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A COMPARATIVE ANALYSIS OF AN ORIGINAL AND A POST-HOC APPLICATION OF LEAN SIX SIGMA METHODOLOGY

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A COMPARATIVE ANALYSIS OF AN ORIGINAL AND A POST-HOC APPLICATION OF LEAN SIX SIGMA METHODOLOGY

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To my husband, Robert – for his steadfast love and support of all that I do.

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DEFINITIONS OF KEY TERMS

5S – seiri (sorting), seiton (streamlining), seiso (systematic cleaning), seiketsu (standardize), and shitsuke (sustain)

Cause & Effect Diagram – also known as Ishikawa Diagram or Fishbone Diagram, it is used to identify possible causes for a problem (ASQ, 2014)

Kaizen- Continuous Improvement. It comes from the Japanese words. "kai" meaning change and "zen" meaning good (Stephenson, 2014)

Kanban - (literally signboard or billboard) is a scheduling system for lean and just-in-time (JIT) production (Summers, 2010).

Lean (Basic meaning) - “Lean” has various meanings, including” to incline or bend from a vertical position”; “of persons or animals without much flesh or fat”; “lacking in richness, fullness, quantity” (Dictionary.com, 2010).

Lean (Meaning in this study) - to create more value for customers with fewer resources, so the fundamental idea of lean is to maximize customer value while reducing or removing waste (Daud, 2010).

Six Sigma – A statistical analysis used to identify process deviations.

Supply Chain - a system with resources and information which transfer raw material or components into finished products or services from a supplier to a customer.

ACRONYMS

BOM – Bill of Material

CCR - Critical Customer Requirement

CRM - Customer Relationship Management

DFSS - Design for Six Sigma

DPMO - Defects per Million Opportunities

EC – Engineering Change

EDI - Electronic Data Interchange

ERP - Enterprise Resource Planning

FMEA - Failure Mode & Effects Analysis

IP - Intellectual Property

IT - Information Technology

JIT- Just In Time

LSS - Lean Six Sigma

NPI - New Product Introduction

PLM - Product Lifecycle Management

PM - Product Manager

ROI - Return on Investment

RPN - Risk Priority Number

SaaS - Software as a Service

SMED – Single Minute Exchange of Die

SPC - Statistical Process Control

SRM - Supplier Relationship Management

TQM – Total Quality Management

WIP - Work-In-Process

ABSTRACT

Qiu, Jin. M.S., Purdue University, May 2014. A Comparative Analysis of An Original and a Post-hoc Application of Lean Six Sigma Methodology. Major Professor: Dr. Chad Laux.

Current society develops faster and faster every day with customers' demands increasing rapidly. Decreasing time for product development and enhancing customer satisfaction are becoming more significant. In the business world, there is no industry that could exist without an efficient supply chain. In the fierce competitive environment of today, the supply chain must address potential problems and risks that may exist and assure continuous improvement.

One common supply chain management practice in many industries is to apply lean methodology to the supply chain model in order to maximize the customers' value and eliminate waste. By eliminating waste, the process can be expedited, a company's costs reduced and profitability improved.

Today, in many industries, applying other principles to the supply chain is very popular. Information Technology software flow synchronizes the physical flow with the data flow and in order to expedite the supply chain process. Application of information technology and Six Sigma philosophy has also become a part of supply chain management.

Lean Six Sigma principles utilize analytical methods to optimize each link of the supply chain to promote a winning customer/supplier model.

Poor supply chain management will harm the health of any business process and could lead to high losses while a well managed and structured supply chain will support a positive direction furthering a company's success. This study analyzes Lean and Six Sigma support of the Supply Chain from multiple angles and addresses certain issues that potentially exist. It is based on an original case study to reduce package Engineering Change lead time and details the revisions the author has taken to improve on that work. The corresponding data analysis from the refined project results show how the package EC process could be improved, the value add based upon the post hoc analysis and the methodology used to benefit the high technology supply chain and overall business performance.

CHAPTER 1. INTRODUCTION

This chapter provides an overview of the supply chain model and Lean Six Sigma principles including the research done as part of the refinements and the associated results. The project develops a statement of the problem, the significance of the problem, the scope and purpose of the study, assumptions, limitations and delimitations. Finally, a summary concludes the information addressed in chapter 1.

1.1 Supply Chain

Supply chain is a system of resources and information that transfers raw material or components into a finished product and/or service from a supplier to a customer. The general structure of a supply chain consists of supplier, procurement, inventory management, manufacturing, logistics, marketing, distribution and retailers and the customer. Three key focus areas of supply chain are how, when and where to get the resources, the costs of materials, and the suppliers themselves.

Manufacturing focuses on transforming raw materials or components into finished products. Distribution focuses on moving the finished goods to different sales regions or delivery to customers directly (Kietzman, 2009).

To ensure a healthy supply chain, a constant flow of material is necessary. Each link should be completed at a certain pace in a seamless and consistent connection. Otherwise, any problem at a single step in the process could impact the entire supply chain.

1.2 Lean Basics

"Lean" has many meanings in the literature. In this study the meaning is to create more value for customers with fewer resources to maximize customer value while reducing or removing waste (Daud, 2010). Lean has diversified characteristics. Just-In-Time (JIT) Principle, Kanban System, 5S Standard, Kaizen Program & Error Proofing Applications, Value-Creation Actions, etc. (Summers, 2010). These lean techniques are adopted extensively today by many industries, which help them by enhancing the profitability, improving product quality and increasing customer satisfaction.

1.3 Six Sigma Basics

Six Sigma, 6σ (can not use upper case sigma, Σ), or 6 Sigma. The Greek letter sigma (Σ, σ) is a statistical term as follows:

Six Sigma measures how far a given process deviates from perfection. The central idea behind Six Sigma is that if you can measure how many 'defects' you have in a process, you can systematically determine how to eliminate each of them and get as close to six sigma quality as possible. To achieve Six Sigma Quality, a process must produce no more than 3.4 defects per million opportunities (General Electric Company, 2013, p4).

Generally, the definition of Six Sigma includes three meanings: a) a pursuit and a goal of quality measurement, b) a scientific tool and management method using the

procedures of Define, Measure, Analyze, Improve and Control (DMAIC) or Design for Six Sigma (DFSS) to design and improve a process, and c) a strategy of operating management. Six Sigma is an innovative management technique for increasing customer satisfaction, reducing business costs and cycle times. It improves the organization's product and process quality, thus improving the organization's profitability. It is a business strategy that with core competencies defined for continuous improvement significantly improves the competitiveness of any company.

1.4 Lean and Six Sigma (LSS)

Lean and Six Sigma both pursue perfection in the management process. One of the core lean principles is value determination, which is an aspect of quality management, whereas Six Sigma seeks approximate perfection in product/process quality. As addressed above, lean carries out JIT principles, kaizen events, etc. By utilizing these lean principles, lean tools and the Six Sigma processes are utilized throughout a company; waste can be eliminated, continuous improvement can be achieved, financial performance can be improved for ultimate, customer satisfaction. In summary, the implementation of the Lean Six Sigma strategy will achieve quality assurance while reducing cost and improving customer satisfaction.

1.5 Information Technology

"Information technology (IT) is the application of computers and telecommunications equipment to store, retrieve, transmit and manipulate data, often in the context of a business or other enterprise" (Unified Systems Management, 2013, p10).

In most business organizations, the type of information technology adopted effects the entire supply chain including internal and external customers. The information generated by the software system links the physical product, process flow and manufacturing status and can be monitored by all internal customers in real time. The external customers, who are the consumers, are highly demanding in today's business world due to fierce global competition. Hence, applying information technology to provide fast and better service to the customer is critical. In addition, to ensure better quality and faster production, a close collaborative relationship must exist between internal organizations and suppliers. This is necessary to assure quick response and information feedback enabling the supply chain to function with higher performance.

1.6 Problem Statement

The package EC process was designed to fulfill an internal customer requirement. In the original package EC case, the team did not clarify how they obtained the project goal, and therefore neglected consideration of the customer needs. Timely generation of deliverables to increase customer satisfaction and to improve the process is key to any organization. In the refined package EC case, the VOC exercise showed that the internal customers were not satisfied with the process at that time and the incoherent process resulted in a large amount of waste.

In addition, some process steps are subjective operations that vary depending on the person performing the operation. The original EC review was such a process whereby an individual reviewed the information contained in the EC for completeness and accuracy with no objective oversight. To ensure subjective steps are controlled, we should have

used an objective method to effectively evaluate the results. Lean Six Sigma is a systematic methodology that can be readily utilized to manage this type of issue tactically. It remains a key element in the management of many of today's top companies in reducing waste and is dependent on accurate data and timely analysis to allow problem identification and resolution. In summary, Lean Six Sigma is necessary to solve the tough problems in the supply chain system to assure success in today's globalized market place.

1.7 Significance of the Problem

In contemporary society, global economic conditions have switched from product competition to global supply chain competition. Lean, Information Technology and Six Sigma applications to supply chain initiatives are an inevitable trend. Historically, a company only focuses on physical products, the supply chain at that time was the physical chain. Now, however, information technology has become more advanced and the information flow drives the flow of the physical chain and expedites the elements in the physical chain. The business model has changed to a project management model, using project management processes to meet budget, schedule and to generate deliveries to meet customer requirements. Today, Lean technique is applied extensively and Six Sigma theory has extended gradually through more industries as we have seen the increased reliance of the modern supply chain on information/data support. From the supplier, company or customer perspective, the needs and benefits of Lean Six Sigma and IT should be taken into account and should present a win-win situation.

1.8 Scope of the Study

By applying lean techniques and information technology, problems in the supply chain can be identified and eliminated in order to expedite the process flow. This project resolves the lack of objectivity and the oversimplification of LSS in the original work. Lean Six Sigma, an advanced data- driven methodology, is used in this refined analysis to interpret and analyze data to resolve remaining supply chain problems.

1.9 Research Questions

The questions driving this research are:

- What research and business values can be additionally identified by a refined Lean Six Sigma package EC project beyond those originally created?
- How can the Lean Six Sigma approach benefit a high technology Supply Chain?

1.10 Assumptions

The assumptions for this project are:

- Manufacturing and supply chain will continue successful operations. The application of the principles outlined in this study can be adapted to any process by consistently adjusting the strategy and tactics.
- After implementing the system improvement, the organizations must monitor the system consistently to maintain a stable process control level.
- Lean Six Sigma implementation will not yield perfect and quick results but instead will show a gradual and continuous improvement.

1.11 Limitations

The following limitations were inherent to the pursuit of this study:

- This study is limited to a single manufacturing location.
- There is no means to access personnel or obtain additional data from the original project.
- Information Technology has extensive meaning, this study only focuses on Product Lifecycle Management (PLM) systems in the supply chain.
- This study is limited to a specific scenario reflecting the analytical results of the supply chain in terms of the methodology application.
- Many methodologies may improve the supply chain system but this study is limited to Lean Six Sigma methodology.

1.12 Delimitations

The following delimitations were inherent to the pursuit of this study:

- This case is representative of a typical high technology operation applying the Lean Six Sigma principles.
- Other methodologies are not considered in this study to improve the supply chain system.

1.13 Summary

This chapter has provided an overview to the research study, including basic introduction, a statement of the problem, the significance of the problem, the research questions and the scope definitions. The next chapter discusses the background and

history of supply chain and Lean Six Sigma with supply chain addressed in segments according to departmental functions. Chapter 2 also describes the functionality of the Lean Six Sigma toolkits.

CHAPTER 2. REVIEW OF LITERATURE

This chapter addresses several aspects including the evolution of supply chain, IT (ERP) systems, and the application of Lean Six Sigma tools.

2.1 Evolution of the Supply Chain

In Supply Chain's long history, the evolution can be traced through many iterations. Below is a description of the supply chain evolution in terms of enterprise relationships and the developing business trends.

2.1.1 Relationship Focus

From the initiation of manufacturing and logistics to the formation of systematical operations, supply chain has developed step by step. In terms of supply chain relationship focus, Folinas, Manthou, Sigala, and Vlachopoulou (2004) classify supply chain development in four stages. Figure 2.1 shows the detail of the four stages.

Figure 2.1 Evolution of Supply Chain (Folinas *et al*., 2004)

At stage 1, the efficiency of the core logistic activities, a company begins to apply supply chain techniques to improve logistics. Business connections are with small size suppliers, and the company and suppliers are isolated. The lack of collaboration limits the strategic development of opportunities.

At stage 2, the coordination of internal organizational processes, cross business processes and cooperation arise to achieve internal excellence. E-commerce is adopted to support internal information systems. The approach of the E-era strengthens partner relationships and enables an organization to focus on services in addition to performance and cost.

At stage 3, inter-enterprise business exchanges, companies break internal borders, extend the business to external partners, and form a dynamic supply chain model. These actions balance the internal improvement and external need through the entire supply chain network.

Finally, at stage 4, dynamic networks are established between virtual organizations; e-business cooperation across many companies is initiated allowing large enterprises and their partners to meet the same objectives. Trusting-collaborative partner relationships are enhanced and information sharing flows freely throughout the partnered systems. As the competition increases global enterprises, the trend in supply chain development is toward even more extensive and intensive e-business (Folinas, Manthou, Sigala and Vlachopoulou, 2004).

2.1.2 Business Trend Focus

The figure below shows six major movements in the evolution of supply chain management based on the model of business trend. Figure 2.2 shows the movements and the developing trend.

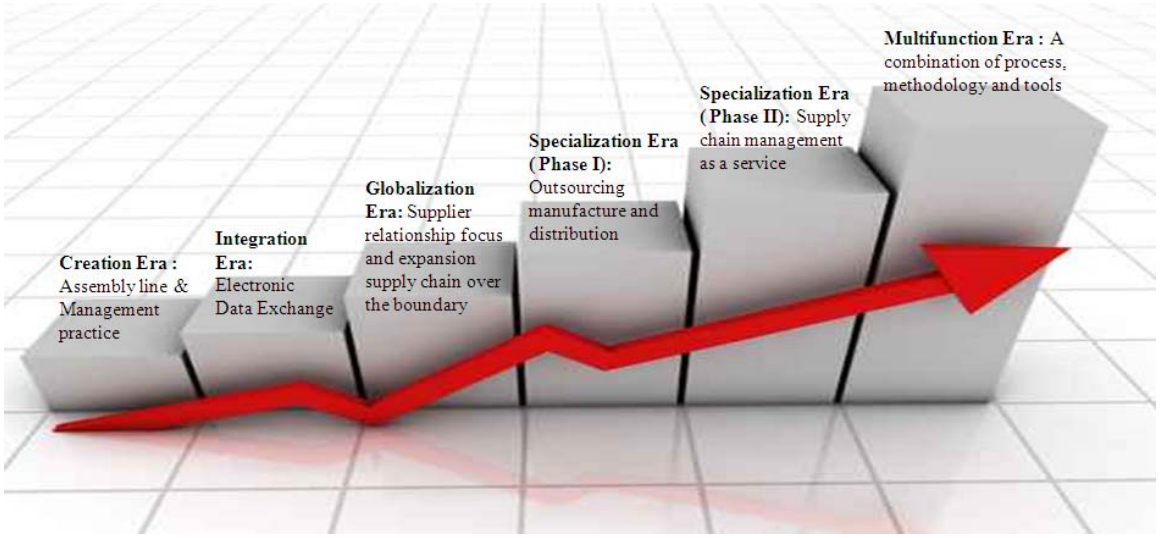


Figure 2.2 Evolution of Supply Chain Management (Daud, 2010)

In the creation era, assembly lines were created in the early 20th century. The characteristics of supply chain management included large-scale changes, downsizing designs and attention to management practices.

In the integration era, development of Electronic Data Interchange (EDI) began in the 1960's. In the 1990's, the Enterprise Resources Planning (ERP) system was first introduced, and continuous development and expansion of the internet and electronic based systems has led to today's ERP systems, which have been extensively adopted and have revolutionized many characteristics of supply chain management. This process evolution has increased value added and cost reduction significantly.

In the globalization era, the attention switched to building supplier relationships and the supply chain model across national boundaries into other continents. The globalization strategy consideration began in 1980s and the characteristics at that time included the strong strategic element of competitive advantage in addition to the obvious besides cost reduction and value added.

In the 1990's, supply chain management entered into the era of outsourcing manufacturing and distribution. Companies started to focus on core competencies and sold off non-core operations or outsourced them to other companies. Under this model, manufacturing and distribution came from several different and individual supply chains. The main supply chain networks were formed into a model that needed to align suppliers, manufacturing, logistics, marketing and customers with the main chain. Success depended on the trust of the many partners in the supply chain.

The outsourcing model depends heavily on the new supply chain model running well and insuring that the data is available to support the physical processes. This era is

named “supply chain management as a service” because many software companies started developing systems and software applications as a service (SaaS). This model is still very popular today.

In the multifunction era, the growing collaboration between business partners is notable and enables multiple partners to conduct multiple-function automated transactions across the end-to-end supply chain. SCM combines the process, service, methodology, tools and options to guide companies to their desired result conveniently, quickly and accurately (Daud, 2010).

2.2 ERP System

Physical product is the key result of a supply chain and data is essential to a successful supply chain. As information technology grows, the information flow supporting the production of the physical product is ever more crucial. An Enterprise Resource Planning (ERP) system is a critical link in the flow of information. It integrates all functions of all departments across a company on a single computer system, providing all department requirements for purchasing, manufacturing, logistics, marketing, finance and even HR. Figure 2.3 shows SAP ERP Graphical User Interface.

Figure 2.3 SAP ERP System (Global Bike Corporation, 2013)

Because ERP owns integration of the information for all these functions, it is used by many employees and is familiar to many organizations. Yet, an ERP vendor, such as SAP, as a representative does not satisfy the current requirements. To keep pace with business development and to continue perfecting its function, extending an ERP system to link a back office system to front office system, such as customer relationship management (CRM), supplier relationship management (SRM) is required. Consequently, the information flow can cover the entire end to end supply chain. Since an ERP system is designed in modules, the flexibility of the system allows different size companies to choose different modules based on their business model. For example, a company with a

service business does not need to purchase the manufacturing module, which represents a huge financial savings for the company (Wailgum, 2008).

Even though ERP seems a perfect system, it has drawbacks such as:

- High cost: most middle or small size companies walk away due to its million dollar cost, depending on the required function, even up to multimillion dollars. The ERP vendors are trying to solve this problem by researching lower-cost ERP systems targeting medium and small size companies.
- Customization: A customized system definitely triggers a user's excitement and captures the user's acceptance; it also provides the user with competitive advantages. Yet, customized service is unique, a lack of experience on the new system construction could increase time and consume valuable resources as well as increase the price dramatically. It could also inhibit formation of a seamless connection between suppliers and customers who use the same ERP system but without customization.
- Data migration: Switching from an old system to the ERP system involves a large data migration with many potential issues including missing data, erroneous data, redundant data, and data that are not compatible with other systems such as Product Lifecycle Management (PLM).

The ERP system improves the quality and efficiency of the business, provides overall decision-making capabilities for the management team, and brings much needed flexibility in adapting to the ever changing business challenges.

2.3 Components of Lean Supply Chain

A Supply Chain is comprised of links, each link being a critical component. In this section, the components of a lean supply chain are discussed.

2.3.1 Lean Supplier

The supplier plays an important role in the entire supply chain by providing the raw materials and components to make the final products to be provided to the customer. The speed with which the supplier is able to deliver raw materials as well as the quality of the materials determines the speed of the end product delivery and the satisfaction of the end consumers. From an organizational perspective, the lower the cost of raw material the more profit for the company and the long-term relationship built between the company's and supplier's mutual trust will expedite the flow of the process. At the beginning of the supplier relationship, the supplier's organization needs to be audited to assure sound business practices and that formal quality processes are in place. This will eliminate many issues at the start by reducing delays in deliveries, eliminating cost surprises, minimizing adverse effects of defective products and providing better customer satisfaction. If lean principles are not well applied in this scenario, a company could find that garbage in results in garbage out, and the company reputation could be ruined.

2.3.2 Lean Procurement

The procurement team is responsible for the direct business relationship with the suppliers including contract negotiations, which must yield an agreement on delivery dates, locations quantities, and costs. Lean procurement ensures just-in-time order-

placement from the procurement team followed by the on-time delivery from the suppliers. This means placing orders and delivering according to the amount of inventory and the needs of the customer to minimize the possibility of inventory and to assure best use of available labor and minimizing warehousing costs.

2.3.3 Lean Manufacturing

In the process of converting raw material into a product, production speed and product quality must be managed at each manufacturing step. The connection between lean and manufacturing is not a new topic. Most companies work diligently in applying principles such as optimizing assembly lines, single minute exchange of die (SMED), setup reduction, kanban system, 5S, etc. to bring dramatic improvements to the manufacturing environment. "Many organizations have made huge progress by applying lean concepts in other functions through the entire supply chain" (Tompkins, 2013, p16).

2.3.4 Lean Logistics

Logistics is a typical area of focus to reduce waste. The benefit of applying lean principles in the article Learn Lean Logistics is a reduction in ready-to-ship and work-in-process (WIP) inventories as well as in warehousing and distribution cost (Lean Logistics, 2013). As long as the ready-to-go goods have not been delivered to the destination, waste needs to be identified and the logistics process needs to be improved.

According to Martichenko, (2013).

By cutting off non-value added processes, the efficiency of the whole can be monitored and the total logistics cost can be reduced. 3PL is a way of outsourcing

the logistics portion to other partners. 3PL serves as a trusted partner in the lean journey by identifying problems, implementing solutions and adding value in global and complex supply chain (p12).

2.3.5 Lean Customer

In today's environment of fast development, customers are more demanding. They need fast response, quick delivery, lower cost, better quality and reliability and first-class service. Customers are not only the end users but are also the last to check the product. A satisfied customer seeks methods to build long term relationships in the total supply chain to reduce costs. Customers exchange expectations and results with business partners that can provide "free" advertising or can undermine product sales if expectations are not met. Customer feedback is the best way to let the company know how their product and services are performing. Constructive suggestions can lead to problem resolution and eliminate potential problems and cross a new threshold of company philosophy for innovation and unprecedented service. Constant vigilance in maintaining the feedback loop with customers, collecting their thoughts is a key to continuous improvement (Tompkins, 2013).

2.4 History of Six Sigma

The beginning of Six Sigma can be traced back to the 18th century but Six Sigma was formally initiated in the 1980s by Motorola. The company "developed a new standard and created the methodology and cultural change associated with it. Six Sigma helped Motorola realize powerful bottom-line results in their organization – in fact, they

documented more than $16 Billion in savings as a result of our Six Sigma efforts" (iSixSigma, 2000, p2).

Since then, Six Sigma has spread extensively to all kinds of industry sectors. In 1995, Jack Welch, the chairman and CEO of General Electric, implemented the Six Sigma philosophy on cost benefit analysis; "the result showed savings ranging between $7- $10 billion. By the late 1990s, two thirds of Fortune 500 enterprises had adopted Six Sigma with the aim of cost reduction and quality improvement"(Gosset, 1999, p7).

2.5 Function and Significance of Lean Six Sigma

Today Six Sigma is not restricted to the quality improvement area. Professionals have linked the concept of lean manufacturing with Six Sigma expanding the concept and touching all links of the supply chain. Lean Six Sigma can be applied in any area in any industry; financial performance, lead time reduction, waste removal, quality improvement, customer satisfaction enhancement, supplier auditing, logistics and transportation. The application of statistical analysis becomes important in identifying problems and addressing problems effectively along the chain. The combination of supply chain, information technology and the application of Lean Six Sigma principles is a comprehensive and advanced approach in organizations.

2.6 Symptoms in the Supply Chain System

Since the inception of the total supply chain model, supply chain has undergone continuous improvement. There are, however, still issues that can plague the process. Several symptoms show up with each iteration of the supply chain strategy. More

organizations are focusing on supply chain design to keep up with today's high-speed technological society. With lower profit margins, higher customer demands in product quality and service and globalization of the supply chain, management strategies require a new model. Lean Supply Chain is one of the prevalent approaches to these challenges and is thought to have significant promise (but not a panacea) to all supply chain issues in the modern global economy.

An excess of disjointed information on lean principles has resulted in some businesses limiting the scope of lean principles. It is more than an approach to manufacturing but should also be considered when facing other globalization issues such as an outdated information system, balancing strategy and culture and the ongoing issues of the disconnected physical product. The corresponding information flow is a major obstacle in the Lean Six Sigma approach. Some of the problems are due to misunderstanding by managers while other problems emerge at the working levels in the contemporary industrial environment. Only if the management team recognizes the importance of every aspect of the supply chain can an optimized supply chain management system be realized.

2.6.1 Symptom 1: Lean Only Applies to Manufacturing

When addressing "waste reduction," "quality improvement," even "service capability," the first step in the supply chain is manufacturing. Even though many industries have tasted the success afforded by focusing on the whole chain instead of part of it, there still exists an indifference to the connection of total lean supply chain, especially among small-size firms.

Manufacturing systems can be improved until they realize their optimum performance, while the supplier, procurement, warehouse, distribution system and marketing could still limit the company's ability to excel. For example, negotiating with suppliers on raw material costs, building long-term relationships with approved suppliers and simplifying the purchasing process all lead to better products delivered more quickly.

2.6.2 Symptom 2: Disjointed Supply Chain

The supply chain is often represented as an end-to-end layout but actually, it is a circular flow. Each step links tightly with the last step or even last several steps to assure preparation ahead of time. A phenomenon found in some organizations is that employees only deal with their own tasks, managers only focus on their team problems, and directors only emphasize their department progress. This separated work deployment results in endless internal and external meetings and negotiations. They find that the best accomplishment in their department does not support the needs of other departments. In this situation, to finish a task, each side needs to negotiate with many upstream and downstream departments to find the individual or team that can settle the matter. It ends up with all sides compromising and thus sacrificing the benefit of its department while the system becomes disorganized. Trade-offs must be made to keep consistency with the top objective of the company. Had each sub-group considered all portions of the supply chain and met the company goals at all work stations, with a smooth flow of work and information, there would have been a major reduction in communication, rework, remodeling, tangible and intangible waste. A disjointed supply chain can harm the lean

supply chain environment, and if the problem remains unsolved or increases in severity, the company could be damaged by better managed competition.

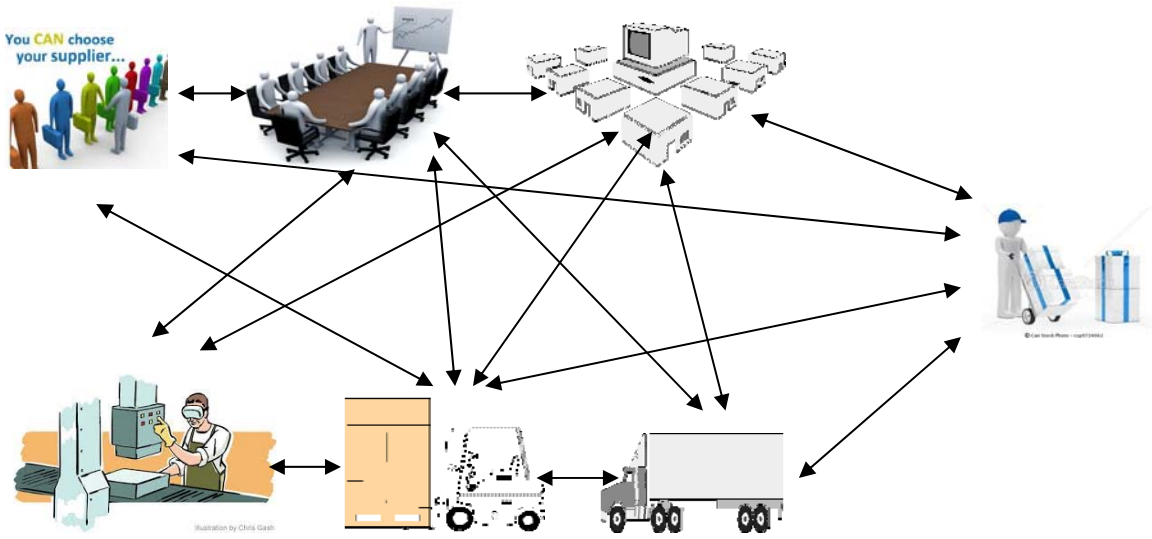


Figure 2.4 Disjointed Supply Chain (Value Innovation Partner Group, 2002-2006)

The disjointed Supply Chain leads to complex layouts, conflicting objectives, ‘protectionist’ attitudes and barriers to teamwork and problem solving (Value Innovation Partner Group, 2002-2006).

2.6.3 Symptom 3: Out of Date Information System when Encountering Globalization

Cooperation is not new among organizations and business to business relationships are closer than ever. For better performance, increased market share, reducing an immature firm’s risk or a company’s strategy adjustment; an organization or departmental unit acquisition by another organization becomes a strategy trend under current business circumstances. Acquisitions and reorganizations often compel companies to maintain multiple information systems. No one is willing to change due to

uncertainty until higher management realizes the severity of the problem. An information integration project could and usually does last several years when companies integrate different system applications. Yet, until the day the seamless information system integration is officially in place; data errors, lost data, system chaos and system collapse are common occurrences. Reorganization is supposed to be a win-win strategy but neglecting information system considerations before incorporation can be a disastrous move for all parties.

2.6.4 Symptom 4: Strategy and Culture Balance when Encountering Globalization

Organization acquisition has become popular among many companies with an alignment of strategy objectives and remodeled processes joining employees from all over the world to work toward common objectives. However, the importance of different education backgrounds, religions, languages and cultures are often overlooked. It is impossible to standardize employees and these differences can easily result in misunderstanding and ultimately to unresolved conflict. When reorganizing, companies should not neglect this hidden problem as it can be a time bomb buried inside the company.

Cultural acceptance and integration are very important in assuring the fluid exchange of ideas and information and in fostering the teamwork needed to make the new organization successful.

2.6.5 Symptom 5: Lack of Lean Six Sigma Approach

If the lean principle applied to the supply chain improves performance, then successful application of the Lean Six Sigma methodology to the supply chain will allow the system to achieve its peak efficiency. Six Sigma is about enhancing profitability, reducing cost, improving quality, productivity and meeting customers' requirements (Summers, 2010). This approach is based on a Return on Investment (ROI), hence it focuses on the entire supply chain. More and more organizations are aware of the significance of Lean Six Sigma methodology, and it is gradually spreading out to businesses' many diverse fields. Yet, some small–size firms refuse to apply Lean Six Sigma theory mistakenly regarding it as only a quality control tool. To them, changing the strategy is a huge challenge involving upfront investment, consuming everyone's time, and impacting work balance on routine tasks. They are not willing to gamble the fate of the enterprise on a strategy with which they are not familiar.

2.7 Functionality and Application of the Lean Six Sigma Tools

From lean components to the symptoms described above, it may be concluded that there are many opportunities to improve any module in the entire supply chain. In this situation, appropriate application to the complex environment is important. Based on the characteristic of Lean Six Sigma, a series of Lean Six Sigma tools and techniques as well as functionality will be introduced in the next section.

2.7.1 SIPOC Diagram

A SIPOC diagram is a high level map providing an overview of the supply chain at the project Define stage. It stands for supplier, input, process, output and customer and it builds a connection between a company's product and the service required by the customer. This drives an organization strategy that aligns the customer needs to the fulfillment process and improves customer satisfaction. For example, a company leases equipment. The supplier in this case is the company and the credit agency; input is the credit report; the process begins with the customer credit review, then the equipment validation, document preparation and ends with funding approval. The output is the lease agreement and the customer is the equipment lessee. This simple example provides an overall picture about the company's leasing business, the flow of the service and the customer fulfillment on the equipment and the service (Basu, 2011). In the package EC case, SIPOC identifies the components for each step, and it is regarded as a miniature of the EC operating model that allows us to acquire typical information in the EC supply chain.

2.7.2 Process Map

"Process mapping is a technique that converts a business process to a visual, step by step illustration. It is used to better understand the existing process and helps to develop a more effective one (Reynolds, 2014)". An oval shape shows the start point and the end point of a process; a rectangle is used to show an activity; a diamond shape is used to show the decision making step, an arrow shows the direction of the process flow. It clearly depicts the general process but especially for a complex process it can reduce the

process to several simple ones, and its flexible structure can add rich resources that cross functions (Basu, 2011). Process mapping provides each detailed EC step in the process, which allows further research on process refinement or the lean process focus. The package EC process mapping will be introduced in chapter 4 and will show the detailed process steps and the process flow from the start point to the end point. The refined process mapping will then show the added swim lane to clarify the responsibility of each process step.

2.7.3 Project Charter

A project charter is a working document that defines a project structure, it is a beginning of the project (Basu, 2011). A successful lean six sigma project using a project charter clarifies the project resources, project breadth, project boundary, project team and the sponsor. The attribute of a regular project is to meet the schedule, meet the budget and meet the customer requirement. Lean Six Sigma principles allow the alignment of the business strategy and the business value in the project charter where the necessity of the project creation is explained.

2.7.4 Cause and Effect Diagram

A Cause and Effect Diagram is also known as an Ishikawa Diagram or a fishbone diagram, due to the resemblance to a fish skeleton. It is used in a team environment during the brainstorming session where all the potential root causes are to be identified. It uses five aspects of problem impacts which are Manpower, Machine, Material, Method and Environment (Basu, 2011). It is a vehicle for team brainstorming root causes and the

potential root causes. Due to lack of a standards required in the map, it triggers the team to consider more comprehensive causes and sub root causes, therefore making it more likely that all important opportunities will be identified.

2.7.5 Statistical Process Control

Statistical Process Control is a method to monitor the stabilization of a process and it clearly shows the process trend and the variation. SPC can also be constructed with upper control limits and the lower control limits giving a visual indication if the process approaches or exceeds the limits. An SPC chart may be utilized in analyzing both historical data and current data (Basu, 2011). The author used SPC in the original package EC case to observe the historical process presentation back in 2007 and it also captures a visual representation of the outliers, which allows focus on a typical problematic step.

2.7.6 Value Stream Mapping

Value Stream Mapping (VSM) describes the flow from the raw material to the end customer and differs from other mapping techniques in that it identifies value added and non-value added activities. A VSM includes a large amount of detailed information, such as inventory, delay, travel time etc. To present the relevant information having a strong connection with the package EC case, the author filtered the mapping information, only keeping the function of identifying the value added and non-value added steps. This simplified the entire value stream mapping with lean systematic thinking. Therefore, it is renamed as Simplified Value Stream Mapping (SVSM) by the author.

2.7.7 Kano Analysis

Kano Analysis is structured with a downward curve, an upward curve and a 45 degree line with an arrow. The downward curve shows the customer required services or the products to prevent customer dissatisfaction. The 45 degree line shows the normal ratio between the product fulfillment and customer satisfaction, the more expectations the product fulfills the more satisfied the customer. The upward curve represents the product or service that exceeds customer expectations. Customers are satisfied with the special product or service but on the other side the customers will not be satisfied with a standard product nor with common service. The author pays close attention to the significance of the product development and marketing strategy, so the analysis on the relationship between product fulfillment and customer satisfaction is particularly important. This study is in addition to the Kano model, which is to analyze the relationship between the package EC fulfillment and the internal customer satisfaction.

2.7.8 FMEA

"Failure Modes and Effects Analysis (FMEA) is a systematic method for evaluating where and how a process might fail and to assess the relative impact of different failures" (Institute for Healthcare Improvement, 2014). "FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures" (Crow, 2002). In the Package EC case, one of the current failure effects is a long EC lead time. A potential failure mode is invalid EC information and further analysis reveals the root cause of the failure mode is that the person initiating the EC did not follow the EC guideline. FMEA then provides the consistent flow from the

effect to the root cause. Based on this root cause identification, taking appropriate actions will prevent it from recurring.

2.8 Summary

Through proper application of Lean manufacturing and Six Sigma theory, the successful revised case shows us the advantage of reducing waste and continuous improvement allowing a more efficient supply chain process.

CHAPTER 3. FRAMEWORK AND METHODOLOGY

This chapter discusses a case used to illustrate the application of Lean Six Sigma principles to an actual business environment. It begins with the basic information of the case and then discusses the analytical tools and their application.

3.1 Software Approach Limitation

As discussed in the previous chapter, supply chain plays a very important role in business. A strong information system as an integral part of the supply chain improves the organizational core competency. Many corporate research and development (R&D) teams are responsible for the support software and systems while other companies contract this work out to specialists. Many of the 'in-house' developed systems fail because the scope of the effort and the resource requirements are underestimated. System service companies, however, see this as a good business opportunity, since enterprise software application is their specialty and they can focus on the needs of the customer creating a high success rate in developing an efficient system. Developing only the new technology to strengthen the competitive ability of the supply chain is not enough. Many systems are involved including Enterprise Resource Planning (ERP), Product Lifecycle Management (PLM) and many are already in place in large organizations. These software systems have been developed by more than 70 software companies, especially the

Software as a Service (SaaS) Society. Outsourcing software to manage the enterprise is a growing trend that will continue to gain popularity. When the majority of organizations use the same approach to run their business, these systems will no longer provide the competitive advantage that they do today.

Following the trend to predict the enterprises business strategy, specialized methodology applications will become the preferred approach to strengthen the supply chain system. For instance, a Lean Six Sigma methodology applied to every link of an organization's supply chain supports improvement to the existing operating efficiencies and also addresses problem-solving and continuous improvement.

3.2 Case Introduction

As quantitative research to reflect the Lean Six Sigma approach, a retrospective case study was conducted as part of this project. The original project was centered on reducing Package Engineering Change (EC) lead time in 2007-2008 fiscal year at Lenovo Inc.

3.3 Case Background

In 2005, Lenovo Group (SEHK: 0992) acquired the Personal Computer (PC) Division of International Business Machines (IBM) Corporation (NYSE: IBM). "Under the terms of the transaction, Lenovo paid IBM US$1.25 billion, comprised of approximately US$650 million in cash and US$600 million in Lenovo Group shares. Lenovo also assumed an additional US$500 million of IBM's debt in this acquisition". (lenovo.com, 2011, p5).

The acquisition included all "Think" products, and all IBM PC Division employees. After the acquisition, Lenovo retained the same engineers, working processes and organizational structure as the IBM PC division had in place prior to the acquisition. IBM, however, maintained the Intellectual Property (IP) rights of some of the key system software, such as Product Life Cycle Management (PLM) software – Product Manager (PM). Lenovo had to pay a large fee to use this software but needed it to maintain business operations and key supplier links. The acquisition was regarded as "snake swallows an elephant" phenomenon. Many industrial professionals were not optimistic about this acquisition even before knowing about the software charges. A mere two years after the acquisition, in order to avoid these charges, Lenovo switched from IBM's PM system to the Windchill system, which is owned by Parametric Technology Corporation (PTC) resulting in a great cost savings to Lenovo.

3.4 Process and Methodology

Lean Six Sigma follows the Define, Measure, Analyze, Implement and Control (DMAIC) methodology in determining the issues, solutions and controls of processes, the flow of the five phases is shown in figure 3.1.

Figure 3.1 Process of Lean Six Sigma

The original Package Engineering Change lead time project began by defining the project charter, with the rationale and the goal based on Six Sigma principles. The financial terms were initially considered during the design phase. Other considerations during the design phase were the opportunity statement, project plan and team selection. The project plan was presented as a Gantt chart and provided a general action plan(s) with corresponding dates and times. The project team members included three members from the Procurement Engineering EC team, the Windchill system engineers and the packaging engineers.

In analyzing the Critical Customer Requirement (CCR), team members from either the component EC team or the Bill of Material (BOM) EC team, were internal customers whose requirements also had to be met. After comparing the old system and new system, the EC team provided feedback to the Windchill project team with their input on how this Windchill system function should be improved.

The original Lean Six Sigma project utilized several tools. Process mapping was used to outline each step from receiving the EC request to submitting the request to the system. By monitoring the time consumption of each step, the team determined which step(s) were key to lead time reduction. An Ishikawa (Fishbone or Cause & Effect) diagram depicted the potential problems from the people, machine, material, method and environment aspects. Failure Mode & Effects Analysis (FMEA) enabled the team to rank the order of the key issues, which was the Risk Priority Number (RPN). The results were further analyzed by severity, occurrence and detection rate. The top three RPN rankings then defined the problems to be addressed that would yield the best lead time improvement. To observe the Package EC variation, Minitab software was used to

analyze the package EC Lead time and the trends. After implementing the corrective actions, the new process was monitored and controlled using the Statistical Process Control (SPC) method. By comparing the old process and the improved process outcomes, the team calculated the business savings. This EC package project saved Lenovo money, met the project schedule and improved the company's serviceability.

After studying LSS principles at Purdue and doing additional research on LSS, the author found that there are opportunities to further improve the package EC process beyond the original work. This will be demonstrated by the comparison between the original project conducted by the Lenovo EC team and the refined work by the author. There were some drawbacks in the original project and there is a better way to address the project and more reasonable Lean Six Sigma tools should have been utilized. The detailed information is introduced in the chapter 4.

3.5 Preliminary Data Introduction

Lean Six Sigma cannot be implemented without data and analytical tools. In the project definition phase, the key is to define a project goal and to determine project issues. In the original study, the package EC lead time was an issue that could be readily seen by accessing the data table from the manufacturing system. That table showed the comparison of package overdue EC part numbers, storage overdue EC part numbers and cable overdue EC part numbers.

Table 3.1 Comparison among quantities of Package overdue EC, Storage overdue EC and Cable overdue EC

Statistic of EC PN (overdue)						
Quantity	Sep'07	Oct'07	Nov'07	Dec'07	Jan'08	Feb'08
Total overdue part(each)	31	1	10	17	18	11
Package overdue part(each)	**14**	**0**	**9**	**13**	**18**	**11**
storage overdue part(each)	0	1	1	1	0	0
Cable overdue part(each)	17	0	0	3	0	0
Overdue Package PN percentage	45.16%	0.00%	90.00%	76.47%	100.00%	100.00%

This table clearly shows that package part numbers were the major contributor to overdue part number EC's from September, 2007 to February, 2008 when the original Lean Six Sigma project targeted reducing the lead time of overdue Package EC's. In the next chapter, there will be a comparison between the approach and outcome of the original project versus the post-Hoc work that that author has completed. Both the original and the refined projects based their analysis on the Package EC lead time from Sept. 2007- Feb.2008 Versus Package EC lead time in May & June, 2008.

Besides focusing on the package EC's, the whole process needs to be taken into consideration. EC owners recorded the duration in each step and for the EC duration in IT transfer (with support from the Information Technology department). The basic Value Stream Map below provides visual assistance to demonstrate how long each step in the original EC release process required.

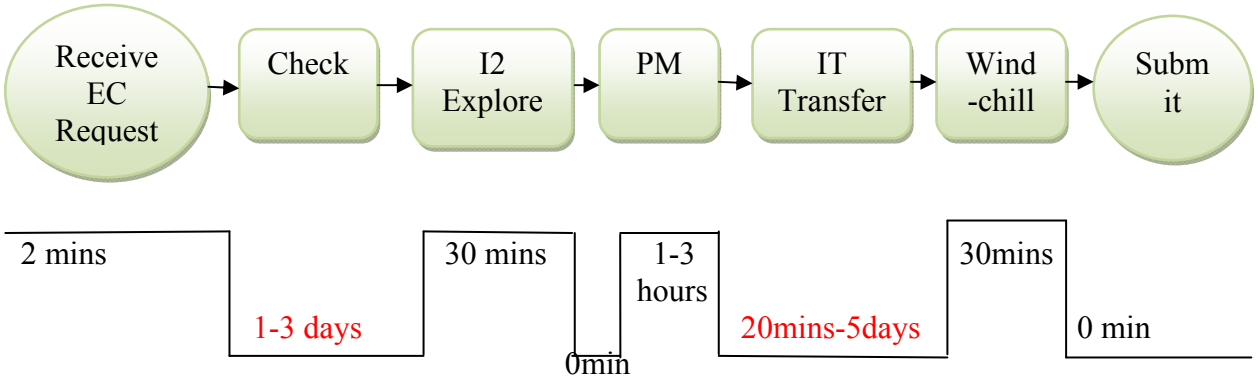


Figure 3.2 Simplified Value Stream Mapping (SVSM)

The durations highlighted in red indicate that the process steps "check" and "IT Transfer" were the two areas in this process which required focus in this study.

3.6 Lenovo Benefits Comparison

By reading the Lenovo Annual Report, Figure 3.3 below shows the profit before taxation on internal software at Lenovo in 2007 & 2008, it shows the profit in 2008 was about $27 billion, while the profit in 2007 was only $13 billion. That explains how a PC company without software sales could still have a huge savings on intangible assets.

9 Profit before taxation

Profit before taxation is stated after charging/(crediting) the following:

	2008 US$'000	2007 US$'000
Amortization of intangible assets		
– Trademarks and trade names (including accelerated amortization of US$30,682,000 (2007: Nil))	50,051	43,634
– Internal use software	26,854	12,895
– Customer relationships	1,698	3,934
– Patent and technology	26,180	28,089
– Marketing rights	22,530	16,285
Auditor's remuneration		
– Current year	4,868	4,200
– Underprovision in previous year	1,289	1,919

Figure 3.3 Profits before Taxation at Lenovo in 2007 & 2008 (Lenovo, 2008)

Figure 3.4 shows that even if construction-in-progress, the expense of internal use software was less in 2008 than in 2007 at Lenovo.

Prepaid lease payments represent the payments for land use rights held by the Group in the Chinese Mainland under medium leases (less than 50 years but not less than 10 years).

18 Construction-in-progress

	Group								Company	
	Buildings under construction		Internal use software		Others		Total		Internal use software	
	2008 US$'000	2007 US$'000	2008 US$'000	2007 US$'000	2008 US$'000	2007 US$'000	2008 US$'000	2007 US$'000	2008 US$'000	2007 US$'000
At the beginning of the year	1,032	8,462	16,868	18,100	2,538	1,403	20,438	27,965	16,500	18,100
Exchange adjustment	110	289	117	(32)	299	190	526	447	74	(32)
Reclassification	(262)	–	43	–	219	–	–	–	–	–
Additions	3,029	2,435	50,015	12,980	14,098	24,186	67,142	39,601	187	4,032
Transfer to property, plant and equipment	(2,094)	(9,972)	–	–	(12,318)	(23,209)	(14,412)	(33,181)	–	–
Transfer to intangible assets	–	–	(17,494)	(14,180)	–	–	(17,494)	(14,180)	(2,868)	(5,600)
Disposals	(944)	(182)	(121)	–	(3,777)	(32)	(4,842)	(214)	–	–
Disposal of discontinued operations (Note 13(a))	–	–	(121)	–	–	–	(121)	–	–	–
At the end of the year	871	1,032	49,307	16,868	1,059	2,538	51,237	20,438	13,893	16,500

No interest expenses were capitalized in construction-in-progress as at March 31, 2007 and 2008.

Figure 3.4 Construction-in-progress at Lenovo in 2007 & 2008 (Lenovo, 2008)

3.7 Summary

The benefit of conducting a Six Sigma project rather than using the subjective judgment approach is that the "pain point" is identified and can be resolved throughout the process. It works regardless of complexity of the issues and processes. The Lean Six Sigma methodology can improve any process if applied with integrity.

Lean Six Sigma theory links various aspects of the business and optimizes the benefits, which are common goals of all organizations. There were many symptoms

mentioned in chapter two. Would extensive application of these principles remove those symptoms?

In chapter 4, Lean Six Sigma analytical tools are used to further analyze the case originally conducted at Lenovo to reduce package EC lead time. The outcomes of the original analysis and post-hoc analysis are compared and include the business case, process mapping, Fishbone diagram, FMEA and SPC. The refined analysis verifies how properly applying the lean six sigma approach removes the causes of enterprise issues, expedites the process flow and fosters continuous improvement. The organizational assessment in the refined case implemented with more functional tools and with new features added creates an enterprise Total Quality Management (TQM) that effectively reflects the Lean Six Sigma contributions.

CHAPTER 4. ANALYSIS AND PRESENTATION OF OUTCOME

This chapter describes a refined application of Lean Six Sigma methodology to the Lenovo package EC project by following the DMAIC process. After a review of literature, it was concluded that a new organizational approach could be used to better analyze the original project and to assure alignment with the current organizational strategy and performance excellence goals. This improved approach is utilized by the introduction of more technical Lean Six Sigma tools and the modification of the original project and focuses on a broader application of Lean Six Sigma functionality including Lean Six Sigma Implementation, Lean Six Sigma Simulation, Lean Six Sigma Sustainability and Lean Six Sigma Supply Chain. The comparison between the original project and this post-hoc study is presented in this chapter. The previous chapter opened with the project creation, which was just a Lean Six Sigma project per the "Define" phase.

4.1 Define Phase

The "Define" phase is a key part of a project with its value determining the meaning and value of doing the project. A project charter, stakeholders identification, SIPOC process, and critical Customer Requirements (CCR) are all categorized in the "Define" phase.

4.1.1 Project Charter - Business Case

The increase in the bottom line in the financial report showed the hidden business value which is the pursuit of the enterprise. For direct benefits, there are two types of saving, soft savings and hard savings. Soft savings are realized by improving the product serviceability, expediting the NPI process by reducing EC lead time to the target. The hard savings are increasing the Package EC's efficiency thus allowing the PE EC team to obtain resources to take more workload in line with Lenovo's business goal. The EC team described the hard savings and the soft savings at the department level in the original work.

4.1.2 Project Charter - Opportunity Statement

Any problem that exists in a company can be a "trigger" for implementing the Lean Six Sigma philosophy. In the Lenovo case, along with the PLM software transition in November of 2007, the Procurement Engineering EC team took over the Package EC responsibility. The lead time of Package EC's had taken longer than four days for several consecutive months, which was considered unacceptable by Lenovo's management team.

4.1.3 Project Charter - Goal Statement & Project Scope

Reducing the package EC lead time to less than four days could expedite the New Product Introduction (NPI) phase, improve the company serviceability, better meet customer expectations and increase Lenovo's bottom line. The project begins with the requirement for an EC, which is initiated by an EC request from the package Technical

Program Manager (TPM) and ends at the successful submission of the EC. The EC team submitted a project plan to assure the process flows smoothly.

In the refined project, the author looked for and found additional opportunities for improvement. First, the original EC team failed to properly define the project scope, the start tick and the end tick on the clock. The addition of these steps enables clear identification of the start and the end points of the EC process.

The original EC team project described the goal statement but confused it with the problem statement, and named the "opportunity statement" as "problem statement". Distinguishing each of these statements is critical to understanding the task and therefore the scope of the project. The refined project corrects all these shortcomings. Serviceability was not necessarily a problem at the company level but any improvement in serviceability means improved customer satisfaction and therefore the company is always looking for ways to improve serviceability. Conducting the Six Sigma project was a way to identify and implement improvements. In Lean Six Sigma principles, problem definition and understanding leads to opportunities. A problem that appears directly in front of us must be resolved. Lean Six Sigma focuses on continuous improvement, which means even if there is nothing wrong either with the product or service, Six Sigma techniques can still be applied to improve the existing status.

4.1.4 Project Charter - Project Plan

Work breakdown structure was used in planning the project. A Gantt chart depicted the work schedule step by step visually providing the whole picture of the project plan, including the steps and tools required for the successful completion of the project. The

EC team categorized these activities into different phases which provided the timeframe for working on the five phases.

Table 4.1 Package EC Project Plan (Procurement Engineering, 2008)

Item	Phase	Deliverables	2008 Date																									
			2-4	2-11	2-18	2-25	3-3	3-10	3-17	3-24	3-31	4-7	4-14	4-21	4-28	5-5	5-12	5-19	5-26	6-2	6-9	6-16	6-23	6-30	7-7	7-14
1	D	Project selection																								
2		Project statement and Objective																								
3		Y define and defect																								
4		Alignment with company strategy																								
5		Finacial benefit																								
6	M	Value strem Map analysis																								
7		Process Map																								
8	A	Fish bone																								
9		C&E																								
10		FMEA																								
11	I	Process Improvement																								
12	C	FMEA(control)																								
13		Value strem Map(after improvement)																								
14		Stat. report (after improvement)																								

4.1.5 Project Charter - Team Selection

Lean Six Sigma projects may utilize team processes such as brainstorming activity to be constructed by team members. Identifying team members and responsibilities can avoid team issues in terms of vague assignments. The original team neglected to identify the project responsibilities and thereby missed an opportunity to better manage the project and assure efficiency. Table 4.2 is the refined project charter developed by the author to clarify each team member's responsibility in a more comprehensive and meaningful way than the original.

Table 4.2 Package EC Project Team Selection

No.	Name	Responsibility
1	Anbi Yan	Data Collection
2	IT Department	Project Support
3	Jin Qiu	Analysis & Verification
4	Oliver Peng	Package Engineer
5	Procurement Engineering Upper Managers	Project Sponsor
6	Windchill Project Team	Project Support
7	Vivian He	Team Lead

4.1.6 SIPOC Diagram

A SIPOC diagram maps the process at a high level and identifies potential gaps between suppliers and input specifications as well as between outputs specifications and customers' expectations, thus defining the scope for process improvement activities (ASQ Service Quality Division, p2). The SIPOC diagram has been added to the refined project to illustrate the 5 nodes from EC generating factors to processes, the results, and then feedback. This helps to understanding the linkage between each node and enables a more robust analysis than the original work.

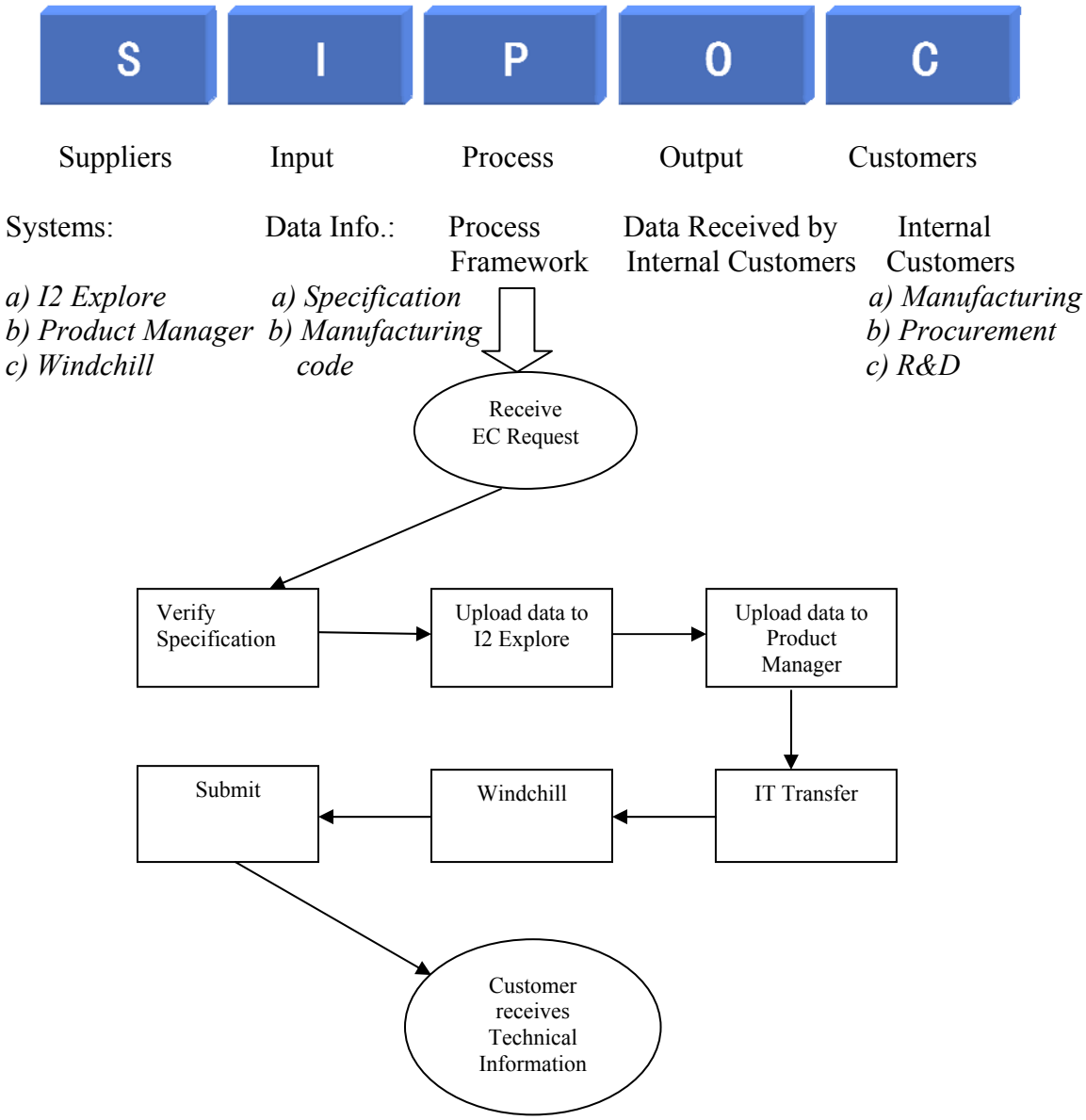


Figure 4.1 Package EC SIPOC Diagram

4.1.7 Transforming the Voice of the Customer to Critical Customer Requirements

The Voice of the Customer is critical to a company's existence. There could be many voices coming from our customers and sorting these voices and transforming them into critical customer requirements is a valuable activity for all organizations in

determining a quality organization strategy. VOC remarks are often broad and general with the customer complaining and it is hard to glean meaningful information. To better serve customers, an organization providing product and service would like to obtain the true requirement from the customers so that critical customer requirements can be transferred into developing the business strategy. Table 4.3 shows the steps missing from the original effort and now added by the author to transform the Voice of the Customer into key customer issues and then into critical customer requirements. We now have a much better understanding of the overall project desired outcome than the original work allowed.

Table 4.3 VOC & CCR of Package EC

CCR	Key Customer Issues	VOC
Package EC Lead time is less than 4 days	Package EC should be within control	Package EC Lead time is too long
	Package EC Lead Time should be within a certain range	Procurement Team could not Place Orders
		R&D could not build Bill of Materials
		Manufacturing could not prepare for a new package assemble

4.1.8 Voice of the Customer - Kano Analysis

The Kano Model is a visual diagram that expresses three statements of customer feedback. From Figure 4.2, the red downward curve is a “must be” flow, it shows high quality characteristics that must be present, otherwise customers are dissatisfied. The blue line represents satisfiers, it shows that the better a company meets customer requirements

the happier the customer is. The green upward curve represents delighters, it shows that product quality and service above and beyond the customer's expectations greatly improves customer satisfaction. If these items are not addressed, the customer's satisfaction might not be impacted at all.

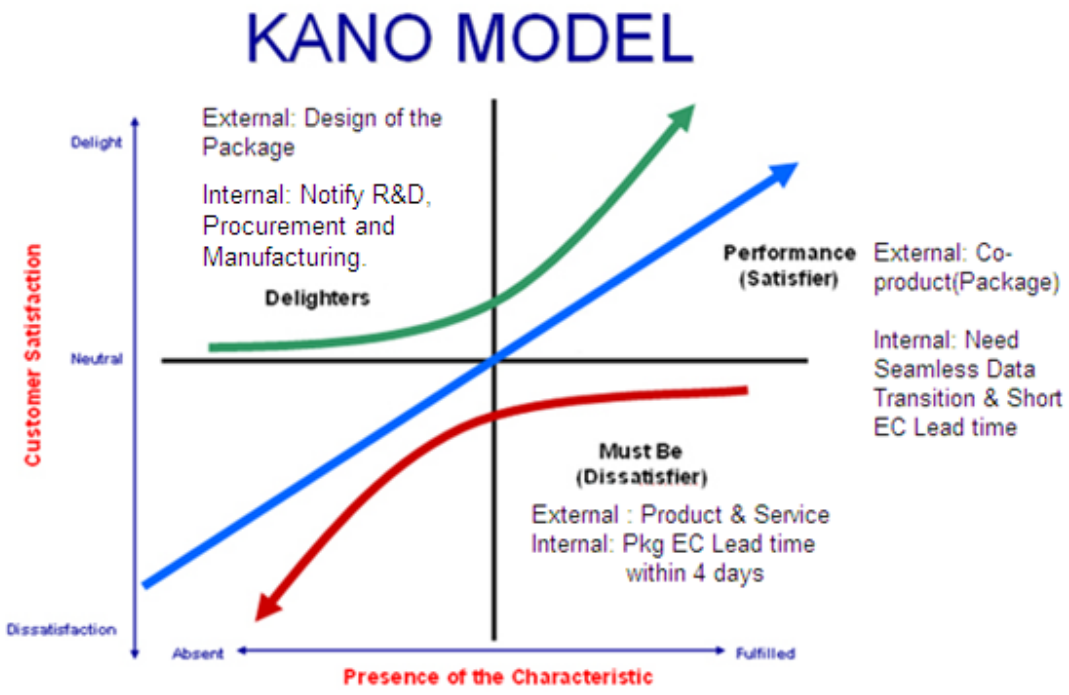


Figure 4.2 Kano Analysis of Voice of the Lenovo Customers (E. George Woodley, 2009)

The Kano Analysis for the internal customer is critical in identifying the requirements which identify key items to be addressed by the project. From this effort, the EC team strategy could have been formulated and extrapolated to the external customers allowing formation of the company strategy but again, this opportunity was missed by the original effort. In the refined project, aligning the company business

strategy with the customer requirements by using the Kano model is a value added exercise incorporated by the author.

There are two types of customers in an organization, external customers and internal customers. In “must be” situation, Lenovo’s external customers require purchased PC’s to have high quality as well as quick and affordable service relating to the product. In terms of the package EC lead time case, internal customers are R&D, procurement and manufacturing and they prefer the package EC lead time less than 4 days. In the “satisfier” situation, for external customer, if the package of the PC has better quality, then the customer is satisfied with the co-product; while the successful data migration and the short EC lead time will more likely please the internal customer. In “delighter” situation, a special design of the package may provide a positive surprise for external customers, and for internal customer, if EC engineers notify R&D, procurement and manufacturing upon the EC completion, it is a bonus for them.

4.2 Measure Phase

The measure phase clarifies how an existing process is performed and how well it meets customer requirements (Wiesenfelder H & Media D, 2014). Process mapping and data collection are necessary preparations for the next phase.

4.2.1 Process Map

Process mapping is a technique where a business process or a workflow is converted into a visual, step-by-step diagram. It is used to better understand an existing process and to help develop a more effective process (Reynolds, 2014). The process map for Package

EC must depict the detailed flow of releasing a Package EC and visually demonstrate the number of processes end to end that are needed to release an EC. A completed EC flow is a released EC verified by system-related internal customers. Figure 4.3 shows the process map of the original package EC project. Figure 4.4 shows a refined process map of the package EC. In the comparison, two major issues can be found in the original process map.

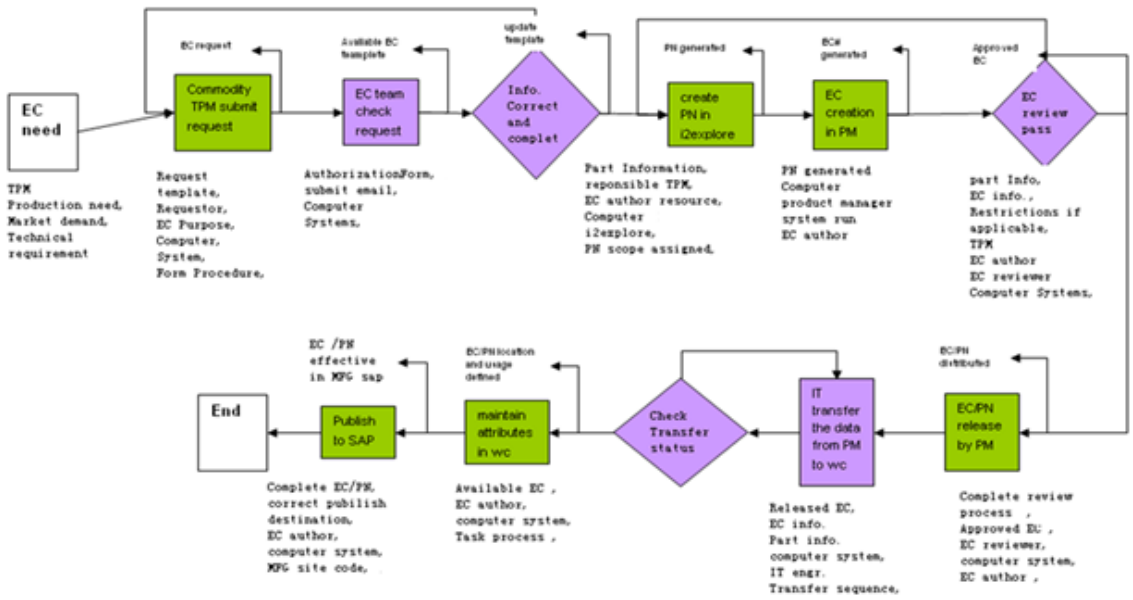


Figure 4.3 Package EC Process Map (Procurement Engineering, 2008)

- The original one has too many explanations. Process mapping should be simple, direct and obtain visual effect.
- Direction of flow was not clear having too many arrows pointing to nowhere.

The refined process map removed the two problems. The new feature of the swim lane shows the relationship of the process partners and clearly identifies the entire

process clarifying the responsibility of each activity, thus, helping the reader understand more effectively. A major improvement vs. the original map.

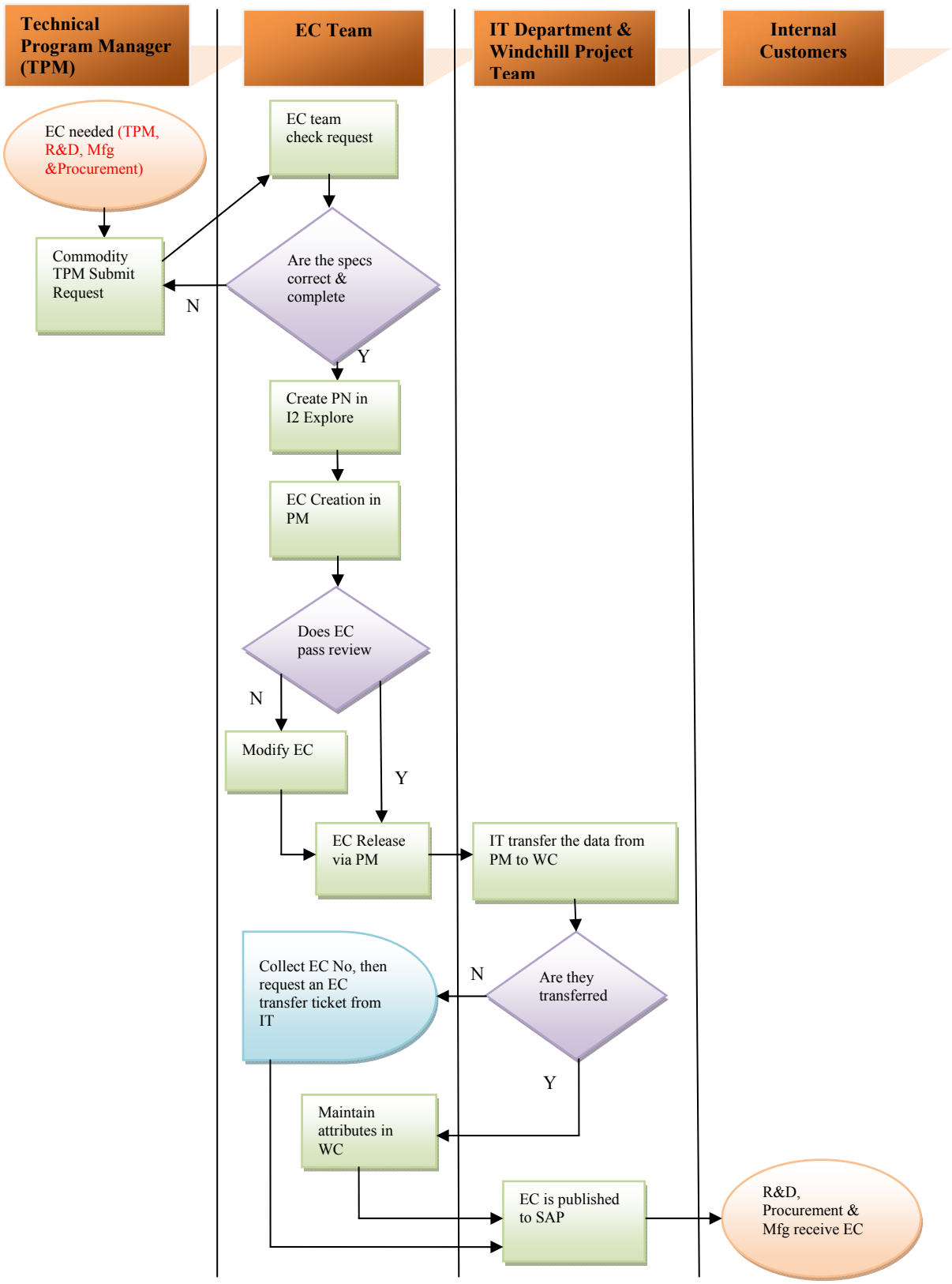


Figure 4.4 Refined Package EC Process Map

4.2.2 Data Collection

Table 4.4 below provides a general picture that proves the problem of the package EC. The data were collected from the PM and Windchill systems directly in 2008 and verified by the IT team.

Table 4.4 Statistic Data of Package EC Lead time (Procurement Engineering, 2008)

Stat. of pkg EC Lead time								
	Sep		Oct	Nov	Dec	Jan		Feb
Total PKG PN q'ty	15		8	26	41	71		25
Average PKG PN Lead time	25.00		1.00	4.19	4.80	3.32		4.20
PKG PN q'ty (lead time>4 Ds)	9	5	0	9	13	13	5	11
Lead time for overdue PKG PN	40	7	NA	7	7	5	9	7
Target	q'ty=0 days<=4		q'ty=0 days<=4	q'ty=0 days<=4	q'ty=0 days<=4	q'ty=0 days<=4		q'ty=0 days<=4

From Table 4.4 above, the average package EC lead time was up to 25 days, which was well beyond the requied EC lead time - 4 days, yet, after one month in the normal range, the lead time was above 4 days again.

4.3 Analyze Phase

The phase “Analyze” is to analyze the data that was collected during “Measure” phase, and it also includes brainstorming to pool the potential root causes with all the possibilities.

4.3.1 Statistical Process Control

A Statistical Process Control (SPC) chart is a tool that improves product quality by reducing process variation and visually identifies any excursions beyond the upper control or lower control limits. The SPC chart below depicts the EC lead time comparison between package and other commodities from the original work.

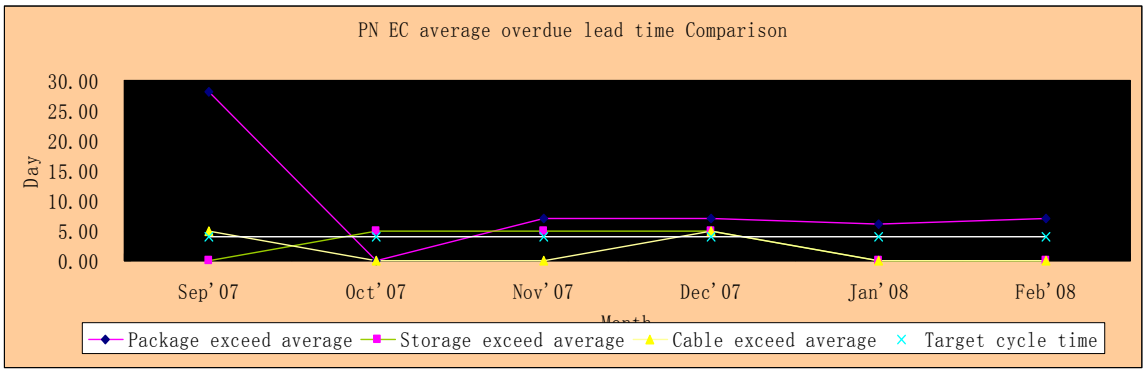


Figure 4.5 SPC Chart - Lead Time Comparison of Commodity Engineering Change (Procurement Engineering, 2008)

From Figure 4.5 above, the EC lead time is approximately 4 days, while the lead time of package EC before Oct.2007 was up to 25 days. In Oct.2007, the lead time fell to 0 but immediately rose above 4 days. A great improvement but it still did not meet the target. To drive the package EC lead time to an average equal or better than the other commodities was the project aim.

Looking closely at the package data by removing other commodities , it helps to focus on the package data description in detail.This chart also shows an upper control limit and a lower control limit allowing easier identification should the EC lead time

exceed the target limits. It clearly shows any month with a lead time beyond the established limits. Single package EC lead time analysis is added in figure 4.6.

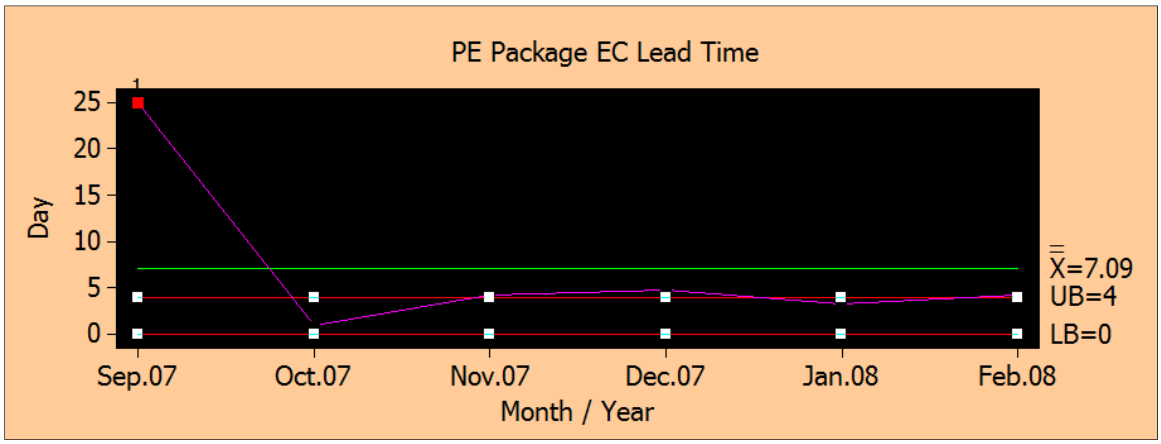


Figure 4.6 SPC Chart – Package EC Lead time against the standard lead time

Test Results for Xbar Chart of Days

```
TEST 1. One point more than 3.00 standard deviations from center line.
Test Failed at points:  1

* WARNING * If graph is updated with new data, the results above may no
          * longer be correct.
```

Descriptive Statistics: Days

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Days	6	0	7.09	3.62	8.88	1.00	2.74	4.20	9.85	25.00

Figure 4.7 Descriptive test results

From Figure 4.6, the lead time fluctuated around 4 days for 4 months and increased beyond 4 days for a 6 month period. From the corresponding test result, the lead time in September was significantly above the standard yielding a mean of 7.09 days and a standard deviation of 8.88.

4.3.2 Ishikawa Diagram (Cause & Effect Diagram)

Since the two objects of the process were pinpointed, the next step was brainstorming all the potential factors that lead to the long EC lead time. Ishikawa (fishbone or cause & effect) diagram, an effective tool in Lean Six Sigma methodology, helped identify potential factors causing the overall effect. Figure 4.8 is the original fishbone diagram, and Figure 4.9 is the improved diagram used in the refined project.

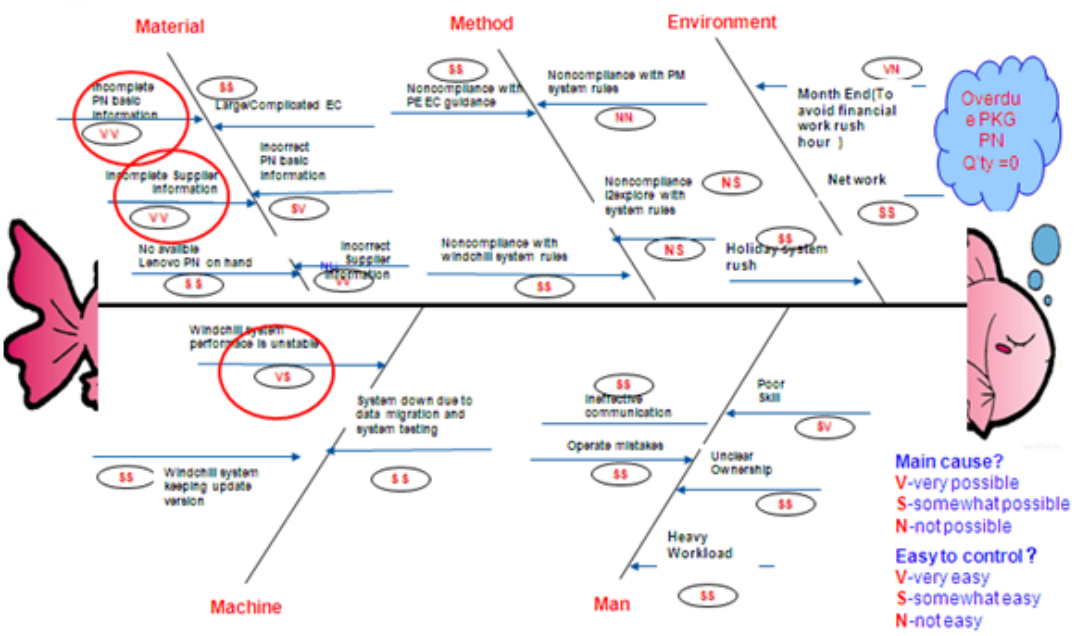


Figure 4.8 Ishikawa Diagram (fishbone diagram) (Procurement Engineering, 2008)

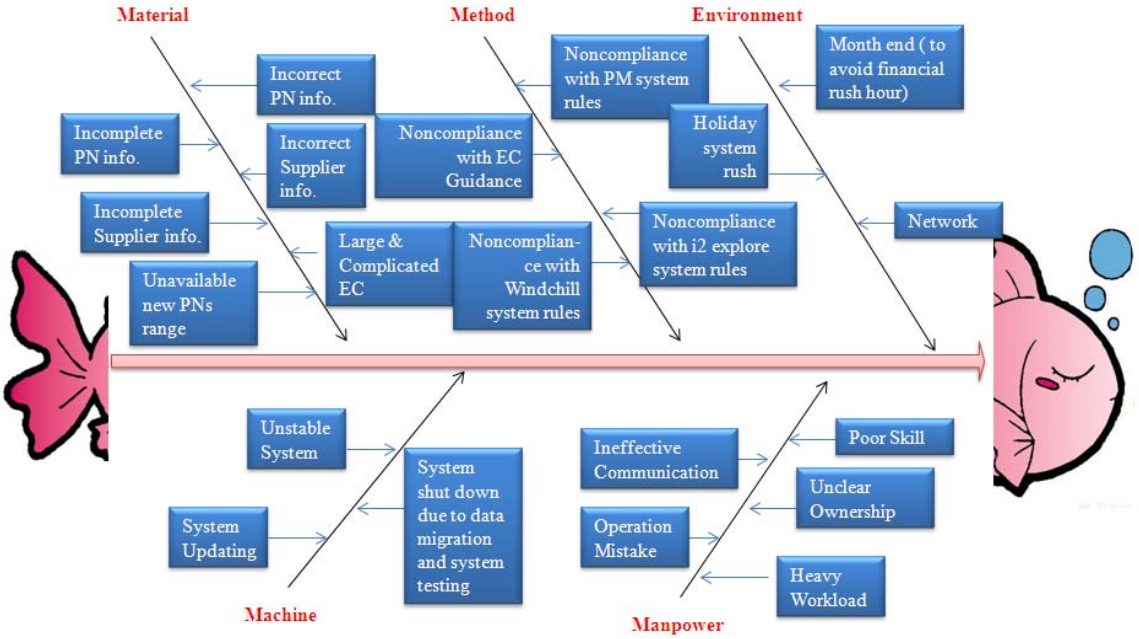


Figure 4.9 Refined Ishikawa Diagram (fishbone diagram)

The EC team did this step well, team members brainstormed all the potential causes for the observed effect. All these potential factors were identified from five comprehensive scopes: the aspects of manpower, machine, material, method and environment. Even though there were some aspects still needing modification in the fishbone diagram that the EC team constructed, each cause was labeled with highly possible main cause, somewhat possible main cause and not possible main cause; very easy to control, somewhat easy to control and not easy to control. These labels should be removed. First, they are most likely subjective judgments and are not in accordance to Lean Six Sigma principles where data driven is the objective, not subjective engineering judgment. As long as the causes are identified other Lean Six Sigma technical tools can be effectively used to objectively rank the root causes. The function of a fishbone

diagram is to identify as many root causes as possible. FMEA is one of the tools that will be introduced in the ensuing paragraph.

4.3.3 Failure Mode & Effects Analysis

FMEA is a tool to identify potential failure modes based on experience with similar products and processes or based on common physics of failure logic. It is valuable in helping to deal with the issues, prioritization and ranking of the high RPN (MBA Brief, 2014).

It is necessary to take a detailed look at the EC steps of the process in using FMEA. First, evaluate the process steps, identify the potential failure mode and failure effects, to determine the potential causes and identify potential methods for control. In FMEA, these steps are evaluated by following three standards: severity, occurrence and detection. The result will determine the RPN in a sequence using the three parameters. Table 4.5 shows the FMEA of EC process.

Table 4.5 Failure Mode & Effects Analysis (Procurement Engineering, 2008)

Process/Product – FMEA (failure mode and effects analysis)									
Process Step	Key Process Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential causes	OCC	Current Controls	DET	RPN
EC Validation	Validated info	Insufficient part info.	Long lead time due to repeating info. confirmation	8	Supplier doesn't provide enough info.	9	TPM request for Parts' info.	2	144
EC transfer	Transfer rules	Unstable system performance	EC can't be transferred between 2 systems on time	8	New system rule conflicts with old system	9	Submit the problem to IT, ask for help to remove EC block	2	144
EC validation	Authorized form	Incorrect EC info.	Long lead time due to repeating info. confirmation	6	TPM are not familiar with EC system rules	9	Ask TPM to correct the wrong specification	2	108
EC creation	System restricts	Invalid EC info.	Long review time due to repeating info. confirmation	6	EC authors don't follow EC guidance	8	Training EC author to obey EC guidance	1	48
EC creation	EC author	EC authors are unavailable	EC hold during holiday	5	EC authors don't work on holiday	3	TPM mark out urgent EC, ask urgent process even during holidays	3	45
EC creation	Computer system	Systems are unusable	EC hold in system	6	Financial rush at the end of month impact system running	1	Remind TPM the system rush before to avoid the period	3	18

To remove the bias and correctly identify the RPN number, the author added process failure mode and effects analysis (PFMEA) evaluation criteria. It provides a guideline to help the FMEA creator with more accurate RPN identification and is preferred over a mere subjective hunch used in the original work.

Table 4.6 PFMEA Severity Evaluation Criteria

Effect	Criteria: Severity of Effect: This ranking results when a potential failure mode results in the degree of different level of EC lead time within Lenovo group.	Ranking
The mistakes result in Lenovo finance loss	Very high severity ranking when a serious mistake delay results in Lenovo finance loss.	10
Impact the normal manufacturing	Very high severity ranking when a potential failure mode affects the normal production in manufacture and Lenovo business.	9
Very High	Very high severity ranking when a potential failure mode affects the manufacturing, but it pushed by Mfg or correct info. without impacting the normal production	8
High	All internal customers couldn't perform their normal task , they are not satisfied	7
Moderate	Impact the procurement team placing order.	6
Low	Impact to form bill of materials by R&D	5
Very Low	Internal Customer need to report to managers	4
Minor	The process need to be pushed by the internal customers. Customer somewhat dissatisfied.	3
Very Minor	The action delayed but only for few days. The problem is fixed in time.	2
None	The delayed action or the problem does not impact any normal process	1

Table 4.7 PFMEA Occurrence Evaluation Criteria

Probability of Failure	Likely Failure Rates	Ranking
Very High: Persistent failures	① More than 10 parts (including 10)and their corresponding specification are impact; or ② EC are held more than twice within a day.	10
	① 9 parts and their corresponding specification are impact; or ② EC are held twice within a day.	9
High: Frequent failures	① 8 parts and their corresponding specification are impact; or ② EC are held once within a day.	8
	① 7 parts and their corresponding specification are impact; or ② EC are held once within a day.	7
Moderate: Occasional failures	① 6 parts and their corresponding specification are impact; or ② EC are held once within a day.	6
	① 5 parts and their corresponding specification are impact; or ② happen several times in a month	5
	① 4 parts and their corresponding specification are impact; or ② happen several times in a month	4
Low: Relatively few failures	① 3 parts and their corresponding specification are impact; or ② happen occasional in a month	3
	① 2 parts and their corresponding specification are impact; or ② happen twice in a month	2
Remote: Failure is unlikely	① 1 or no part and their corresponding specification are impact; or ② happen once or zero times in a month	1

Table 4.8 PFMEA Detection Evaluation Criteria

Detection	Criteria	Suggested Range of Detection Methods	Ranking
Almost Impossible	**Absolute certainty of non-detection.**	Cannot detect, cannot forecast or is not checked by TPM or EC author	10
Very Remote	**Controls will probably not detect.**	Control is achieved with indirect or random checks only either by TPM or EC author	9
Remote	**Controls have poor chance of detection.**	Control is achieved with EC author check only	8
Very Low	**Controls have poor chance of detection.**	Control is achieved with TPM check only	7
Low	**Controls may detect.**	Control is achieved with double check	6
Moderate	**Controls may detect.**	Control is achieved with charting methods, such as SPC (Statistical Process Control).	5
Moderately High	**Controls have a good chance to detect.**	Error can be detected by longer time,	4
High	**Controls have a good chance to detect.**	Error can be detected and can be forecasted	3
Very High	**Controls almost certain to detect.**	Error can be detected relatively easily and can be forecasted	2
Very High	**Controls certain to detect.**	The item has been error proofed and can be detected very easily	1

4.3.4 Process Analysis

From the process map in figure 4.4, the EC release is not a simple action, instead, an EC release needs multiple people and several actions to allow completion. The entire flow needs the cooperation of cross-functional departments as well as the EC team in order to pinpoint the value added actions and non-value added actions and identify the critical factors that lead to efficient and effective EC turnaround time improvements. A simplified value stream map was shown as figure 3.2 in chapter 3 describing the EC release process.

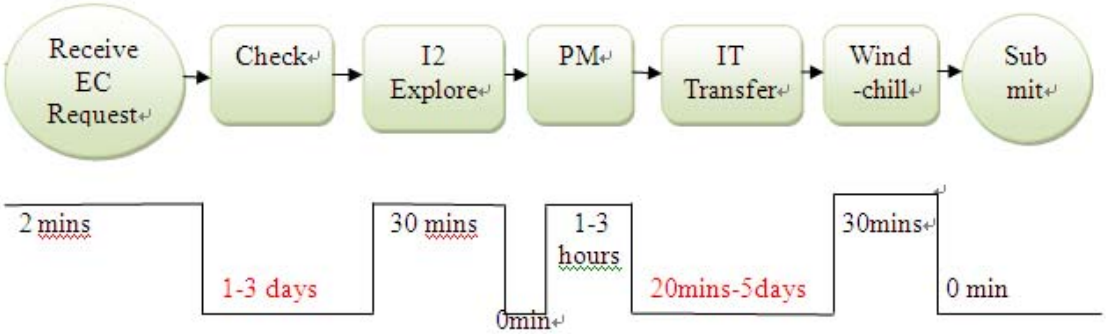


Figure 4.10 Simplified Value Stream Mapping (SVSM) (Same as figure 3.2)

In the SVSM above, the goal was to determine which step(s) could be shortened or even eliminated. We were to keep the processes that are useful to customers, that is, only keep the processes that are valuable to customers and the product & service that they are actually paying for. Therefore, determining the steps with no value was our key focus. In the process, receiving EC request, loading specification of a part into i2 explore, PM and Windchill are all required steps to complete a part release, so the steps “check” and “ IT

transfer" are non-value added activities. This SVSM visually provides the duration in each step where the duration highlighted in red in these steps are triggers that a problem exists and further action is needed to remove the non-value added process step or to reduce the step time.

Kaizen is a Japanese word for continuous improvement that is often less high-tech than innovation improvement, and it focuses on small incremental improvements. The EC creation is one major activity in the process and therefore warrants a closer evaluation. As part of the refined project, the author added this section in using lean thinking to identify the value added and non-value added steps allowing us to pinpoint the opportunities in the process and enabling us to reach a quick preliminary conclusion.

4.4 Improve Phase

During this phase, actions were needed to solve the problems and improve the performance. According to the RPN score, only the three factors in the top list needed to be addressed.

RPN Rank 1: Insufficient Part Information.

Actions: The TPM arranged a meeting with supplier to clarify the requirements. To avoid supplier providing late and/or incorrect part specifications, the TPM added two auditing requirements to the supplier.

A. The TPM is to check supplier's control processes during each regular audit.
B. PE team is to review the supplier's service and support quarterly, and document it in the QBR (Quarterly Business Review) scorecards.

RPN Rank 2: Unstable to transfer system performance.

Actions:

A. The EC author is to submit problems to project team directly. This method enabled the project team to solve an urgent EC case quickly and thus prevent a problem EC from impacting order placement to manufacturing. The table below is a screenshot from the Windchill system containing seven EC reports.

Table 4.9 The Tickets for held EC (Procurement Engineering, 2008)

	Ticket #	Content
1	INC00000008108	(Winchill)a CN user reported failed to upload files
2	INC000000068498	Urgent (Windchill)China user reported 2 ECs was holding in WC.
3	INC000000056147	(Windchill)China user reported 14 ECs was holding in WC about two monthes
4	INC000000065189	Urgent (Windchill)China user reported 2 ECs was holding in WC.
5	INC000000055903	(windchill)A CN user reported the EC number are holding at windchill system
6	INC000000044736	(Windchill)China user reported some released ECs have not reached Windchill yet
7	INC000000043332	(Windchill)China user reported some released ECs have not reached Windchill yet

B. Attend user acceptance tests to assure the system performance.

C. Continue tracking the system performance, report any issues expeditiously.

RPN Rank3: Incorrect EC information

Actions:

A. Assure the TPM clearly understands the EC system requirements for all supplier information. The EC engineers to provide training to the TPM about the system requirement.

B. The EC engineers standardize the attributes by a drop down list or by detailed documentation.

4.5 Control Phase

After "improve" phase, the result should be tested and controlled to a specified level, or reinitiate the "improve" phase if the outcome is not satisfactory. The table below shows the RPN levels from the original and the refined projects. Table 4.10 shows the comparison RPNs before and after the improvement prepared by the EC team. Table 4.11 shows the comparison RPNs before after improvement by following the criteria.

Table 4.10 RPN Comparison before and after improvement (Procurement Engineering, 2008)

Current Controls	RPN (Before)	Action Recommended	Action Taken	SEV	OCC	DET	RPN (After)
TPM request for part's info from supplier whenever is incomplete	144	Strong supplier management, ask more support from supplier	Meeting with supplier, consider it into audit item	8	2	2	32
Submit the problem to IT, ask for help to remove the EC block.	144	Submit the problem to new system project team, requesting for system root cause solving	Discuss with project team to solve the system conflicts and test validation	8	2	2	32
Ask TPM to correct the wrong specification	108	Provide system use training for TPM and do Q&A based on their needs.	Provide system use training for TPM and do Q&A based on their needs.	6	2	2	24

Table 4.11 RPN Comparison before and after improvement (After criteria added)

Current Controls	RPN (Before)	Action Recommended	Action Taken	SEV	OCC	DET	RPN (After)
TPM request for part's info from supplier whenever is incomplete	144	Strong supplier management, ask more support from supplier	Meeting with supplier, consider it into audit item	8	1	2	16
Submit the problem to IT, ask for help to remove the EC block.	144	Submit the problem to new system project team, requesting for system root cause solving	Discuss with project team to solve the system conflicts and test validation	8	1	2	16
Ask TPM to correct the wrong specification	108	Provide system use training for TPM and do Q&A based on their needs.	Provide system use training for TPM and do Q&A based on their needs.	6	1	2	12

Establishing these criteria simplified the accuracy of severity levels and the probability levels of each item. In the refined table, the degree of occurrence dropped to 1 that is less likely to occur in terms of insufficient part number information, unstable system performance and incorrect EC information, thus the RPN has been changed to 16, 16 and 12 accordingly.

The causes have been identified and distinct methods were used to solve the problem. From the RPNs after improvement, it is clear that this is an efficient means to resolve and control. Meanwhile, after monitoring the EC process, the lead time of step "check" has been reduced from 1-3 days to 1-3 hours and the lead time of "IT transfer" has been maintained from 20 mins-5 days range to a stable 20 minutes.

Figure 4.11 below is the SVSM process with the time improvement at the "Check" and "IT Transfer" steps.

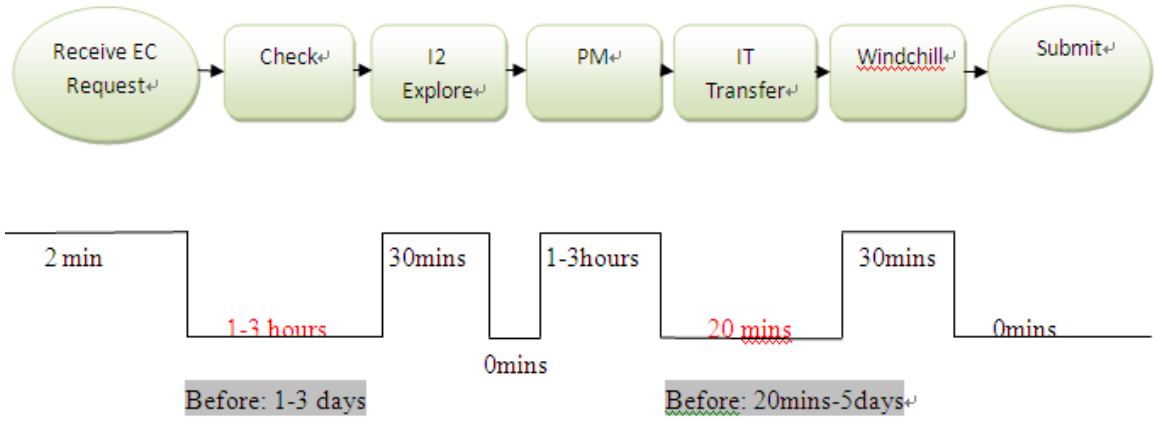


Figure 4.11 Simplified Value Stream Mapping (SVSM) after improvement

Along with the project deployment, we can see the obvious improvement since March 2008 in the control chart below showing the overdue EC numbers or lead time

period reduced gradually. We even found there were no overdue EC's in May and June. The graph clearly shows a positive trend.

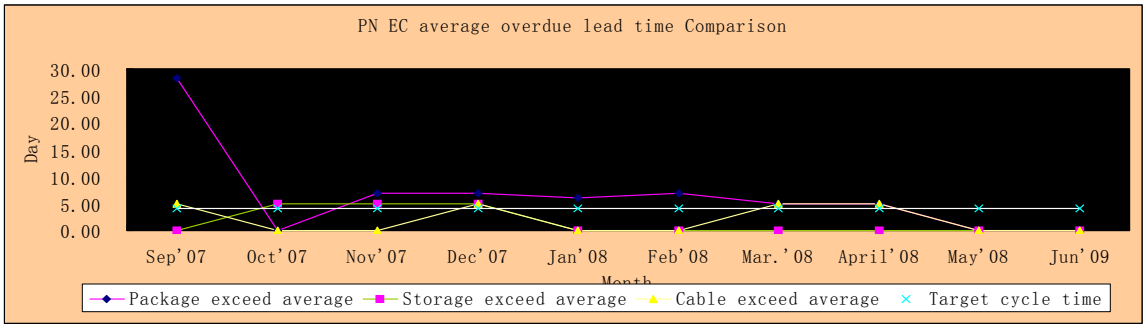
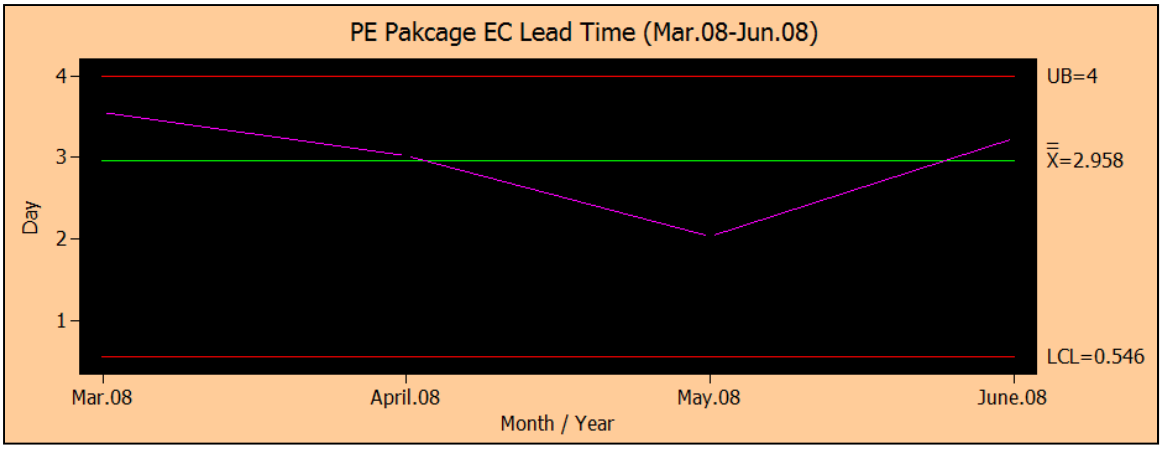


Figure 4.12 EC average overdue lead time Comparison (Sep.07-Jun.08) (Procurement Engineering, 2008)

Figure below shows the package EC lead time after improvement. The process falls in between the upper control limit, 4 days and the lower control limit. The sample mean is 2.958 and the standard deviation is reduced to 0.656, which means the new process is more stable.



Xbar Chart of Days

Descriptive Statistics: Days

Variable	N	N*	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Days	4	0	2.958	0.328	0.656	2.030	2.277	3.125	3.470	3.550

Figure 4.13 SPC of PE Package EC lead time after improvement.

The PE EC team failed to separate the data set before and after process improvement and therefore it was hard to distinguish early Sept. 07 through Jun. 08. Nor is it easy for the reader to discern the results. The author picked out the data set from Mar. 08 after the process improvement and conducted an SPC analysis visually conveying to the reader that the improved process falls between the upper spec limit and the lower spec limit, the average mean of lead time is 2.958 which is lower than 4 days, and the standard deviation is reduced to 0.656 which indicates the updated process has small variation.

CHAPTER 5. CONCLUSIONS, DISCUSSION, AND RECOMMENDATIONS

This study has applied multiple lean six sigma tools to the original package EC lead time case. It has demonstrated that through the post-hoc analysis the LSS project is different and improved from the original and used a better methodology to address the same issue by the addition of lean principles. The post-hoc analysis addresses the case in a comprehensive manner by establishing the project in an empirical application and evaluation. The refined study is deployed from a leadership perspective, from multidisciplinary team organization to process partner relationships and from the department bottom line to the business strategy. It indicates these aspects are a necessary consideration along with the package EC case analysis in developing an enterprise core competency. From the literature review, the case provided has shown that the process redesign can reduce the waste, remove the gaps and expedite the process flow, thus reducing the overall lead time of the process. The refined Lenovo case study of package EC lead time reduction applied disciplined use of Lean Six Sigma tools and through adding functional tools, VOC, Kano analysis as well as project refinement has increased the efficacy and accuracy of the study. By doing post-hoc analysis, we can better understand the problem and develop further research, either for better problem solving or for prevention in the future. It can also be replicated and adapted to many similar cases.

5.1 Summary of Significance

As a part of the Supply Chain process, the improved package EC process can be a milestone in refining the overall supply chain. Any kaizen event built up can yield amazing results. Multiple process improvements, a large amount of savings, increased customer satisfaction, enhanced market share and strengthened supply chain core competencies. Combining the original PE EC team and author's refined project leads us to conclude that proper application of Lean Six Sigma techniques can specifically identify potential problems and better focus on the root cause. It helps us to better plan the project from the business case by aligning the company's strategy with the opportunity for improvement as performed in the refined project. The project scope is more accurately determined and we can better see the whole picture of the project after the refinements. We can comprehensively evaluate the project from the beginning. The DMAIC process provides a step-by-step guide in managing the project. All these are improved by the 'second look' performed by the refined project.

The industry models rapid changes has forced us to recognize that the acquisition model is sometimes critical as companies acquire partial or entire organizations to assure their continued success in meeting business needs. From either physical integration or system and software license utilization, all elements including seemingly trivial elements need to be considered during an acquisition activity. The Lenovo case is worthy of study from the beginning of the acquisition to today's amazing business success, the cascade of lean six sigma projects reflect the power of the methodology. This study is a pilot analysis on the system transition, it can be and will be replicated in a similar fashion to

any organization, thus, replicating the business success in other endeavors to achieve the win-win result.

5.2 Sustainability

The EC process in this study shows an individual case and gives us cause to consider its outcome. By following the Lean Six Sigma structure, the lead time of the step "check" has been successfully reduced. We should strictly follow the path that successfully improved and controlled this process in the refined project by building a lasting relationship with the internal customers. Once the trust has been established, the EC author can use the routine method and 'check' the EC request status with a rapid glance so the step "check" time can be further reduced. The utilization of the visual management techniques are based on the trusting relationship between the EC team and the Technical Program Managers. This reflects the theory of Lean Six Sigma, which facilitates discovery of broad or detailed aspects either from the obvious to the hidden opportunities that exist throughout the entire supply chain and establishes an essential network focusing on establishing and sustaining long term relationships.

5.3 Recommendations

As for the step" IT transfer", the ticket submissions allow us to solve the urgent EC holds, yet we would not know this is a problematic EC until the time runs out. Any further studies should focus on the smooth system transfer and the reduction of the data transfer time possibly synchronizing two or more systems so the "IT transfer" time would be 0 or only a few seconds delayed, thus ultimately optimizing the process.

This study further demonstrates the improvement of an integrated process with business strategy and customer relationship analysis. Our view on lean six sigma usage is not restricted to physical parts flow in fabrication but includes the abstract information flow. More and more Lean Six Sigma projects should be studied throughout each aspect of the supply chain. Once we put all the projects together, through the business case, it is possible to find more savings exist in the different function sectors and that could yield huge savings for the organization. Lean thinking and Six Sigma strategy should never be separated as LSS is a valuable guide to the business as it strives to identify opportunities for consistent continuous improvement.

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