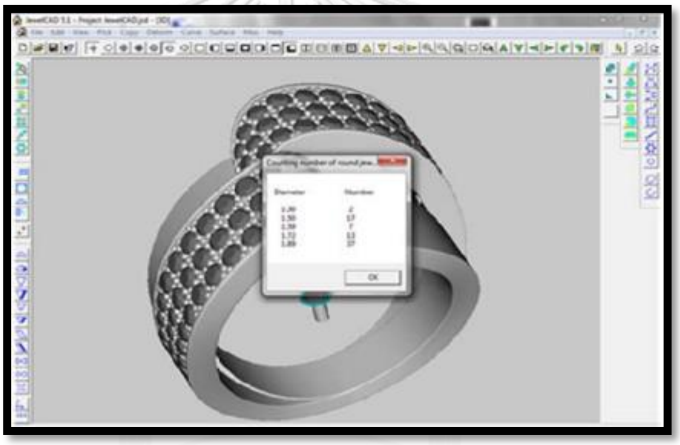

Figure 29: JewelCAD Showing Customer Design Possibilities for the Jewellery Design

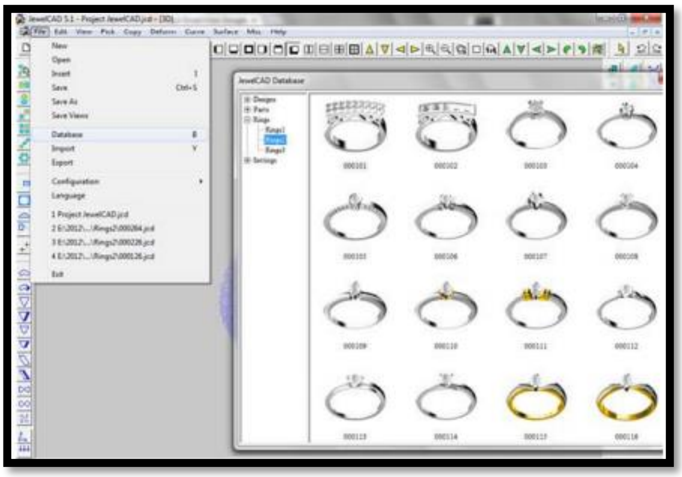

Figure 30: JewelCAD Library

As illustrated in Figure 30, JewelCAD possess a virtual inventory, where the data of all the customers, and the previous jewellery designs could be stores, these ready references will help the company in importing different shapes and sizes of jewellery design, which in turn will not only reduce the time required to design and development of a specific jewellery, but more importantly it also helps in ensuring that the design meets customer expectation as the prototype is shown to them during the initial phases. Moreover, another major attribute of using JewelCAD is that it will help the company in development of new and innovative design concept following the same designs, which in turn will give the company a competitive edge in the highly saturated jewellery market.

4.5.2.2 Rhinoceros

This tool will be used for editing, analysing, and translation of surfaces and curves of the diamonds which are embedded in the jewellery. A major attribute due to which the researcher has selection Rhinoceros, is the ability of the tool to design and development different shapes which is quite complex, through utilisation of 3D digitizers, moreover it also makes the design process more efficient, due to the ability of the tool to work alongside a wide range of geometric data. A major aspect due to which this tool will help the case study company in reducing waste and improving the product design process is the ability to develop prototypes in 3D format, which after customers' feedback can be animated or rendered in order to ensure the final design is accurate and as per the customer specs. Using, this tool the researcher will follow non-parametric approach, which means that in case customer rejects the first prototype design or asks to make certain changes in the design, the changes are only made to certain dimensions of the design without affecting the other dimensions, this will not only reduce the production time but moreover it will also reduce the human effort in the design and the product development process. An illustration of the Rhinoceros tools is given in the Figures 31, 32, 33 and 34.

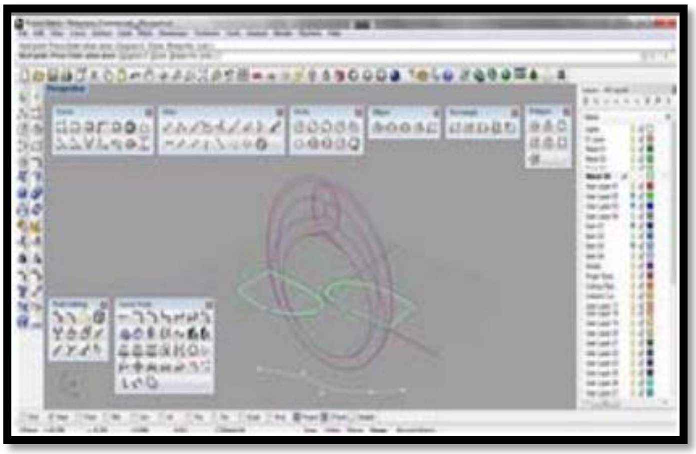

Figure 31: Initiating the Jewellery Design Process Using 2D Approach

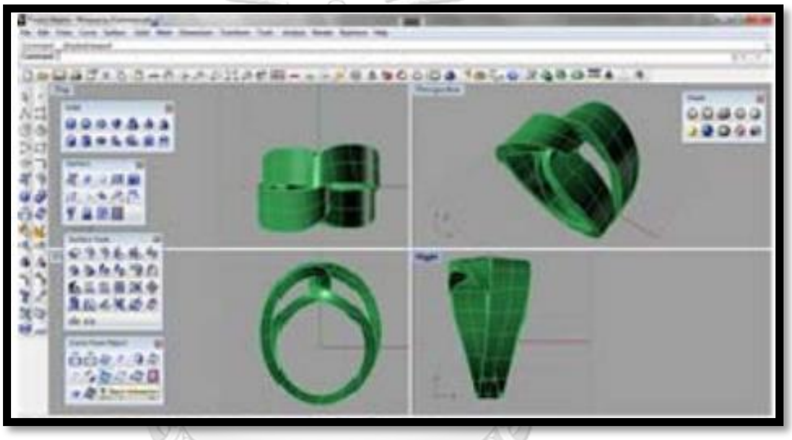

Figure 32: Retrieving Customer Data from Virtual Library in order to Develop the Solid Structure as per customer Specifications

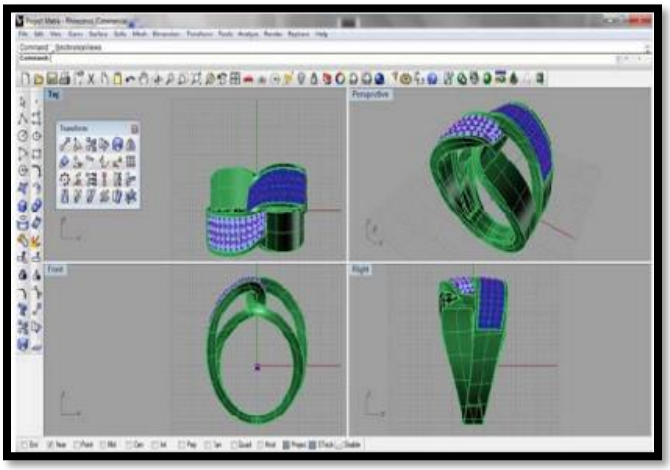

Figure 33: Showing Customer Different Design Prototypes

Figure 34: Render Image Function in order to Display Different Design Possibilities for Jewellery

4.5.2.3 Gemvision Matrix

In order to automate the jewellery design process at the case study company, the researcher will utilise Gemvision Matrix, which in turn will provide the company to design the jewellery in a much faster manner, while at the same time ensuring strict control over the jewellery design process. The software will provide the company with interactive controls that will enable the company to adjust the various aspects of the design during the initial phase, and it will also enable the company to manage a customised virtual library of the designs. A major reason due to which the researcher has selected Gemvision Matrix is that it will provide the company with more efficient and realistic animation as well as rendering tools, which will help the company in development of realistic animation files and design which can be shown to the customers in order to avail their feedback during the initial phases of the design process. The software is highly flexible due to the ability to store customer and design data in the library which facilitates the quick design and build process, while in case of rejection from customers; changes can be made in the design quickly using wide range of styling sheets available in the virtual library. An illustration of the Gemvision Matrix tools is given in Figure 35, 36 and 37.

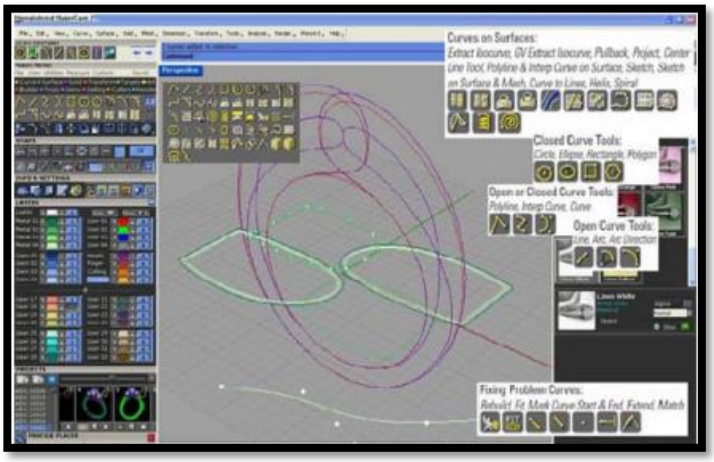

Figure 35: Utilisation of Virtual Database for Making 2D Curve

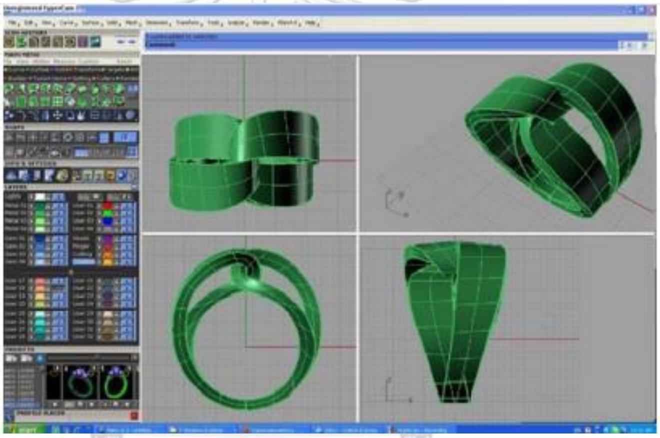

Figure 36: Approaching Prototype Development for Solid Modelling to Enhance the Overall Efficiency of the Design

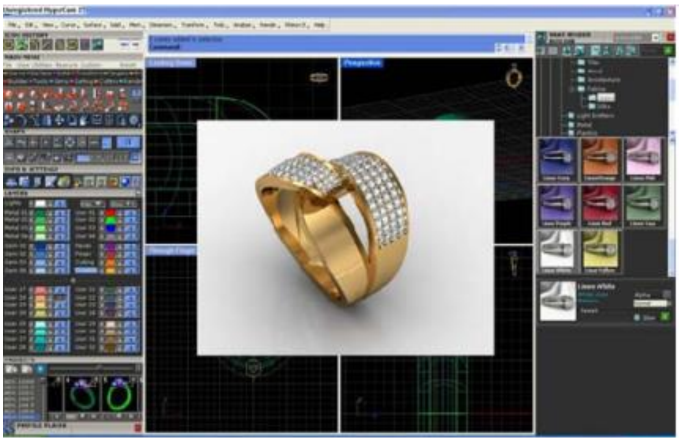

Figure 37: Realistic Rendering to Show Customer Different Design Prototypes

4.5.3 Controlling and Monitoring of Design Process Using Concurrent Engineering

As mentioned in the methodology, the team will utilise Concurrent Engineering model during the improvement phase. The product development with integration of CAD and customer approval were included as an additional step before the casting, in order to reduce the waste which usually occurs due to the rejection from the customers, as the customer's state that the final designed product is not as per their specification. Using concurrent engineering, product development process with an integration of CAD is added to the process which in turn will help in improving the overall efficiency of the design process. Moreover, customer approval process is added in the process where primary 3D design prototype is shown to the customer, in order to verify whether the product design is as per their given specs or not. Thus, the quality of the design was increased and waste was reduced through creation of an inter-check between the designers and the customer, allowing to reduce overall waste and costs which were previously incurred in the designing of jewellery.

An illustration of the proposed production process with integration of product development phase with the introduction of CAD and 3D Printer to help in designing and creating product prototype, and customer approval phase to help in approving the design of prototype before going to the casting process is given in Figure 38:

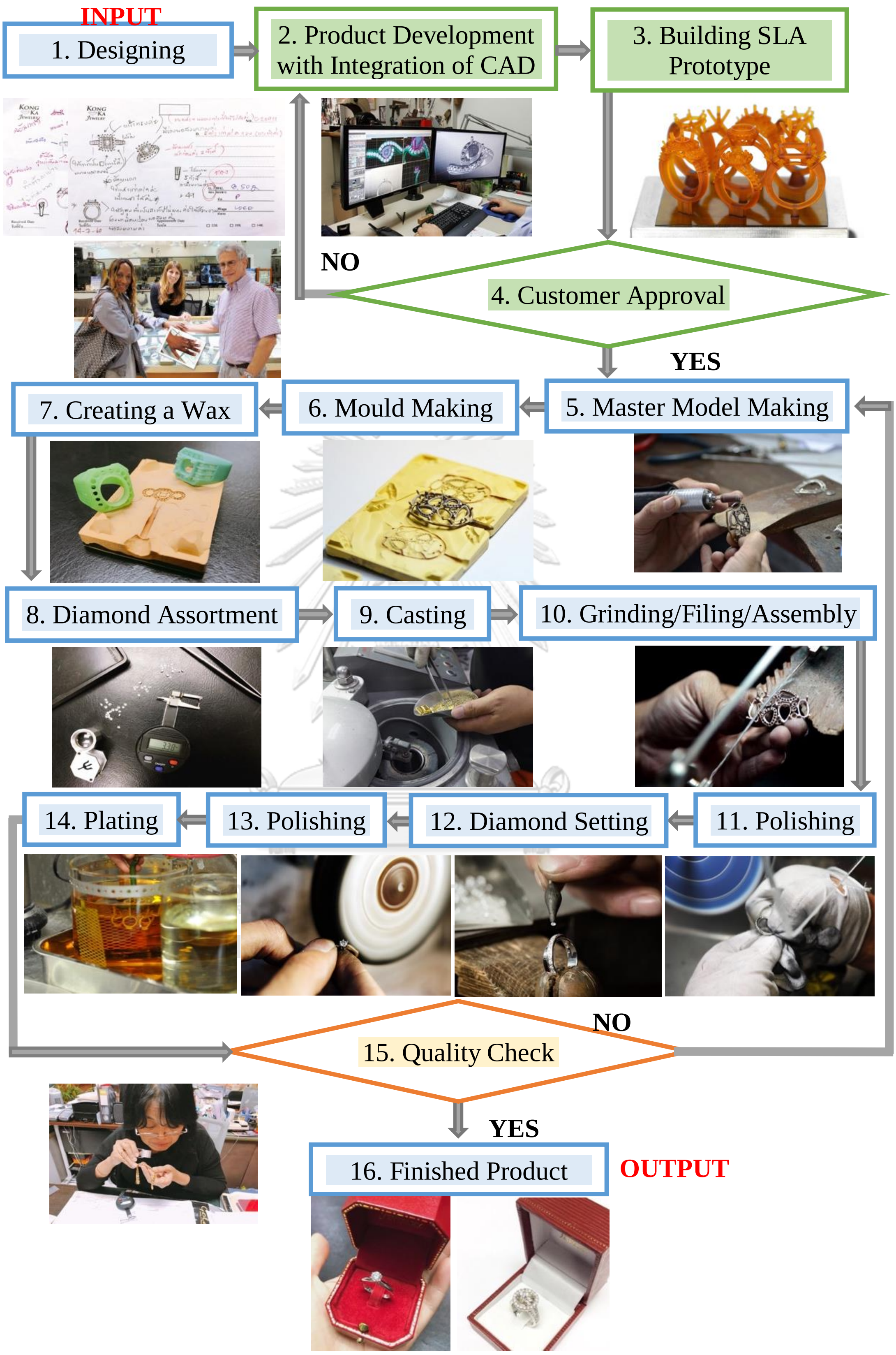

Figure 38: Proposed Production Process with Integration of Product Development and Customer Approval Process

A graphical illustration of the new concurrent engineering product development process is given in Figure 39:

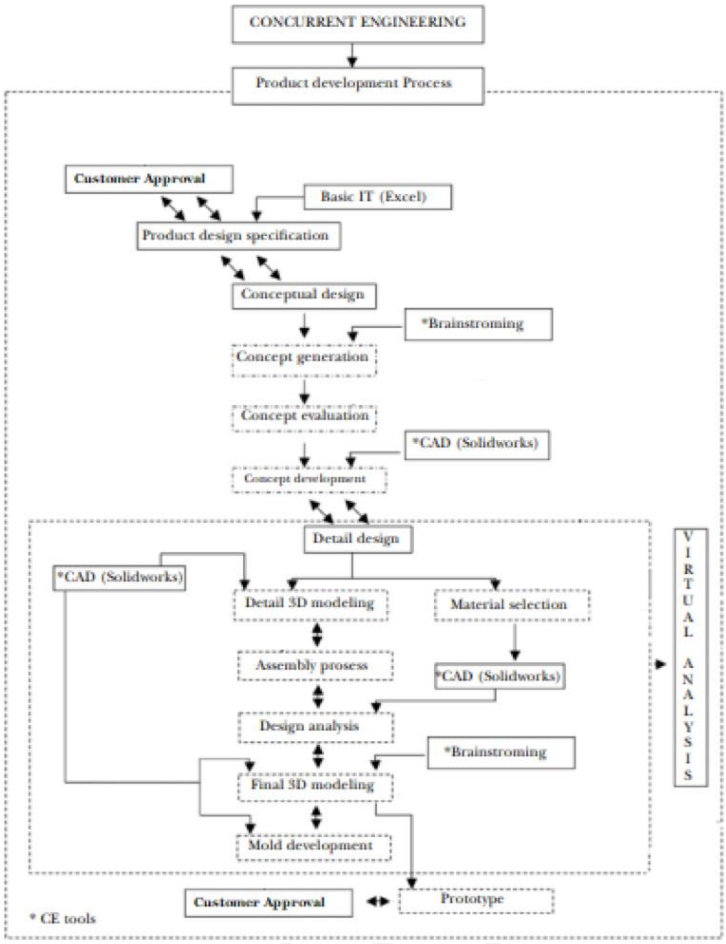

Figure 39: New Concurrent Engineering Product Development Process for the Case Study Company

4.6 Control

4.6.1 Integration of Advanced Product Quality Planning System for Controlling Design Process

In the control phase, the team followed up the progress by collecting data and arrange meeting periodically. The process improvement team formed a cross-function team, which involved the engineers, the designers, and the customers, therefore, once the designers have developed a prototype using 3D software, it was shown to the customers in order to avail their feedback, once the customer approved the product it then move towards the production phase where the engineers worked over the development of the final product. Hence, Advanced Product Quality Planning system allowed the case study company to establish a mechanism called Voice of Customer, due to which the design team clearly understood the customers' requirements, while the design team communicated the customer the technical as well as other special characteristics with respect to the design of the jewellery. Therefore, integration of the APQP model helped the case study company in identifying the changes required in the design at a very early phase, which in turn led towards reduction of the overall cost and wastage at the company, more importantly, it also led towards a higher level of customer satisfaction. The Advanced Product Quality Planning system for controlling design process is illustrated in Figure 40 below.

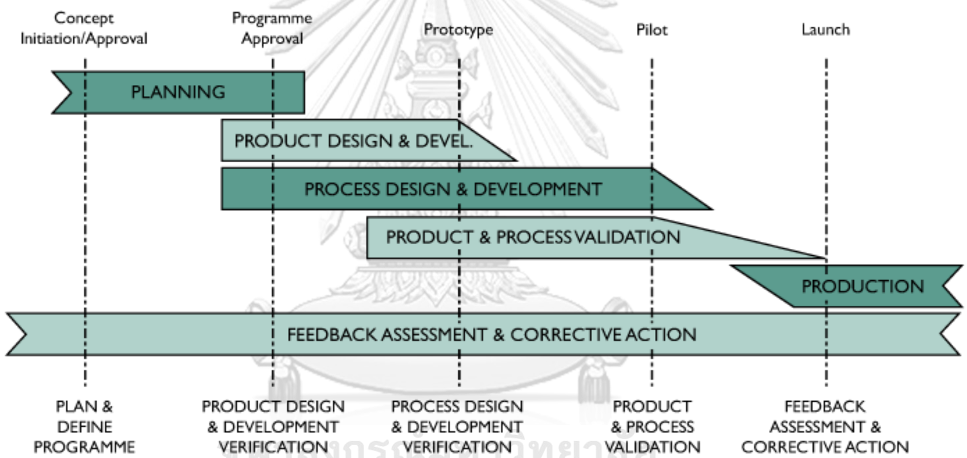

Figure 40: Advanced Product Quality Planning System for Controlling Design Process Model

The implementation of APQP in the initial phases of development allowed the team to take certain set of actions, in case the customer rejected the design. Thus, through adoption of APQP the researcher ensured that risk of change is managed through identification of the design issue in the early process, rather than in the lateral phases, which was already proving to be extremely costly for the case study company. An illustration of this could be seen from the graphs below, as previously (Figure 41) the discovery of the failure mode, took a long period of time and it was almost at the end of the process where the company determined that the customer has rejected the product, which in turn led towards increasing the cost of developing counter-measures. Whereas, after the implementation of the APQP as illustrated in Figure 42, this time of determination of failure mode was reduced, as the case study company was able to identify the discrepancies in the design process at an early phase through the utilisation of CAD model, through the development of a prototype of the final product. This in turn led towards the reduction of the cost as well as the wastage, which company previously faced due to inadequate or obsolete product development process.

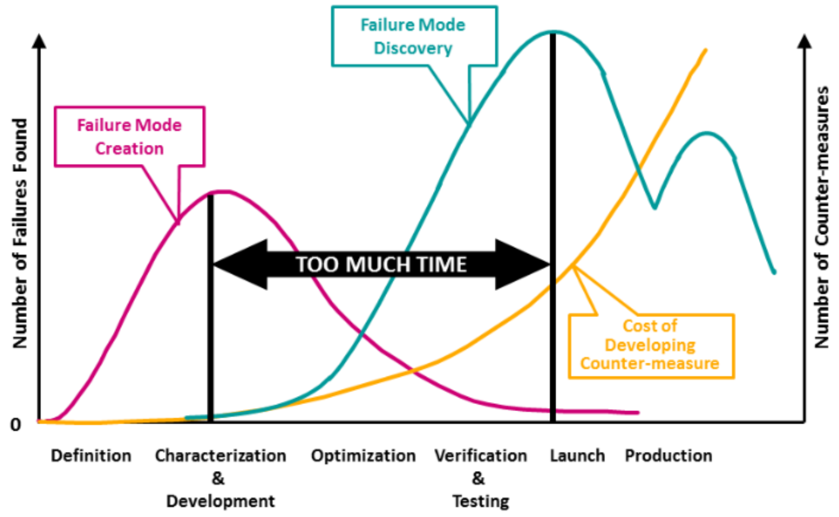

Figure 41: Identification of Failure with Traditional Method

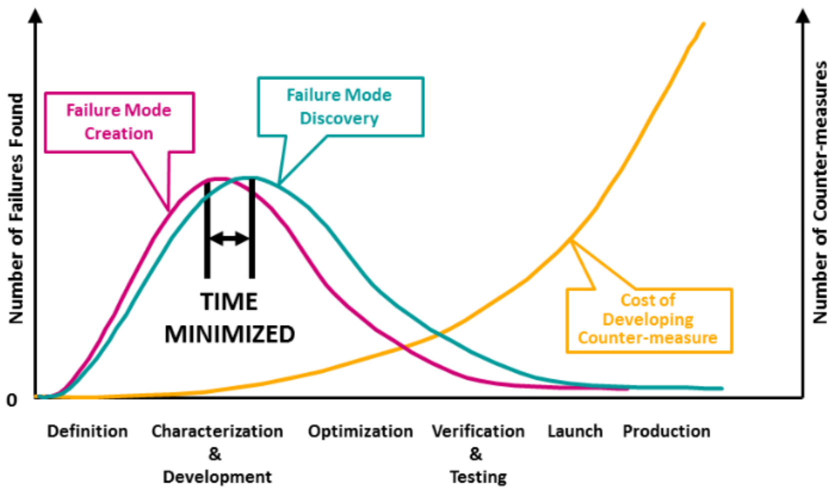

Figure 42: Identification of Failure with DMAIC Model

After successful implementation of APQP in the case study company, following were some of the major benefits which were identified by the researcher:

- The resources were directed through the identification of set of vital items from a list of various inadequate items
- Helped in the promotion of change during the early phase of the design process
- Avoiding late changes through adequate communication with the customers, and through anticipation of the failure and preventing it in the early phase
- Availability of multiple options for mitigation of risk through identification of the risk in the early phase
- Ensuring on-time delivery of product at the lowest cost possible with zero waste
- Determination and adoption of lower cost solution through utilisation of CAD design software

Lastly, the following table (Table 17) shows the action plan that the process improvement team has followed.

Table 17: Action Plan

No.	Action Step	Person Responsible	Start date	Finish date
1.	Employee training	Process Engineer	01/12/17	31/12/17
2.	Review the process before working	Production Manager	15/12/17	31/12/17
3.	Implement Daily Planning using an ERP software	Marketing Manager	01/01/18	25/06/18
4.	Introduction of CAD and Rapid Prototyping for jewellery designing	Designer and Craftsman	01/01/18	25/06/18
5.	Controlling and monitoring of design process using Concurrent Engineering	Production Manager	01/01/18	25/06/18
6.	Create Advanced Product Quality Planning for controlling design process	Quality Control Operator	01/01/18	25/06/18
7.	Performance evaluation	The Process Improvement Team	26/06/18	26/06/18

4.7 Results After Performing DMAIC Production System

Table 18 summarises the results of product rejection and design quality achieved through the new improved DMAIC production method implemented in January – June 2018.

Table 18: Results of Product Rejection and Design Quality after Implementation of DMAIC Production System

Item	Production Quantity	No. of Design Error Items	Quantity of Rejection	Design Quality	Percentage of Rejection
Ring	70	9	8	87%	10%
Earrings	66	8	6	88%	9%
Pendant	54	8	7	85%	13%
Bangle	20	3	3	85%	15%
Necklace	15	3	2	80%	14%
Bracelet	10	2	1	80%	13%
Brooch	8	1	1	88%	13%
Total	243	34	28	Average 85%	Average 12%

Figure 43 provides an illustration of the results of product rejection after implementation of DMAIC production system in January – June 2018.

Figure 43: Results of Product Rejection After Implementation of DMAIC Production System

Figure 44 provides an illustration of the results of design quality after implementation of DMAIC production system in January – June 2018.

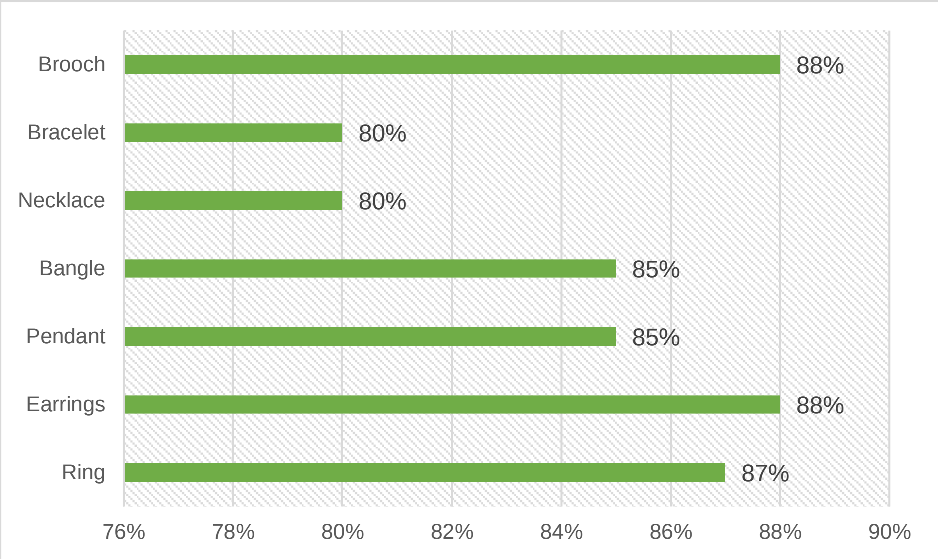

Figure 44: Results of Design Quality After Implementation of DMAIC Production System

Table 19 summarises the results of number of design error items achieved through the new improved DMAIC production method implemented in January – June 2018.

Table 19: Number of Design Error Items After Implementation of DMAIC Production System

Item	Production Quantity	No. of Design Error Item	% of Design Error Item	No. of Design Error Item Found at Design Phase	% of Design Error Item Found at Design Phase	No. of Design Error Item Found at Launch Phase	% of Design Error Item Found at Launch Phase
Ring	70	9	12.85%	7	77.78%	2	22.22%
Earrings	66	8	12.12%	5	62.50%	3	37.50%
Pendant	54	8	14.81%	6	75%	2	25%
Bangle	20	3	15%	2	66.67%	1	33.33%
Necklace	15	3	20%	2	66.67%	1	33.33%
Bracelet	10	2	20%	2	100%	0	0%
Brooch	8	1	12.50%	1	100%	0	0%
Total	243	34	Avg. 14.37%	25	Avg. 78.37%	9	Avg. 21.62%

Table 18 indicated that, the production quantity of the company in January – June 2018 was 243 and the number of design error items were 34 which was calculated as 14.37% of the total products produced. Moreover, the number of design error items found at product design phase was 25 which was calculated as 78.37% while the number of design error items found at launch phase was 9 which was calculated as 21.62% of the number of design error items. Figure 45 illustrated the percentage of design error items found at design phase and launch phase in January – June 2018.

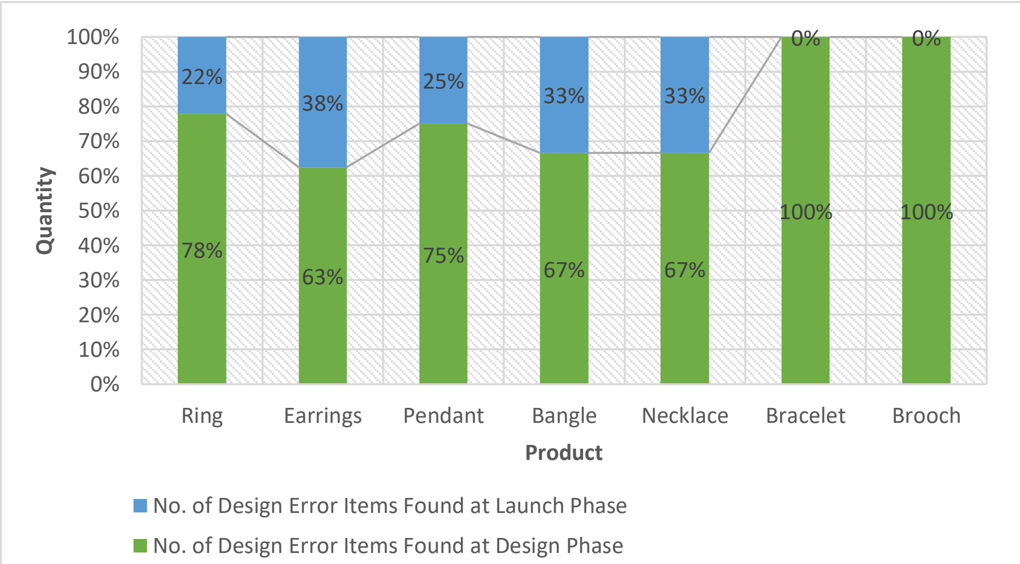

Figure 45: Percentage of Design Error Items Found at Design Phase and Launch Phase After Implementation of DMAIC Production System

As we can see from Figure 45, time of determination of design errors was reduced, as the company was able to identify the discrepancies in the design process at an early phase though the development of the cross-functional team and the utilisation of CAD software.

4.8 Summary of the Implementation and Results Chapter

Hence, in the end, it could be concluded that the implementation of the DMAIC model did not only helped in reduction of costs and waste in the design process, but utilisation of Daily Planning using ERP software, CAD and development of product prototypes using 3D printer and Concurrent Engineering model helps in improving, controlling and monitoring of design process by making customers, designers and artisans to be involved with product from the beginning. Furthermore, the Product Development phase with an integration of CAD and Customer Approval phase have been added to the production process.

As the customers, designers and artisans are being able to be involved with product from the beginning, the designers through development of prototypes availed feedback from the customer in the early phase which provided the company with the flexibility of making changes in the design of the jewellery to meet the customer needs. Moreover, through the integration of the APQP model, the process improvement team formed a cross-function team, which involved the engineers, the designers, and the customers which allowed the firm to able to determine the failure or defects in the design process in the early phase through collection of customer feedback. This enabled the company to integrate Voice of Customer function and ensured that risk of change is managed through identification of the design issue in the early process, rather than in the lateral phases. Therefore, the adoption of DMAIC model certainly proved to be extremely beneficial for the case study company.

CHAPTER 5 – CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In this section of the study, the researcher will provide an overview of the overall results and conclusions, which were drawn from the study. Moreover, the researcher will provide a brief illustration of the problems and obstacles in the research and also the future recommendations which could be adopted by the researchers while conducting the future study in the similar area.

5.2 Overview of Research Strategy and Results

The major purpose behind the utilisation of DMAIC in the product design process in the case study company was to enhance the overall quality of the product designed and delivered to the customer; through reduction of errors in the design process. The integration of DMAIC tool in the product design process enabled the case study company to improve the quality of jewellery design operation through following a five-step approach. The current problem that the case company being faced was identified in the first phase. In the next phase, Cause and Effect Analysis was performed in order to determine the major cause leading towards increasing number of rejections and waste at the company, the root causes of the problem were created and prioritised by utilisation of FMEA and were graphically summarised using Pareto Chart. The result revealed that the current design process being followed by the case study company was quite monotonous and obsolete. Moreover, since the company specialised in manufacturing of customised jewellery, the absence of customer interaction and communication during the design phase was determined as the major reason behind the higher number of rejections.

Afterwards, the innovated solutions for eliminating delay in delivery product to customers as well as product not as per customer specifications were discussed. In the improve phase, the action plan was created with an integration of the daily planning system using an ERP software, CAD and development of product prototype, and Concurrent Engineering. Lastly, in order to monitor and control the product development process, APQP was integrated, as this model will allow the firm to monitor the up-front quality of the product being developed, while at the same time the case study company will also be improved the product output through ensuring that the final products delivered by the firm comply with the customer requirements and supports the new continual.

Therefore, through utilisation of the Six Sigma DMAIC model the researcher introduced the customer acceptance phase in the initial phase of the design process, therefore instead of creating a wax design a 3D prototype was created using CAD software such as JewelCAD, Rhinoceros and Gemvision Matrix, which was shown to the customer in order to avail the feedback from the customer. In case customer stated that the design was perfect the designer moved to the production phase, in case of customer rejected or identified some errors in the design of the jewellery, the changes were made using CAD and a new and updated design was presented to the customer once again for approval. Therefore, this enabled the company to integrate Voice of Customer function, due to which the designers through coordination with the clients were able to design products specifically as per their requirements. Moreover, this allowed the company to reduce waste as the changes in the design were identified in the initial phases of the design process, which also led towards reduction of waste, due to the fact that customers were presented with a prototype of the design in case they rejected it changes were made in the design using 3D CAD technology, which ensured that there was no waste of expensive gold and most importantly labour working hours.

Therefore, after the implementation of Six Sigma DMAIC tool within the product development process, it could be concluded that the case study company enjoyed a number of benefits with respect to reduction of a number of rejection rate from the customers. Most importantly, it allowed the firm in delivering product as per customer specification which in turn led towards fulfilling the requirements of the customers as the results revealed that an average percentage of quality design significantly increased. Finally, average degree of customer satisfaction with the production process increased 6.45% from 75% to 81.45%, with product as per specifications increase 12.8% from 68% to 80.8% and with adherence to the delivery schedules increase from 10.6% from 65% to 75.6%.

The overview of research strategy and outcomes for each research methods can be illustrated in Table 20.

Table 20: Overview of Research Strategy and Results

Research Phase	Tools and Techniques	Result
1. Design Phase	• SIPOC Diagram • Process Improvement Team Customer Satisfaction Survey • Company Process Flow Chart • Design Quality and Product Rejection Rate • Identification of the key performance indicators	✓ The team are able to find the problems occurred in the process. ✓ Led towards designing of KPI's
2. Measure Phase	• Brainstorming • Cause and Effect Diagram • Failure Mode and Effect Analysis • Pareto Chart	✓ The root causes of delay in delivery and product not as per customer specifications are found which are wrong design production, wrong design production, communication breakdown, obsolete and degrading machines, poor time management, outdated production system & strategies, inattention and time pressure of employee and raw materials and parts unavailable
3. Analyse Phase	• Brainstorming	✓ The optimal solutions are found which are daily planning system using ERP software, CAD and development of product prototype and Concurrent Engineering
4. Improve Phase	• Brain Storming • Action Plan	✓ New DMAIC production system with cross-functional team
5. Control Phase	• Advanced Product Quality Planning System	✓ Voice of Customer ✓ Ensured that risk of change is managed through identification of the design issue in the early process, rather than in the lateral phases

5.3 Comparisons of Results Before and After Performing DMAIC Production System

5.3.1 Comparison of the Percentage of Rejection

The following figure (Figure 46) illustrated the comparison of the percentage of rejection before (June – December 2017) and after implementation of DMAIC production system (January – June 2018).

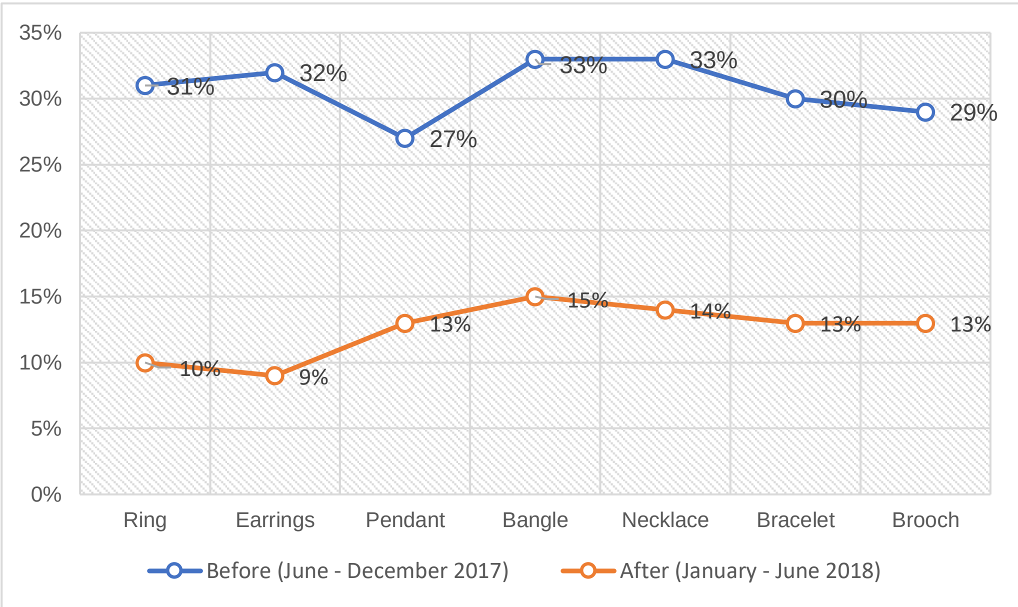

Figure 46: Comparison of the Percentage of Rejection Before and After Implementation of DMAIC Production System

From Figure 46, it is clearly visible that there was a massive improvement in the production of the jewellery due to the implementation of the DMAIC methodology. As before implementation (June – December 2017), the company produced 248 products and 77 products of all the production quantity had been rejected from the customers, which can be calculated as 31% rejection rate and after implementation (January – June 2018), the company produced 243 products and 28 products of all the production quantity had been rejected from customers, which can be calculated as 12% rejection rate. An essential aspect to note here was the massive reduction in the rate of rejection of the jewellery specifically Ring and Earrings which are the signature products of the case study company.

5.3.2 Comparison of the Percentage of Design Quality

The percentages of design quality before (June – December 2017 and after implementation of DMAIC production system (January – June 2018) are compared in Table 47 below.

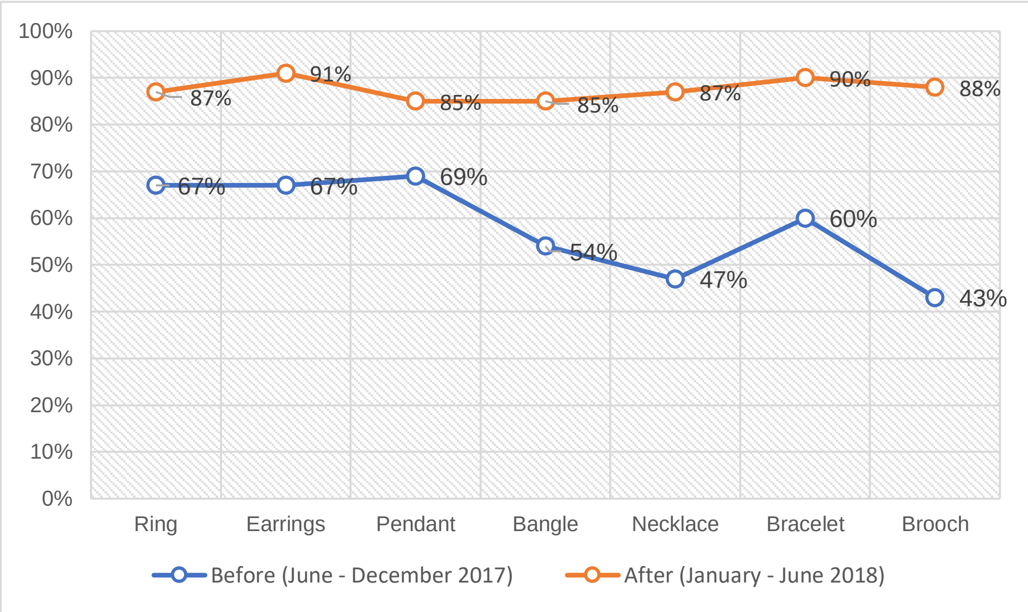

Figure 47: Comparison of the Percentage of Design Quality Before and After Implementation of DMAIC Production System

Before implementation of DMAIC production system (June – December 2017), total number of design items were 248 and total number of design error items were 90, which can be calculated an average of design quality as 58% and after the implementation (January – June 2018), total number of design items were 243 and total number of design error items were 30, which can be calculated an average design quality as 88%. As a result, it can be concluded that after implementation of DMAIC production system, the average percentage of design quality was significantly improved.

5.3.3 Comparison of the Percentage of Design Error Items Found at Launch Phase

The following figure (Figure 48) demonstrated the percentage of design error items found at launch phase before (June – December 2017) and after implementation of DMAIC production system (January – June 2018).

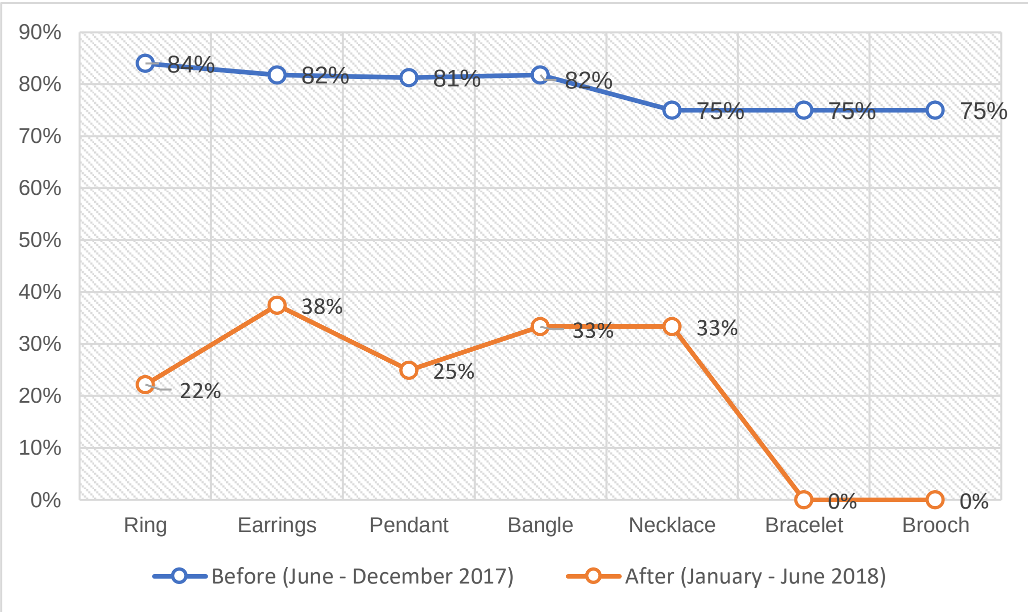

Figure 48: Comparison of the Percentage of Design Error Items Found at Launch Phase Before and After Implementation of the new DMAIC Production System

There is a reduction of number of design error items after implementation of DMAIC production system, as before the implementation (June – December 2017), total 248 products were produced with 90 products came with error designs and 71 products with design error were found at launch phase which can be calculated as 79.13% design error found at launch phase. However, after implementation (January – June 2018), total 243 products were produced with 34 design error items and 9 products with design error were found at launch phase which can be calculated as 21.62% design error found at launch phase. This information revealed that, there was a significant reduction of the design error items and also the design error items found at launch phase. This in turn led towards the reduction of the cost and wastage, which the company previously faced due to a communication breakdown between customers, designers and artisans.

5.3.4 Comparison of the Degree of Customer Satisfaction with Production Process and Service

The process improvement team has conducted the customer satisfaction survey after implementation of the new DMAIC production system in June 2018. The result of the survey revealed that, the overall satisfaction of the customers with the production process was increased, especially in the satisfaction with adherence to the delivery schedules and product as per specifications aspects which are the major focus of the study. Comparison of the average degree of customer satisfaction with the production process before and after implementation can be illustrated in Figure 49.

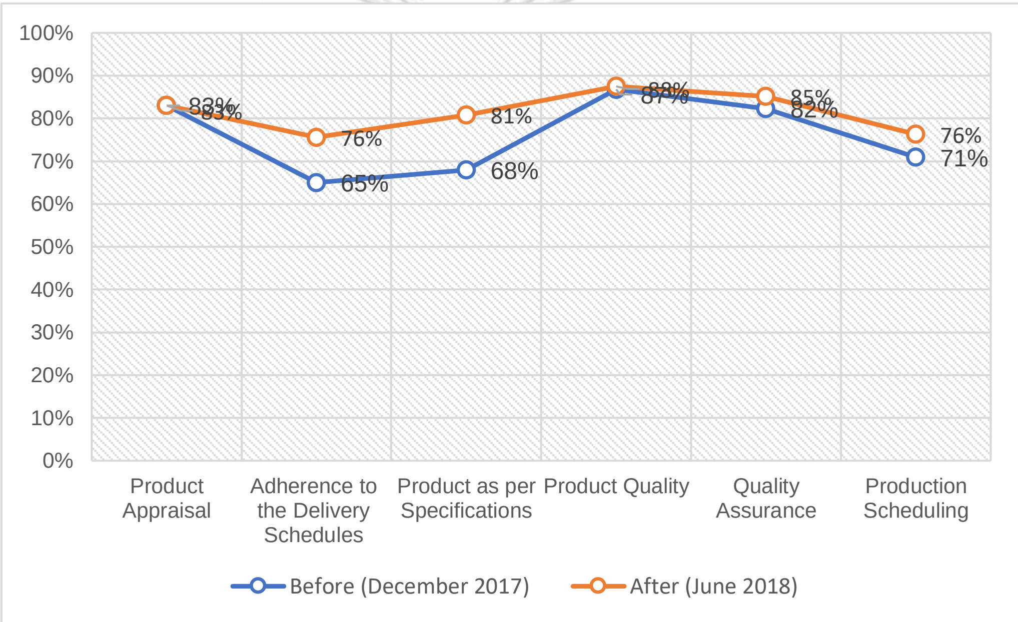

Figure 49: Comparison of the Average Degree of Customer Satisfaction with the Production Process Before and After Implementation

For the customer satisfaction with the service, the result of the survey revealed that the overall satisfaction of the customers with the service was also increased. An average degree of customer satisfaction with the service before and after implementation can be illustrated in Figure 50.

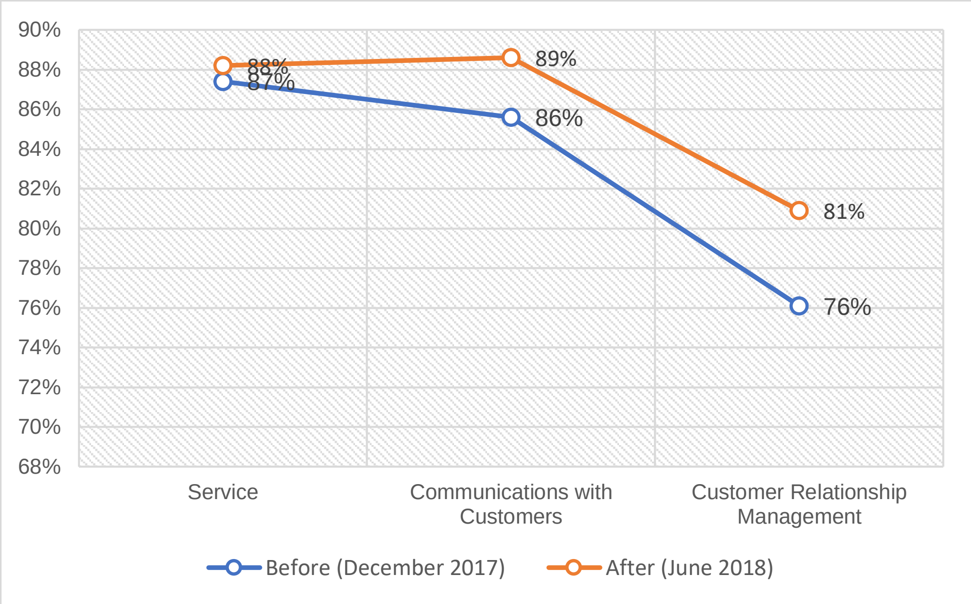

Figure 50: Average Degree of Customer Satisfaction with the Service Before and After Implementation

5.4 Conclusion

In conclusion, the introducing Six Sigma DMAIC approach made the case study company experienced a number of benefits with respect to elimination of waste in the production process with reduction of product rejection rate from customers, reduction of costs incurred in the production process, improvement of design quality of final product, reduction in time consumed in the stock control and inventory management, and most importantly it allowed the firm in delivering product as per customer specification which in turn led towards fulfilling the requirements of the customers and finally reduction of number of product rejection from the customers. These improvements would increase not only customers' satisfaction but also employees' and owners' satisfaction as well.

5.4 Problems and Obstacles in the Research

Sometimes there were difficulties in setting up meetings with employees and staffs due to each member has own responsibility and overloaded work. Hence, there was not much available time to convene and discuss about the project. Besides, there were communication difficulties between the process improvement team members and employees due to some employees not trying to cooperate with the new production system. This is because some of the older employees are reluctant to embrace new technology as they used to what they usually do, which in turn led them to ignore the new instructions.

5.5 Recommendations

Although the overall performance of the product design process is developed and the results are satisfactory, however, continuous improving should be performed in order to maintain a good level of product design. Following are some recommendations for further improvement:

1) In order to ensure that the best quality of product delivered to customers, the company should mainly focus not only on the design process but should also focus on other processes.

2) Regarding rejection of product by the customers according to defect occurred by the quality of raw material such as gold or from the casting process, these problems could not detect in the production process due to the main focus of this research has focused only product design process.

3) Although the material quantity and time are precisely planned with the ERP software, delay in delivery of raw material happened in many cases are inevitable. Therefore, the case study company should also develop supplier relationships in order to improve material delivery performance.

4) The project review meeting should be held regularly in order to help in controlling and sustaining the new product design process as well as monitoring for future problem.

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APPENDICES

Appendix A: Customer Satisfaction Survey and Results

Appendix A 1:Customer Satisfaction Survey

<u>แบบสำรวจความพึงพอใจของลูกค้าที่มีต่อระบบการผลิตสินค้าและคุณภาพการบริการ</u>

<u>Customer Satisfaction Survey on Production Process Efficiency and Overall Service Quality</u>

บริษัท คงคาจิวเวลรี่ ขอขอบพระคุณลูกค้าทุกท่านที่ให้ความไว้วางใจเลือกสินค้าและ บริการของเราเสมอมา ทางบริษัทฯขอความกรุณาจากท่านสละเวลาอันมีค่าในการตอบแบบ สอบถามเกี่ยวกับประสิทธิภาพในการผลิตสินค้ารวมถึงคุณภาพในการให้บริการ โดยแบบสอบ ถามนี้จัดทำขึ้นโดยมีจุดมุ่งหมายเพื่อการพัฒนาระบบการผลิตรวมถึงคุณภาพการบริการให้ดี ยิ่งขึ้นอย่างต่อเนื่อง เพื่อความพึงพอใจของท่านในการใช้บริการในครั้งต่อๆไป

โดยคำตอบของท่านถือว่าเป็นข้อมูลอันมีค่าและจะถูกเก็บเป็นความลับ ซึ่งจะถูกนำมา ใช้เพื่อปรับปรุงระบบการผลิตและคุณภาพของการให้บริการเท่านั้น

Kongka Jewelry would like to thank all customers for their trust in our products and services. The company is committed to continuously improving its production system and quality of service. We kindly ask you to taking valuable time to participate in the questionnaire about the efficiency of production process and quality of service which will help us for the improvement of the production system as well as the services.

Your answers are considered valuable and will be kept confidential and will be used to help us for the improvement of the production system and quality of service only.

ส่วนที่ 1: ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม
Part 1: Personal Information

กรุณาทำเครื่องหมาย √ หน้าข้อความต่อไปนี้
Please tick √ in front of your chosen answer

1.1	เพศ Gender	☐ ชาย	☐ หญิง
1.2	สัญชาติ Nationality	☐ ไทย	Non-Thai (……………………....)
1.3	สินค้า Product	☐ สำเร็จรูป	☐ Made-to-Order

ส่วนที่ 2: ประเมินประสิทธิภาพ/ความพึงพอใจของลูกค้าที่มีต่อระบบการผลิตสินค้า
Part 2: Production Process Efficiency Measures

กรุณาทำเครื่องหมาย √ หน้าข้อความที่ตรงกับความคิดเห็นของท่านมากที่สุด
Please tick √ in front of your chosen answer

ระดับความพึงพอใจตั้งแต่ 1-10 คะแนน โดย 1 หมายถึงพึงพอใจน้อยที่สุด และ 10 หมายถึงพึงพอใจมากที่สุด
On a scale of 1 to 10 how satisfied are you? Where 10 is extremely satisfied and 1 is extremely dis-satisfied

ลำดับ No.	รายการ Contents	ระดับความพึงพอใจ Degree of Satisfaction									
		1	2	3	4	5	6	7	8	9	10
2.1	การประเมินราคาสินค้า Product Appraisal										
2.2	การส่งสินค้าตรงต่อเวลา/สินค้าเสร็จตรงตามเวลาที่กำหนด On Time Delivery										
2.3	สินค้าสำเร็จถูกต้องตรงตามความต้องการของท่าน Product According to Requirements										

2.4	คุณภาพของสินค้าที่ท่านได้รับ Product Quality										
2.5	การรับประกันคุณภาพ/ความเรียบร้อยของสินค้าที่ท่านได้รับ Product Quality Assurance (No Defects)										
2.6	การจัดลำดับงานและตารางการผลิต Production Scheduling										

ส่วนที่ 3: ประเมินประสิทธิภาพ/ความพึงพอใจของลูกค้าที่มีต่อการให้บริการ
Part 3: Overall Service Quality Measures

กรุณาทำเครื่องหมาย √ หน้าข้อความที่ตรงกับความคิดเห็นของท่านมากที่สุด
Please tick √ in front of your chosen answer

ระดับความพึงพอใจตั้งแต่ 1-10 คะแนน โดย 1 หมายถึงพึงพอใจน้อยที่สุด และ 10 หมายถึงพึงพอใจมากที่สุด
On a scale of 1 to 10 how satisfied are you? Where 10 is extremely satisfied and 1 is extremely dis-satisfied

ลำดับ No.	รายการ Contents	ระดับความพึงพอใจ Degree of Satisfaction									
		1	2	3	4	5	6	7	8	9	10
3.1	การบริการ Services										
3.2	การติดต่อสื่อสารกับลูกค้า Communication with Customer										
3.3	การจัดการความสัมพันธ์ระหว่างลูกค้า Customer Relationship Management										

ส่วนที่ 4: ข้อเสนอแนะ
Part 4: Comment and Suggestion

กรุณาทำเครื่องหมาย √ หน้าข้อความต่อไปนี้
Please tick √ in front of your chosen answer

4.1	ท่านจะกลับมาซื้อสินค้าที่นี่อีกหรือไม่ Will you return to Kongka Jewelry?	☐ ใช่ Yes	☐ ไม่ใช่ No
4.2	ท่านจะแนะนำร้านคงคาจิวเวลรี่ให้เพื่อนหรือคนรู้จักหรือไม่ Will you recommend Kongka Jewelry to friends and relatives?	☐ ใช่ Yes	☐ ไม่ใช่ No
4.3	ข้อเสนอแนะอื่นๆ Other Comments or Suggestion …………………………………………………………………………………… ……………………………………………………………………………………		

ขอบคุณทุกท่านค่ะ
Thank you for your cooperation.

Appendix A 2: Customer Satisfaction Survey Result

Degree of Satisfaction		Production Process Efficiency Measures						Overall Service Quality Measures			Comment and Suggestion		Gender	Total
		Product Appraisal	Adherence to the Delivery Schedules	Product as per Specifications	Product Quality	Product Quality Assurance	Production Scheduling	Service	Communication with Customers	Customer Relationship Management	Will you return?	Will you recommend to friends?		
Total Count on Degree of Satisfaction														
Before	(1)	2	5	4	0	2	3	0	0	1	No 14	No 18	Male 39	100
	(2)	1	6	5	0	1	1	0	0	1				
	(3)	0	4	3	0	1	2	0	1	2				
	(4)	1	7	5	1	2	4	1	0	1				
	(5)	2	18	20	2	5	17	3	2	7				
	(6)	3	13	12	3	2	13	4	6	12	Yes 82	Yes 84	Female 61	
	(7)	13	15	1	12	5	11	3	9	19				
	(8)	25	9	11	22	29	15	29	25	21				
	(9)	27	12	14	24	26	18	22	26	19				
	(10)	26	11	13	36	27	16	38	31	17				
After	(1)	1	1	1	0	0	0	0	0	0	No 7	No 9	Male 43	100
	(2)	0	3	0	0	1	0	0	0	0				
	(3)	0	1	1	0	0	2	0	0	1				
	(4)	1	3	3	0	1	3	1	0	1				
	(5)	3	13	10	4	3	14	2	2	5				
	(6)	3	9	7	5	4	10	4	4	10	Yes 93	Yes 91	Female 57	
	(7)	15	10	16	4	8	12	5	5	17				
	(8)	27	17	18	24	26	19	23	23	21				
	(9)	25	21	23	25	28	21	25	27	20				
	(10)	25	22	21	38	29	19	40	39	25				
Average Degree of Satisfaction														
Before		83%	62%	65%	86.80%	82.30%	70.90%	87.40%	85.60%	76.10%				
After		83.40%	75.60%	80.80%	87.50%	85.10%	76.30%	88.20%	88.60%	80.90%				
Percent Increased		0.4%	13.60%	15.80%	0.70%	2.80%	5.40%	0.80%	3%	4.80%				

*Customer Satisfaction (CSat) = (Sum of All Scores/No. of Respondents) x 10

VITA

Panporn Lertkachonsuk was born on November 6th, 1987 in Bangkok, Thailand. She has got high school certification in English-Chinese programme from Saint Joseph Convent School in 2006. Since her family business is a jewellery manufacturing company, it inspires her to do the research on product design process improvement in a jewellery manufacturer.

In 2010, she obtained a Bachelor of Science Degree in Engineering Management (International Programme) from Sirindhorn International Institute of Technology (SIIT), Thammasat University. After graduating, she has started working as an Operations Director at Kongka Jewellery company. Eight years' experience with the jewellery company has enhanced her strategic planning, skills to tackle problems, as well as assisted in developing an effective expansion strategy. With a solid professional foundation, it is time to hone her leadership, strategic, and entrepreneurial skills in order to expand her grasp on decision-making, leadership, and power which will help her to manage any complex issues she might face when running her own business.

Thus, she decided to study a dual degree programme to pursue a Master of Engineering in Engineering Management from Regional Centre for Manufacturing Systems Engineering, Faculty of Engineering (RCMSE), Chulalongkorn University and a Master of Science in Engineering Business Management from Warwick Manufacturing Group (WMG), the University of Warwick in 2015. Involvement in RCMSE and WMG is an excellent opportunity to gain further skills and know-how to run her own business, an invaluable chance to network with other entrepreneurial people.