CONTRACT MANUFACTURING MANAGEMENT FOR AN OPTICAL DEVICE PRODUCTION COMPANY

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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การใช้ผู้ผลิตตามสัญญา (contract manufacturer) เป็นแนวโน้มที่เพิ่มขึ้น ในการจ้างผลิตและการผลิตเพื่อลดต้นทุนและเพิ่มผลกำไร ดังนั้นบริษัทที่ว่าจ้างผู้ผลิตจะเผชิญกับความท้าทายภายนอกและภายใน เพื่อรักษาความสามารถในการแข่งขันและส่งมอบผลิตภัณฑ์ใหม่ในเวลาและงบประมาณที่กำหนด บริษัท ผลิตอุปกรณ์นำแสง ได้ถูกเลือกเป็น บริษัท กรณีศึกษาสำหรับการวิจัยนี้ ดังนั้นวัตถุประสงค์ของงานวิจัยนี้คือการปรับปรุงการบริหารจัดการการผลิตตามสัญญา

การศึกษาครั้งนี้ประยุกต์ใช้หลักการ Six Sigma DMAIC มาเป็นวิธีการในการปรับปรุงเกณฑ์การประเมินสำหรับการทำสัญญาการคัดเลือกผู้ผลิต นอกจากนี้ยังมีการปรับปรุงในเกณฑ์การประเมินประกอบด้วยเทคโนโลยีการผลิตและความสามารถในการพัฒนาผลิตภัณฑ์ใหม่ นอกจากนี้การศึกษาครั้งนี้ใช้ยุทธศาสตร์การวางแผนล่วงหน้าเพื่อคุณภาพ หรือที่รู้จักกันทั่วไปว่า Advance Product Quality Planning (APQP) แนวความคิดในการควบคุมและติดตามการการพัฒนาผลิตภัณฑ์ใหม่ ในช่วง New Product Introduction (NPI) กิจกรรมในการผลิต เพื่อเพิ่มความมั่นใจในความสำเร็จของการเปิดตัวและการพัฒนาผลิตภัณฑ์ใหม่และผลของการปรับปรุงและการดำเนินการจะวัดประสิทธิผลการผลิต ผลิตภัณฑ์ใหม่ เพื่อให้เป็นไปตามขั้นตอน และการศึกษาจะดำเนินการเพื่อเข้าใจถึงความสำคัญของการจัดการการผลิตตามสัญญา ในที่สุดการประเมินผลการผลิตตามสัญญาและองค์ประกอบการผลิตตามสัญญาจะรวมอยู่ในกระบวนการห่วงโซ่อุปทานในการสนับสนุนการผลิตภายนอก

ผลที่ได้แสดงให้เห็นว่า เชิงกลยุทธ์ที่ดีกว่าในการควบคุมและติดตามการการพัฒนาผลิตภัณฑ์ใหม่ ที่ทำการผลิตที่ผู้ผลิตตามสัญญา ช่วยให้ทีมพัฒนาผลิตภัณฑ์สามารถเลือกผู้ผลิตตามสัญญาที่ดีและเหมาะสมกับความต้องการในการพัฒนาผลิตภัณฑ์ใหม่ นอกจากนี้ยังตรวจสอบวิธีการในการจัดการผลิตตามสัญญา ที่มีการแสดงผลที่ดีกว่าในการควบคุมความคืบหน้าและลดผลกระทบจากความล่าช้าใด ๆ ที่เกิดขึ้นในแต่ละช่วงเวลาของการพัฒนาผลิตภัณฑ์ใหม่

ภาควิชา ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต ลายมือชื่อนิสิต .....

ลายมือชื่อ อ.ที่ปรึกษาหลัก .....

สาขาวิชา การจัดการทางวิศวกรรม

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The use of contract manufacturer is an increasing trend in outsourcing of production and manufacturing to reduce cost and maximize the profit. Consequently, the companies that outsource their manufacturing to contract manufacturers are facing external and internal challenges to maintain competitiveness and deliver new products on time and on budget. An optical device production company is selected as Case Study Company for this research. Therefore, the objective of this research is to improve contract manufacturing management.

This study applies Six Sigma DMAIC methodology to improve assessment criteria for contract manufacturer selection. In addition, improvement in assessment criteria is consisted of manufacturing technology and capability to support new product development. Furthermore, this study utilizes strategic Advance Product Quality Planning (APQP) concepts to control and follow up New Product Introduction (NPI) activities at the selected contract manufacturer to ensure the success of new product launch. The outcomes of improvement and implementation are benchmarked against reference current new product in NPI phase, and the study is performed to understand the importance of contract manufacturing management for NPI activities. Finally, contract manufacturing assessment and contract manufacturing elements are incorporated into the supply chain process to support outsource manufacturing.

The results have shown that strategic items outperformed at the reference contract manufacturer allow product development team to select contract manufacturer that best fit their requirements, also, examine methodology to manage contract manufacturer which have better visibility to control the progress and minimize the impact of any delayed activities.

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

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1. CHAPTER I
INTRODUCTION

1.1 Background of the Research

In several businesses, outsourcing to contract manufacturer is becoming a popular alternative to in-house manufacturing. Many companies realized that the best solution to achieve the best output is to specialize that in which they are most proficient by outsourcing the manufacturing or production to its contract manufacturer.

Contract manufacturing often provides benefits to both parties. For the companies who do outsourcing, they can access to the technology that do not possess, faster time to market, free up capacity bottleneck, and minimize the investment to own the operation. For the contract manufacturers, the products that are given to them are using their core competencies. Thus, they have the needed technologies and skills to produce the products and can make more benefits through high volume production.

However, the decision to engage with contract manufacturer always involves risks. The company must ensure the outsource operation is well managed without negative impact to the efficiency and quality of work.

This research provide a deep dive in the contract manufacturing management for New Product Introduction (NPI) by examining the contract manufacturing process of the optical devices through a case study of product development team of a case company. Also, provides a solid guidance for contract manufacturing management that directly adds values to the company who outsource manufacturing process and its new production to contract manufacturer.

1.2 Statement of the Problems

This research will study the phenomenon of contract manufacturing selection and management through a case company whose contract manufacturing process is examined. For the purpose of confidentiality, the company will be referred as “The Case Company” and the contract manufacturers for the case company will be referred as “CM1”, “CM2”, “CM3” and “CM4”.

The Case Company is in telecommunication industry, there is a fairly short product life cycle because trends and applications in telecommunication change regularly. The Case Company announced for the manufacturer of optical devices in Asia. Several businesses and projects of The Case Company are now using contract manufacturers.

However, it can be seen from the past that the Case Company was facing problems to successfully launch new product produced by the selected contract manufacture within the expected timeline.

Thailand operation of The Case Company was established in 2009 to develop the optical devices using contract manufacturer in Thailand. In the past four years, The Case Company had moved its production to three contract manufacturers in Ayutthaya, Pathumthani and Chonburi province in order to manufacture the three new products. As of now, The Case Company has its manufacturing at the contract manufacturers located in Pathumthani province and Chonburi province which run two different products, and foreseen the possibility to either manufacture in Pathumthani or Chonburi to run all activities in one place.

Light source product moved from CM1 to CM2 in Year2010 within product life cycle. Move again in Y2011 from CM2 to CM3 to develop fiber laser product. Move again in Y2012 from CM3 to CM1 within product life cycle. See Figure 1-1 to illustrate the move of the products in three different contract manufacturers.

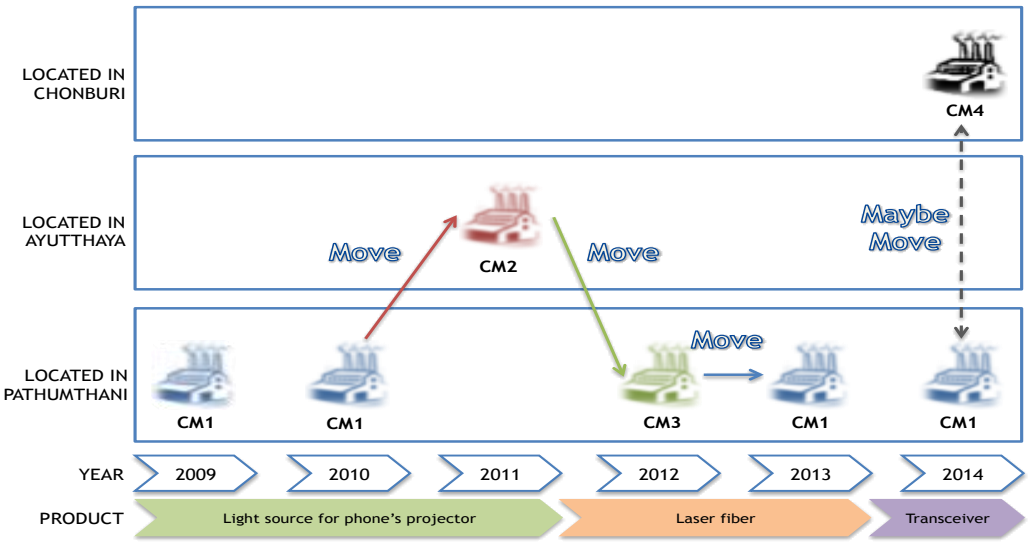

Figure 1-1: Move of products to various contract manufacturers

The moves were occurred within product life cycle during introduction phase, the product itself has a relatively short life cycle, and of cause, the move delayed product launch, cost more money, spent more time, and lost the opportunity to deliver new products into markets within the target timeline. The reasons for each move of products are also different as shown in Table 1-1 Reasons to move Light source product from CM1 to CM2.

Table 1-1: Reasons to move Light source product from CM1 to CM2

Product	Contract Manufacturer		Timeline for New Product Development: Program approval	Prototype	Pilot	Launch	Move During Product life cycle: NPI Phase: Design & Development	Product Design & Development	Process Design & Development	Product & Process Validation	Production Phase: Growth	Maturity	Decline
Light source	CM1	Plan	10/2009	2/2010	5/2010	11/2010		✖					
	CM1	Actual	10/2009	Fail --> MOVE from CM1 to CM2									
	CM2				Delay 8/2010	Delay 1/2011				Discontinue			
	Reason for the move: Technology constraint: CM1 capability and core technology did not meet the requirement of light source product. CM1 lacked of experince in assembly process such as die bonding and wire bonding.												

The case company went through contract manufacturer selection process and started developing light source product at CM1 in year 2009. Process technologies required for Light source are die attach, wire bond, optical alignment, seam seal and

test. The status of process technology readiness at CM1 when starting engagement is shown in Table 1.2: CM1 Process Technology Readiness. Two process technologies that were required for light source products are Eutectic die attach and Aluminum wedge bond, these two process were available and under process validation to maximize process window in order to support various product types. These two processes were targeted to qualify in year 2008 during November to December.

Table 1-2 CM1 Process Technology Readiness

Technology Requirements for Light Source Product			
Process Technology	**Status**	**Qualification plan**	**Date**
Die attach			
Epoxy die attach	Qualified	Process qualification	07/31/06
Eutectic die attach	Validation	Validation to maximize process window	09/30/08
		Process qualification	12/30/08
Wire bond			
Gold ball bond	Qualified	Process qualification	06/01/07
Aluminum wedge bond	Validation	Validation to maximize process window	08/31/08
		Process qualification	11/30/08
Optical alignment			
Fiber alignment	Qualified	Process qualification	03/30/07
Lens alignment	Qualified	Process qualification	05/30/07
Seam seal			
Epoxy lid seal	Qualified	Process qualification	11/30/06
Hermetic seal	Qualified	Process qualification	05/30/07
Functional Test			
Electrical test	Qualified	Process qualification, modify test software for each product	06/30/07
Optical test	Qualified	Process qualification, modify test software for each product	06/30/07

The case company engaged with CM1 in year 2009 and planned to build the prototype Light source in February 2010, at that time, the eutectic die attach process and aluminum wedge bonding process at CM1 were not qualified for production yet, still under process validation, qualification was likely to delay to June 2010 and would cause the prototype product delay for another as well, see Figure 1-2:

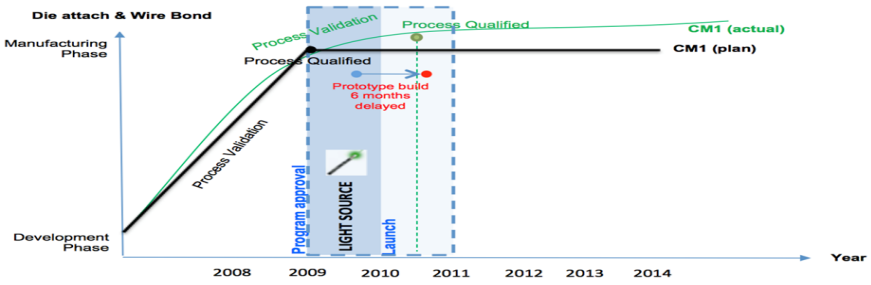

Figure 1-2: Delay of process qualification at CM1

To minimize the impact to prototype schedule, the case company was searching for other contract manufactures which had process capability, and ready to

develop prototype light source in short period of time. From 2nd contract manufacturer selection, the case company looked for the capability to do eutectic die attach and aluminum wire bond and found CM2 has process capability available to support prototype light source product, see Figure 1-3, CM2 had process qualification since 2008 and capable to start prototype light source.

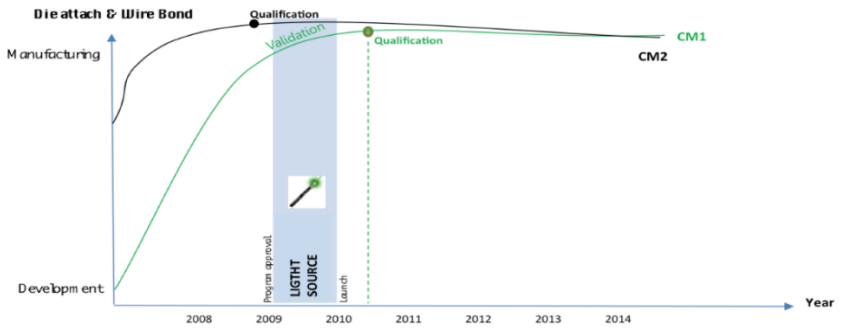

Figure 1-3 Compare CM1 and CM2 die attach & wire bond process readiness

With this reason, technology constraint at CM1, the case company decided to move Light source product from CM1 to CM2 in 2010. Unfortunately, the move was occurred during product life cycle in development phase, the product itself has a relatively short life cycle, and it took several months to produce the prototype even the process capability was available at CM2. Launch schedule was delayed and the product was dis-continued from end-customer. The case company failed to launch Light source product at the selected contract manufacturers, both at CM1 and CM2, within the specific timeline and lost the opportunity to enter the market due to end-customer dis-continued to introduce Light source product for phone's projector.

1.3 Objective of the research

The objective of this thesis is to improve contract manufacturing management for the optical devices production company, case company, which includes Contract manufacturer selection and Contract manufacturing management during New Product Introduction.

The improvement of contract manufacturing management helps to manage materials flow, information flow, control the quality of manufacturing process, quality of the product, and delivery of the product during New Product Introduction (NPI) phase by using the fundamental of product quality planning, or Advance Product Quality Planning (APQP) tool, which is widely used in the industries and organizations.

1.4 Scope of the research

The research has two areas of focuses.

First is to ***select*** the Contract Manufacturer (CM), CM selection gap identification, look at how the company can identify and select the contract manufacturer that fit all needs and be capable to support new products in the development product roadmap.

Second is to ***manage*** the contract manufacturer, to keep the contract manufacturer focused on the development of new products based on product specification and development plan, including the successful of prototype build and launching new product.

1.5 Expected Benefits

The success criteria can be both qualitative and quantitative, for the research, the success criteria has been defined prior to start the research, which are;

Improvement: The contract manufacturer management that will be used on New Product Introduction, which include the selection of contract manufacture and the contract manufacturer management.

KPI: Schedule tracking and critical path to launch new product. Number of launched products

Once the contract manufacturing management in this research has been fully implemented, the expected benefits of contract manufacturing management are:

Support and contribute to the company doing outsource its products / manufacturing to contract manufacturer. Understand the needed responsibility from contract

manufacturer since start engagement to develop new product and carry on for mass production.

Improve the competitiveness and productivity of contract manufacturing works and contribute to remove the obstacles and risks at contract manufacturing process. Define the negative aspects of contract manufacturing that requires management intention.

1.6 Research Methodology

The research is mainly descriptive the case company, so the problem will be described and analyzed in the detailed manner. The main phases of the research are literature review, case study, and analysis. The case study is the phase that defines the body of the research in five steps with tollgate review after each step. Using the approach of DMAIC (Define, Measure, Analyze, Improve, and Control) will be identified in this research.

Define phase will lay out the foundation of the research, the research team will accurately define the problem, identify the customer to deliver the solution to, identify the requirement, and determine the skill and core team for project research.

Measure phase is happened when the process is identified with input and output of each process step. Measure the baseline to identify, validate, develop, and improve as required from establishing baseline performance and critical to quality.

In the analyze phase, the critical to process input and output will be identified, root causes will be determined.

In the improve phase, the critical inputs that are the driver to the performance will be controlled to maintain the reliability and performance.

In the control phase, the long-term measurement and action will be established, standard procedure will be developed.

2. CHAPTER II
LITERATURE REVIEW

The literature review in this research is to study the theoretical framework in order to understand the theory and apply as a guideline to improve current process of contract manufacturing management for an optical production company. From research team brainstorming, there are several methods that can be used for problem solving and process improvement, such as DMAIC and Kaizen. Since the problem from this research is complex, DMAIC should be the selected method which helps research team from skipping crucial steps and increases the chances of a successful project [1]. However, DMAIC is not an implementation method for best practices, but method to discover best practices as it is a data-driven, customer-focused, structured problem-solving framework [2] to improve the existing process and reduce variation in output.

The review consists of two main areas: Six Sigma DMAIC Methodology and Advance Product Quality Planning from AIAG (The Automotive Industry Action Group).

2.1 Six Sigma DMAIC Methodology

Over a period of time, several methodologies had been used to improve quality, productivity, and enhance customer satisfaction. Among those methodologies, Six Sigma DMAIC is one of the most effective.

According to "The Certified Quality Engineer Handbook, Third Edition, ed. Connie M. Borror, ASQ Quality Press, 2009, pp. 321–332", DMAIC is a data-driven quality strategy used to improve processes. It is an integral part of a Six Sigma initiative, but in general can be implemented as a standalone quality improvement procedure or as part of other process improvement initiatives such as lean. DMAIC is an acronym for the five phases that make up the process:

(D) Define the problem, improvement activity, opportunity for improvement, the project goals, and customer (internal and external) requirements.

(M) Measure process performances, collect the data how process in currently perform, determine the starting point or baseline and look for the root cause of the problems.

(A) Analyze the process in an effort to narrow down and verify the root causes of variation and poor performance.

(I) Improve process performance by addressing and eliminating the root causes and move on to solution development.

(C) Control the improved process and future process performance to sustain the newly achieved improvement.

DMAIC is the most popular methodology to implement Six Sigma, and aims to improve processes or reduce deviations.

At every step in the DMAIC roadmap, specific tools are used, and most of the tools are statistical, to manage a process improvement project. DMAIC process is illustrated in Figure 2-1 as a guideline to identify purpose and output of each DMAIC process, the most comment technique in Six Sigma. Tools for DMAIC project / process include Project Charter, SIPOC, VOC, Pareto charts, control charts, fishbone diagrams, FMEA, Control Plan, descriptive statistics and advanced statistical analysis. The diagram in Figure 2-2 shows various tools for DMAIC process, however, not every tool will be used on a project, depending on the type of project and information.

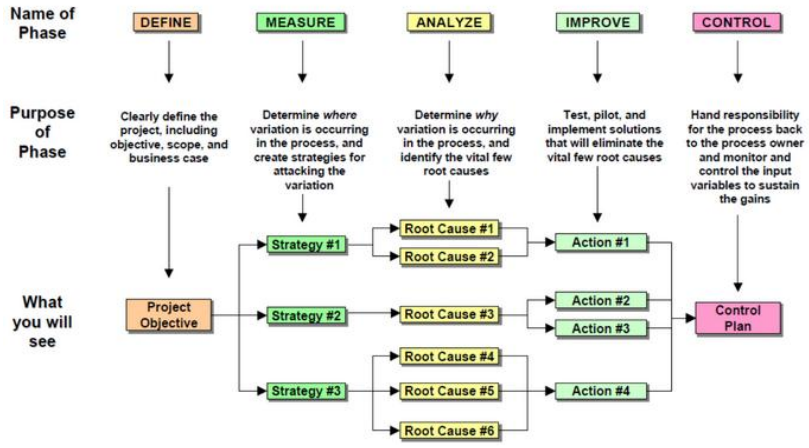

Figure 2-1: DMAIC Process – Purpose and Output (Lean Institute wrote by Alok K. Vermar NSRP Panel 09/09)

Figure 2-2: DMAIC Six Sigma Toolbox (Polymer Innovation; Increase profit using Process Management Tool, Jeffrey Gotro, 2013)

2.1.1 Define Phase

The objective of the define phase, according to Heidi Wiesenfelder (H&S. CDM Consultancy, 2011), is to clarify the purpose and scope of the project, in order to get a basic understanding of the process to be improved, and for determining the perceptions and expectations for quality to ensure what is going to be done and how to evaluate the project's progress and ultimate success.

2.1.1.1 Project Scope

The project scope defines project boundaries or the area or processes in the organization. It also defines the major components of the project. The inclusion of project scope in the DMAIC project charter helps retain the focus of the Six Sigma team toward achieving the goal and prevent scope-creep (Simon Misiewicz, 2010, Lean, Six Sigma and ToC DMAIC Process Improvement)

2.1.1.2 Project Charter

A project charter is a short document, usually one page in length that lists out the summary scope, objectives, and stakeholders of a project. The project charter is

the first deliverable of a project and finds use to secure project approval and authorize the powers for the project manager. It is the foundation of the project and serves as a reference point during the planning and implementation stage. The DMAIC project charter is a key deliverable of the “Define” phase of DMAIC. A good DMAIC project charter seeks to make clear the reason for the Six Sigma intervention. It could detail customer expectations, the deviance of the existing state from such an optimal state, the cost, effort, and resources required to achieve the optimal state, consequences of not taking action, potential benefits, cost benefit trade off, and the like. The Define phase of Six Sigma needs to incorporate such information.

2.1.2 Measure Phase

The objective of the measure phase is to identify the defects or failures in the product, gathers valid baseline information about the process and to evaluate and understand the current state of the process [3]. In measure phase, the research team will determine the baseline from after new product had been approved from the management to start the engagement with contract manufacturer.

2.1.2.1 Voice Of Customer (VOC)

Customer satisfaction is the major objectives for a Six Sigma, what is customer really want [4], VOC data is usually acquired by customer interviews, a direct interaction with and observation of the customer, through focus group, by surveys, voice of customer can be illustrate in figure 2-3.

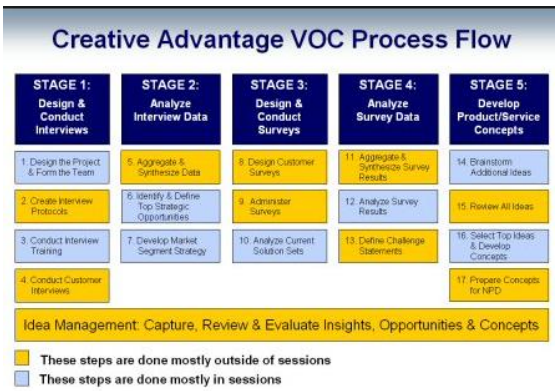

Figure 2-3: Voice Of Customer Flow

[Source: http://www.greenbookblog.org/]

2.1.2.2 Process Map and Flow Chart

A process map helps to define factors or activities that lead to the outputs of the process. It can be used for both products and services. A process is certainly a conversion of inputs to outputs [4]. The SIPOC diagram (see figure 2-4) is a high-level process map which includes Suppliers, Input, Process, Output, and Customers.

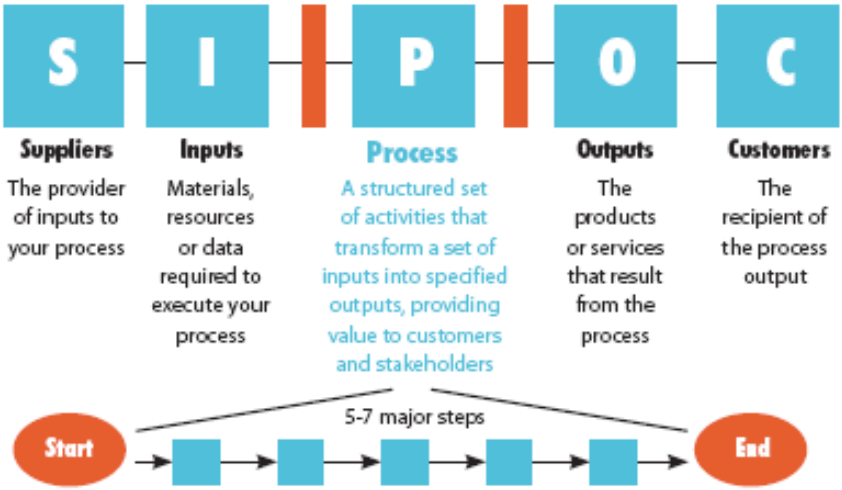

Figure 2-4: SIPOC Diagram [5]

2.1.3 Analyze Phase

The objective of the analyze phase is to determine the possible root cause and understand the relationship between process variable and the outcome performance to develop awareness about potential process improvements [6].

2.1.3.1 Analysis Cause-and-Effect Matrix

Cause-and-Effect Matrix, see sample in figure 2-5, is a very useful tool that often used to correlate the Critical to Quality aspects of the project to the Cause-and-Effect of the problem, according to BMGI Organization from IASSC (International Association for Six Sigma Certification) in the United State, the C&E Matrix can also be used to prioritize the input variables that have the highest impact to the problem and choose the right input variable for further analysis and improvement.

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Cause & Effect Matrix

Rating of Importance to Customer		10	8	8														
#	KPIV	Grass Color (deep green preferred)	Thickness of Grass	Weeds (none preferred)													Total	% Rank
1	Fertilizer Type	10	10	10													260	19%
2	Watering Frequency	10	10	5													220	16%
3	Mower Height	10	7	7													212	15%
4	Fertilizer Frequency	7	10	7													206	15%
5	Watering Duration	10	10	3													204	15%
6	Cutting Frequency	7	7	7													182	13%
7	Operator Experience	3	3	5													94	7%
8	Brand of Mower	1	1	1													26	2%
9																	0	0%
10																	0	0%
11																	0	0%
12																	0	0%
13																	0	0%
14																	0	0%
15																	0	0%
16																	0	0%
17																	0	0%
18																	0	0%
19																	0	0%
20																	0	0%
Total		58	58	45	0	0	0	0	0	0	0	0	0	0	0	0		

Figure 2-5: Example of Cause and effect matrix [7]

2.1.3.2 Cause-and-Effect Diagram

The cause-and-effect diagram is a formal tool regularly useful in un-layering potential causes [6]. Cause-and-effect diagram is used to organize and display all of the knowledge for problem-solving process as also known as an Ishikawa diagram or fishbone diagram was developed in 1950 by the late Professor Kaoru Ishikawa [8].

2.1.3.3 Failure Modes and Effects Analysis (FMEA)

FMEA is a technique for quality improvement of products and processes [8]. FMEA is widely used in various engineering projects constructed under FMEA team which identify the activities to reduce or eliminate the potential error occurrence in a system or process and will manage on the implementation and documentation of these activities. Basically, FMEA is used to prioritize the different potential sources of variability, failures, errors, or defects in a product or process by using the steps outlined in Table 2-1.

POTENTIAL																	
FAILURE MODE AND EFFECTS ANALYSIS																	
FMEA Type (Design or Process):			Project Name/Description:									Date (Orig.):					
Responsibility:							Prepared By:					Date (Rev.):					
Core Team:												Date (Key):					
Design FMEA (Item/ Function) Process FMEA (Function/ Requirements)	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Controls Prevention	Current Controls Detection	Detec	RPN	Recommended Actions	Responsibility & Target Completion Date	Actions Taken	Sev	Occur	Detec	RPN

Table 2-1: Table of Failure Modes and Effects Analysis [8]

2.1.3.4 Why-Why Diagram

Why-why diagram is similar to cause-and-effect diagram which helps to detect the cause-effect relationships. The Why-why diagram structures a problem statement and generates a hierarchy of causes and sub-causes by repeatedly asking the question "why?" [9], until the root causes are determined. Figure 2-6 illustrates the systematic structure of why-why diagram.

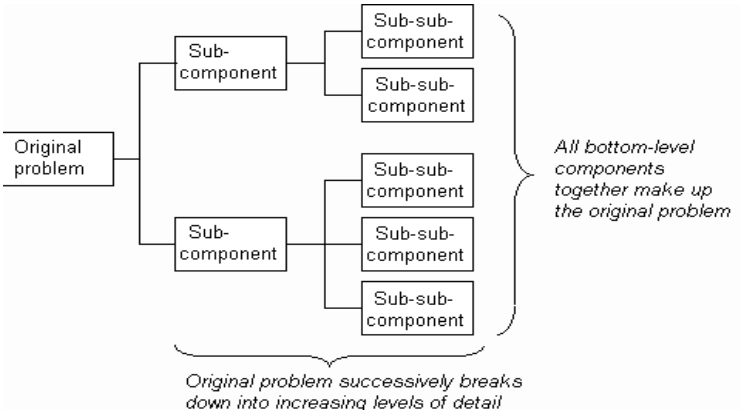


Figure 2-6: Sample of why-why diagram [Source: The Chartered Quality Institute]

2.1.4 Improve Phase

The objective of the improve phase is to test pilot and implement the solution. Tools include pilot testing and FMEA to prove the implementation

2.1.5 Control Phase

The objective of the control phase is to monitor and control to sustain the good results. Tools include process implemetation and monitoring plans.

2.2 Advance Product Quality Planning (APQP)

Advance Product Quality Planning (APQP) has been used for managing and controlling the process of developing the new product. According to the APQP concept of Automotive Industry Action Group (AIAG, 2008)[10], APQP is a process which assists the company, especially the automotive industry, to define the plan for design and development of new products. APQP consists of six phases which are shown in figure 2-7.

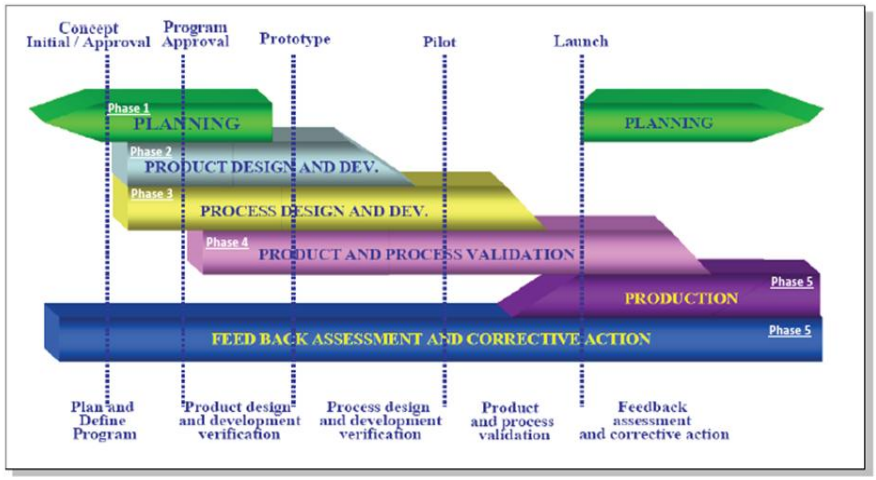


Figure 2-7: Advance Product Quality Planning (AIAG)[10]

2.3 Contract Manufacturing

2.3.1 Definition of contract manufacturing

Contract manufacturing is a process that establishes a working agreement between two companies. One company custom builds parts on behalf of their client.

The client does not have to maintain manufacturing facilities or hire labor in order to produce their finished goods.

Several definitions for contract manufacturing can be found in scientific and managerial publications. According to QFinance, The Ultimate Financial Resource, described the contract manufacturing as:

"Having another firm produce product or part"

On the other hand, contract manufacturing can be described as (define by Total Molding Services, Inc):

"An organization capable of manufacturing and/or purchasing all the components needed to produce a finished product or device."

To sum up the contract manufacturing definitions presented above, a definition for the purpose of this study has been created. Contract manufacturing means:

"Contract manufacturing is a form of outsourcing which can be beneficial to the companies involved. Both parties can focus on their core competencies. The receiving company does not bear the burden of running a manufacturing facility. The contract manufacturer specializes in the type of work being complete."

2.3.2 Strategic of contract manufacturing

Contract manufacturing seems to offer cost advantage for the company and also provide other advantages over internal manufacturing. However, the company should not overlook the other ways to extract the maximum value that contract manufacturing offers. Include designing a suitable manufacturing strategy which complements the circumstances and requirements of the company as well as the nature of project concerned, choosing the right contract manufacturing and managing and monitoring a contract manufacturing effectively.

In order to gain the benefits of using contract manufacturing, it is best to take a strategic approach. Here are the areas that will be focus in this thesis to come up with strategic of contract manufacturing.

a) Timing and reason: The companies should be able to answer all these questions in order to get contract manufacturing work. Is it the right time to get involve with contract manufacturing? Which of the development phase that the company should outsource their products? Did the companies analyze their position and see the need to get into outsourcing.

b) Effective management: To handle contract manufacturing, the system management has to be developed and effectively use in order to dive and consolidate contract manufacturing operational performance. The contract manufacturers should allow the companies to have a have a certain amount of control of their products.

2.3.3 Benefits and risks of using contract manufacturer

The main benefits of using contract manufacturer

a) Cost saving: The companies save on their cost of capital because they do not have to pay for a facility and the equipment needed for production. They can also save on labor costs such as wages, training and benefits. Some companies may look for contract manufacturers in low-cost countries such as China, to benefit from the low cost of labor.

b) Skilled expertise: The companies can take advantage of skills that they do not possess, but the contract manufacturer does. Contract manufacturers provide expertise and experience to improved overall productivity and efficiency.

c) Core competence: The companies can focus on their core competencies if they outsource their productions to contract manufacturer.

d) Increase flexibility: Contract manufacturers have a very flexible operation that allows quick changes in products and scheduling. This allows the companies to make quick changes when necessary to meet market demands.

e) Shift from a fixed to a variable cost model: The companies that use contract manufacturers do not invest capital in floor space and equipment to produce their products. If the project ends or the product changes, and the equipment cannot be used, the company will not responsible to those costs. Those costs are variable and will go away if the project is cancelled. Those fixed costs are the full responsibility of the contract manufacturers.

The main risks of using contract manufacturer

a) Transfer of critical know-how: When engage with contract manufacturer, the companies will sharing their formulas or technologies to the contract manufacturers, this increases the potential risk for intellectual property claims. Appropriate provisions should be built into the contract to protect the critical know-how and intellectual property.

b) Quality: When entering into contract manufacturing, the companies must make sure that the manufacturer's standards are aligned with their own. The companies have to rely on the contract manufacturers for having good process and quality control of their product.

c) Loss of control: Without direct control over the manufacturing, the companies will lose their ability to respond to demand fluctuations. It will be impossible for the companies to control certain aspects of the contract manufacturer's business, which can result in failure to meet business objectives.

d) Relationship: The companies must keep in mind that the manufacturer has other customers. The companies cannot force them to produce their product before a competitor's. Most companies mitigate this risk by working cohesively with the contract manufacturer and awarding good performance with additional business.

e) Project management: A key process faced by both the companies and the contract manufacturer is new product introduction (NPI). New product introduction are incorporating numerous activities of multiple

functions such as engineer, sourcing, manufacturing and quality control within the contract manufacturer's organization. Most companies often delays an NPI projects and coordinating of these activities getting more complex in contract manufacturing environment.

In several researches (among others Marshall et al., 2007; Iloranta & Pajunen-Muhonen, 2008) the age of the relationship was named to be one of the essential factors behind the success in contract manufacturing. Contract manufacturing success is not given and the activity can turn out to be risky if not planned, executed, and managed right. The biggest risks found in the existing contract manufacturing research were risk of losing the competitive edge and creating a new competitor, loss of control of quality and other important aspects, difficulty to measure process and supplier, and realization of the cost savings. With these risks, several improvements and counter actions were introduced. Generally a healthy relationship and mutual trust as well as open communication between the companies offer a good basis for problem solving.

With reference to the Public book Outsourcing Management for Supply Chain Operations and Logistics Service by Folinas, Dimitris, published in IGI Global, Aug 31, 2013 [11]. Logistic and supply chain management had been a vital part of every economy and business industry. The successful growth of using contract manufacturer has prompted a number of researches and has resulted in several books and papers. However, the majority of the researches had concentrated on;

The practice of outsourcing manufacturing to contract manufacturer

The analyze of the outsourcing of logistic services

Planning of outsource to contract manufacturer

Management of contract manufacturing partnerships

Promote the best practice in the application of contract manufacturing

However, there are doubts as many researches are not clearly identified the best practice to micro manage the progress of contract manufacturing activities during new product introduction and the methodology to address and overcome the

problem occurred during product development to avoid any delay of the overall project.

This study, contract manufacturing is limited only to production related activities as defined in the beginning of this part. The main reasons behind the decision to transfer the responsibilities to contract manufacturer are cost savings, concentration on company's core competencies, limited capabilities to invest in the newest technology, and seek for flexibility. Several gains can be realized at once, but the requirement is thorough search for the right contract manufacturer.

3. CHAPTER
DEFINE CONCEPT AND METHODOLOGY

From chapter I, introduction of this research, it clearly identified that there is a gap in current contract Manufacturer selection and management process to focus on the feasibility review and needed technologies to develop new products. No solid guidance and systematic management to control, follow up and measure the output of each New Product Introduction (NPI) phase. These gaps are leading to lose the opportunity to launch new product produced at the selected Contract Manufacture within target timeline.

The studies of the case company were formed into this research to find the most efficient contract manufacturer to develop new products in accordance to product roadmap and needed technology, see Figure 3-1, and seek to identify areas where contract manufacturers are not meeting case company expectations to launch new products, and to jointly address the issues in order to meet the expectations and build up long-term partnership.

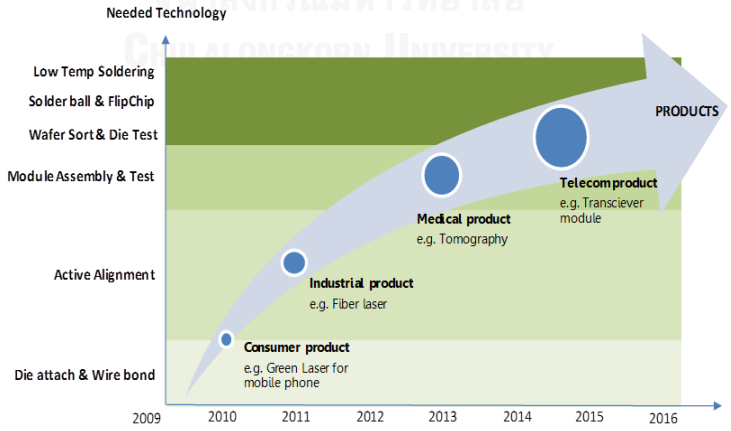


Figure 3-1: Product roadmap and needed technologies

Therefore, this research aims to improve contract manufacturing management for the optical devices production company, case company, which includes contract manufacturer selection and methodology to manage the materials flow, information

flow, control the quality of manufacturing process, quality of the product, and delivery of the product during New Product Introduction (NPI) phase by using the fundamental of product quality planning, or Advance Product Quality Planning (APQP) tool, which is widely used in the industries and organizations.

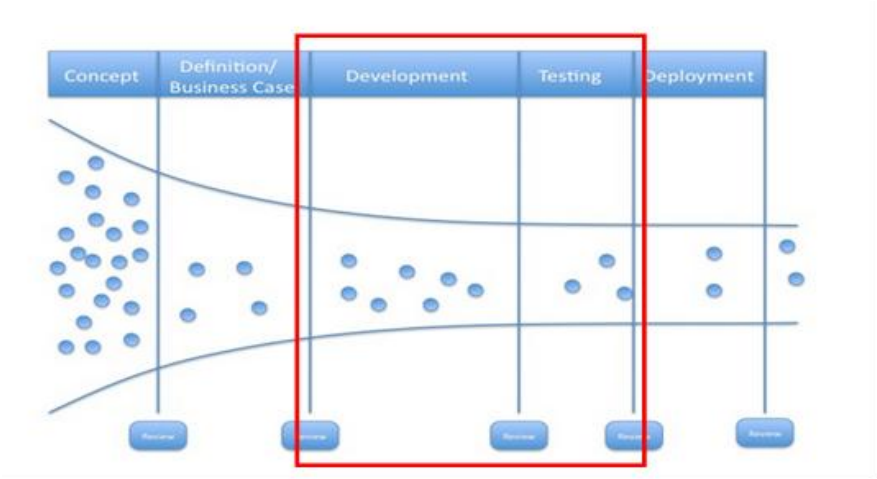
3.1 Concept and Scope of the research

The research has two areas of focuses.

First is to ***select*** the Contract Manufacturer (CM), CM selection gap identification, look at how the company can identify and select the contract manufacturer that fit all needs and be capable to support new products in the development pipeline (see Figure 3-3 and Figure 3-4).

Second is to ***manage*** the contract manufacturer, to keep the contract manufacturer focused on the development of new products based on product specification and development plan, including the successful of prototype build and launching new product (see Figure 3-5).

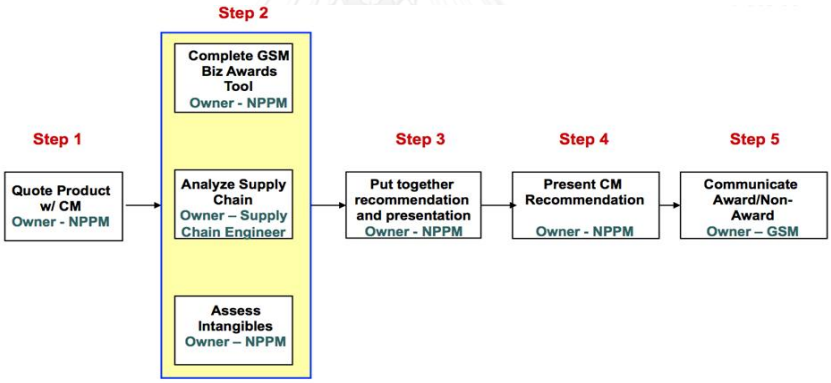
The focus of the research is only the technical tasks at development stage and testing stage of New Product Development Process as shown in Figure 3-2. Currently, the case company is using the supply chain awards tools and supply chain analysis tools to select the contract manufacturer. The criteria for selection are cost, technical expertise, supply chain logistic and material management, and performance of the contract manufacturer. Process steps for contract manufacturer selection are divided into 5 steps as shown in Figure 3-3 and Figure 3-4. This research is only focused at the 3rd part of step 2 – Assess Intangibles (focus on the engineering / prototype build performance, and other New Product Introduction (NPI) activities at the potential contract manufacturer) by reviewing current Contract Manufacture assessment, identifying the gap in category of technology and design, to improve Contract Manufacturer assessment which will include the requirements of new products in company's product roadmap.



[Reference picture from: Product strategy – Best Practice in strategy and product management, Michael Kapp.[12]]

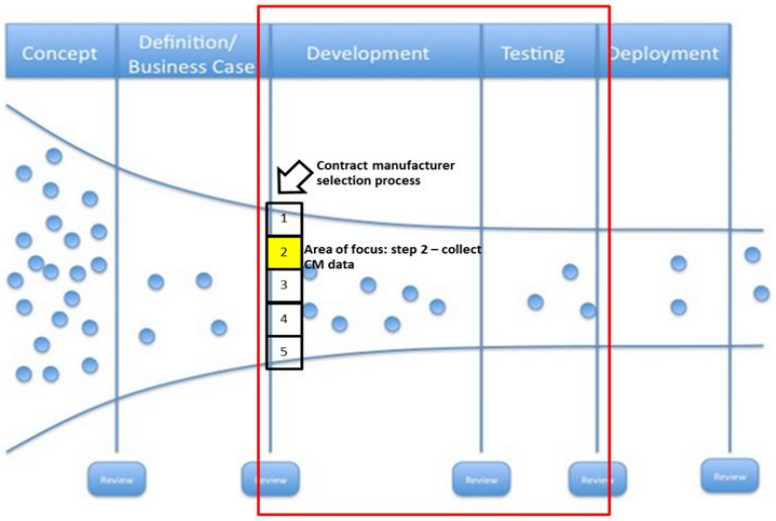
Figure 3-2: New Product Development Process

This research is only focused on the technical tasks at Development Stage and Testing Stage.



(Note: NPPM stand for New Product Program Manager)

Figure 3-3: Contract Manufacturer Selection Process being used at the case company



[Reference picture from: Product strategy – Best Practice in strategy and product management, Michael Kapp.]

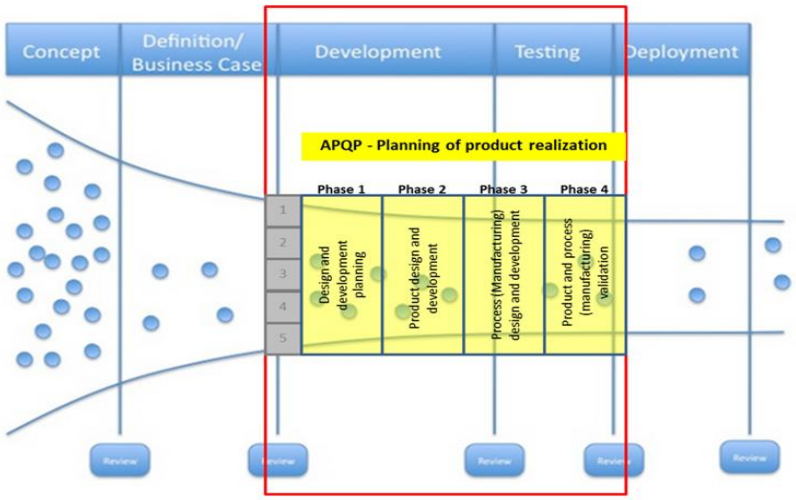
Figure 3-4: Contract Manufacturer Selection Process

The selection process takes place at the beginning of Development Stage This research is only focused at step 2 – Assess Intangibles, of CM Selection Process

After the contract manufacturer had been selected, the research will then focus on the contract manufacturing management by applying the technique of Advance Product Quality Planning (APQP) as a structure method of defining and establishing the steps necessary and requirement for quality planning of new product development into manufacturing process at contract manufacturer as shown in Figure 3-5. The scope of Advance Product Quality Planning (APQP) implementation is to create the systematic way to manage New Product Introduction (NPI) project, includes the methodology to manage manufacturing system, process & quality system, and data management system.

The research is only related to contract manufacturing selection and contract manufacturing management for development stage and testing stage in new product development process that being used at the case company, the research does not include outsourcing process, outsourcing strategy, of new product to the contract manufacturer. The influence factors making the decision to outsource the

manufacturing function has been examined from corporate strategy, and will not be discussed in this research.



[Reference picture from: Product strategy – Best Practice in strategy and product management, Michael Kapp.]

Figure 3-5: Steps necessary for New Product Introduction

3.2 Research Methodology

The research is mainly descriptive the case company, so the problem will be described and analyzed in the detailed manner. The main phases of the research are literature review, case study, and analysis. The case study is the phase that defines the body of the research in four steps as shown below

STEP 1: Define – Understand goals & Planning

Define project charter

Project planning

Preliminary architecture for Contract Manufacturing Management

Note: Refer Chapter 1 and 3 in this research report

STEP 2: Establish requirements – Analyze, evaluate, develop and recommend

Identify the needs, collect the data from previous, survey and brainstorming.

Identify gaps in current contract manufacturer management

Analyze the data and generate the key list of needs, identify process and criteria

Note: Refer Chapter 4 and 5 in this research report

STEP 3: Implementation – Prepare a written plan and execute the strategy

Select pilot CM for implementation

Design the architecture, information, and structure.

Create a suitable model

Note: Refer Chapter 6 in this research report

STEP 4: Monitor & Adjust – Monitor the performance and document process

Develop contract manufacturing management system in the extranet

CM management system implementation

Monitor the result

Refine and complete contract manufacturer management

Document the process and train to user, core team at both case company and global organization

Launch and publish the contract manufacturer management for widely use

Note: Refer Chapter 7 in this research report

3.3 Contract Manufacturing Process

The manufacturing processes of the case company are mostly located at the contract manufacturer. The company is producing the optical devices for Laser industrial products and IT products in various architectures such as collaboration, Data center & Virtualization, and Enterprise Networks.

The company identified its core competency as “Product Designing”. So, to focus on it, the company outsources all other non-core activities, including manufacturing, to contract manufacturers and suppliers. The supply chain network of the company is shown below in figure 3-6.

Figure 3-6: Supply chain network of the case company

Previously, all manufacturing decisions were made from the supply chain headquarter in San Jose, California. The company had announced to have its Asia Manufacturing Operations in Singapore in 2001 and Thailand in 2009, in order to lower the cost and shorten customer lead times. Currently, the company has Asian contract manufacturers in Singapore, Malaysia, China and Thailand.

For Thailand operation, the company developed, and plan to develop, many products at several contract manufacturers located in the center of Thailand, see figure 3-7 to illustrate products produced at the contract manufacturer and figure 3-8 to illustrate current technology and equipment available at the contract manufacturer.

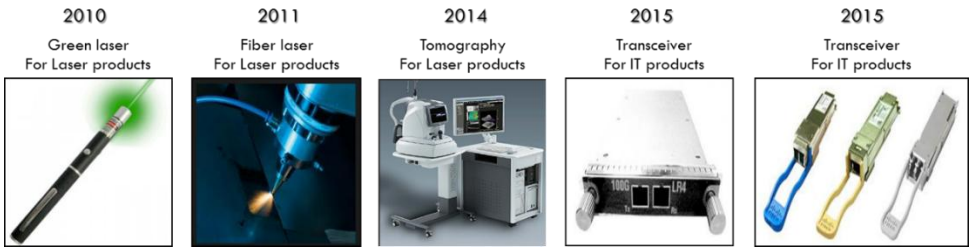


Figure 3-7: Products produced at the contract manufacturer

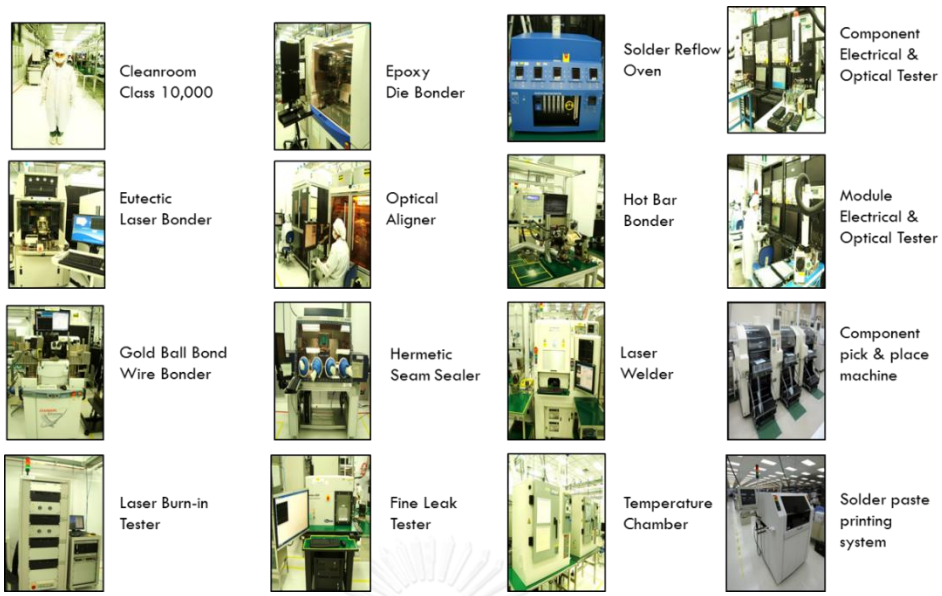


Figure 3-8: Current technology and equipment at contract manufacturer

3.4 SIPOC Process Mapping

The process mapping for developing the optical devices at the contract manufacturer is constructed in this section to having better recognize of the supplier, the input to the process, the customer and the output of the process as illustrate in figure 3-9.

Suppliers	Inputs	Process	Outputs	Customers
Program manager Hardware engineer Product engineer Supply chain manager Demand planning manager IT & Software engineer Material vendors Equipment vendors	Product design Product requirement Bill of Material Product specification Process Technology requirement Future product roadmap Demand forecast Supply chain & Technology requirement Target cost Product & Service Process specification Material specification Test specification Process Equipment Test Equipment Material Resources Process / Product characteristic Information Technology Material requirement planning Production facility & capacity Procedures Qualified product / process	Product & Process design and development CM interface / contract CM selection Technology transfer & Development Process set up Manufacturing set up Product & Process qualification Mass production EOL	Define Product Requirement Process Manufacturer assessment Quotation Contract manufacturer engagement procedure Review Design for Manufacturing (DFM/DFA) Process equipment Materials Resources Technology roadmap / R&D Process of Record / Parameter Process control Process validation Process capability Work Instruction Procedure Quality control Manufacturing & Test data Manufacturing Management System Prototype / Qualification Timeline First Customer Shipment Products / Revenue	Internal customer Management Manufacturing Engineer Production Staffs Contract manufacturer

Figure 3-9: Process Mapping to develop new product at the contract manufacturer

3.5 Define problem

From the historical data as defined in chapter 1, the case company had failed to launch new product at the selected contract manufacturer within timeline and cause the huge delay to deliver the products to the markets. Therefore, the research team had been setup to closer look and analyze the problem to come up with the solution to successfully launch new product at the contract manufacturer within timeline. The problem statement, business case, and goal statement, and project charter has been published as illustrate in figure 3-10.

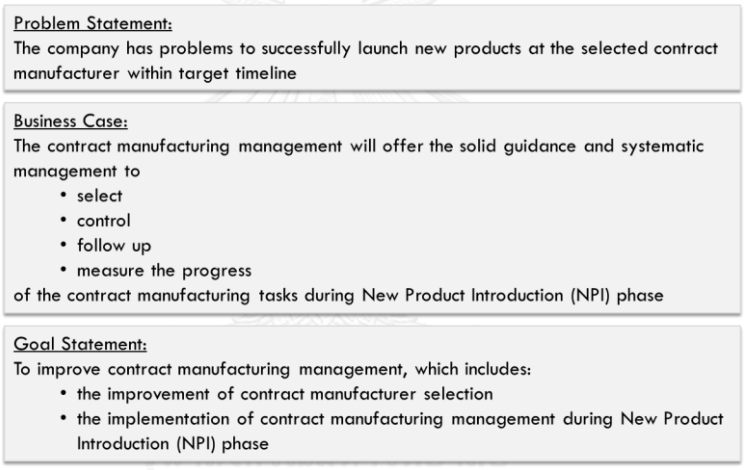


Figure 3-10: Define problem and goal of the research

3.6 Set up research team

The effective team member for driving process improvement projects throughout an overall organization is essential. The research team had been forming a cross functional team within the company and include the external party (Business unit leader from contract manufacturer) to acquire and leverage different knowledge and expertise of each functional that can help to improve current process for assessment and management contract manufacturer more effectively. The team brainstorming helps to identify the root cause of the problem, effect of the problem and to reduce the failure to launch new product at the selected contract

manufacturer, the research team consists of people from cross function as define in figure 3-11, most people are in direct contact with the contract manufacturer.

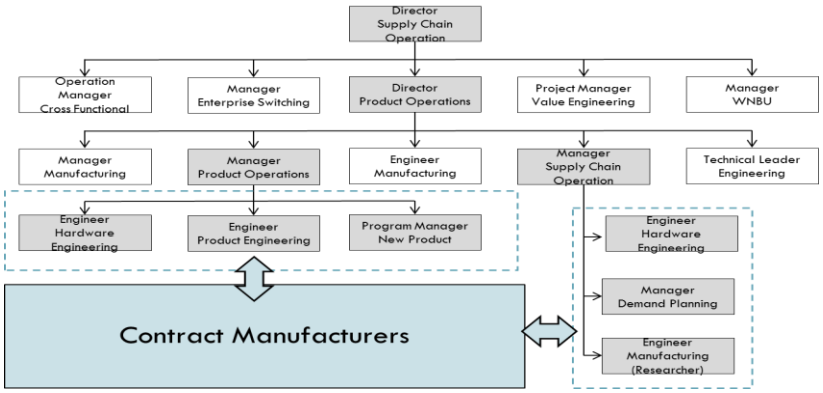


Figure 3-11: Research team from cross functional function

The team is responsible to select the appropriate tools and techniques to identify the improvement of assessment and management of contract manufacturer mainly focus on new product development and NPI.

3.7 Project Charter

The project charter which summarized the background of the research, scope, voice of customer, goal and team responsibility is shown in figure 3-12.

Project Title:	Contract Manufacturing Management for an optical device production company
Background and reason for selecting the project:	The company has problems to successfully launch new product produced at the selected contract manufacture within target time line
Project goal:	To improve current process of contract manufacturing management, which includes: • Contract manufacturer selection • Contract manufacturing management for New Product Introduction (NPI) phase
Timeline:	Implementation in April2015
Voice of customer:	The effectiveness of contract manufacturer selection and contract manufacturing management
Project scope:	Contract manufacturer selection: Improve contract manufacturer selection to fits all needs of new products in product development pipeline. Contract manufacturing management: Implement contract manufacturing management for New Product Introduction (NPI) phase to focus on the development of new products to meet product's specification and development plan
Team member:	Project leader: New Product Program Manager Manager: Product Operation Manager / Supply Chain Manager / Demand Planning Manager Mentor: Quality Manager Team: Hardware Engineer/Product Engineer/Manufacturing Engineer/Quality Engineer/Manager External: Contract Manufacturing Business Unit Leader
Expected benefits:	• Meet company's KPI to introduce new product to production within specific time line • Support and contribute to the company, the implementation of the improved contract manufacturing management can be a solid guideline to the company to develop and implement to other areas, other regions, and other product types

Figure 3-12: Project Charter of the research

3.8 Summary of Define Phase

In define phase, after understanding the current process for contract manufacturer assessment, contract manufacturer management, process mapping, and current situation of the case company, it is found out that the major problems were

occurred during contract manufacturer engagement. In addition, there is no solid process or procedure to maintain and manage works at the contract manufacturer during new product introduction (NPI). The contract manufacturing management of the company is carried throughout the product development cycle from concept approval through deployment, thus the review for the assessment and NPI management was not be specific and detailed for individual new products. To achieve this objective, an effective cross-functional project team is formed to support and brainstorm to identify the potential causes of problem and implement to solution to avoid similar problems that may occur.

4. CHAPTER IV
MEASURE

The problem was identified in the previous chapter. In this chapter, measure phase, is the measurement procedure to collect the data, attribute data to analyze the problem starting from baseline.

4.1 Determine the baseline

Once new product had been approved from the management, the program manager will have open communication with the potential contract manufacturers to gather information to manufacture new product and decide who should be engaged with. Figure 4-1 illustrates baseline for contract manufacturing engagement and contract manufacturing management for New Product Introduction.

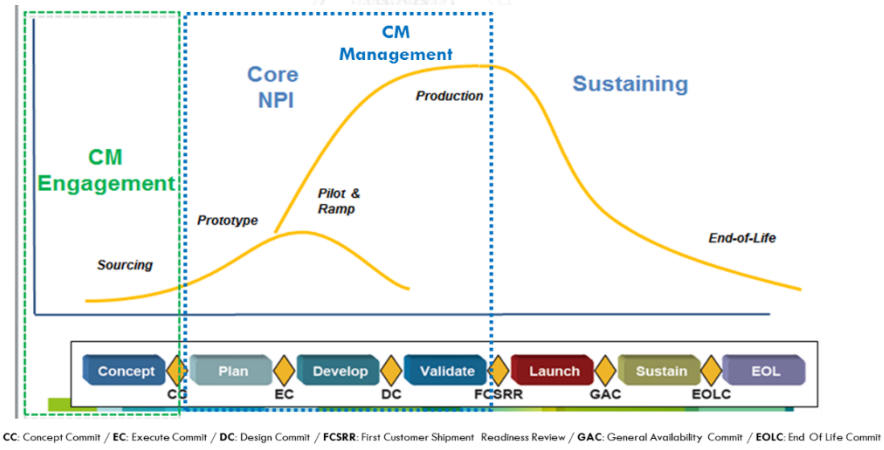


Figure 4-1: Baseline of contract manufacturing management and NPI activity

New Product Program Manager, project leader, is responsible to coordinate with the team to establish the support structure, project plan, timeline, and activities to execute to meet the needs of business as illustrate in figure 4-2.

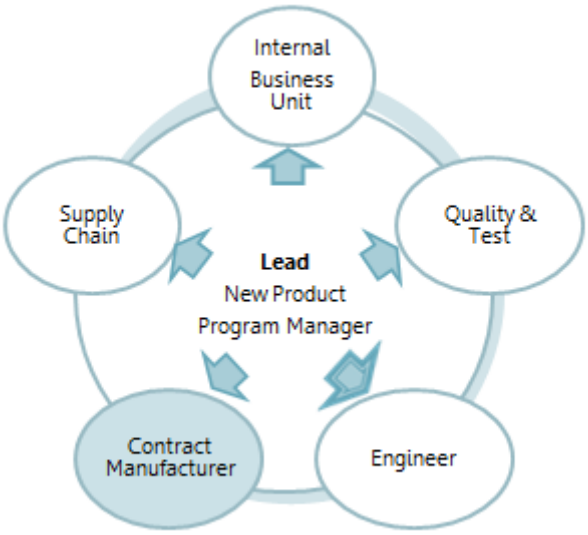


Figure 4-2: New Product Program Manager to coordinate all works

The tool that being used in the measure phase to understand baseline and requirement were selected from research team brainstorming and agreed to use VOC (Voice of Customer) and then convert the VOC to CTQ (Critical to Quality) in order to design a process for developing the improvement of contract manufacturer manufacturing capability assessment where input from the customers (internal customers consists of new product development team, and supply chain team) can quickly and clearly be developed into improved assessment criteria.

4.2 Voice of Customer (VOC)

4.2.1 Voice of customer plan

The research team has brainstormed to define customer segmentation, collect the data, generate list of customer needs and then translate the voice of customer to critical to quality as illustrate in figure 4-3 and figure 4-4.

Figure 4-3: VOC plan

Customers	Segments	Group1: Engineer	Group2: Program manager	Group3: Supply chain and external	VOC responsible	Profile/Need
Product Operation Team	Team leader & Prod. Op. Management	Matt Broner	Paul Negus	Leo Ihigachi	All	-Need awareness of CM management -Need to know where to apply
	Team member	Boonika, Krit, Siriluck	Jason Hung	Varanon, Pataraporn	All	-Need to improve CM management Responsible for content, delivery, deployment, method
Internal customer	Silicon Photonic	Mark Webster	Chuck Tuner	Jim Carlson	Zhen Bao	-Need awareness of CM management -Share experience and advise what/when/where/how to CM management from project/process/quality perspective -Provide input if any new products plan relate to CM in 2015
	Tomography	Ralp Koudi. Dan Necial	John Brennan	Wipark	Panut	
	100G/40G Transceiver Module	Mary Nadeau, Fred Warning, Dave Pidei	Kathy Yanusiki, Bob Botti, Dave Casselman	Worasak	Boonika	
Supply chain team	-	Wanchai	Ro Tecson	-	Nicha	-Provide input and experience -Advise from supply chain perspective
Asia operation and Thailand operation	Currently working with CM	Boonika, Krit, Siriluck	CL Lee, Don Lam, J. Matt Fangman	-	Boonika	-Need awareness of CM management -Use CM management tool to work with each CM

Figure 4-4: VOC customer segmentation

4.3 Critical to Quality (CTQ)

From figure 4-4, it can be concluded that what customer need is the effective Contract Manufacturing selection (assessment) which is more specific to new product development to ensure manufacturing capability at the potential contract manufacturer, the effective contract manufacturing management which can control and visible the progress of new product to ensure launching schedule. The research team has analyzed all data collected and converted the voices of customer to Critical to Quality of contract manufacturing management as shown in figure 4-5.

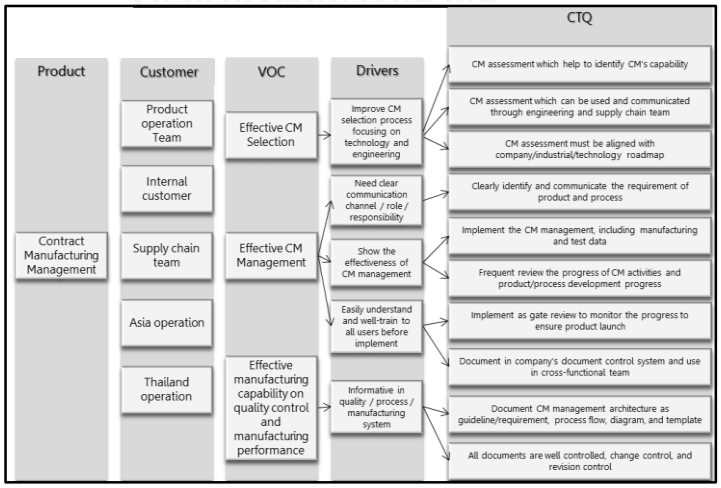
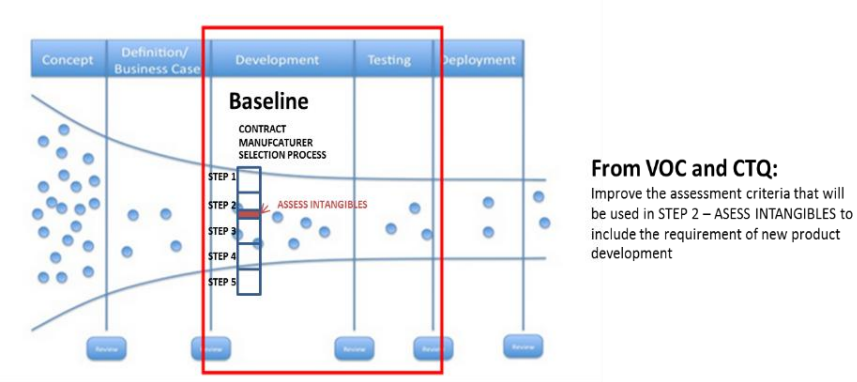


Figure 4-5: Convert from VOC to CTQ

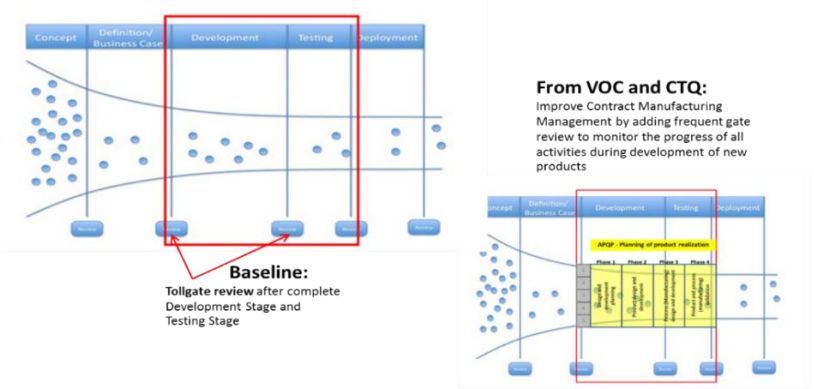
4.4 Things to improve from baseline

From VOC and CTQ in item 4.2 and 4.3, it can be seen that all concerns that are dealing with contract manufacturing selection and contract manufacturing management need improvement in the assessment criteria to be more specific and include the requirements of new product development, and also need to improve the effectiveness of contract manufacturing management to monitor the progress and ensure the success of developing new products at the selected contract manufacturer as described in figure 4-6 and figure 4-7.



[Reference picture from: Product strategy – Best Practice in strategy and product management, Michael Kapp.]

Figure 4-6: Improve Contract Manufacturer Selection Process from Baseline



[Reference picture from: Product strategy – Best Practice in strategy and product management, Michael Kapp.]

Figure 4-7: Improve Contract Manufacturing Management from Baseline

Moreover, the implementation of the improvement will be effective to have more visibility and control to predict the delay, prevent the consequence of the delay and ensure the success of launching new product within target timeline. Ideally, the development plan and actual outcome will be matched as shown in figure 4-8.

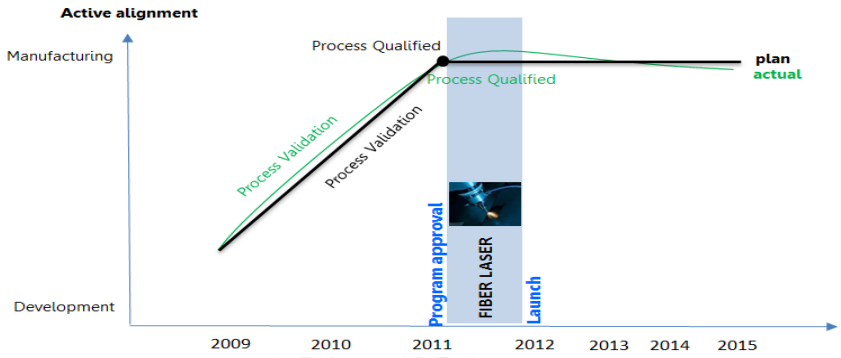


Figure 4-8 : Ideal development plan and actual outcome

4.5 Summary of the measure phase

In measure phase, the problems were determine from the Voice of customer which foreseen the problem and have direct impact the failure of launching new product at the selected contract manufacturer within timeline. The voice of customer was then converted to the critical to quality, with this approach, the research team can ensure that problem and goal of the research are truly defined related to the need of customer who need the effective contract manufacturing selection and management to ensure the success of launching new product within timeline. This approach also helps with time cutting solution to implement the necessary information to move forward to analyze phase in cause and effect.

5. CHAPTER V
ANALYSIS

To sustain competitive advantage, it requires continuous improvement for a company to maintain its strength in marketplace, create sustainable growth, and measure the performance of new product development launch into market. The company highly focuses on technology strategy of the contract manufacturers and it was questioned during in-depth assessment. In this chapter, technology requirement which shape the technology strategy for new product development from potential contract manufacturer will be evaluated according to the literature review and team brainstorming investigated under two topic, key criteria for contract manufacturer assessment to select the contact manufacturer to develop new product and strategic procedure for NPI (new product introduction) model by performing Cause-and-Effect Diagram, Cause-and-Effect Matrix, and explore Failure Mode and Effect Analysis (FMEA) to determine the potential causes and factors that caused the failure of launching new product at the selected contract manufacturer, and select the factors that have high Risk Priority Number (RPN) for future analysis to define the corrective actions.

5.1 Cause-and-Effect Diagram

It is important to the company to explore all things that could cause the failure to launch new product at the selected contract manufacturer in specific timeline, before thinking about the solution. Cause and Effect analysis give us a useful way of doing the analysis which combines brainstorming with a type of mind map that push the team to consider all possible causes of problem, rather than just focus on one that is most obvious.

Brainstorming is conducted from six people from different department and organization which includes Hardware engineer, Product engineer, Manufacturing engineer, Quality engineer, Program Manager, and Contract Manufacturing Business Unit

Leader. The program manager leads brainstorming session follow the steps described below:

Step 1: Appoint team meeting to share the knowledge and understanding the importance to successfully launch new product

Step 2: Brainstorm among the team members to identify all possible causes of problem include Man, Machine, Method, Environment, Material, and Measurement.

Step 3: Create Cause-and-Effect Diagram and analyze the diagram to investigate the most likely causes.

The causes identified for failure to launch new product at the selected contract manufacture within timeline illustrate in figure 5.1, the diagram shows numerous of root causes and contributing factors and generate deeper levels of causes using cause-and-effect matrix to narrow down all suspects.

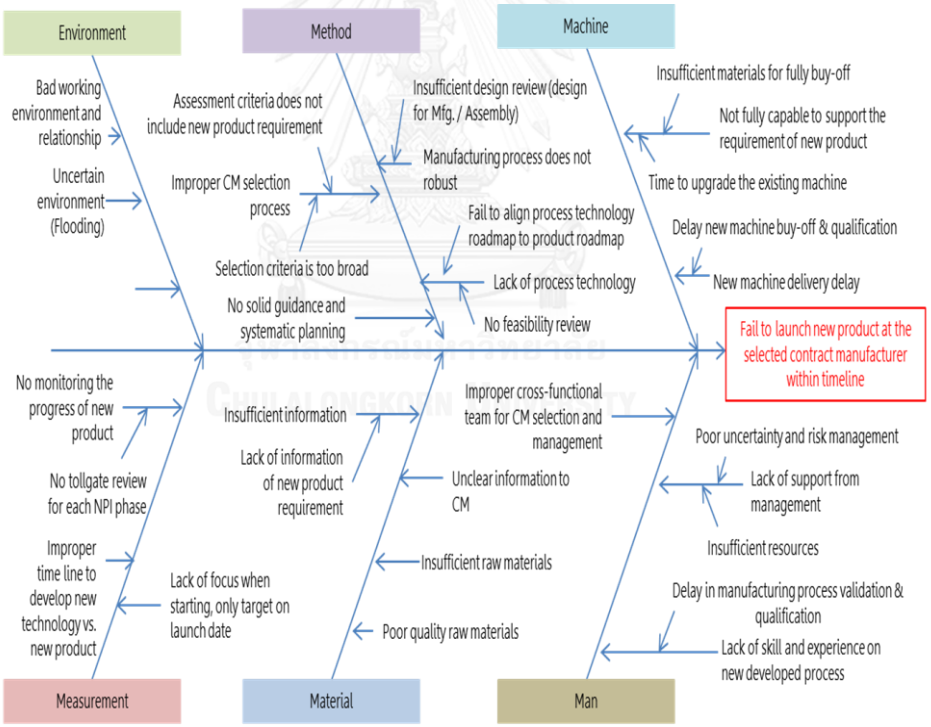


Figure 5-1: Cause-and-Effect Diagram

5.2 Cause-and-Effect Matrix

The suspected causes of failure to launch new product at selected contract manufacturer within timeline had been listed out from the cause and effect diagram,

this section will be using cause-and-effect matrix to narrow down a list of suspected caused to a more manageable ones, use cause-and-effect matrix to determine which of those suspected causes should be looked at first, and also, which of those suspected causes meet the Voice of Customer and impact to Critical to Quality.

To create cause-and-effect matrix, the team analyze from the Voice of Customer *(VOC)* and convert them into the factors that are Critical to Quality *(CTQ),* they can be named as **"*Output Variables*",** then assign a Priority factor to each output variable. The research team uses a scale of 1-10:

"1" means No correlation

"3" means Low correlation

"5" means Moderate correlation

"7" means High correlation

"10" means Very strong correlation

Next, the research team identified the ***"Input variable"*** by extract from the potential causes in cause-and-effect diagram.

Once the ***Output variables*** and ***Input variables*** had been identified, the research team then rank how strongly each input variables impact the output variables. The research team prefers to use a ranking scheme 1-10:

"1" means no impact

"3" mean little impact

"5" means marginal impact

"7" means strong impact

"10" means very strong impact

Last thing is to do cross multiple correlation ranking and sum of each input variable, and then prioritize the impact and importance of each factors using Pareto.

The cause-and-effect matrix of fail to launch new product at selected contract manufacturer is illustrated in Table 5-1.

Identify and Rank Voice of Customer (VOC) and convert to Critical to Quality (CTQ), this had been identified in the Measure Phase, the research team ***ranks the CTQ or "Output variables"*** as shown below:

Rank 10: Assessment of CM technology capability

Rank 9: Assessment of CM communication capability through engineering and supply chain

Rank 8: Assessment of CM technology roadmap align with product roadmap

Rank 7: Management of CM with tollgate review to ensure product launch

Rank 6: Management of CM with the identification of product/process requirement

Rank 5: Management of CM with capability to review Mfg. data and Test data

Rank 4: Management of CM with frequent review activities and progress

Rank 3: Management of CM with controlled document and widely uses in cross-functional team

Rank 2: Management of CM with includes all guideline and requirement

Rank 1: Management of CM with well control in change and revision

Table 5-1: Cause-and-Effect Matrix

				CTQs - **Output Variable**	CM Assessment - Identify CM's capability	CM Assessment - Communicate through engineering and supply chain	CM Assessment - Align with roadmap	CM Management - Implement as gate review to ensure product launch	CM Management - Identify requirement of product/process	CM Management - Capability to review Mfg data and Test data	CM Management - Frequent review CM activity and progress	CM Management - Controlled document and widely use in cross functional team	CM Management - Include all guideline and requirement	CM Management - Well control in change and revision	
	Causes of the failure - **Input Variable**				10	9	8	7	6	5	4	3	2	1	Total
Fail to launch new product at the selected contract manufacturer with timeline	Machine	1	Delay new machine buy-off & qualification	MAC1	8	1	9	8	2	2	7	1	3	1	277
		2	Time to upgrade the existing machine	MAC2	7	1	8	7	7	4	6	1	3	1	288
		3	Insufficient materials for fully buy-off	MAC3	1	1	4	4	4	1	6	1	1	1	138
	Method	1	No feasibility review in the CM assessment	MET1	9	8	8	8	8	4	5	1	7	1	388
		2	Fail to align process roadmap to product roadmap	MET2	8	6	9	8	8	2	6	3	6	6	371
		3	Insufficient design review (Manufacturing / Assembly)	MET3	6	6	6	7	8	3	5	5	6	5	326
		4	Assessment criteria does not include new product requirement	MET4	9	9	8	6	7	3	5	5	7	5	388
		5	CM selection criteria is too broad	MET5	8	8	7	2	6	2	4	4	7	6	316
		6	No solid guidance and systematic planning	MET6	3	6	1	8	7	3	6	7	8	8	274
	Environment	1	Bad working environment and relationship	ENV1	1	1	1	1	1	1	1	8	1	1	76
		2	Uncertain environment (Flooding)	ENV2	1	1	1	8	1	1	9	1	1	1	136
		3	Improper cleanroom environment (particle/temp/hum)	ENV3	3	2	2	2	6	1	1	1	6	1	139
	Measurement	1	No tollgate review for each NPI phase	MEA1	1	2	8	9	7	8	9	2	1	5	286
		2	Improper timeline to develop new technology vs. new product	MEA2	1	1	9	6	6	8	8	2	6	5	264
		3	Lack of focus when starting, only target on launch date	MEA3	7	7	6	8	8	6	7	6	6	5	378
	Material	1	Lack of information of new product requirement	MAT1	5	7	7	6	8	4	3	2	1	3	302
		2	Insufficient information to CM	MAT2	2	8	8	6	8	2	2	1	5	6	283
		3	Insufficient raw materials	MAT3	1	1	4	4	4	1	6	1	1	1	138
		4	Poor quality raw materials	MAT4	1	1	4	4	4	1	6	1	1	1	138
	Man	1	Improper cross-fucntional team for CM selelction and management	MAN1	8	8	6	5	7	2	7	6	1	1	336
		2	Delay in manufacturing process validation & qualification	MAN2	8	1	9	8	2	2	7	1	7	1	285
		3	Insufficient resource	MAN3	1	1	4	4	4	1	6	1	1	1	138
		4	Poor uncertainty and risk management	MAN4	1	1	1	8	1	1	9	1	1	3	138

From the cause-and-effect matrix, it can be interpreted that cause MET1 – No feasibility review in the CM assessment and cause MET4 – Assessment criteria does not include new product requirement, which have score 9, have strong impact to identify CM's capability, and CM's capability, which have score 10, has very strong correlation to the failure to launch new product, and they show highest total score 388.

On the other hand, cause ENV1 – Bad working environment and relationship, which have score 1, has no impact to identify CM's capability but have strong impact, score 8, to CM management in the controlled document and widely use in cross functional team. However, the controlled document and widely use in cross functional team, which have score 3, has low correlation to the failure to launch new product.

After determine the impact of input variables to each output variable in cause-and-effect matrix, the research team use Pareto chart to narrow down the causes or input variables for further analysis as shown in figure 5-2. From figure 5-2, it can be seen that the total score of each input variables (causes) influence failure to launch new products (effects) respectively.

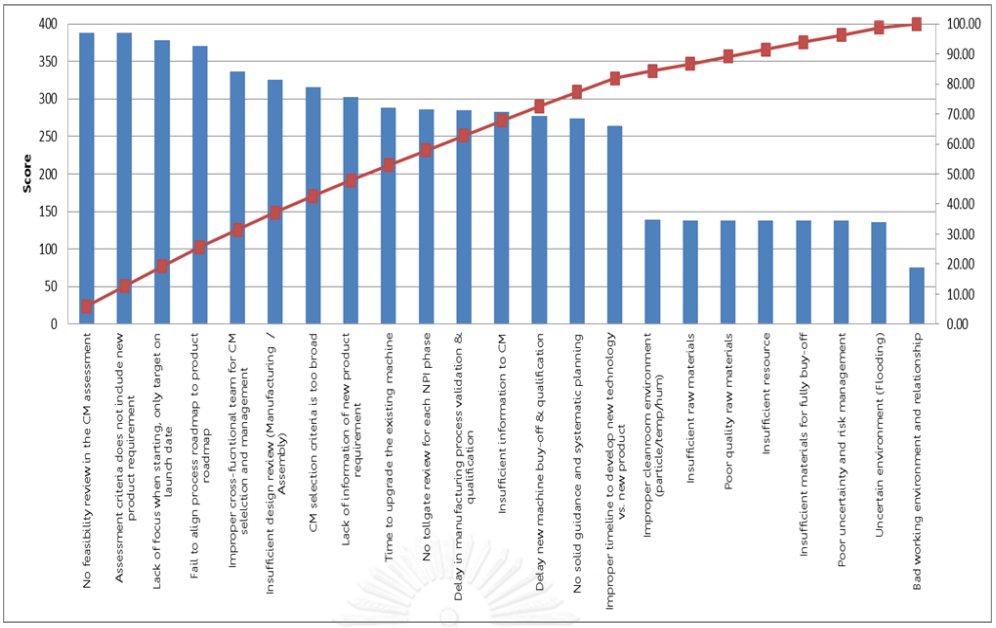


Figure 5-2: Pareto Chart

Therefore, the research team learns that the following 15 out of 23 input variables seem to be most important and most impact to the output variables where the research team should focus first.

Input variable 1: No feasibility review in the CM assessment

Input variable 2: Assessment criteria does not include new product requirement

Input variable 3: Lack of focus when starting, only target on launch date

Input variable 4: Fail to align process roadmap to product roadmap

Input variable 5: Improper cross-functional team for CM selection and management

Input variable 6: Insufficient design review (Manufacturing /Assembly)

Input variable 7: CM selection criteria is too broad

Input variable 8: Lack of information of new product requirement

Input variable 9: Time to upgrade the existing machine

Input variable 10: No tollgate review for each NPI phase

Input variable 11: Delay in manufacturing process validation & qualification

Input variable 12: Insufficient information to CM

Input variable 13: Delay new machine buy-off & qualification

Input variable 14: No solid guidance and systematic planning

Input variable 15: Improper timeline to develop new technology vs. new product

The research team applied Pareto principle 80/20 to the observation, more generally, that the most things are NOT 1/1, where each unit of input variable contributes exactly the same amount of output. With this Pareto principle helps research team to make decisions on allocation time, resources and effort based on this principle, therefore, the prioritize of potential causes are listed and selected for further study in Failure Mode and Effect Analysis (FMEA), the majority of the effect (fail to launch new product) came from the following causes as shown in table 5-2, where 15 factors were selected which account for 81.91%

Table 5-2: Cause of Failure to launch new products

Key process input variables	Code	Score
No feasibility review in the CM assessment	MET1	388
Assessment criteria does not include new product requirement	MET4	388
Lack of focus when starting, only target on launch date	MEA3	378
Fail to align process roadmap to product roadmap	MET2	371
Improper cross-fucntional team for CM selelction and management	MAN1	336
Insufficient design review (Manufacturing / Assembly)	MET3	326
CM selection criteria is too broad	MET5	316
Lack of information of new product requirement	MAT1	302
Time to upgrade the existing machine	MAC2	288
No tollgate review for each NPI phase	MEA1	286
Delay in manufacturing process validation & qualification	MAN2	285
Insufficient information to CM	MAT2	283
Delay new machine buy-off & qualification	MAC1	277
No solid guidance and systematic planning	MET6	274
Improper timeline to develop new technology vs. new product	MEA2	264

The results from Cause-and-Effect Matrix and Pareto Chart are important prerequisite for further tools that will be used in the research, such as, FMEA, and the Process Control Plan.

5.3 Failure Modes and Effects Analysis (FMEA)

The results from cause-and-effect matrix and Pareto chart brought the research team to explore further study in Failure Modes and Effects Analysis (FMEA) in order to analyze failure of an existing process and plan for the improvement goals, a step-by-step approach for identifying all possible causes in contract manufacturer selection process, this research focus on selection criteria in technology and manufacturing, or

contract manufacturer management during New Product Introduction (NPI) phases. The improvement goals will be defined based on the risk priority number (RPN) which provides guidance for ranking potential failures they should be addressed. Calculate the RPN which equal to Severity (S) x Occurrence (O) x Detection (D).

Severity (S): The significance impact of the effects of the failure

Occurrence (O): The frequency of the failure

Detection (D): The ability to identify the failure before it occurs

Six participants from different department and organization which includes Hardware engineer, Product engineer, Manufacturing engineer, Quality engineer, Program Manager, and Contract Manufacturing Business Unit Leader, are involved in FMEA team. All participants help to identify all components, systems, processes, and functions that could potential fail to launch new products which described in Table 5-6.

Critical for analysis:

Generally, FMEA uses three criteria to analyze the problem (1) severity of effect, (2) occurrence, the frequency of problem is likely to occur, and (3) detection, how good the problem can be detected from current control procedure. Participants from FMEA team had set and agreed on a ranking between 1 to 10 use available data to qualify the decision the FMEA team making, further explanation of FMEA ranking in shown in Table 5-3, 5-4, and 5-5.

Table 5-3: Typical severity evaluation criteria (Ben-Daya et al., 2009)[13]

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

Table 5-4: Typical occurrence evaluation criteria [13]

Occurrence	**Description**	**Low num.**	**High num.**
	Occurrence ranking the frequently of failure occurring during the expected lifetime of the process	Not likely to occur	Inevitable
Frequency	**Possible failure rate**		**Ranking**
Very high	Failure is almost inevitable (>1:3)		10
High	This process or similar process have often fail (1:6)		9
	This process or similar process have often fail (1:9)		8
Moderate	This process has occasional failures, but not in major proportion (1:50)		7
	This process has occasional failures, but not in major proportion (1:150)		6
Low	Isolate failures associated with similar processes (1:800)		5
	Isolate failures associated with similar processes (1:4500)		4
	Isolate failures associated with similar processes (1:30K)		3
Very low	Only isolated failures associated with this process or almost identical processes (1:150K)		2
Remote	Failure unlikely. No failures ever associated with this process or almost identical processes (1:1.5M)		1

Table 5-5: Typical detection evaluation criteria [13]

Detection	**Description**	**Low num.**	**High num.**
	Detection ranking the probability of problems being detected before the problem occurred	Very likely to be detected	Not likely to be detected
Detection	**Severity of effect**		**Ranking**
Absolutely no detection	Design control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no design control		10
Very remote	Controls probably will not detect the existence of failure mode		9
Remote	Remote chance the design control will detect a potential cause/mechanism and subsequent failure mode		8
Very low	Very low chance the design control will detect a potential cause/mechanism and subsequent failure mode		7
Low	Low chance the design control will detect a potential cause/mechanism and subsequent failure mode		6
Moderate	Moderate chance the design control will detect a potential cause/mechanism and subsequent failure mode		5
Moderately high	Moderately high chance the design control will detect a potential cause/mechanism and subsequent failure mode		4
High	High chance the design control will detect a potential cause/mechanism and subsequent failure mode		3
Very high	Very high chance the design control will detect a potential cause/mechanism and subsequent failure mode		2
Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode. Reliable detection controls are known with similar processes. Process automatically prevents further processing.		1

From the typical FMEA criteria as described in table 5-3, 5-4, and 5-5, the research team has applied and created our own FMEA criteria as shown below and create the FMEA for this failure as shown in table 5-6, FMEA for failure to launch new product at the selected contract manufacturer within timeline.

Severity (S): The significance impact of the effects of the failure

Ranking 10: Fail to launch new product

Ranking 9: More than 12 month Delay the overall program to launch new product

Ranking 8: More than 6 month Delay the overall program to launch new product

Ranking 7: More than 3 months Delay the overall program to launch new product

Ranking 6: More than 1 month Delay some portions of the overall program

Ranking 5: Delay some portions of the overall program but can be recovered

Ranking 4: Delay can be noticed with action plan

Ranking 3: Delay can be noticed and can take immediate action

Ranking 2: No effect the customer delivery

Ranking 1: No effect to the overall program

Occurrence (O): The frequency of the failure

Ranking 10: Very high persistent failure, 100% of new product development

Ranking 9: Very high persistent failure, 90% of new product development

Ranking 8: Frequent failure, 80% of new product development

Ranking 7: Frequent failure, 70% of new product development

Ranking 6: Occasional failure, 60% of new product development

Ranking 5: Occasional failure, 50% of new product development

Ranking 4: Occasional failure, 40% of new product development

Ranking 3: Relatively few failure, 30% of new product development

Ranking 2: Relatively few failure, 20% of new product development

Ranking 1: Failure is unlikely, 10% of new product development

Detection (D): The ability to identify the failure before it occurs

Ranking 10: Absolute non detection, cannot detect or check the delay of new product

Ranking 9: Very remote, the control with random checks for the delay of new product

Ranking 8: Remote, the control checks the delay happen

Ranking 7: Very low, the control checks the delay already happened, poor chance of detection

Ranking 6: Low, the control may detect the delay from the historical data

Ranking 5: Moderate, the control may detect the delay from the consequence of the delay

Ranking 4: Moderate high, the control has good chance to detect the delay during validation

Ranking 3: High, the control has good chance to detect the delay during set up

Ranking 2: Very high, control has good chance to detect the delay during CM selection

Ranking 1: Vey high, the control certain to detect any delay from CM assessment

Table 5-6: Failure Modes and Effects Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA)									
Process:	Launch new product at the selected contract manufacturer					Project:		Contract Manufacturing Management	
Core team:	Program Manager New Product, Hardware Engineer, Product Engineer, Manufacturing Engineer, Quality Engineer, Researcher, External (CM business unit leader)								
Item	Key Process Input Variables	Potential Failure Mode	SEV	Potential Cause	OCC	Current Control	DET	Recommended Action	RPN
1	No feasibility review in the CM assessment	Delay new product launch	7	Time to develop new process or technology is longer than expect	8	Assessment form for manufacturing technology capability	8	Update CM assessment form to include the feasibility review based on CM current capability and CM technology development plan	448
2	Assessment criteria does not include new product requirement	Effect future product launch	6	Current manufacturing assessment does not reflect the requirements of new products in product roadmap	6	Assessment form for manufacturing technology capability	7	Update CM assessment form to include the requirement of new products in the roadmap	252
3	Lack of focus when starting, only target on launch date	Delay new product launch	7	Uneffective review of new product introduction	7	Regular CM meeting to update the progress of new product	7	Add gate review to measure the progress of each development phase	343
4	Fail to align process roadmap to product roadmap	Delay new product launch / Fail to launch new product at the selected CM	8	CM did not aware and did not prepare to support future products in the raodmap	6	Yearly CM Assessment	7	More frequent meeting to support future products and include feasibility review of the future products that plan to launch in 2 years (at least)	336
5	Improper cross-fucntional team for CM selelction and management	Delay new product launch / Fail to launch new product at the selected CM	8	Scope and area to consider in team meeting is narrow and limited, no specific area expertise invloved	7	Current team member for CM assessment does not include people from new product development team	7	Re-organize team member for CM assessment to add the expertise from new product development team	392
6	Insufficient design review (Design for Manufacturing /Design for Assembly)	Unrobust process causing low yield or high cycle time	6	Insufficient information during design review	5	Design review	7	Create check list of needed information to develop new product. Specific per product type and requirement	210
7	CM selection criteria is too broad	Delay new product launch / Fail to launch new product at the selected CM	8	Lack of specific information and requirement for each new product	8	Review technical expertise from CM assessment	7	Update CM assessment form to include the specific requirement of each new products	448
8	Lack of information of new product requirement	Delay new product launch	7	Insufficient information for design review	6	Design review	7	Create check list of needed information to develop new product	294
9	Time to upgrade the existing machine	Delay new product launch	7	Existing machine is not capable to meet the requirement of new product	6	Assessment form for manufacturing technology capability	7	Update CM assessment form to include the requirement of new products	294
10	No tollgate review for each NPI phase	Delay new product launch	7	Lack of visibility to track the status of new product introduction	8	Regular CM meeting to update the progress of new product	7	Implement procedure for NPI phases tollgate review	392
11	Delay in manufacturing process validation & qualification	Delay new product launch	7	Equipment readiness delay. Process readiness delay.	6	Regular CM meeting to update the progress of new product	7	Implement procedure for NPI phases tollgate review	294
12	Insufficient information to CM	Delay new product launch	7	Lack of specific information and requirement for each new product	5	Regular CM meeting to update needed information for each new product	7	Implement procedure for NPI phases tollgate review. This will include INPUT (needed information) and OUTPUT (results) for each NPI phase	245
13	Delay new machine buy-off & qualification	Delay new product launch	7	Equipment readiness delay. Process readiness delay.	6	Review technical capability from CM assessment	7	Technical capability review in CM assessment should cover machine requirement and specification that will be used	294
14	No solid guidance and systematic planning	Delay new product launch	7	No procedure for NPI phase review	8	Regular CM meeting to update the progress of new product	8	Implement procedure for NPI phases review	448
15	Improper timeline to develop new technology vs. new product	Delay new product launch	7	Contract manufacturer did not aware about customer's product roadmap.	6	Yearly review technology capability, technology assessment	7	More effective and frequent meeting to support future products	294

From FMEA team meeting, the failure modes had been assessed and highlighted the areas where corrective action can be taken, however, there is no definitive RPN threshold to decide which area should receive the most attention, from

RPN score in table 5-6, it can be seen that all detection of all failures is very low and remote which fall into detection score 7 and 8. The research team had agreed to focus their attention on all 15 failure modes to improve current control procedure as shown in table 5-7.

Table 5-7: Selected causes of failure, input variables, and its RPN value

Item	Key Process Input Variables	RPN
1	No feasibility review in the CM assessment	448
2	CM selection criteria is too broad	448
3	No solid guidance and systematic planning	448
4	Improper cross-fucntional team for CM seleletion and management	392
5	No tollgate review for each NPI phase	392
6	Lack of focus when starting, only target on launch date	343
7	Fail to align process roadmap to product roadmap	336
8	Lack of information of new product requirement	294
9	Time to upgrade the existing machine	294
10	Delay in manufacturing process validation & qualification	294
11	Delay new machine buy-off & qualification	294
12	Improper timeline to develop new technology vs. new product	294
13	Assessment criteria does not include new product requirement	252
14	Insufficient information to CM	245
15	Insufficient design review (Design for Manufacturing /Design for Assembly)	210

When the priorities had been agreed, the research team will generate the appropriate corrective actions in order to reduce the occurrence of failure and improve the detection, moreover, the research team had done further analysis use why-why diagram to get into the root causes of problem in order to define the corrective actions of each failure modes.

5.4 Why-Why Diagram

Moreover, the research team has created the Why-Why Diagram of the failure to launch new product at the selected contract manufacturer with timeline as a tool for cross checking and confirmation the causes of failure and actions which are correspondent to the recommended actions in the FMEA. The why-why diagrams are illustrated in figure 5-3, 5-4, 5-5, and 5-6.

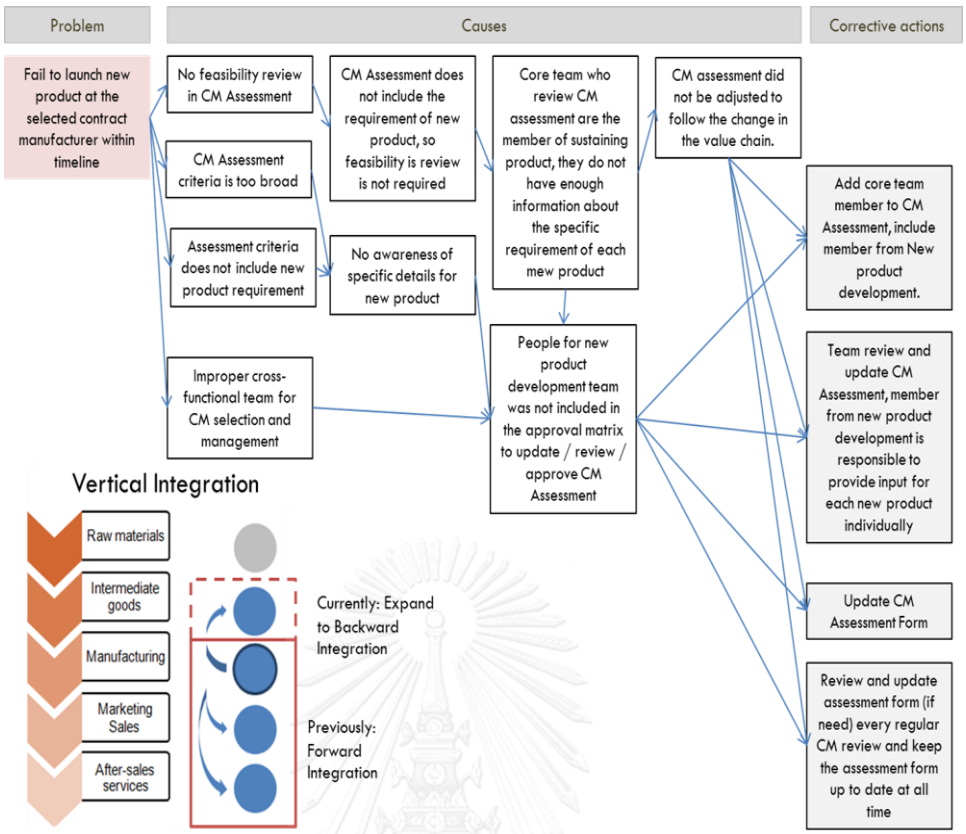


Figure 5-3: Why-Why Diagram

From why-why diagram in figure 5-3, it can be seen that the corporate supply chain strategy of the case company had been changed from “forward integration”, the company had expanded to backward integration. In the past, the case company bought the components from all 1st tier suppliers, built main print circuit board assembly (PCBA) from contract manufacturers, and assembled the components and main board into modules at the contract manufacturers, then supplied to market. However, in the past years, the case company had expanded to backward integration, expanded manufacturing to produce some main components, not just only the main boards. Before expend manufacturing into component level, the case company also evaluated the contract manufacturer and selected the most capable contract manufacturer from the assessment results based on assessment criteria. The research team noticed that the criteria being used in contract manufacturer assessment did not be adjusted or modified to the details specific for those main components that the case company would developed, the criteria is still mainly focused on surface mount technology (SMT). Therefore, the criteria in the assessment form need to be adjusted and updated

to include the requirements of new products to be developed at the selected contract manufacturer.

Continue to investigate more into failure root cause analysis using why-why diagram as illustrated in figure 5-4, the research team focus on the current procedure of contract manufacturer selection and procedure to manage the selected contract manufacturer throughout new product introduction (NPI) phases, the team realized that there is no solid guidance and systematic procedure the manage NPI activities to ensure product launch.

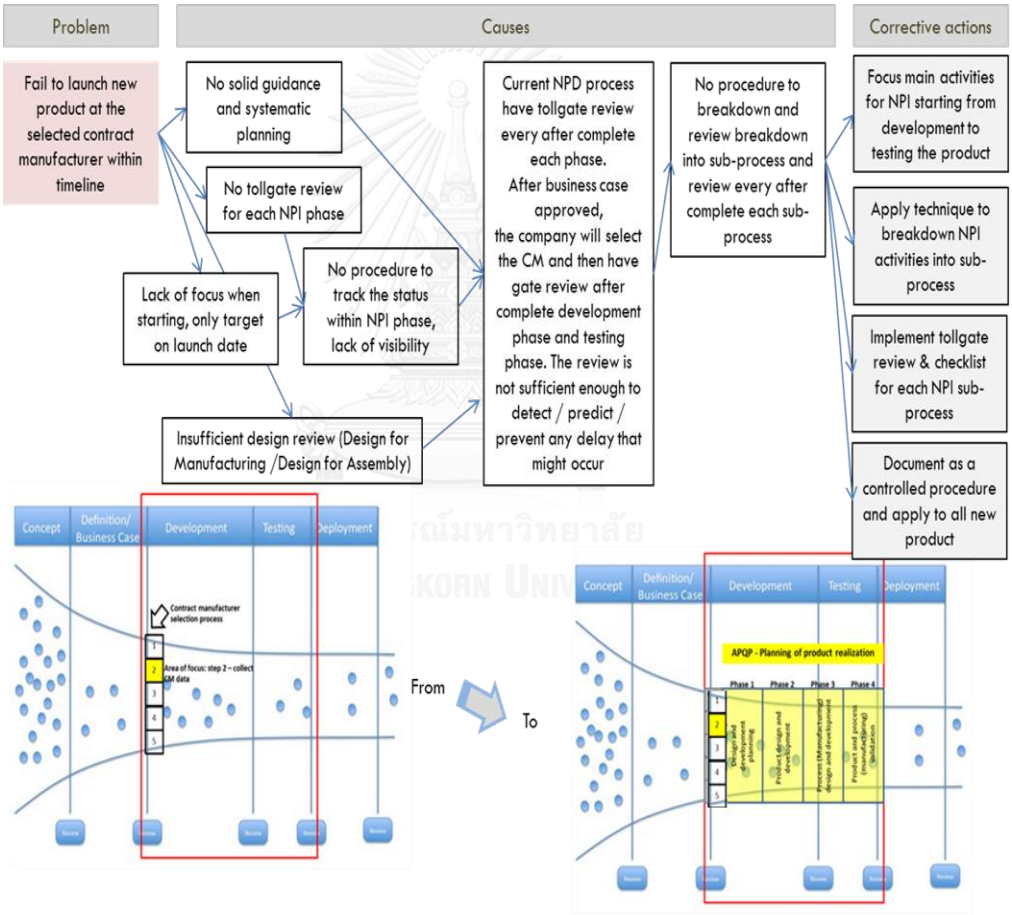


Figure 5-4: Why-Why Diagram (continue)

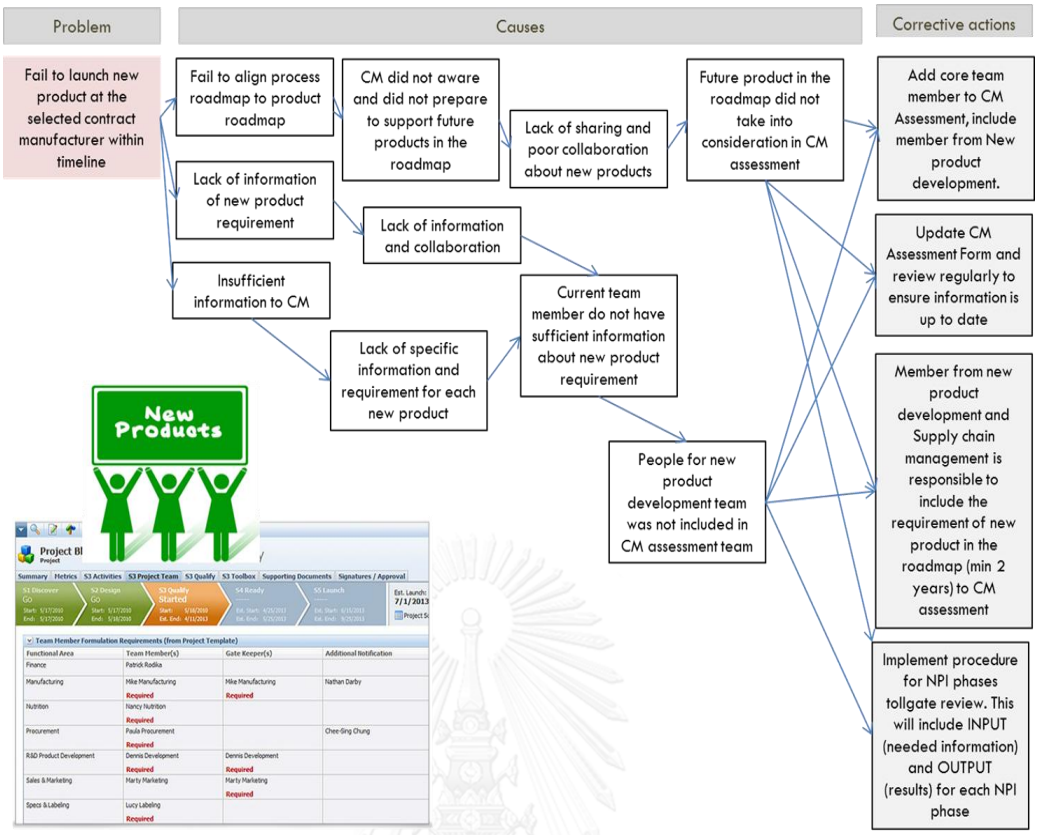


Figure 5-5: Why-Why Diagram (continue)

Figure 5-5 illustrates the root cause why selected contract manufacturers failed to align their technology process roadmap to the requirements of new products in product roadmap, the information that the case company provided to contract manufacturer does not include the requirement of product roadmap, people who have these information did not participate or get involved in the assessment process.

Similarly to what described in figure 5-6, lack of necessary information and lack of people from cross-functional team to cover full supply chain flow.

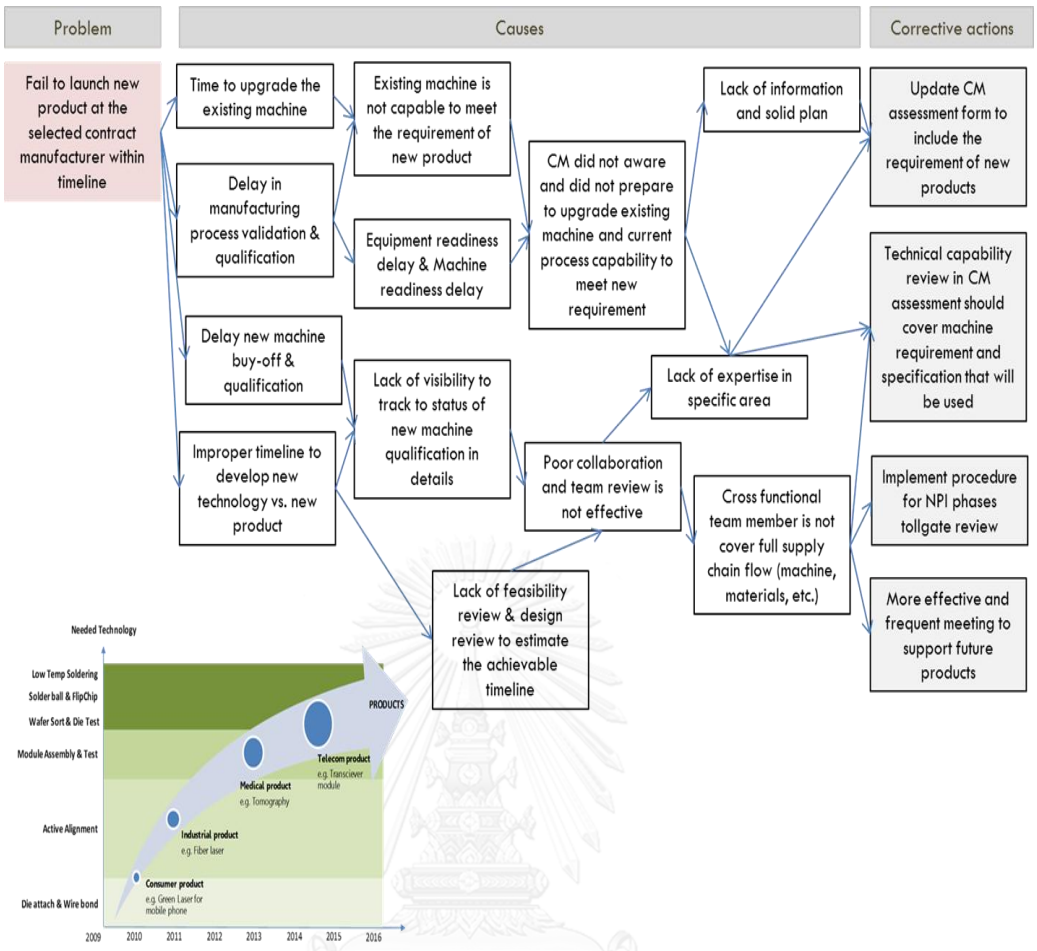


Figure 5-6: Why-Why Diagram (continue)

The selective factors will also be experiment by using hypothesis testing and regression analysis in the improve phase to confirm the statistical significant of causes to the failure to launch new product at the selected contract manufacturer within timeline.

5.5 Summary of analyze phase

In the analyze phase, the cause of causes of problem had been determine focusing on the possible causes and narrow down to select the main factors that most influence the failure to launch new product at the selected contract manufacturer within timeline using the techniques of Cause-and-effect diagram, cause-and-effect matrix, Pareto chart, Failure modes and effects analysis, and Why-why diagram. To identify the causes of defect using those techniques, the brainstorming was conducted with the participants from different departments within the company and one participant from external party, leader from contract manufacturer, who have experiences, knowledge and background in contract manufacturer selection, contract manufacturer management, and the requirement of new products in company's product roadmap. The causes of problems were identified, and lead to the implementation of the corrective actions of each individual root cause of the problem which cover contract manufacturing assessment and contract manufacturing management for New Product Introduction (NPI) phases.

6. CHAPTER VI
IMPROVEMENT

The analysis from previous chapter obtains the root causes of the problem and the recommended actions to remedy the failure to launch new product at the selected contract manufacturer was identified. In order to improve current process of contract manufacturing management for an optical device production company, it is important to gather the relevant information and define the requirement for an effective contract manufacturing selection. After the contract manufacturer had been selected, the methodology to manage contract manufacture will be implemented at the selected contract manufacturer to ensure the success of launching new products. The improve phase is using the element of APQP (Advance Product Quality Planning) methodology, this phase will also define the gap of current contract manufacturing selection, critical problem is the selection process and management process, define scope and goal of the improvement plan.

After the analysis of factors that influence the failure of launching new products at the selected contract manufacturer, the analysis results reveal that there are many significant factors include the contract manufacturer selection process, assessment, core team member, new product information, and procedure to manage contract manufacturer during New Product Introduction (NPI) phase. Therefore, in this chapter is considering the causes found during analysis phase and selecting the appropriate solution to reduce the failure of launching new product using Advance Product Quality Planning (APQP) techniques.

6.1 The improvement of Contract Manufacturer Assessment

The potential contract manufacturers for new product (and/or current contract manufacturer to develop new product) are identified through information sources including quote product, supply chain management, proto performances, NPI activities, and First Customer Shipment (FCS) timeframe. The company performs contract manufacturing assessment to ensure the reliability and capability of the potential

contract manufacturer. Therefore, the contract manufacturing assessment must be reputable with the involvement of all concerns, must validate capability of contract manufacturer in the specific area of each new product development, and must be associated with company supply chain and value chain strategy. This chapter seeks to add and provide further information on the role that future capability is also important and critical to success towards new product development. To improve current contract manufacturer assessment in manufacturing technology capability, the researcher collect empirical evidence through the core team member from new product development group (Product Operation Organization) and deep dive into the improvement of the assessment criteria as illustrated in figure 6-1.

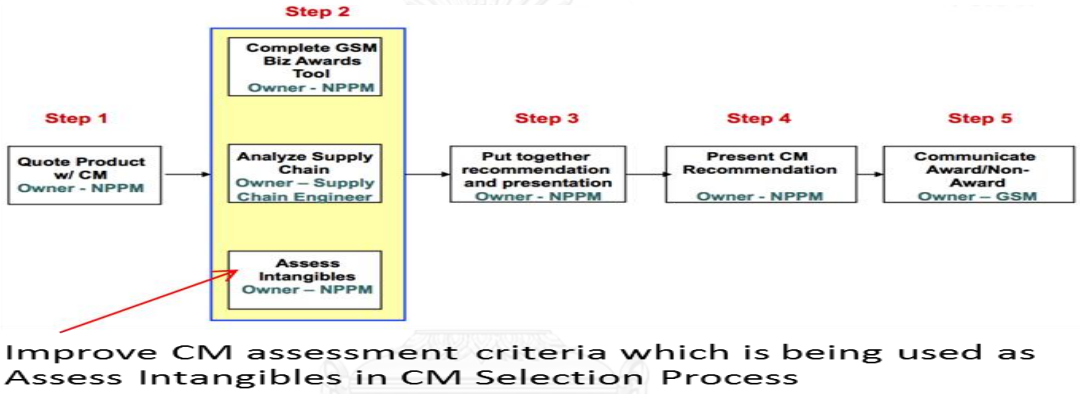


Figure 6-1: Improve CM Assessment Criteria – Assess Intangibles

The assessment criteria that are selected and related to the development of new product are in the Assessment Section 0: Manufacturing Technology Capability and Assessment Section 1: Manufacturing Technology as shown in figure 6-2.

III. Manufacturing Assessment: Sub-Section Scores

Contract Manufacturer Survey - Sub-Section Scores																
		Core Requirements (a)			Non-Core Requirements (b)			Total Score					Core Requirement # of Questions		Non-Core Requirement # of Questions	
Need to revise	Sub-Sections	Self Assess.	Auditor Assess.	Wt.	Self Assess.	Auditor Assess.	Wt.	Self Assess.	Auditor Assess.	Wt.	Normalize Self Assess.	Normalize Auditor Assess.	Self Assess.	Auditor Assess.	Self Assess.	Auditor Assess.
	Section 0: Manufacturing Technology Capability															
	0.1 Equipment Qualification & Process	88%	80%	100%			0%	88%	80%	10%	9%	8%	13	10	na	na
	0.2 Product Materials	50%	50%	100%			0%	50%	50%	10%	5%	5%	10	6	na	na
	0.3 Process Control & Analysis	64%	71%	100%			0%	64%	71%	10%	6%	7%	7	7	na	na
	0.4 SMT Process (Stencil printing	53%	70%	100%			0%	53%	70%	10%	5%	7%	15	15	na	na
	0.5 Wave, Through Hole Assembly,	80%	60%	100%			0%	80%	60%	10%	8%	6%	20	20	na	na
	0.6 Mechanical Assembly (Heat sink,	83%	57%	100%			0%	83%	57%	10%	8%	6%	23	23	na	na
	0.7 Structural Test (5DX, ICT and	85%	62%	100%			0%	85%	62%	10%	8%	6%	13	13	na	na
	0.8 Training – assembly operators,	88%	69%	100%			0%	88%	69%	10%	9%	7%	8	8	na	na
	0.9 Technology Capability	0%	0%	100%			0%	0%	0%	20%	0%	0%	154	154	na	na
Need to revise										100%	34%	33%				
											Red	Red				
	Section 1: Manufacturing Technology															
	1.1 Product Qualifications	75%	83%	70%	75%	50%	30%	75%	73%	30%	23%	22%	4	3	4	3
	1.2 Product Compliance	50%	50%	70%	56%	67%	30%	54%	62%	10%	5%	6%	1	1	9	6
	1.3 Component Engineering	83%	67%	70%	75%	75%	30%	80%	70%	30%	24%	21%	3	3	4	4
	1.4 Test	38%	63%	70%	60%	60%	30%	45%	62%	15%	7%	9%	4	4	5	5
	1.5 Test Process & Quality Control	88%	63%	100%	0%	0%	0%	88%	63%	15%	13%	9%	4	4	0	0
										100%	72%	68%				
											Yellow	Yellow				

Figure 6-2: Current Manufacturing Assessment: Sub-Section 0 and Sub-Section 1

6.1.1 Section 0: Manufacturing Technology Capability

Manufacturing technology capability and New Product Development is one of the asset criteria which can be used to explain how the potential contract manufacturer achieves success in New Product Development. Manufacturing Technology Capability includes technology, strategy, knowledge, process, and organization [14, 15]. The research in the innovation literature supports the view that highly innovation firms perform better than less innovative ones. With a high level of innovative and future development capability, the firm is able to improve current products and processes [16], develop new ideas and transform into new products, processes, and systems [17]. Capability of new product development at contract manufacturer should not be assessed by using just one aspect of innovation capability from the contract manufacturer, but by using the input from the case company product roadmap more effectively and simultaneously, and should include a brief description given below hypothesis.

Hypothesis 1: Strategic planning capability for new product development performance

Strategic Planning Capability (SPC) is the capability to formulate and adopt different types of plans that can both adapt to and exploit environment changes in the highly competitive environment [15]. Linkage between innovation strategy at contract manufacturer and case company product roadmap is important for effective new product development.

Hypothesis 2: Technology capability for new product development performance

Technology Capability (TECHC) is the ability to use sophisticated technologies in new product development, the rapidity of integration of new technologies, and proactively developing new technologies and creating new product ideas[12, 17]. Contract manufacturer technical skills and R&D resources are important to bring new

technology capability and better help to design the manufacturing processes to support new products.

Hypothesis 3: Manufacturing Capability for new product development performance

Manufacturing Capability (MC) is the ability to transform R&D results to products in accordance with product design requirement and can also be manufacturer in production batches [4]. Ability to adopt computer-aided design/engineering (CAD/CAE) to manufacturing process and reduce new product development cycle time is important to new product development performance.

Hypothesis 4: Inter-functional Coordination Capability for new product development performance

Inter-functional Coordination Capability (ICC) is the ability to constitute a well-established organizational structure and process, coordinate the work, promote cross-functional interaction and integrate performance from different organization [18]. It influence new product development performance through organization to share the knowledge, involvement and commitment to project can speed up new product development

Conduct of additional assessment criteria of Manufacturing Technology Capability for New Product Development

Current criteria for manufacturing technology is shown in Table 6-1, this paper has adopted the above factors, SPC (H1), TECHC (H2), MC (H3), and ICC (H4) and perform hypothesis testing / regression analysis to estimate the capability and new product development performance, which respondents in this research has been reviewed and agreed to include these new criteria to the assessment for new product development results in length of development cycles, fraction of first customer shipment, development productivity, percentage of successful new products or the portion of sales from new products vs. current products in each quarter [19].

SPC includes capability to adjust planning to the changes, integrate internal resources to the external requirements

TECHC includes items of technology, R&D personnel, and rapidity to integrate new technology

MC includes items of capability of manufacturing personnel and technical capability of the manufacturing equipment

ICC includes coordination and cooperation of cross functional department, accuracy and efficiency of internal and external communication

Table 6-1: Manufacturing Assessment: Sub-Section Scores

Section 0: Manufacturing Technology Capability	
0.1	Equipment Qualification & Process
0.2	Product Materials
0.3	Process Control & Analysis
0.4	SMT Process (Stencil printing through Reflow)
0.5	Wave, Through Hole Assembly, and Hand Load Solder Process
0.6	Mechanical Assembly (Heat sink, hardware and press fit), Rework & Failure analysis
0.7	Structural Test (5DX, ICT and Boundary Scan)
0.8	Training – assembly operators, materials handling
0.9	Technology Capability

The research team has conduct exploratory factor analysis, regression analysis, as shown in Table 6-2, to test whether of each factor is the valid indicator of the assessment for new product development, regression analysis helps to endure good and reliable decision-making process to improve the contract manufacturer assessment with clear understanding on how a change in assessment criteria can affect the successful of launching new product at the selected contract manufacturer.

In this study, Technology Capability for New Product Development is the response factor and SPC, TECHC, MC, and ICC are the independent factors (Regressors).

The use of seven-point Likert response scales (from 1-7) and statistical software to run a regression analysis, the research team obtains the output shown in table 6-2, this regression analysis helps to estimate the capability and performance [18].

Table 6-2: Regression Analysis

Variables	Mean	S.D.	Std. Beta	Std. Error	Sig.	VIF
SPC (H1)	5.82	0.934	0.274*	0.065	0.000	2.750
TECHC (H2)	5.51	1.090	0.472*	0.051	0.000	2.317
MC (H3)	5.42	1.010	0.062**	0.055	0.255	2.314
ICC (H4)	5.60	0.983	0.009**	0.058	0.877	2.375
Adj. R2	0.566					
F	65				0.000	
*p<0.001 **p>0.05 non- significant						

Regression results are explained in the following. Hypothesis 1, there is a positive relationship between Strategic Planning Capability (SPC) and new product development performance. The results support this Hypothesis 1 with positive number and significant (Beta=0.274; p<0.001). Hypothesis 2, there is a positive relationship between Technology Capability (TECHC) and new product development performance. The results support the prediction of Hypothesis 2 with a strong influence on new product development performance (Beta=0.472; p<0.001). Hypothesis 3, suggest Manufacturing Capability (MC) will have a positive influence on new product development performance, the results are not support (Beta=0.062; n.s.). And the last, Hypothesis 4, Inter-functional Coordination Capability (ICC) also has no statistic significant influence on new product development performance (Beta=0.009; n.s.). The

Variance Inflation Factor (VIF) was used to check the potential multicollinearity, refer to a situation where at least two independent factors (SPC and TECHC) are highly correlated. The Taken all results together, the highest value, VIF=2.750, come from Strategic Planning Capability (SPC), however, the value are within the acceptable range. Also, the Technology Capability (TECHC) is the largest positive influence and important to new product development performance.

From analysis result, it provides evidence that SPC and TECHC have significant impact on new product development performance and should be included in the contract manufacturing assessment criteria. Therefore, the assessment, section 0, has been updated as shown in Table 6-3.

Table 6-3: Manufacturing Assessment: Sub-Section Scores (updated)

Section 0: Manufacturing Technology Capability	
0.1	Equipment Qualification & Process
0.2	Product Materials
0.3	Process Control & Analysis
0.4	SMT Process (Stencil printing through Reflow)
0.5	Wave, Through Hole Assembly, and Hand Load Solder Process
0.6	Mechanical Assembly (Heat sink, hardware and press fit), Rework & Failure analysis
0.7	Structural Test (5DX, ICT and Boundary Scan)
0.8	Training – assembly operators, materials handling
0.9	Technology Capability
0.10	Technology Capability for New Product Development

Item 0.10 had been added to section 0: Manufacturing capability assessment, and will be break down into two sub-items based on research team discussion under Technology Strategic Planning Capability and Technology Capability of new product development.

Sub-Section 0.10(a) Technology Strategic Planning Capability

The implementation of technology strategic planning process at contract manufacturer was driven by the fast development of new technology to integrate technology strategy with business strategy [20]. The technology strategic planning capability includes the following sub-items as shown in table 6-4.

Add - Roadmap of the development of technology

Add - Development goal

Add - Development plan

Add - Measure the performance of the development routine

Table 6-4: Add Section 0.10(a) Strategic Planning Capability

		Assessment Guideline		Not Applicable	Not In-Place (Rating 0)	Partially In-Place (Rating +0.5)	Fully In-Place (Rating +1.0)	Initial Rating
Sub-Section 0.10: New Product Development								
	0.10.(a) Strtegic Planning Capability							
1	Does supplier have roadmap of development of technology?	**Verify that technology roadmap has been created with align to the needs of products and markets** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1
			Auditor Assessment				x	1
2	Does supplier have development goal? What is current technology? What kind of technology that will be developed? What are the future products that will be using the developped technology? When the develop technology with be available?	**Verify that the S.M.A.R.T. goal of technology development has been create.** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1
			Auditor Assessment			x		0.5
3	Does supplier have development plan to support future technology and future product in the roadmap?	**Verify that R&D activities have been carried and reviewed to achieve technology development goal** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1
			Auditor Assessment			x		0.5
4	Does supplier have procedure to measure the performance of the development routine ? What is the % success rate compare to the goal?	**Verify that R&D activities have been carried and reviewed to achieve technology development goal** Provide evidence via procedure, data or picture as applicable.	Self Assessment			x		0.5
			Auditor Assessment			x		0.5

Sub-Section 0.10(b) Technology Capability

The implementation of technology capability is driven by the understanding of core technology capability of company as internalize and rivals as externalize, and

innovation process to support the need of products and markets. The technology capability includes the following items as shown in table 6-5.

Add - Core technology capability of the company

Add - Core technology capability of the competitors

Add - R&D planning to identify potential technology capability

Add - Technology life cycle

Table 6-5: Add Section 0.10(b) Technology Capability

	0.10.(b) Technology Capability							
1	Does the core technology capability meet the requirement of new product?	**Verify that core capability technology meet most of the requirement of new product** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1
			Auditor Assessment				x	1
2	Does the core technology capability have competitive advantage when compare with others in the same industry?	**Verify that competitive advantage of core technology capability** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1
			Auditor Assessment				x	1
3	Does supplier have R&D planning to identify the development of potential technology capability?	**Verify R&D planning to develop new potential technology capability that can be considered as core technology of the firm in near future** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1
			Auditor Assessment				x	1
4	Does supplier have technology life cycle that describe the cost and profit of a product from technology development to market maturity and decline?	**Verify the technology life cycle of the existing technology at the firm and new technology to be developped** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1
			Auditor Assessment				x	1

From the analyze phase, the research team realized that if the selected contract manufacturer lack of technology capability, it would impact time, quality, and cost to launch new products. Therefore, the assessment of technical capability possesses by potential contract manufacturer using information from self-assessment, company profile and site visit and given a weight based on strategic supplier selection analysis, moreover, the collaboration between the contract manufacturer and case company will also provide the good alignment between two firms in technology roadmap and product roadmap. The potential contract manufacturer was evaluated

to address the supporting distributes that are important to develop and launch new products within the specific timeline.

6.1.2 Section 1: Manufacturing Technology

Manufacturing technology usually focus on existing processes using lean management to eliminate waste occurs in the manufacturing process. Nowadays, many companies that are using contract manufacturers, including the case company, require constantly rising and changing in shorter product life cycles [21]. The companies cannot effort to invest in a specific production line, they are looking for the right manufacturing technologies and resources, cost efficiency from contract manufacturers. In this section, the research team explores the decision to choose the appropriate manufacturing technologies by referring to product requirements. The requirements and relevant characteristics of each new product must be specific, it is important to focus on product characteristics that are important to manufacturing process. The systematic approach to identify product characteristic will be implemented as additional assessment criteria for manufacturing technology in section1.2: Product & Manufacturing Compliance as shown in table 6-6.

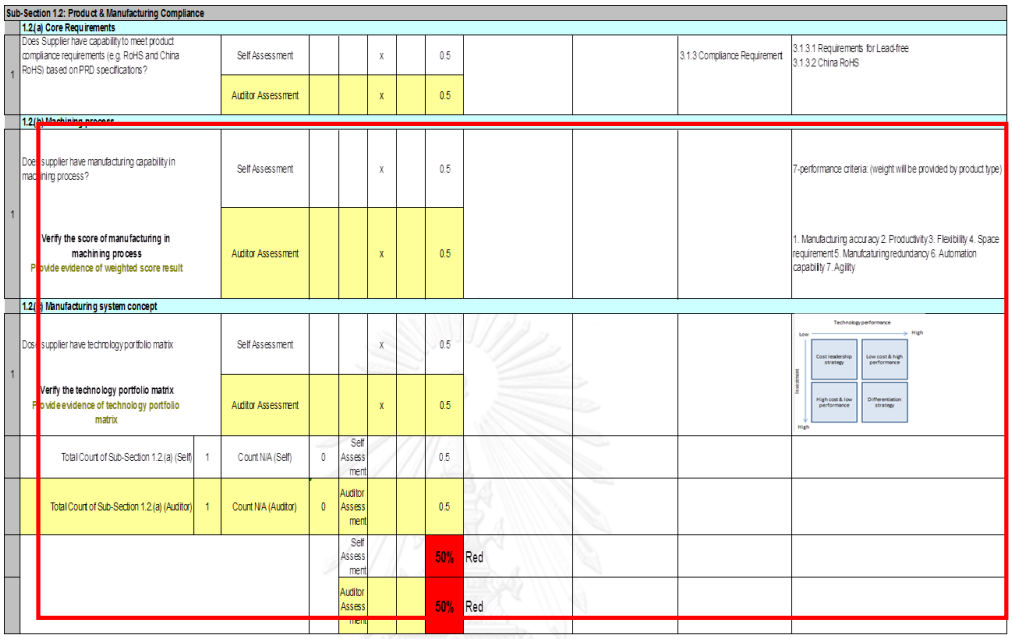
Table 6-6: Current criteria in section 1.2 Product & Manufacturing Compliance

Sub-Section 1.2: Product & Manufacturing Compliance													
1.2.(a) Core Requirements													
1	Does Supplier have capability to meet product compliance requirements (e.g. RoHS and China RoHS) based on PRD specifications?		Self Assessment			x		0.5			3.1.3 Compliance Requirement	3.1.3.1 Requirements for Lead-free 3.1.3.2 China RoHS
			Auditor Assessment			x		0.5				
	Total Count of Sub-Section 1.2.(a) (Self)	1	Count N/A (Self)	0	Self Assessment			0.5				
	Total Count of Sub-Section 1.2.(a) (Auditor)	1	Count N/A (Auditor)	0	Auditor Assessment			0.5				

The research team had reviewed and agreed to add section 1.2(b) Manufacturing capability in machining process and section 1.2(c) Manufacturing system

concept as shown in table 6-7. The details and the main reasons to add these two sections are described below.

Table 6-7: Add Sub-section 1.2(b) and Sub-section 1.2(c)



Sub-Section 1.2: Product & Manufacturing Compliance											
1.2(a) Core Requirements											
1	Does Supplier have capability to meet product compliance requirements (e.g. RoHS and China RoHS) based on PRD specifications?	Self Assessment			x		0.5			3.1.3 Compliance Requirement	3.1.3.1 Requirements for Lead-free 3.1.3.2 China RoHS
		Auditor Assessment			x		0.5				
1.2(b) Machining process											
1	Does supplier have manufacturing capability in machining process?	Self Assessment			x		0.5				7-performance criteria (weight will be provided by product type)
	Verify the score of manufacturing in machining process Provide evidence of weighted score result	Auditor Assessment			x		0.5				1. Manufacturing accuracy 2. Productivity 3. Flexibility 4. Space requirement 5. Manufacturing redundancy 6. Automation capability 7. Agility
1.2(c) Manufacturing system concept											
1	Does supplier have technology portfolio matrix	Self Assessment			x		0.5				
	Verify the technology portfolio matrix Provide evidence of technology portfolio matrix	Auditor Assessment			x		0.5				
	Total Count of Sub-Section 1.2 (a) (Self)	1	Count N/A (Self)	0	Self Assessment		0.5				
	Total Count of Sub-Section 1.2 (a) (Auditor)	1	Count N/A (Auditor)	0	Auditor Assessment		0.5				
					Self Assessment		50%	Red			
					Auditor Assessment		50%	Red			

Sub-Section 1.2 (b) Manufacturing Capability in Machining Process

Most manufacturing technologies can be indicated into two categories based on material processing principles [22], additive manufacturing (pre-machining process) and subtractive manufacturing (machining process). However, this research focuses exemplarity on subtractive manufacturing to cover machine tool concept determining technical performance for an efficient manufacturing support new product development. Through the characteristic of new product in company product roadmap, the following machine technical performances are selected to ensure successful manufacturing technology:

Manufacturing accuracy using high precision machining

Productivity

Flexibility to adapt to new product requirements

Space requirement

Manufacturing redundancy to ensure its stability and reliability

Automation capability to improve quality and productivity

Agility, fast adapt

The research team has set the criteria to evaluate manufacturing capability in machining process as above, and also weight the score for each performance, 1=lowest importance to product characteristic / 5=highest importance to product characteristic. The case company will be providing the weight score for each product type, and the contract manufacturer weight the performance of available machines to select the most appropriate one. Refer table 6-8, sample of weighted scoring machine manufacturing capability [1].

Table 6-8: Sample of weighted scoring machine manufacturing capability

		MachineA		MachineB		MachineC	
Performance criteria	Weight	performance	Sum.	performance	Sum.	performance	Sum.
Manufacturing accuracy	5	2	10	2	10	2	10
Productivity	4	2	8	1	4	2	8
Flexibility	3	3	9	4	12	3	9
Space requirement	1	2	2	1	1	2	2
Manufacturing redundancy	4	2	8	2	8	3	12
Automation capability	5	3	15	1	5	2	10
Agility	4	3	12	4	16	2	8
Results		64		56		59	

Weight score will be provided with specific for each product & process

Sub-Section 1.2 (c) Manufacturing System Concept

The assessment of manufacturing system concept was done by applying the strategic consideration and market position as illustrate in technology portfolio matrix shown in figure 6-3, modifying from the layout of Boston Consulting Matrix and Mckinsey-Portfolio matrix.

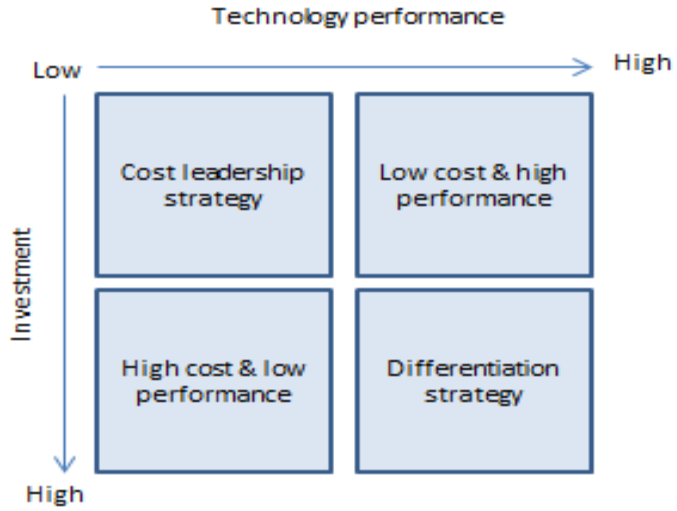


Figure 6-3: Technology Portfolio Matrix

With this framework, the manufacturing system of each contract manufacturer falls into lower left field is not an attractive choice, in the other hand, if it falls into the upper right field is the most attractive choice. While the manufacturing concept that falls into other two fields is the most realistic that will be using strategic decision based on specific product portfolio matrix.

6.1.3 Critical to Quality Section

In this section, research team aims to review the critical to quality section in the assessment form as it has made significant impact on the successful of launching new product of the company, the definition of Critical-to-Quality (CTQ) had borrowed some ideas from Key Characteristic (KC) method, this feature is defined as a CTQ of the manufacturing process.

In new product development, the process mapping of each new product will be defined, each manufacturing operation in the process flow chart have its own CTQ characteristic. For example, at pin grinding process, the CTQ of pin grinding process is pin finished diameter and pin circularity. Analysis stratum, Cp and Cpk, is measured for the CTQ characteristic.

Due to the changes in product requirements and variety of product type, this section, Critical to Quality, in the assessment form will be adjusted and modified by new product development team to provide the critical characteristics of each product, no specific or generic CTQ.

Previously, the CTQ of Surface Mount Technology (SMT) was defined in this section, moving forwards, new product development team will create the specific template for each new product type and will be reviewed by cross-functional team before share to potential contract manufacturer as part of the assessment criteria.

6.2 The implementation of contract manufacturing management for New Product Introduction (NPI)

From analyze phase, it can be said that the systematic approach to monitor the progress of new product development during NPI phase does not exist. No procedure to breakdown NPI activities into sub-process with tollgate review, this gap has high impact to the successful of launching new product at the selected contract manufacturer within timeline. Therefore, the research team had created one Work Instruction under the title of "Quality Planning Process Procedure" using the knowledge and technique from Advance Product Quality Planning (APQP) which is widely used in various industries.

The purpose of this Work Instruction is to establish the steps necessary and requirement for quality planning of new products, processes, or technologies into manufacturing process at the selected contract manufacturers.

This Work Instruction is designed to create a systematic approach for proposing, justifying, and managing engineering projects that involved in new product, product transferred, and new technology concept at the contract manufacturer.

This Work Instruction is created with reference to various documents at the contract manufacturer and at the case company itself, such as, quality manual, design rule of product and process, machine buy-off and procurement requirement, failure analysis system procedure, failure modes and effects analysis, measurement system analysis, design of experiment, manufacturing capability, contract review procedure,

change control procedure, JEDEC standard, advance product quality planning handbook, and etc.

The responsibility was defined for each product leader, program manager, and cross functional team from internal organization and external party. Following are the procedures of quality planning process:

6.2.1 Responsibilities

6.2.1.1 It is the responsibility of all personnel or project leaders involved with new package development, new process and new technology projects to utilize the Planning of Product Realization (PPR)

6.2.1.2 It is the responsibility of New Product Development team to ensure that this document is maintained and updated as required

6.2.1.3 Project leader and Program manager will be responsible for leading the project and coordinating the entire program, organize the cross functional team for regular meetings to review and update the program which includes project timeline, goals, bill of materials, process flow and equipment, etc., ensure that all the required documentation of each phase is completed, coordinate with all concerns to conduct training class of new process/product introduction prior to engage with contract manufacturers.

6.2.1.4 The cross functional team will be formed by project leader with the responsibility to support the entire program in each phase. The team includes representatives from Engineering, Manufacturing, Technical Support, Quality Assurance, Material Control, Production Control, and Purchasing as appropriate.

6.2.2 Planning of Product Realization (PPR)

6.2.2.1 The new product, process, and technology shall be planned and developed in according to the planning of product realization diagram as shown in Appendix 2

6.2.2.2 The planning of product realization shall be consistent with the requirements of the other processes of the Quality Management System

6.2.2.3 The planning of product realization shall determine the following items as appropriate:

a) Quality objective and requirement of product
b) Need to establish processes, documents and provide resources specific to the product
c) Required verification, validation, monitoring, inspection and test activities specific to product and criteria for product acceptance
d) Record necessary information and results to provide evidence that the realization processes and resulting product meet requirements

6.2.2.4 The output of this planning shall be in a form as described above

6.2.2.5 The product realization shall include all processes: from incoming material through shipping and warehousing

6.2.2.6 The FMEA and Control Plan shall be included

6.2.2.7 Requirement and reference to technical specifications shall be included in the planning of product realization as a quality plan

6.2.2.8 Acceptance criteria shall be defined. For attribute data sampling, the acceptance level shall be less than 3 sigma defects

6.2.2.9 A Non-Disclosure and Confidentiality Agreement (NDA) or computer password is required to ensure the confidentiality of contracted products and projects under development and related product information

6.2.2.10 Change control Procedure

a) Change control procedure shall be prepared to control and react to changes that impact product realization
b) The effect of changes, including those changes caused by supplier, shall be assessed
c) The verification and validation activities shall be defined to ensure compliance with all requirements
d) Changes shall be validated before implementation

e) For proprietary design, impact on form, fit and function, (including performance, and/or durability) shall be reviewed with cross functional team, so that all effects can be properly evaluated

f) Effects of process changes shall be verified before and after characterization of the appropriate device parameters

6.2.3 Design and Development

6.2.3.1 Design and Development planning

a. Program manager shall plan and control the design and development of products as specified in each step of Planning of Product Realization in Appendix 2

b. Program manager shall prepare plan for each design and development activities. The plan shall describe or reference these activities and define responsibility for their implementation

c. Program manager and team should be Multi-Disciplined, and represent all departments that are required to successfully implement new product and use a multidisciplinary approach to prepare for product realization, including:

    I. Development/Finalization and monitoring of Special Characteristic

    II. Development and review of FMEAs including actions to reduce potential risks

    III. Development and review of Control Plans

d) The design and development activities plan shall be reviewed, updated, verified and validated as appropriate for each design and development stage

6.2.3.2 Design and Development input

a. Team feasibility study should be conducted whenever the input is received. All input information shall be entered into the “Phase 1” form and reviewed by cross-functional team
b. A feasibility study result shall be recorded and maintained
c. Design output in each phase of Planning of Product Realization shall be documented and reviewed as per project timeline before moving to the next phase. The record shall be used, the Checklist with a cross-functional team review and sign-off. The design output can be verified and validated against design input requirements
d. Product design input shall be identified, documented and requirements reviewed, including the following:
    i. Special characteristics, identification, traceability and packing
    ii. Use of previous project design, computer analysis, supplier feedback, internal input, field data and other relevant sources for current and future projects of a similar nature
    iii. Target for product quality, life, reliability, durability, maintainability, timing and cost
e. Manufacturing process design input shall be identified, documented and requirements reviewed, including the following:
    i. Product design output data
    ii. Target for productivity, process capability
    iii. Experience from previous developments
f. The Special Characteristics shall be identified and included:
    I. All special characteristics in the control plan
    II. Identify process control documents including drawings, FMEAs, Control Plans and operator instructions, include those process steps that affect the special characteristics

6.2.3.3 Design and Development Output

a. Output of design and development shall be provided in a form that enables verification against the design and development input and shall be approved prior to release. Use phase review and sign-off sheet in Appendix 2
b. The design and development output shall meet the design input requirement, contain or reference product acceptance criteria and specify the characteristics of product that are essential for its safe and proper use, such as operating, storage, handling, maintenance and disposal requirements. It shall provide appropriate information for purchasing, production and for service provision
c. Design output shall use the following tools and techniques for correlating design and product requirements to process target values:
    i. Computer aided design (CAD) for dimensioning, tolerance and simulation
    ii. Machine Capability Study (MPCPS)
    iii. Design of Experiment (DOE)
    iv. Material Property and Compatibility comparison
    v. Evaluation
    vi. Reliability test
d. The Product and Manufacturing Process design output shall be expressed in terms that can be verified and validated against design input requirements. The Product and Manufacturing Process design output shall include:
    i. Design FMEA and/or Process FMEA
    ii. Special product and Process characteristic specification
    iii. Engineering drawing
    iv. Engineering specification
    v. Material specification

vi. Process flow chart

vii. Control plan

viii. Floor layout

ix. Work instruction

x. Process approval acceptance criteria

xi. Result of error-Proofing activities, as appropriate

xii. Data for quality, reliability, maintainability and measurability

xiii. Method of rapid detection and feedback of product/manufacturing process nonconformities (Real Time Inspection, Gate buyoff, Corrective Action Report, feedback from Testing)

xiv. Note: Every change of package & material design in each APQP phase, Design FMEA (DFMEA) must be revised and must perform process characterization before having engineering build / qualification run

b) Process FMEA (PFMEA) shall consider all process from incoming material receipt to shipping and warehousing. For some specific process differences for parts within family may require supplements to the family PFMEA. i.e. new equipment, new materials

6.2.3.4 Design and Development Review

a) The design and development shall be performed in accordance with planned arrangements. The design and development review shall evaluate the ability of the results, identify any problems, and propose necessary actions

b) The design and development review shall include representative of functions concerned with the design and development stages being reviewed

c) The reviews are normally coordinated with design phases and include manufacturing process design and development

d) Records of results from reviews and any necessary actions shall be maintained

e) The measurement at specified stages of design and development shall be defined, analyzed, and reported with summary results as an input to management review

6.2.3.5 Design and Development Verification

a) Verification shall be performed in accordance with planned arrangements to ensure that the design and development outputs have met the design and development input requirements

b) Records of the results of the verification and any necessary actions shall be maintained

c) Verification of design/process characterization and certified test application shall obtain customer approval when required

d) If any parameter; any process/product condition which differ from specified parameter, may come out from DOE , engineering trial or any method, be used during the verification, the parameter and its record should be included in the process characterization report

6.2.3.6 Design and Development Validation

a) Design and development validation shall be performed in accordance with planned arrangement to ensure that the resulting product is capable of meeting the requirements for the specified application or intended use

b) Whenever practical, validation shall be completed prior to delivery or implementation of the product

c) Records of results from validation and any necessary actions shall be maintained

d) Design and development validation shall be performed in accordance with customer requirements including project timing

e) Design rule modification should result when the design is no longer robust under the current process conditions

6.2.3.7 Product approval process

a) The product approval should be subsequent to the verification of the manufacturing process, including the joint verification of cross-functional team

6.2.3.8 Control of design and development changes

b) Design and development change shall be identified and records maintained

c) Any changes shall be reviewed, verified and validated as appropriate and approved before implementation

d) Review of design and development changes shall include evaluation of the effect of the change

e) Records of the results for the review of changes and any necessary actions shall be maintained (including all changes during the product program life)

f) The control of design and development changes shall include long-term planning for process changes and technology development. The plan shall include:

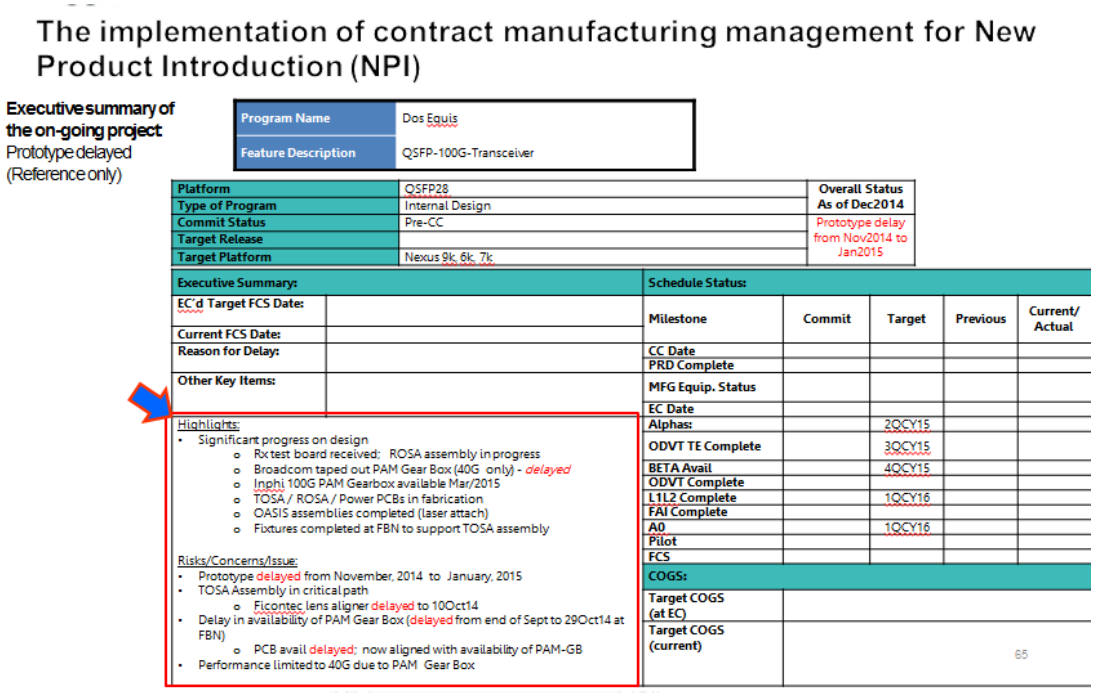
   I. Technology roadmap

   II. Quality roadmap

   III. Product development roadmap

6.3 Pilot and Implementation for on-going project

Following figure 6-4 and 6-5 illustrate the implementation of the improvement CM assessment and the improvement of CM Management by adding the control to monitor the progress of all NPI activities.



The implementation of contract manufacturing management for New Product Introduction (NPI)

Executive summary of the on-going project
Prototype delayed
(Reference only)

Program Name	Dos Equis
Feature Description	QSFP-100G-Transceiver

		Overall Status As of Dec2014
Platform	QSFP28	Prototype delay from Nov2014 to Jan2015
Type of Program	Internal Design	
Commit Status	Pre-CC	
Target Release		
Target Platform	Nexus 9k, 6k, 7k	

Executive Summary:

EC'd Target FCS Date:
Current FCS Date:
Reason for Delay:
Other Key Items:

Highlights:
- Significant progress on design
  - Rx test board received; ROSA assembly in progress
  - Broadcom taped out PAM Gear Box (40G only) - *delayed*
  - Inphi 100G PAM Gearbox available Mar/2015
  - TOSA / ROSA / Power PCBs in fabrication
  - OASIS assemblies completed (laser attach)
  - Fixtures completed at FBN to support TOSA assembly

Risks/Concerns/Issue:
- Prototype delayed from November, 2014 to January, 2015
- TOSA Assembly in critical path
  - Ficontec lens aligner delayed to 10Oct14
- Delay in availability of PAM Gear Box (delayed from end of Sept to 29Oct14 at FBN)
  - PCB avail delayed; now aligned with availability of PAM-GB
- Performance limited to 40G due to PAM Gear Box

Schedule Status:

Milestone	Commit	Target	Previous	Current/ Actual
CC Date				
PRD Complete				
MFG Equip. Status				
EC Date				
Alphas:		2QCY15		
ODVT TE Complete		3QCY15		
BETA Avail		4QCY15		
ODVT Complete				
L1L2 Complete		1QCY16		
FAI Complete				
A0		1QCY16		
Pilot				
FCS				

COGS:

Target COGS (at EC)	
Target COGS (current)	

Figure 6-4: Executive summary from NPI Tollgate Review

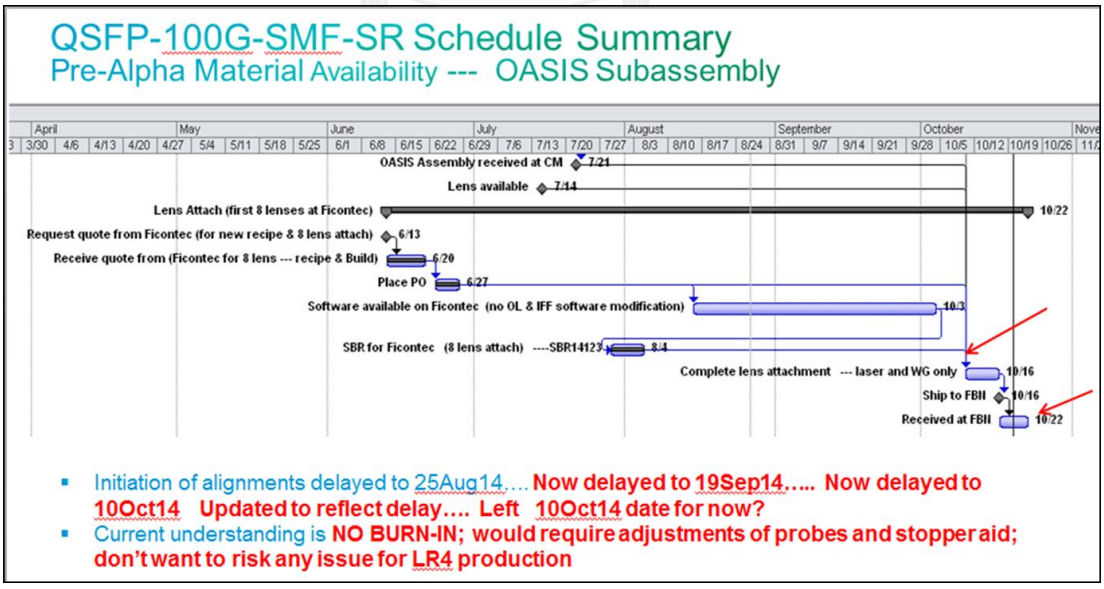


Figure 6-5: Executive summary from NPI Tollgate Review (continue)

From the current status of the on-going project, QSFP Transceiver, it shows that the project is now facing the delay of the prototype build.

Areas that causing the delay are shown below:

Lens alignment process: The ficonTEC aligner was delayed from the supplier in Germany from Aug2014 to Oct2014

Lens alignment set up and qualification: Equipment qualification at CM1 was delayed from Sep2014 to Nov2014

Process qualification: Lens alignment process qualification was delay from Oct2014 to Dec2014

Prototype build: Prototype build was delayed from Nov2014 to Jan2015

The indication and the consequence of this delay will cause the delay of the overall project. The problem is high priority and will have high impact to Product Operation organization to deliver QSFP 100G Transceiver to production (A0 release) in Q1Y2016. The new product development team performed deep dive solution analysis with automation team who is taking care of the delivery of ficonTEC lens alignment machine by doing conditionally acceptance machine test at supplier site in Germany and ship the machine to contract manufacturer to support prototype build under engineering supervision with all solid document and action plan from machine supplier, and then perform final machine acceptance test at contract manufacturer site, instead of supplier site, to avoid any further delay to the overall project.

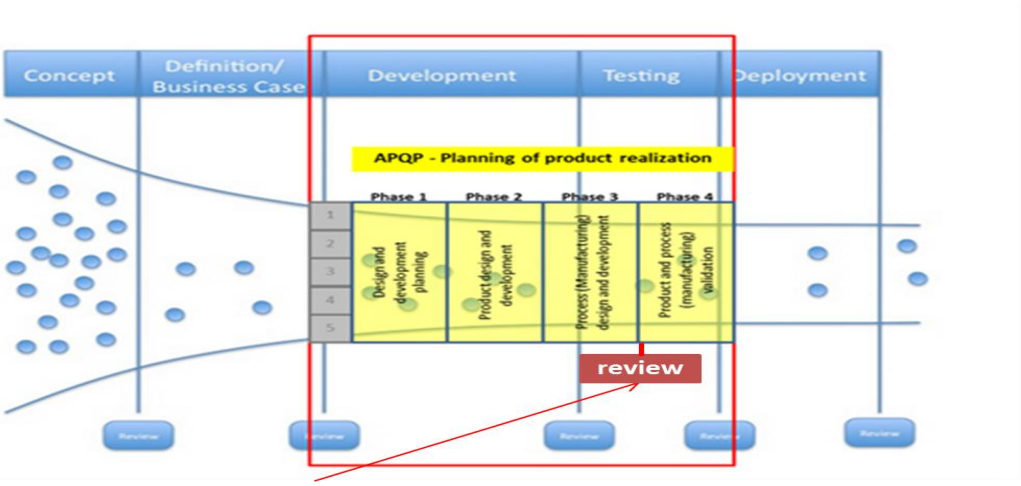


Figure 6-6: NPI Tollgate Review during NPI Phase

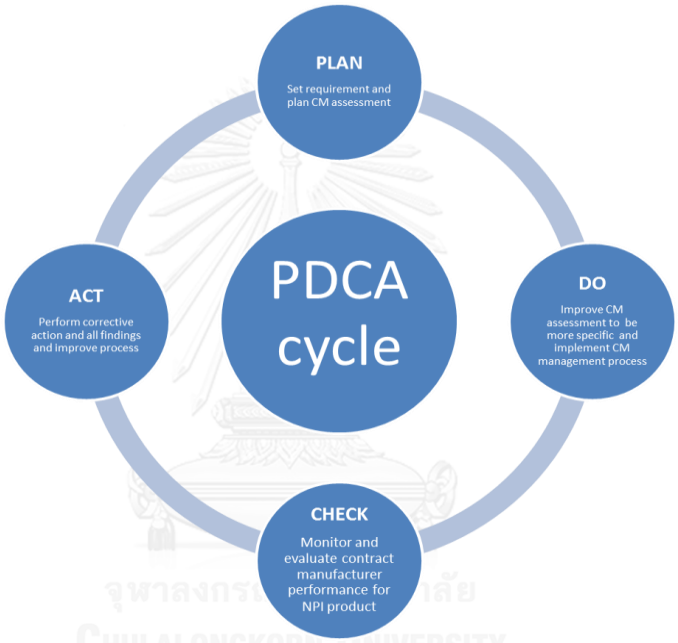
6.4 Summary of improve phase

In the improve phase, the cause of causes of problem and the recommended solutions to reduce the failure to launch new product at the selected contract manufacturer within timeline had been determine focusing on the assessment criteria of contract manufacturer selection and contract manufacturing management for new product introduction (NPI) whereby pre-operationalized abilities and capabilities are measured in the most direct approach to the specific product requirements. Therefore, this approach is appropriate for case company to closely monitor the progress of new product development to ensure successful launch of new products building with appropriate technologies and capabilities.

Once the case company obtained the quotation from potential contract manufacturer, the new product program manager (NPPM) will perform manufacturing assessment. Each assessment criteria will be classified into sub-section as defined in Appendix 1. After the contract manufacturer is selected, new product program manager (NPPM) will start all NPI activities follow the processes defined in section 5.2: The implementation of contract manufacturing management for New Product Introduction (NPI). The study and implementation in the improve phase had determined with correspond PDCA cycles (Plan Do Check Act) as shown in figure 6-7.

However, to ensure the consistent performance of contract manufacturer assessment and contract manufacturing management for NPI, the case company should consistently monitor contract manufacturer performance o perform the corrective actions of all findings and improve process.

However, the lesson learned from this implementation at the case company will be define in this paragraph for further improvement in other projects for supplier selection and supplier management which are similar to this research. The recommendations are shown below:



[Reference picture from: Avalution Consulting – Business Continuity Consulting]

Figure 6-7: PDCA cycles being used in the improve phase

Role and responsibility of the cross functional team must be clearly identified to avoid any confusions that may occurred during implementation of new method and procedure.

The objective of new implementation must be communicated to all concerned department with fully support from management team.

The transition from existing process to new implementation must be planned and reviewed ahead of time to avoid any delay for the transition.

7. CHAPTER VII

CONTROL

The root causes of the problem had been defined, the solution to ensure the success of launching new product at the selected contract manufacturer within timeline had been determined in the previous chapters. In this chapter, control phase, is to sustain the implementation of the improvement. To ensure that the contract manufacturing assessment will be up-to-date and will be updated to provide the specific requirements for the specific new products before sharing to the potential contract manufacturers, and to ensure that the procedure for contract manufacturing management for new product introduction is commonly been used in the case company, the research team had created a tool called CMSM tool (Contract Manufacturing System Methodology) in case company's internet/extranet share point that can be accessed from either inside the company or at the contract manufacturer. The Work Instruction for CM Selection Criteria and CM Management during NPI phase had been documented in the company's document control system with group of concerns are being trained to officially implement the process and work instruction. The record of the document control system is shown in figure 7-1.

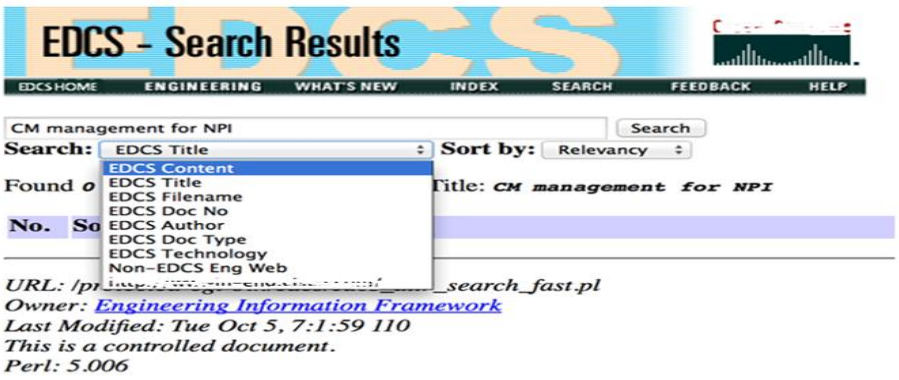


Figure 7-1: EDCS Electronics Document Control System for Work Instruction

7.1 Implement CMSM tool

The CMSM tool and Work Instruction had been implemented at the contract manufacturer which includes:

Information and result of “Quality Planning Process Procedure of each new product, refer Appendix 2

SCAR (Supplier Corrective Action Request)

Change control (ECR/ECO) – Contract Manufacturer Process change control

Lot Traceability

Then create external site with secure communication & collaboration with Contract Manufacturer site, change control, document management. Also include the data collection to monitor multiple attributes, critical attribute, monitor and display, data file template. The CMSM tool will be described in figure 7-2 and 7-3.

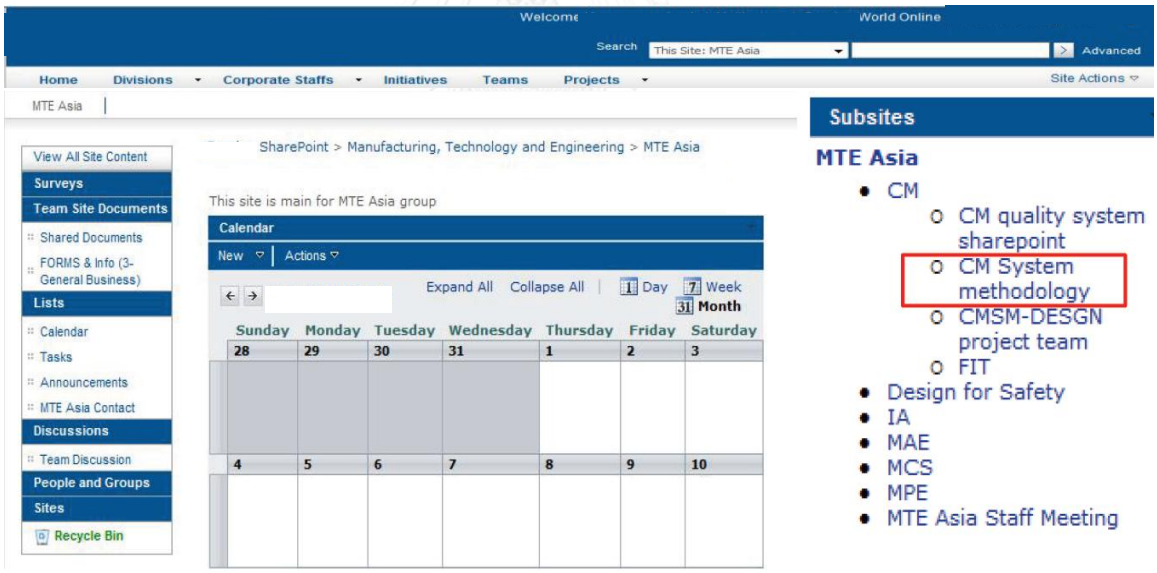


Figure 7-2: CMSM in Extranet Share Point

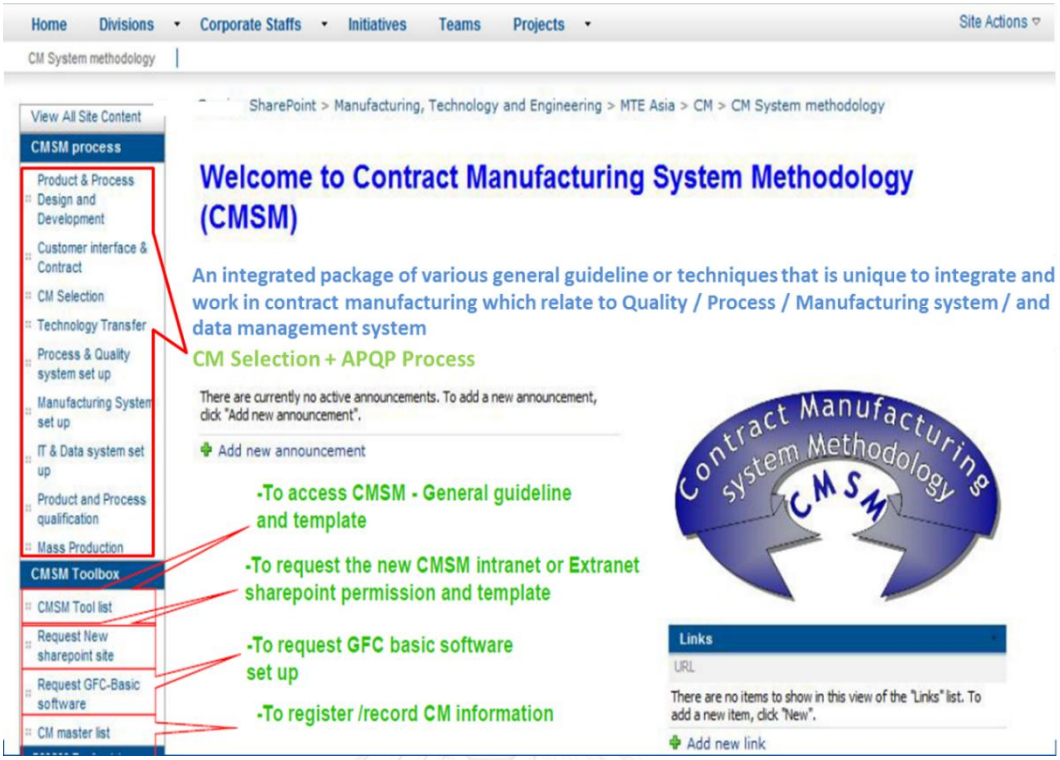


Figure 7-3: CMSM Toolbox

The process flow chart to create CMSM for each new product on the extranet where selected contract manufacturer can access and can store information is shown in figure 7-4 with the corporation with New Product Program Manager and IT department.

How to use the CMSM tool, after entering company extranet site, MTE Asia, chooses sub-site “CM-System Methodology” to enter “CMSM Process” and “CMSM toolbox”.

CMSM Process contains the information stating from CM selection through Mass production follows APQP Process. While CMSM toolbox contains the tools that will be used in CMSM process, for example, guideline and template, TI requests, etc.

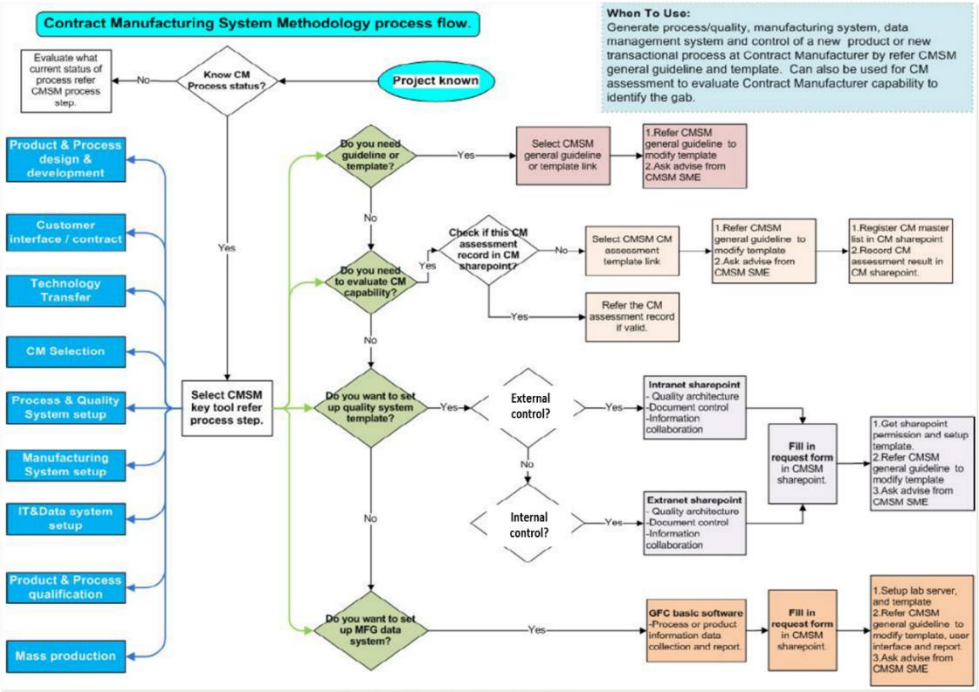


Figure 7-4: CMSM Process Flow Chart

7.2 Summary of control phase

In the control phase, the control method to access and use contract manufacturing management tool (CMSM) and the Work Instruction are constructed in implemented on the company extranet site where the selected contract manufacturer and also access to the site in order to search, download, and store all needed information for each new product. The CMSM tool consists of the information from assessment (first engagement and annual assessment) and also the needed information / results from each NPI phase follow Quality Planning Process Procedure as described in previous chapter. The CMSM had successfully implemented at the pilot contract manufacturer site which helps to improve the visibility of the project's progress, improve process control and process discipline at the contract manufacturer, provides more effective quality system and control such as change control at the company will be deployed as a change control at the contract manufacturer, provides more effective in engineering data analysis and process investigation from process and product parameter data collection and reporting.

8. CHAPTER VIII
CONCLUSION AND RECOMMENDATIONS

This research applied Six Sigma DMAIC methodology to ensure the success of launching new product at the selected contract manufacturer within timeline by improving current procedure and criteria for contract manufacturer assessment in manufacturing capability to support new product and implementing the procedure to monitor and ensure the progress of new product development in NPI phase using APQP (Advance Product Quality Planning) techniques.

The Six Sigma DMAIC methodology consists of five phases; define phase, measure phase, analyze phase, improve phase and control phase. The focuses and outcomes of each phase leads the research team to create the additional section in the assessment form to support the success of developing new product at the selected contract manufacturer, and also create the tool and procedure that is successfully deployed for all NPI activities. The standard procedure had been constructed and implemented to monitor the progress and success of new product development.

8.1 Conclusion

The performance of the contract manufacturer to develop new products for the case company is critical to deliver new products to markets within the specific timeline. The assessment helps to measure the performance of the contract manufacturer even before engagement and help to increase the visibility into their operation and manufacturing capability. This research had discussed the business case for manufacturing assessment and evaluation to support new product, it described in the research and in the assessment form what the case company should measure the potential contract manufacturer in order to ensure their manufacturing capability with more focus on new product requirements. Moreover, the implementation of contract manufacturer management helps the company to have better visibility and control over the contract manufacturer performance in all NPI activities, uncover and remove

the hidden delay drivers, reduce risk, and increase competitive advantage with better development timeline, understand on how to leverage contract manufacturer capability, and align actual practices between the case company and its contract manufacturer to improve performance metrics in delivery time and quality of the products. From the analytics of this research, it identified root cause of failure to launch new product, understand contract manufacturer performance, and provide the solution to prevent problem and facilitate performance improvement through contract manufacturer assessment and contract manufacturing management procedure.

8.2 Limitation of the research

This research is focusing only the successfully to launch new product at the selected contract manufacturer within timeline. Focusing on the improvement of contract manufacturer assessment, this research is only improved two sections out of total seven sections in the assessment because those five section are under responsible of other Global supply chain and Quality engineer which are more impact to the sustaining product rather than new development product.

Section 0: Manufacturing Technology Capability: Include in research scope

Section 1: Manufacturing Technology: Include in research scope

Section 2: Document Control and Change Management: *Not in research scope*

Section 3: Supply Chain Management: *Not in research scope*

Section 4: Operations: *Not in research scope*

Section 5: Quality Management System: *Not in research scope*

Section 6: Fulfillment, Logistics & Services: *Not in research scope*

The potential contract manufacturers could be selected even if they are weak in the manufacturing but strong in other supply chain aspects. The ideas and concepts from the research and also be expanded to other areas in Section 2 to Section 6 to strengthen the effectiveness of Contract Manufacturing Assessment.

8.3 Recommendations

To develop a robust criteria for contract manufacturing assessment in manufacturing capability, and to develop an easy-to-deploy procedure for contact manufacturing management during new product introduction phase, the method should be sound and the approach should be practical that can be widely used in all type of products to be developed at the contract manufacturer. The global supply chain team needs to implement this controlled procedure as part of contract manufacturer adding process with support from corporate management team. Having the active support from management team and stakeholders is critical to the success of the development of new product, as well as the continued success of the implementing contract manufacturing management procedure. The best way is by doing and practice in real project. During the team formation of any new project, it is necessary that team member should come from different and various department that can bring their knowledge, background and expertise of product requirement and manufacturing requirement, in order to collect, brainstorm variety of ideas within the process of new product development.

Further study should include the development of new products and service in other segment, such as telecommunication and data center which are in the potential growth and market share of the company. Also, include the improvement of other areas in the assessment, mainly on the supply chain, which have not been included in this research.

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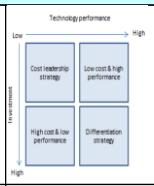
APPENDIX

Appendix 1: Contract Manufacturing Assessment

Section 0: Manufacturing Technology

Section 0. Manufacturing Technology											
		Assessment Guideline		Not Applicable	Not In-Place (Rating: 0)	Partially In-Place (Rating: +0.5)	Fully In-Place (Rating: +1.0)	Initial Rating	Supplier's Response and all applicable reference documents	Auditor Comments
Sub-Section 0.10: New Product Development										
	0.10.(a) Strtegic Planning Capability									
1	Does supplier have roadmap of development of technology?	**Verify that technology roadmap has been created with align to the needs of products and markets** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1		
			Auditor Assessment				x	1		
2	Does supplier have development goal? What is current technology? What kind of technology that will be developed? What are the future products that will be using the developped technology? When the develop technology with be available?	**Verify that the S.M.A.R.T. goal of technology development has been create.** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1		
			Auditor Assessment			x		0.5		
3	Does supplier have development plan to support future technology and future product in the roadmap?	**Verify that R&D activities have been carried and reviewed to achieve technology development goal** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1		
			Auditor Assessment			x		0.5		
4	Does supplier have procedure to measure the performance of the development routine ? What is the % success rate compare to the goal?	**Verify that R&D activities have been carried and reviewed to achieve technology development goal** Provide evidence via procedure, data or picture as applicable.	Self Assessment			x		0.5		
			Auditor Assessment			x		0.5		
	0.10.(b) Technology Capability									
1	Does the core technology capability meet the requirement of new product?	**Verify that core capability technology meet most of the requirement of new product** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1		
			Auditor Assessment				x	1		
2	Does the core technology capability have competitive advantage when compare with others in the same industry?	**Verify that competitive advantage of core technology capability** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1		
			Auditor Assessment				x	1		
3	Does supplier have R&D planning to identify the development of potential technology capability?	**Verify R&D planning to develop new potential technology capability that can be considered as core technology of the firm in near future** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1		
			Auditor Assessment				x	1		
4	Does supplier have technology life cycle that describe the cost and profit of a product from technology development to market maturity and decline?	**Verify the technology life cycle of the existing technology at the firm and new technology to be developped** Provide evidence via procedure, data or picture as applicable.	Self Assessment				x	1		
			Auditor Assessment				x	1		
					Self Assessment			**88%**	Green	
					Auditor Assessment			**69%**	Yellow	
	Total Count of Sub-Section 0.8.(a) (Self)	8	Count N/A (Self)	1	Self Assessment			7		
	Total Count of Sub-Section 0.8.(a) (Auditor)	8	Count N/A (Auditor)	1	Auditor Assessment			5.5		

Sub-Section 1.2: Product & Manufacturing Compliance

Sub-Section 1.2: Product & Manufacturing Compliance											
	1.2.(a) Core Requirements										
1	Does Supplier have capability to meet product compliance requirements (e.g. RoHS and China RoHS) based on PRD specifications?	Self Assessment			x		0.5			3.1.3 Compliance Requirement	3.1.3.1 Requirements for Lead-free 3.1.3.2 China RoHS
		Auditor Assessment			x		0.5				
	1.2.(b) Machining process										
1	Does supplier have manufacturing capability in machining process?	Self Assessment			x		0.5				7-performance criteria: (weight will be provided by product type)
	Verify the score of manufacturing in machining process Provide evidence of weighted score result	Auditor Assessment			x		0.5				1. Manufacturing accuracy 2. Productivity 3. Flexibility 4. Space requirement 5. Manufcaturing redundancy 6. Automation capability 7. Agility
	1.2.(c) Manufacturing system concept										
1	Dose supplier have technology portfolio matrix	Self Assessment			x		0.5				
	Verify the technology portfolio matrix Provide evidence of technology portfolio matrix	Auditor Assessment			x		0.5				
	Total Count of Sub-Section 1.2.(a) (Self) 1	Count N/A (Self)	0	Self Assessment			0.5				
	Total Count of Sub-Section 1.2.(a) (Auditor) 1	Count N/A (Auditor)	0	Auditor Assessment			0.5				
				Self Assessment			50%	Red			
				Auditor Assessment			50%	Red			

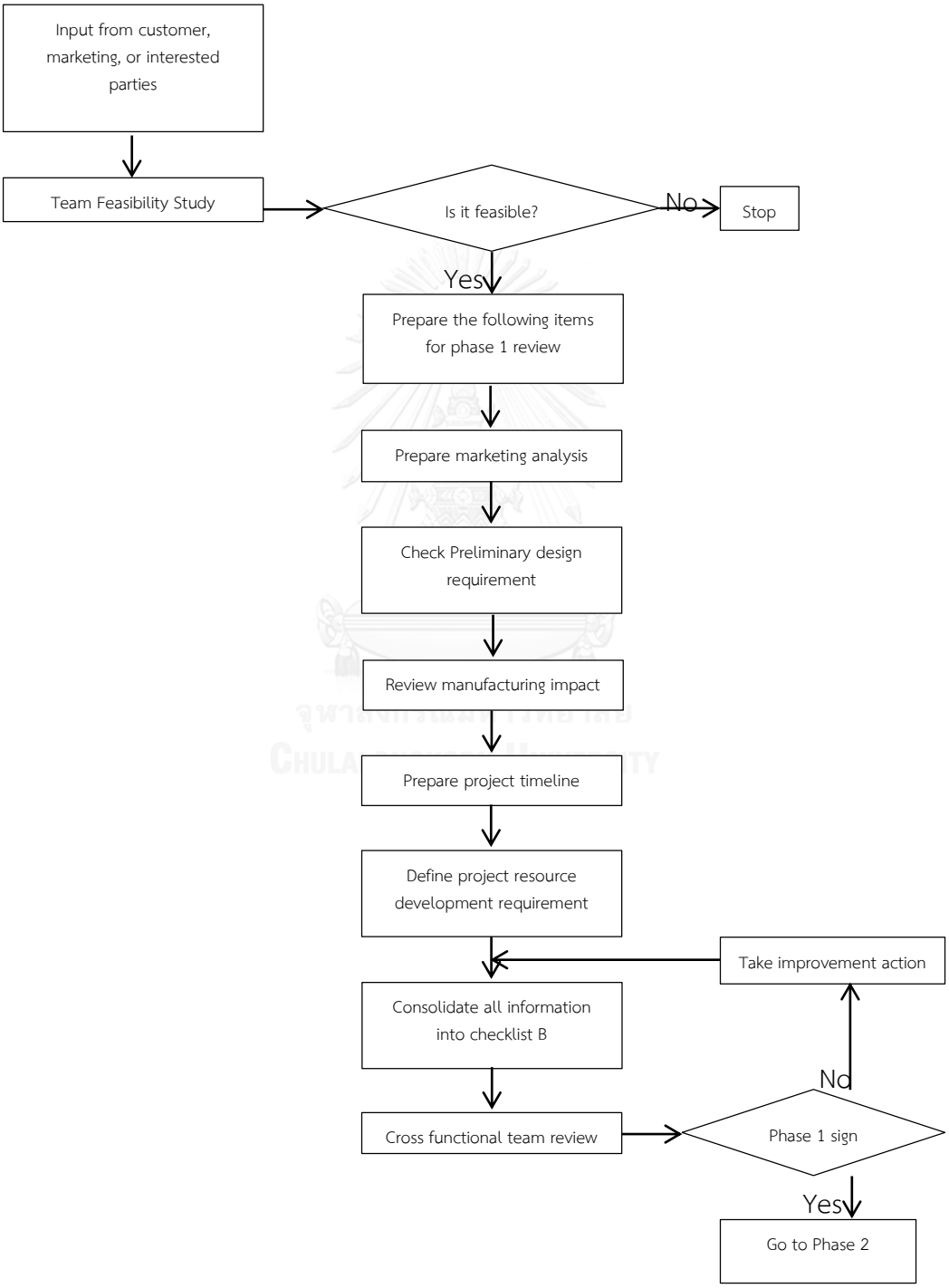
Critical to Quality Section

Critical To Quality Section										
	Critical To Quality	Not Applicable	Not-in-Place (Rating: 0)	Partially In-Place (Rating: +0.5)	Fully In-Place (Rating: +1.0)	Rating	Supplier's Response and all applicable reference documents	Auditor Comments	Core Requirements Doc. Section #	Verification Guideline
1	**Tin-Lead/Lead free** Are all line changeover setup tools clearly identified for use in Pb-free assembly, and stored separately if needed? a. Squeegee blades b. Spatulas c. Paste dispenser nozzles d. Soldering iron tips e. Stencils (if separate stencil required) Where a dedicated pb-free line is not available, is there a procedure for line changeover between pb-free and SnPb?					FALSE			3.1.7.1 Requirement for Lead-free	For mixed tin-lead/lead free supplier only 1. Verify the tool is clearly identified and stored separately? 2. Verify the changeover procedure/checklist when a dedicated pb-free line is not available
2	**Tooling/machine program Mgmt** Are all the stencil/tool/fixture/machine program revisioned controlled, and referenced to applicable product documentation? and all the stencil /tool /fixture /machine program are well maintained?					FALSE				1. Verify the product documentation and cross reference stencil/tool/fixture marking. 2. Ensure supplier has a process in place to track history of changes. 3. Inspect a few stencil for cleanliness and any evidence of defects (Damaged, clogged apreatures).
3	**Process Control Metrics** Is there a metric in place to monitor process quality? (a) Stencil Printing Process (height/volume control, etc) (b) Pick and Place Process (Pick up rate, etc) (c) Reflow Process (profile, post-reflow defect,etc) (d) Wave Solder (profile, post-wave defect,etc) (e) AXI/5DX (yield, etc) (f) ICT (yield, etc) (g) test yield single station and ETE					FALSE			3.1.4 Process Control Requirement	Verify that the process and control limits are established and reviewed periodically.
6	**Component Assembly** Evaluate the material handling, layout, critical process in assembly flow referring to the process mapping and process flow chart					FALSE				1. Information of the specific product will be provided by new product development team, DO NOT perform the assessment witout this information

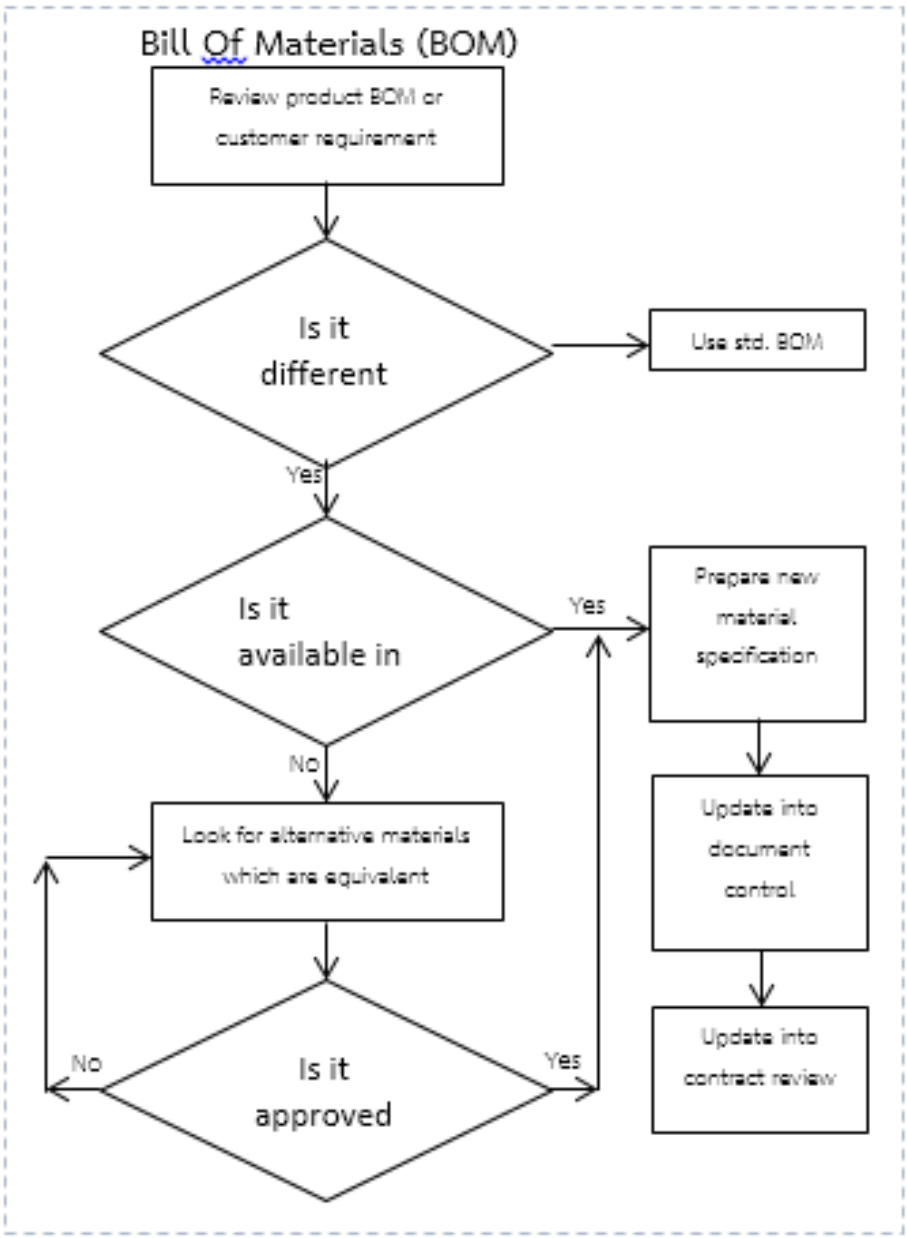
Appendix 2: Contract Manufacturing Management NPI Phase review

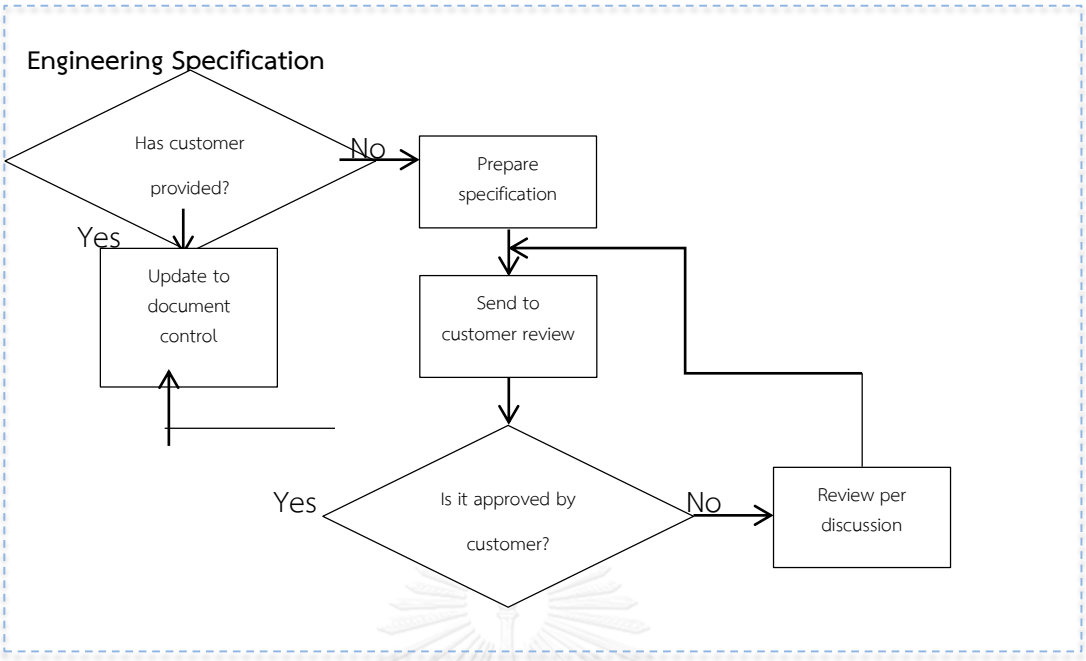
Diagram of Planning of product realization

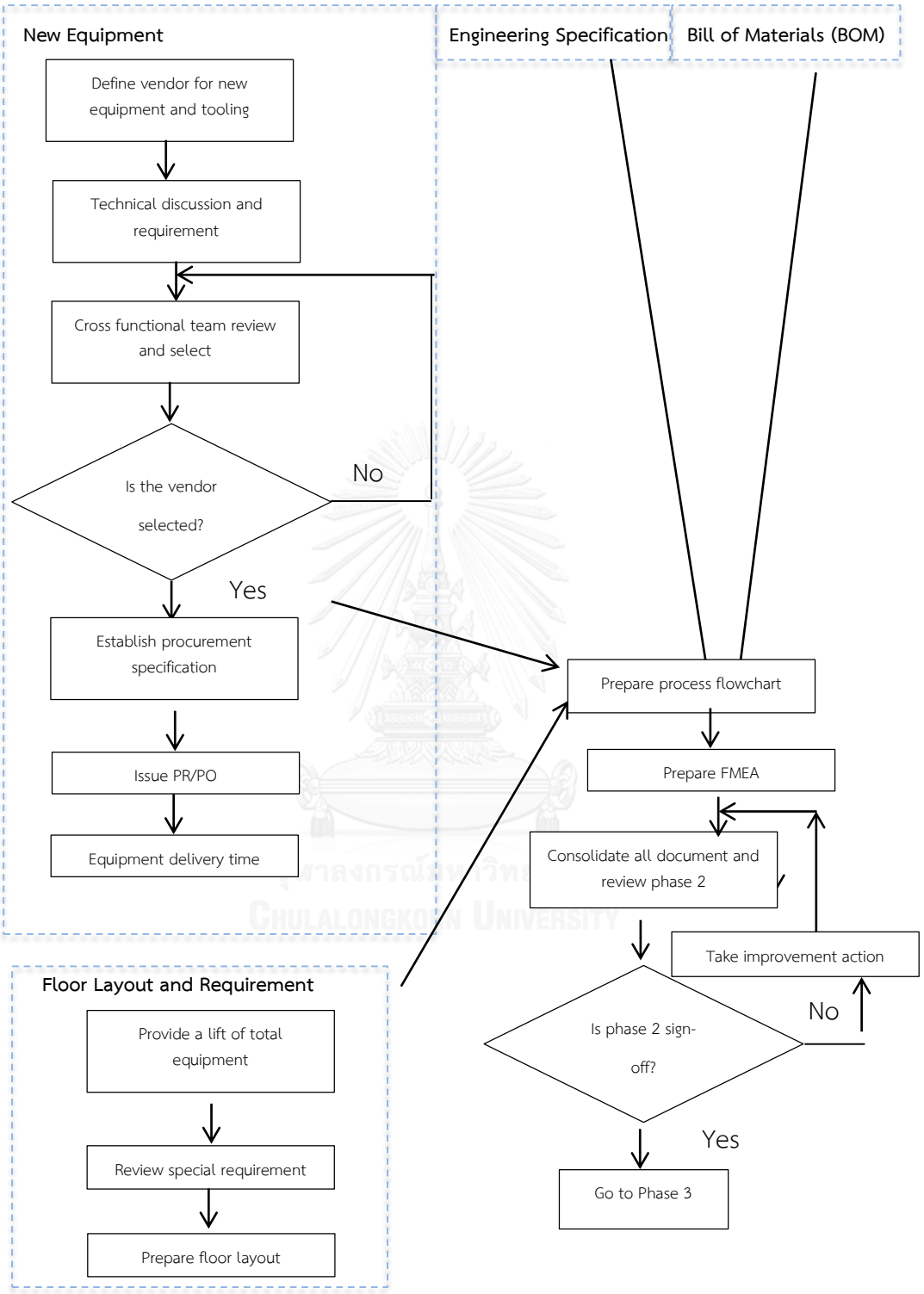
Phase 1: Design and Development Planning



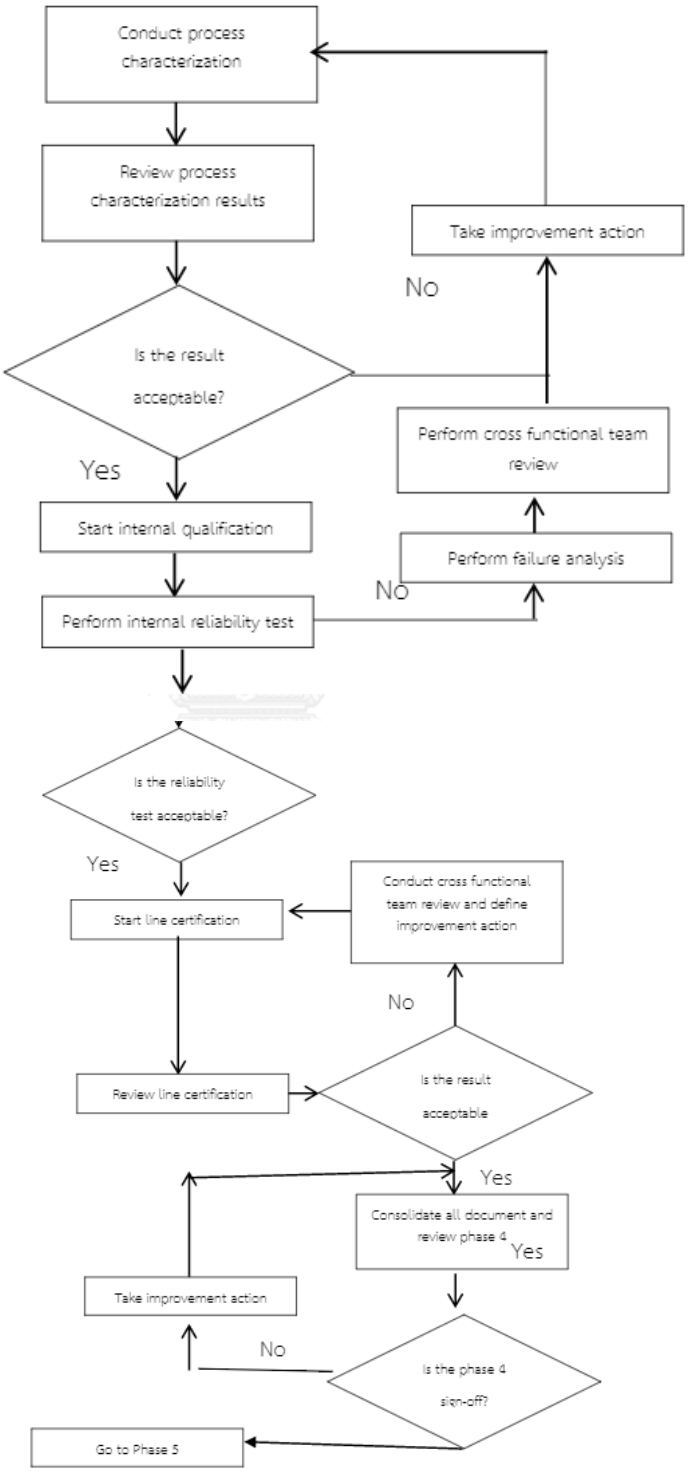
Phase 2: Product Design and Development






New Equipment
Define vendor for new equipment and tooling
Technical discussion and requirement
Cross functional team review and select
Is the vendor selected?
No
Yes
Establish procurement specification
Issue PR/PO
Equipment delivery time
Floor Layout and Requirement
Provide a lift of total equipment
Review special requirement
Prepare floor layout
Engineering Specification
Bill of Materials (BOM)
Prepare process flowchart
Prepare FMEA
Consolidate all document and review phase 2
Take improvement action
Is phase 2 sign-off?
No
Yes
Go to Phase 3

Phase 4: Product and Process (Manufacturing) validation



VITA

Ms. Boonika Na Thalang was born on January31. th, 1982 in Bangkok, Thailand. She completed his undergraduate degree in Electronics Engineering from Assumption University. In 2013, she undertook his postgraduate dual-degree programme in Engineering Management, and Engineering Business Management jointly offered by Regional Centre for Manufacturing System Engineering, Chulalongkorn University, and Warwick Manufacturing Group, University of Warwick, respectively.