CHAPTER 2
LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1. Literature Review

The Six Sigma methodology is a straightforward project management tool developed to solve a problem encountered both in manufacturing and service industries. It is a well-disciplined structured approach utilized to achieve process with low variability and high accuracy, the goal is to produce high quality products (Salah et al., 2010). Motorola at first place created a systematic step to achieve a sigma level of six in which a process produces equivalent output of 3.4 defects per million opportunities (DPMO). General Electrics (GE) later introduced measure, analyze, improve and control phases. “Define” phase later added to form today’s Six Sigma well-known define, measure, analyze, improve and control (DMAIC) problem solving methodology. The method has gained a popularity among *Fortune 500* companies to improve their performance (Goh, 2002) such as GE, 3M and Honeywell.

The lean methodology is a method of streamlining a process by eliminating waste, variation and work imbalance. Lean is a costumer-focus principle that create values at lowest cost and at shorter lead time. It derives from the Toyota Production System (TPS) that is initiated in automobile industry. Lean is achieved by eliminating waste such as non-value added activities. There is an obvious connection between waste and variability in the process. Waste results in rework or scrap, which is caused by existing variability in the process. The connection indicates the relation of Six Sigma and Lean (Salah et al., 2010). The success of lean cannot be achieved without the support from the concept of autonomation and zero-defect which involves awareness on continuous improvement and full participation of all employees in an organization.

Lean and Six Sigma complement each other, combination of these two methods gives comprehensive tools to solve problems. Lean Six Sigma (LSS) is described as a methodology focuses on waste and variable reduction using a systematic DMAIC phase as the problem-solving method. Lean accelerates Six Sigma by solving problems and improving processes which results in increased revenue, reduced costs and improved collaborations. Both methodologies should be viewed as the platform to guide the cultural and operational changes, leading to a complete transformation of the organization (Pacheco, 2015).

Montgomery (2010) believes that lean improvement project can be adopted using DMAIC, the combination of Six Sigma and lean is associated to a continuous improvement philosophy and to a knowledge of a system, as proposed by Deming. Souraj (2010) proposed six model types of lean and six sigma implementation found in organization as shown in Figure 2.1. The first model type presents Six Sigma used as a tool in lean project. The second model type presents some lean tools that is forced into DMAIC structure. The third model type presents separate use of lean and Six Sigma to tackle different problems. The models illustrate the flexibility of LSS that can be utilized according to the problem and its tools both adopted from Six Sigma and lean manufacturing can be suited to the project requirements.

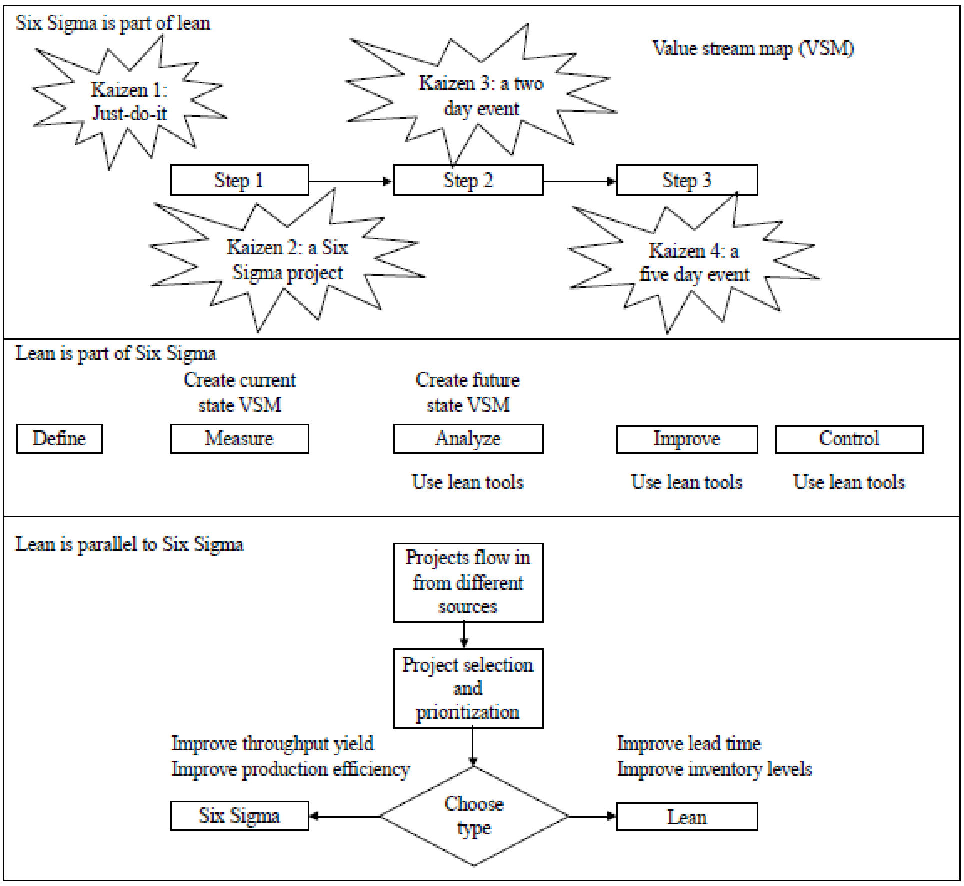


Figure 2.1. Three LSS Models (Souraj, 2010)

In recent years, LSS has been used not only in large manufacturing companies but also both in service such as bank, healthcare and manufacturing such as agriculture, automotive and pharmacy (Anderson and Kowach, 2014). Several LSS projects have been proven successful not only in large manufacturing organizations, but also in SMEs. Previous LSS case studies have been successfully implemented worldwide from wood furniture industry by Guerrero et al. (2017), automotive industry by Swarnakar et al. (2015), textile industry by Adikorley et al. (2017), rubber glove manufacturers by Jirasukprasert et al. (2014), automotive electronic components industry by Tan Ping Yi et al. (2012).

Guerrero et al. (2017) conducted research on small wood furniture industry in Mexico with 60 employees. The current problem lies on the product's quality reflected on financial returns and constant complaints from wholesaler. The author demonstrates DMAIC for implementation of LSS in the furniture industry. In define phase, the industry suffered from losses of almost $82,000 per year mainly due to reworking cost of furniture. In measure phase, number of DPMO is calculated. As addition, R&R study using ANOVA is performed to validate the system. It is proved that the measuring error is small compared to total variation, that means the baseline of quality has been set and the project can proceed to the next phase. In analyze phase, root cause analysis showed that type of wood, type of cuts, moisture content and worker factors contribute to defect of the furniture product. In improve phase, selecting the first-grade wood can improve customer trust by reducing cycle time, rework time and delivery time. Additional improvement recommendation is to produce a better type of cut, maintaining moisture content, and worker's skill training. The improvement resulting in defect and waste reduction by 25 percent and 13 percent respectively. In control phase, SPC and control chart are introduced to monitor and control the process metrics. The author also emphasized the importance of theoretical knowledge on LSS project by both managers and employee. Major challenge faced in the implementation is due to industry that is lack of familiarity with LSS, managers are hesitant to introduce LSS tools. Informality of processes in manufacturing process, lack of awareness and lack of procedures that can indicate that the company has a documented quality management system.

Dragulanescu et al. (2015) studied issues on organization deficiency caused by repetitive process, non-value added activities and lack of managerial planning in the production stages of automotive industry. The problem is defined from customer feedback on the products visualized in SIPOC chart. In measure phase, activities were categorized into essential value-adding activities and non-essential value-adding activities visualized in current state value stream map (VSM) and according to 7 types of waste. In analyze phase, root cause analysis showed that the shortcomings are significantly caused by setting scrap overall length low and seat uneven. In improve phase, work cell was proposed to improve process flow and eliminate waste, quick changeover to reduce inventory level, SMED to reduce machine setting time, *poka yoke* to decrease defect rate and improve layout effectiveness. In control phase, periodic 5S audit was conducted, group technology is applied and control chart to check the defect rate. According to VSM map on the implementation of DMAIC method, there was an improvement in the completion schedule of the activities of collection / delivery, registration and labelling of parcels by 33 minutes/day, productivity in generating documents per hour increased by 44% and the company annually saves 98,438 Euro with detail of 48.438 Euro on the total hours saved and 50,000 Euro on reducing the number of undelivered parcels.

Swarnakar et al. (2015) deployed Lean Six Sigma (LSS) framework to facilitate defect reduction and enhance bottom line results of an automotive component manufacturing organization. Six Sigma DMAIC was used as a problem-solving methodologies. Several Six Sigma tools such as process capability analysis and pareto used in measure phase. While lean manufacturing tools such as SMED, VSM, 5S, Kaizen are used to improve the current system. The outcome of the deployment was 50% reduction in DPU, 42.18% increase in OEE, 14.9% reduction in changeover time, 0.1% improvement in FTY, 40.35% reduction in manufacturing lead time, 7.10% decrease in cycle time, 9.52% decrease in manpower and 50% increase in production per day for automotive component.

Jirasukprasert et al. (2014) successfully implemented Six Sigma with DMAIC stage to reduce defects in rubber gloves manufacturer. The journal indicates pure Six Sigma DMAIC methodology without combination of lean aspects. Initially, number of DPMO calculated was 195,095 or equivalent to sigma level of 2.4. “Leaking glove” is the highest cause of defect shown by Pareto chart. Improvement is done by conducting design of experiment (DOE) to investigate the direct effect of conveyor speed and temperature. Implementing conveyor speed of 650 RPM with heating temperature of 230ºC can reduce the defect to 83,750 and thus improve its sigma level from 2.4 to 2.9. Design controls were used to monitor the process and ensure that the implemented process remained in control. Unlike other LSS researches that combine the strength of Six Sigma and lean manufacturing methodology, this journal did not consider the other six types of waste that might bear significant result than defect in the production process.

Adikorley et al. (2017) explored LSS project with qualitative approach, started by literature review from LSS implementation generally in many kinds of industry then limit the scope of study into implementation in textile industry. Interview was conducted with company's lead Master Black Belt about LSS strategy, impact, and success factors within the company. The researchers then review three successful LSS projects in the company which contribute to annual saving of $577,000. As a result, first project aimed to reduce changeover time was able to achieved reduction by 37% on the first product line. The sigma level was increased to 3.74. In the second project aimed to reduce contamination, the improvement was able to reduce contamination to 2.73 per week, resulting in a 4.32 sigma level. The third project aimed to reduce changeover time in Line 5439, the improvement such as work training and standardized work instructions were able to dropped changeover time from 9.267 hours to 4.642 hours with sigma level of 3.74. Based on the three projects presented, communication is found to be important and more than 70% of the employee receive training. This indicate LSS was implemented as culture. While technically, DMAIC methodology found on all of these projects along with tools such as FMEA, fishbone diagram, SMEDs, process map was used successfully. However, the research cannot be generalized since it is a single descriptive case study or three projects in one textile manufacturer.

Arunagiri et al. (2016) have carried out identification of major waste and major contributing factors to major waste using fuzzy analytical hierarchy process (fuzzy AHP) and Binary Logistic Regression (BLR) respectively. Since most of journals only focuses on the use of lean tools, Arunagiri commented the importance of finding out and eliminating lean waste. The outcome of lean waste reduction can reduce manual effort and save investment capital on the improvement project. The case study in the journal was a survey conducted in international exhibition in India. Major lean waste identified using fuzzy AHP is waiting. In order to identify major contributing factor to waiting, literature review is conducted which results in 11 contributing factors, then BLR model is conducted to identify the top three major contributing factors which are operator waiting time, distance between work stations and load cycle time. The reduction of three major contributing factors can increase production rate, optimized movements and increase in machine hour availability. Previous research with the same objective also conducted by Khalil et al. (2013) using Waste Relations Matrix (WRM).

Yi et al. (2012) investigated losses of electronic components using LSS with DMAIC as the project management methodology. In define phase, problem statement is clearly stated to investigate and generate mixture of strategies which suit the relevant causes. In measure phase, process flow was constructed to better understand the system. In analyze phase, cause effect tool is used to analyzed the source of the variability which 30 percent contributed by machine thrown out or wrong placement due to identification error during machine inspection. In improve phase, new SOP was developed, kaizen team was formed to motivate workers individually to improve their performance. Other solutions such as changing shop floor layout, creating new standard operating procedure (SOP) of loading and unloading were implemented among setup operators. In improve phase, kaizen team is formed to reinforce continuous concept such as work quality, seven types of waste and action plan using lean tools such as VSM, 5S. Performance audit such as 5S audit also being conducted to evaluate the conformance of the process to the standards. The result of implementation showed reduction of component losses within the week of 26 to 41. Losses are reduced up to 18 percent, or in monetary unit equivalent to USD 7,680 to USD 6,400 or about 18 percent. The journal emphasized the success of implementing six sigma into lean manufacturing project based on the first LSS framework model stated by Souraj (2010). Furthermore, the success also provide confidence to organization by perceiving numerous alternative improvement methods

Albliwi et al. (2014) reviewed 37 papers from the period of 2000 to 2013 with purpose of identifying gaps to prevent users from not getting maximum benefits of the combines lean and six sigma methodologies or LSS. The research showed that the use of lean tools and techniques such as VSM, 5S, etc., was most common in most cases as it is non-statistical and Six Sigma tools only was more familiar in US manufacturing companies than European manufacturing companies. Lean tools also can be more familiar with the manufacturing atmosphere in Indonesia which are dominated by SMEs. As an addition, the paper also found that there is lack of sustainable framework to sustain LSS implementation.

Adikorley et al. (2017) explored Lean Six Sigma project and program success in the textile and apparel industry. There are three LSS projects using DMAIC problem solving methodology. As a sample, first project involved changeover time reduction of PP/PET extruded fiber. The objective is to reduce changeover time which typically takes an average of 15.5 hours. The purpose of the project is to reduce it by 25% to 3.9 hours of changeover time. In measure phase, the detailed process map of steps was constructed, a XY analysis matrix, a why-why analysis, and FMEA. In analyze, root cause analysis is used to identify steps that are independent or not with other steps. In improve, the step of changing was rearranged and SMED was introduced. The operators were trained on new standard and processes that were also being documented. In control phase, new standardized work remained and changeover time continued to be monitored. The result showed that changeover time was reduced to an average of 9.85 hours, a 37% reduction surpassing the project goal of 25%. Based on literature review on waste reductions and quality improvements, the literatures are summarize and classified by objectives, philosophies adopted, tools used, and results as shown in Table 2.1.

Table 2.1. Literature Review on LSS Tools Comparison

No.	Journal Title	Objectives	Philosophy	Tools Used	Results
1	Applying Lean Six Sigma in the Wood Furniture Industry: A Case Study in a Small Company (Guerrero, Leavengood, Gutierrez-Pulido, Fuentes-Talavera and Silva-Guzman, 2017)	Improve the product's quality due to problem reflected in financial returns and constant complaints from wholesalers about the defect.	Lean manufacturing and Six Sigma	DMAIC, Gage R&R, fishbone diagram, skill training, statistical process control, and control chart	The firm has potential to reduce defects and waste reduction by 25% and 13% respectively and increase sales productivity by approximately 14% in the first year.
2	Quality and competitiveness: A Lean Six Sigma Approach (Dragulanescu and Popescu, 2015)	Overcome organizational shortages caused by repetitive processes, non-value adding activities and lack of planning.	Lean manufacturing and Six Sigma	DMAIC, SIPOC diagram, value stream mapping (VSM), fishbone diagram, Single-Minute Exchange of Dies (SMED), 5S	Improvement in the the activities of collection / delivery, registration and labelling of parcels by 33 minutes/day, productivity in generating documents per hour increased by 44% and the company annually saves 98,438 Euro.
3	Deploying Lean Six Sigma framework in an automotive component manufacturing organization (Swarnakar and Vinodh, 2015)	Deploy LSS framework to facilitate defect reduction and enhance bottom line results of an automotive component manufacturing organization.	Lean manufacturing and Six Sigma	DMAIC, process capability analysis, Pareto diagram, VSM, SMED, kaizen	50% reduction in DPU, 42.18% increase in OEE, 14.9% reduction in changeover time, 40.35% reduction in manufacturing lead time, 7.10% decrease in cycle time, 9.52% decrease in manpower and 50% increase in production per day.

Table 2.1. (Cont'd)

4	Lean Six Sigma application in the textile industry: a case study (Adikorley, Rothenberg and Guillory, 2017)	Explore Lean Six Sigma project and program success in the textile and apparel industry.	Lean manufacturing and Six Sigma	DMAIC, Failure Mode and Effect Analysis (FMEA), fishbone diagram, SMED, process mapping	By reducing variation and eliminating waste, changeover time was reduced by 37% on the first product line and on the second line, the reduction resulted in an increased sigma level to 3.74. Contamination was reduced on the third line resulting in a 4.32 sigma level. CSF identified were clear vision for LSS.
5	A Six Sigma and DMAIC application for the reduction of defects in a rubber gloves manufacturing process (Jirasukprasert, Garza-Reyes, Kumar and Lim, 2014)	Current sigma level is 2.4 caused by leaking gloves defect.	Six Sigma	DMAIC, design of experiment (DoE), design control	Implementing conveyor speed of 650 RPM with heating temperature of 230ºC can reduce the defect to 83,750 and thus improve its sigma level from 2.4 to 2.9.
6	Identification of Major Lean Waste and Its Contributing Factors Using the Fuzzy Analytical Hierarchy Process (Arunagiri and Gnanavelbabu, 2016)	Identify major lean waste from seven types of waste founded in automobile industry using Fuzzy AHP and identify major contributing factors for major waste using Binary Logistic Regression (BLR).	Lean Manufacturing	Fuzzy analytic hierarchy process (FAHP) and binary logistic regression (BLR)	Waiting is identified as major lean waste by Fuzzy AHP with value of 20.9%, while three major contributing factors for waiting are operator waiting time, distance between work stations, unload and load cycle time. The reduction of three major contributing factors can increase production rate, optimized movements and increase in machine availability.

Table 2.1. (Cont'd)

7	Reducing electronic component losses in lean electronics assembly with Six Sigma approach (Yi, Feng, Prakash and Ping, 2012)	Investigate losses of electronic components and to generate a suitable mixture of strategies for the relevant causes.	Six Sigma	DMAIC, process flow, tracing process, fishbone diagram, Pareto chart, standard operating procedure (SOP), kaizen team, backflush procedure, preventive maintenance, FIFO system, and performance audit	Reduce component losses to a lower level within week 26 to 41, Losses were reduced from USD 7,680 to USD 6,400. It is also important to build a suitable team that promote the success of the implementation projects regularly to grow awareness.
8	A systematic review of Lean Six Sigma for the manufacturing industry (Albliwi, Antony and Lim, 2014)	Explore the most common themes within LSS in the manufacturing sector, identify any gaps in those themes that may prevent users from getting the most benefit from their LSS strategy.	Lean manufacturing and Six Sigma	Cause and effect analysis, VSM, 5S, DoE, and Pareto chart	Lean tools and techniques such as VSM, 5S, etc., was most common in most cases as it is non-statistical and Six Sigma tools only were more familiar in US manufacturing companies than European manufacturing companies.
9	Selection of Lean and Six Sigma Projects in Industry (Kornfeld and Kara, 2013)	Explore literature to identify how industry selects Lean and Six Sigma projects	Lean manufacturing and Six Sigma	DMAIC, XY analysis matrix, 5 why-why analysis, FMEA, SMED, worker training, standard procedure	Industry is not satisfied with the result of Lean and Six Sigma projects using subjective and informal methods such as brainstorming when selecting the project portfolio. Instead, multi-attribute decision making tools such as AHP and PROMETHEE are better in project selection and application.

Table 2.1. (Cont'd)

10	Reducing Major Lean Waste in PT. Asia Forestama Raya with Lean Six Sigma Approach (Suhendra, 2017)	Determine the most dominant waste in the production process of plywood, analyze the root cause of the most dominant waste, reduce the most dominant waste using LSS tools.	Lean manufacturing and Six Sigma	AHP, DMAIC, CTQ, SIPOC, SIPOC, project charter "as-is" process mapping, process capability, fishbone diagram, PFMEA, worker training, work instruction, Andon system	

2.2. Theoretical Background

This section presents theories such as Lean Manufacturing, Six Sigma concept and tools, the Analytic Hierarchy Process (AHP) which are found in the following case study.

2.2.1. Lean Manufacturing

Lean is a term spawned in the book "*The Machine That Changed the World*" by Womack et al. (1990) as a result of comprehensive study about Toyota Production System (TPS) by Massachusetts Institute of Technology (MIT). The study revealed the success of Toyota and other Japanese automobile industry to overtake Ford and the rest of USA automobile industry. The ambition that they quickly achieved by focusing on productivity, quality and product development through application of lean principles despite having lack of resource and infrastructure. The fundamental principles of Lean (Toyota Production System) explained by Antunes et al. (2008) are as follows:

a. the mechanism of production function

b. the non-cost principle;

c. the wastes in the production systems.

The core idea of lean manufacturing is to eliminate wastes from the production process. By eliminating wastes in the production process, industry can provide value to customer at lower costs (Shingo, 1989). According to Antunes at al. (2008) and Bornia (2002), waste is conceptualized as an unnecessary operations or movements that generate costs and do not add value to the system, therefore need to be eliminated from the system. According to research conducted by the Lean Enterprise Research Centre (LERC), fully 60% of production activities in a typical manufacturing operation are waste. Toyota categorized seven types of wastes:

a. Overproduction

Company may produce more than necessary because of loose parts, products and materials. It is produced before or without order. Poor organization of storage may lead inventory to fill all available space. Overproduction prohibits the smooth flow of materials and actually degrades quality and productivity (McBride, 2003). The costs will rise due to inventory cost and other setback is difficulty to detect defects.

b. Waiting

According to EMS Consulting Group, typically more than 99% of a product's life in traditional batch-and-queue manufacture will be spent waiting to be processed. Much of a product’s lead time is tied up in waiting for the next operation. The factors that caused the situation is due to poor material flow, long production runs, and distances between work centers are too great. The waiting also become the concern of Goldratt (1984) in his book “*The Goal”* define bottleneck restricts the output of the entire system. An hour lost in one station can lead to one hour lost to the whole factory plant.

c. Transportation

All transportations may not be eliminated, but they have to be kept to the very minimum. Excessive material movement also can damage the product. Material handling also will cost a company while moving material may not increase their quality. One of classic example in manufacturing plant is looking for a pallet truck to move crates or pallets is a common occupation in the workshops. People most often claim for more trucks, but a proper set of rules, parking areas and discipline to bring them back after use is enough to solve availability problems.

d. Inappropriate processing

Utilizing costly and complex tools in the production process while simpler tool can solve the problem is also a waste. Companies need to spend money to buy tools that is not only expensive but also can consume space, jeopardize floor layout, poor operating procedures. Procedures and work guides which are not constantly updated also create a useless operation.

e. Unnecessary inventory

Excess inventory is a result of overproduction and waiting. The most common case is excess Work in Process (WIP) that will impede and tie up the cash flow (Arunagiri and Gnanavelbabu, 2014). Unnecessary inventory increases lead time, consume space, bear holding costs, and inhibits hidden defects.

f. Unnecessary motion

This waste is related to ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching. These are also health and safety issues. Jobs with excessive motion must be redesigned to prevent losses due to injuries and compensation. Among those excessive motion also includes walking to search missing item, bending to find missing documents and others.

g. Defects

Defects can be in the form of mistake by not following the right sequence, forgotten part that could not be seen in the messy area, spoiled parts because of dirt and others. The illustrations also demonstrate how important workplace organization for reducing defects. McBride (2013) stated that quality defects resulting in rework or scrap are a tremendous cost to organizations. Associated costs include quarantining inventory, re-inspecting, rescheduling, and capacity loss.

The first step in achieving that goal is to identify and reduce the seven wastes. As Toyota and other world-class organizations have come to realize, customers will pay for value added work, but never for waste. The strive for reaching world-class organizations by continuous improvement (CI) on the production process.

Lean provides extensive set of tools that can help to improve production process by removing waste. Lean is originated from automobile industry. However, it is not true and common misconception that lean is only suited to manufacturing industry. The success on implementation of lean can be achieved through stability of the system. According to Dennis (2007), activities (such as standard work, 5 Senses (5S), autonomation, TPM, Kanban, production levelling) and standardization (A3 thinking, standardized work, Kanban, Hoshin planning and 5S) can promote stability in the production process.

2.2.2. Six Sigma

Sigma, σ, is a letter in the Greek alphabet used by statisticians to measure the variability in any process. It is a rigid, focused, and highly effective quality principles and techniques aim to achieve error-free business performance. Six Sigma is not famous for its statistical techniques, but how it relies on tried and true methods that have been utilized in organization for the past decades.The term is not only famous among large manufacturing industry, but recently the application can also be implemented in small-medium enteprise (SME) and service industry. According to Pyzdek and Keller (2010), Six Sigma is a rigorous, focused, and highly effective implementation of proven quality principles and techniques. Incorporating elements from the work of many quality pioneers, Six Sigma aims for virtually error-free business performance. Bailey et al. (2001) comments that Six Sigma has the highest record of effectiveness compared to other widely used improvement approaches such as TQM, business process re-engineering and lean enterprises.

Six Sigma was originated from Motorola, when they are taken over by Japanese firm that produces Quasar Television in 1970s. Under Japanese firm, Motorola soon produced 1/20th as many defects as they have produced under Motorola management. With the same workforce, technology, and designs, it is clear that the problem lied on Motorola's management. In 1980s, Motorola started to initiate quality path of Six Sigma, later Motorola become the leader in profit and quality. Motorola managed to win the Malcolm Baldrige National Quality Award in 1988. The Six Sigma methodology then spread and developed by companies such as GE and AlliedSingal (Pyzdek & Keller, 2010). The development of DMAIC by GE is the most popular and effective Six Sigma project management tools.

The success of Six Sigma is regarding to benefits this methodology conveyed. Some authors argue that the main benefits Six Sigma contribute to industry are cost reduction, cycle time improvements, defects elimination, an increase in customer satisfaction, increase profits (Pyzdek and Keller, 2010; Stamatis, 2004; Dale et al., 2007; Breyfogle III et al., 2001). Banuelas et al. (2005) also argue the benefits of Six Sigma are increase in process knowledge, participation of employees in Six Sigma prhects, and problem solving using statistical thinking. An integral part in Six Sigma development is DMAIC. DMAIC stands for define, measure, analyze, improve and sustain which are interconnected and systematically help organizations to solve problem and improve processes (Jirasukprasert, 2014). Dale et al. (2007) briefly defined DMAIC as follows:

a. Define

   The early stage of DMAIC process involves defining team's role and goals of improvement activity. Common tools used in this phase are Voice of Customer (VoC) which is translated into Critical to Quality (CTQ) tree, supplier-input-process-output-customer (SIPOC) diagram, and project charter (including scope and boundary) of the DMAIC project (Gijo et al., 2011).

b. Measure

   Selecting measurement factors to be improved (Omachonu and Ross, 2004) and providing a structure to evaluate current performance as well as assessing, comparing and monitoring subsequent improvements and their capability (Stamatis, 2004).

c. Analyze

   The stage is to identify the root cause or defects of the problems (Omachonu and Ross, 2004), understand why the defects take place and assess the priority of defects to have improvement opportunities (Adams et al., 2013). Tool used to analyze the root cause of the problem occurred are cause effect diagram.

d. Improve

   The process is to find solutions in form of statistical techniques and experiments to generate possible improvement to reduce the problems identified in the analyze phase (Omachonu and Ross, 2004).

e. Control

   After improvements are implemented, it is essential to ensure the new improvements to be sustained. Process improvement besides being monitored and controlled, also need to be documented and institutionalized (Stamatis, 2004).

In statistics perspective, Six Sigma is a process that only produce 3.4 defect per million opportunity (DPMO). The concept is based on how the manufacturing process can achieve conformance with specifications which low in variation. Thus, standard variation is the basis of Six Sigma. The number of standard deviations that can fit within the boundaries set by the process represent Six Sigma. It is believed that ideal goal for Sigma level is 3.4, but statistically Six Sigma means 2 defects per million opportunity (DPMO) due to 1.5 sigma shift. The shift calculated Motorola as the Long Term Dynamic Mean Variation acts as buffer created as a compensation factor in order to protect the long term processes from unknown variation such as under standard environment conditions and environmental condition changes. Number of defect for several sigma shift of mean is shown in Table 2.2.

Table 2.2. Number of Defect and n-Sigma Shift from Process Mean

Source: dmaictools.com (2009)

Sigma Conversion Chart

Long Term Sigma Level	Short Term Sigma Level	Defects Per Million	Long Term Sigma Level	Short Term Sigma Level	Defects Per Million
4.5	6	3	1.9	3.4	28,717
4.4	5.9	5	1.8	3.3	35,930
4.3	5.8	9	1.7	3.2	44,565
4.2	5.7	13	1.6	3.1	54,799
4.1	5.6	21	1.5	3	66,807
4	5.5	32	1.4	2.9	80,757
3.9	5.4	48	1.3	2.8	96,800
3.8	5.3	72	1.2	2.7	115,070
3.7	5.2	108	1.1	2.6	135,666
3.6	5.1	159	1	2.5	158,655
3.5	5	233	0.9	2.4	184,060
3.4	4.9	337	0.8	2.3	211,855
3.3	4.8	483	0.7	2.2	241,964
3.2	4.7	687	0.6	2.1	274,253
3.1	4.6	968	0.5	2	308,538
3	4.5	1,350	0.4	1.9	344,578
2.9	4.4	1,866	0.3	1.8	382,089
2.8	4.3	2,555	0.2	1.7	420,740
2.7	4.2	3,467	0.1	1.6	460,172
2.6	4.1	4,661	0	1.5	500,000
2.5	4	6,210	-0.1	1.4	539,828
2.4	3.9	8,198	-0.2	1.3	579,260
2.3	3.8	10,724	-0.3	1.2	617,911
2.2	3.7	13,903	-0.4	1.1	655,422
2.1	3.6	17,864	-0.5	1	691,462
2	3.5	22,750			

Defect per million opportunites (DPMO) is a possibility for defectproduct in one million opportunities. The calculation of DPMO is the basis for Sigma level calculation. Sigma level calucalation rooted from the calculation of total opportunities (TOP), defect per opportunities (DPO), and DPMO. The calculation of TOP, DPO, and DPMO is shown in equation 2.1 to 2.3.

$$\mathrm{TOP} = \mathrm{O} \times \mathrm{U} \quad (2.1)$$

$$\mathrm{DPO} = \frac{\mathrm{D}}{\mathrm{TO}} \quad (2.2)$$

$$\mathrm{DPMO} = \mathrm{DPO} \times 10^6 \quad (2.3)$$

Where O is opportunity of defect (number of CTQ), U is number of product being inspected, DPO is number of nonconformity per opportunities. The value of DPMO can be converted into Sigma value by using Microsoft Excel, the formula is shown in equation 2.4.

$$Sigma = \mathrm{NORMSINV}\left(\frac{(10^6 - \mathrm{DPMO})}{10^6}\right) + 1{,}5 \quad (2.4)$$

2.2.3. The Integration of Lean Manufacturing and Six Sigma

Lean Six Sigma (LSS) is a business improvement methodology that aims to maximize shareholder value such as customer by improving quality, speed, customer satisfaction, and costs. It is achieved by combining the best tools found in Six Sigma and lean manufacturing. The tools can increase speed while also increasing accuracy in the implementation (Laureani & Antony, 2012).

Organizations face rising costs and increasing competition every day. LSS allows organization to combat the problem by providing structured and systematic methodology bear benefits such as:

a. Increases revenue by streamlining processes. The products or services can be completed faster and more efficient at no cost to quality.
b. Decreases costs by removing waste from a process and solving problems cause by a process such as defects in a product or service that cost organization money. LSS helps organization to fix processes that cost valuable resource.
c. Improve efficiency by maximizing organization efforts toward delivering a satisfactory product or service to customers which allows organization which allows organization to allocate resources produced in new improved processes towards growing business.
d. Develops effective employees by promoting active participation and results in an engaged and accountable team. Transparency throughout all levels of the organization promotes shared understanding of how each person is important to the organization's success.

Salah et al. (2010) stated that LSS approach enables people to choose the right tools to attack different problems, either quickly in the form of Kaizen event or using more n depth analysis for complex projects as shown in the example in Figure 2.2.

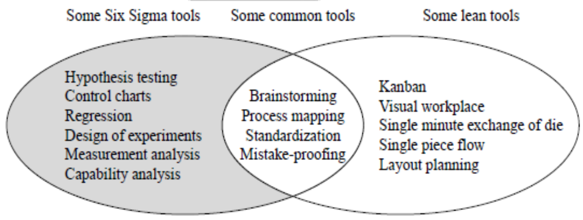


Figure 2.2. Example of Six Sigma and Lean Common Tools

2.2.4. Analytical Hierarchy Process

The human brain is divided into two halves or hemispheres, Sperry (1968) conducted split-brain research found that the left hemisphere of the brain is connected to logic, linear thinking, sequencing. While, the right hemisphere is connected to imagination, holistic thinking, intuition and others. A decision-making process basically is a combination between two elements of brain hemispheres. The issue is in which part of decision maker's brain that dominantly involves in the decision-making process. Many models eventually developed by human being as an effort to simplify the problem and ease the logic part of human brain, thus neglecting the emotional part of human brain. However, in the right brain hemisphere there is an element that is actually a combination logic and emotion, which is instinct. It is very important when the problem is very complex and full of uncertainty so logic consideration cannot simply provide resolution. (Bambang, 1992).

The Analytic Hierarchy Process (AHP) is a decision-making model basically covers the drawbacks of previous models. It was developed by Thomas L. Saaty in the late 1970s. The main tool in this model is a functional hierarchy with human perception as the input. With hierarchy, a complex and unstructured problem can be separated into groups and the group then arranged in the form of hierarchy. Furthermore, AHP model constructs the numerical pairwise comparison of an element with other elements in every level (Saaty, 1994). AHP technique is based on mathematics and psychology.

The difference of AHP with other models is on the type of the input. Previous models used the input that is quantitative or from secondary data. Automatically, the models only process a quantitative aspect. AHP model use the human perception that is considered as an expert as the main input. Human perception is a qualitative input which is important when it comes to a complex and unstructured real-world problems. The advantage of AHP is on its ability to solve multi-objective and multi-criteria problems. Unlike, linear programming that solve one objective with many criteria or constraints. The AHP model is flexible especially in constructing the hierarchy which enable the model to capture several objectives and several criteria at once. The AHP model also has the capability to solve problems that has opposite objectives and opposite criteria. The conditions enable AHP model to be used in real-world problems such as conflict, planning, projection and resource allocation. The steps in AHP method are shown in Figure 2.3.

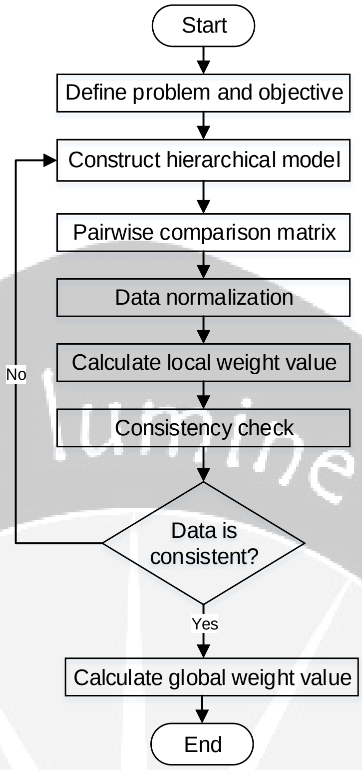


Figure 2.3. AHP Methodology Steps (Saaty, 1994)

a. Define the problem

   The problem in existing system is defined to determine the goal or objective. The objective must be determined clearly, it will be used as the top level of hierarchical model that will be explain in the next step.

b. Construct hierarchical model

   The problem will be modeled in the hierarchy structure based on observation and current problem understanding. The hierarchy is a basic tool used to overcome variability and solve complex system. By breaking down reality into homogeneous clusters and subdividing theses clusters into smaller ones, we can integrate large amounts of information into the structure of a problem and form a more complete picture of the whole system. The existing problem is transmitted into arithmetic form. Simple decision structure consists of three levels which are objective, criteria, and alternative. The three hierarchy levels is shown in Figure 2.5.

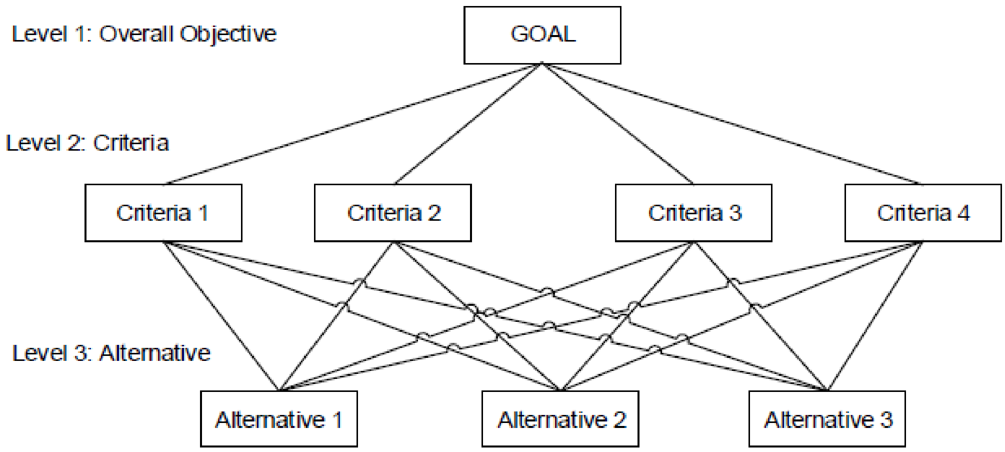


Figure 2.4. Simple Levels of Hierarchical Structure (Saaty, 1994)

c. Pairwise comparison

After developing the hierarchy, the decision makers judged the relative importance of all the elements. The goal is to identify the importance level relative to its criteria and sub criteria. They quantified these judgements by assigning the numbers from 1 to 9 and sometimes they disagreed. This involves the special ability in perceiving relationships among the things being observed, to compare pairs of similar things against certain criteria, and to discriminate between both members of a pair by judging the intensity of their performance for one over the other. The fundamental numeric scale developed to distinguish the intensity between elements (Saaty, 2012:73) is shown on Table 2.3.

Table 2.3. The Fundamental Numeric Scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgement slightly favor one activity over another.
5	Strong importance	Experience and judgement strongly favor one activity over another.
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to describe it.

This scale defines and explains the values 1 through 9 assigned to judgements in comparing pairs of like elements in each level of a hierarchy against a criterion in the next higher level. Experience has confirmed that a scale of nine units is reasonable and reflects the degree to which we can discriminate the intensity of relationships between element (Saaty, 2012:73).

In the beginning of pairwise comparison process, the numeric scale is inputted on square matrix with the dimension of n x n. The sample matrix for pairwise comparison is shown on Table 2.4.

Table 2.4. Sample Matrix for Pairwise Comparison

C	A_1	A_2	· · ·	A_7
A_1	1	5	· · ·	
A_2	1/5	1		
⋮	⋮			
A_7				1

For collaborative or group judgements on the element, the pairwise comparison value needed to be synthesized in the form of mean value using geometric mean.

Saaty and Aczel (1994) proved that geometric mean as general separable (S) synthesizing functions which only satisfies conditions such as unanimity (U), homogeneity (H) and reciprocal property (R) which is assumed even for a single n-tuple of the judgement of n individuals, where not all x_k are equal. The explanation of unanimity (U), homogeneity (H) and reciprocal property (R) according to Zopounidis and Pardalos (2010) are as follows:

i. Unanimity condition (U) means if all individuals give the same judgement *x,* that the judgement should also be the synthesized judgement.
ii. Homogeneity condition (H) means if all individuals judge a ratio *u* times as large as another ratio, then the synthesized judgement should also be *u* times as large.
iii. Reciprocal property (R) condition means the synthesized value of the reciprocal of the individual judgements should be the reciprocal of the synthesized value of the original judgement.

The mathematical equation for geometric mean is as follow:

$$\mu_{jk} = \sqrt[n]{a_{jk_1} a_{jk_2} \dots a_{jk_n}} \quad (2.5)$$

Annotation:

μjk = geometric Mean i^{th} row and j^{th} column

n = number of expert

d. Data normalization

Data normalization is the process of organizing the column (attributes) and tables (relations) of a relational data to reduce data redundancy and improve data integrity so is it is not unambiguous. Data is normalized by dividing each result in pairwise comparison matrix to the total of the corresponding column. The normalization is solved using mathematical equation as follow:

$$\bar{A}_{jk} = \frac{a_{jk}}{\sum_{j=1}^{n} a_{jk}} \quad (2.6)$$

Annotation:

$\bar{A}_{jk}$ = the result of dividing the value of the i row of the j column with the total value of the j column

a_{jk} = pairwise comparison value of the i row of the j column

$\sum_{j=1}^{n} a_{jk}$ = Total pairwise pairs of the j column

e. Calculate priority vector

Priority vector is also called as the normalized principal Eigenvector. The priority vector shows the relative weights among the things that are being compared, while Eigenvalue indicates how much the eigenvector is shortened or lengthened after multiplication by matrix *A* without changing the vector orientation. In other words, eigenvalue represents the influence of a criteria to the characteristics of related matrix. Priority matrix or the normalized principal Eigenvector is acquired by calculating the mean of each matrix row, the mathematical equation is shown as follow:

$$w_j = \frac{\sum_{j=1}^{n} \bar{A}_{jk}}{m} \quad (2.7)$$

Annotation:

w_j = eigenvector (priority vector) of j element

$\bar{A}_{jk}$ = total data normalization on j column

m = total element in a matrix

Eigenvalue value can be obtained from the summation of products between each element of Eigenvector and the sum of columns of the reciprocal matrix. Eigenvalue can be calculated by using mathematical equation as follow:

$$A \,.\, w = \lambda \,.\, \mathrm{w} \qquad (2.8)$$

Annotation:

A = Matrix

w = Eigenvector

λ = Eigenvalue

f. Consistency check

In decision making problems it may be important to know how good the consistency is, because it is important to avoid a decision to be based on judgements that have such low consistency that appear to be random. Certain degree of consistency between criteria and alternative needed to get valid results in the real world. The AHP measures the overall consistency of judgements by means of a *consistency ratio*. The value of consistency ratio should be 10 percent or less. In fact, 5% for a 3 x 3 matrix, 9% for a 4x4 matrix, and 10% for larger matrix. If it is more than 10 percent, the judgement may be somewhat random and should perhaps be revised. Consistency Index (CI) can be calculated with the formula as follow:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \qquad (2.9)$$

Annotation:

CI = Consistency Index

λ_{max} = Maximum Eigenvalue

n = ordo matrix number

The consistency test done repeatedly in each hierarchy level. Value of Consistency Ratio (CR) can be calculated with the formula as follow:

$$CR = CI/CR \qquad (2.10)$$

Annotation:

CI = Consistency Index

RI = Random Index

Random Consistency Index (RI) is a direct function of the number of factors being compared. RI is an appropriate Consistency Index (CI). The value of RI is shown in Table 2.5 (Saaty, 1994).

Table 2.5. Random Consistency Index (RI)

Ordo Matrix (n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

g. Calculate global weight value

The global weight value can be calculated by multiplying the value of the criterion weight, the weight value of sub-criteria and the value of the alternative weight. Global weight can be calculated with the formula as follow:

$$w_j^s = \sum_{k=1}^{m} w_{jk}^s . w_j \text{, j=1,…,n} \quad (2.11)$$

Annotation:

w_j^s = global weight of alternative j

w_{jk}^s = priority vector of alternative j with respect to attribute j

w_j = weight of attribute j

n = matrix ordo

2.2.5. Six Sigma DMAIC Tools

The tools used in DMAIC phase such as project charter, critical-to-quality (CTQ) tree, supplier-input-process-output-customer (SIPOC) diagram, process mapping, measurement system analysis, control chart, pareto chart, fishbone diagram, failure mode and effect analysis (FMEA), work instruction, check sheet, and hypothesis testing are explained as follows:

a. Project Charter

Project charter is a document that states elements such as problem statement, project objective, deliverables, sponsor and stakeholder groups, team memers, and project schedule. The document also can be considered as a contract between project team and its sponsor (Pyzdek and Keller, 2010).

Kublak and Benbow (2009) explained project charter as document that highlight the purpose of the project. Every charter must contains the following points:

i. Objective: determine the objective of the project.

ii. Benefit: how organization can perform better if the project has reached its objective
iii. Scope: set the project boundary in term of cost, time, and resources.
iv. Result: define the criteria or measurement of project accomplishment.

The example of project charter presented by Pyzdek and Keller (2010) is shown in Figure 2.5.

Project Charter

Project Name/Title: Order Processing Efficiency			Start Date: 9/17/07
Problem/Project Description: Current capacity in Sales/Customer Support area is constrained, while there are untapped opportunities for increased sales. We should limit, wherever possible, Sales involvement in order processing to free up resource for active lead follow-up and sales generation. In addition, errors and/or gaps in information acquired during Order Processing procedure have a negative impact on time required to generate, and/or receipt rate of, email marketing and software renewals to existing clients. This has an especially large potential impact, since it requires correction by senior sales staff, who might otherwise have more time to engage with clients, develop marketing efforts, or work with product development staff.			
Project Scope (Process, Product, functional areas): Limited to software products.			
Project Objectives & Goals:	*Metric*	*Baseline*	*Goal*
To decrease cycle time & costs of specific Sale Department activities: ➢ Order Processing by 50%+ ➢ Marketing to existing clients by 80+% ➢ Software renewals by 80+%	Cost/Order Time/campaign Time/update	$32 download $40 shipped 2-4 hours 2-4 hours	$16 download $20 shipped 20 minutes 20 minutes

Business Need	
Customer Impact:	Improved notification rate for renewals & upgrades; reduction in total cycle time as procedure more streamlined.
Shareholder Impact:	Increased sales potential, immediately on upgrades, but also for future sales with availability of sales staff; Reduced cost for order processing. Reduced costs for marketing & renewal campaigns.
Employee Impact:	Clearer responsibilities; Less interruption in process flow.

Project Sponsor:	*Stakeholder Group:*	*Signature / Date*
Peter Keene, VP	Sales & Operations	
Team Black Belt: Patrick Killihan		
Team Members: Don Debuski	Customer Support	
Helen Winkleham	Shipping & Packaging	
Anne Sheppard	Accounting	

DEFINE	MEASURE	ANALYZE	IMPROVE	CONTROL
Objective DateComplete	*Objective DateComplete*	*Objective DateComplete*	*Objective DateComplete*	*Objective Date Complete*
➢ Project Def. 9/17/07 ➢ Top level Process Def. 9/19/07 ➢ Team Formation 9/19/07	➢ Process Definition ____ ➢ Metric Def. ____ ➢ Estimate Baseline ____	➢ Value Stream Analysis____ ➢ Analyze Variation ____ ➢ Determine Drivers____	➢ Implement Process____ ➢ Assess Benefits____ ➢ Evaluate Failure Mode____	➢ Standardize Methods____ ➢ Control Plan____ ➢ Lessons Learned____

Figure 2.5. Example of Project Charter (Pyzdek and Keller, 2010)

b. Critical to Quality

Kublak and Benbow (2009) stated that critical to quality (CTQ) is a costumer requirement on quality characeteristics in general terms which is not specific and not measurable. Quality characteristics explained by Montgomery (2013) are as follows:

i. Physical: length, weight, voltage, and viscosity
ii. Sensoric: taste, appearance, and color
iii. Time orientation: reliability, durability, and serviceability

Product characteristics are classified by Evans and Lindsay (2007) as follows:

i. Performance: it is the main functionality charactersitcs of the product.
ii. Feature: accessory of a product.
iii. Reliability: the probability for a certain product to function after period of time and condition.
iv. Compliance: how many physical characters and its performance comply with the standard.
v. Durability: number of usage before the degradation of performance or product must be replaced.
vi. Service level: service quality, warranty, fixing competency.
vii. Estethics: how does the product look, felt, heard, and smelled.

Fulfilling customer requirement is often considered as minimum limit for a organization to sustain its business (Evans and Lindsay, 2007). The understanding of CTQ can help project team to select which Six Sigma project is the most important and bear significant results. CTQ identification requires the understanding on customer voice (voice of customer), the requirement expressed by the language of the customer itself which mostly general and not measurable, for example strong, light, etc.

Quality characteristics which are very general can be converted into a more measurable and specific using the tree diagram. According to Munro et al. (2015), tree diagram helps to breakdown main topic into several activities that influenced the main topic. The example of CTQ tree diagram presented by Pyzdek (2002) can be seen in Figure 2.6.

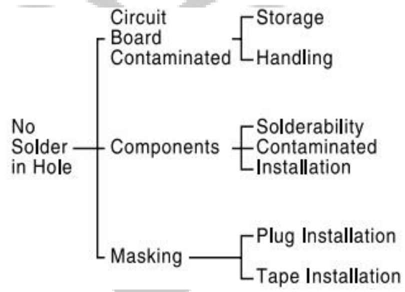


Figure 2.6. Example of CTQ Tree Diagram (Pyzdek, 2002)

c. SIPOC Diagram

High level mapping determine the DMAIC project scope by identifying the current process being studied, input and output of the process, and the supplier and customer. One of the example is supplier-input-process-output-customers diagram or known as SIPOC diagram, it is visualized in the form of work flow which shows the important elements in a process and help the project team to identify the party involved in the process from how the party acquire the input, how the process adds value. Input is a product or sevice needed by organization to produce value-added product (Evan and Lindsay, 2007). Output is the result of an input being processed, different output may have different customers. Both input and output can be originated from internal or external parties. A SIPOC diagram is one of the most useful models for business and vice processes, the example of SIPOC diagram presented by Yang and El-Haik (2003) is shown in Figure 2.7.

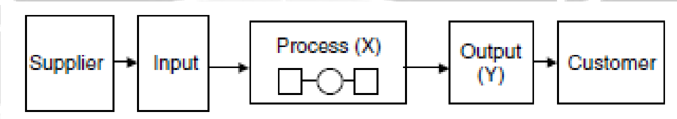


Figure 2.7. Example of SIPOC Diagram (Yang and El-Haik, 2003)

d. "As-Is" Process Map

Process mapping is an visualization method to ease the analysis and the agreement on redundant tasks, uncovering hidden interactions between process and people, and focus on the vital process that affect quality and customer satisfaction (Savory and Olson, 2001). Process map in Six Sigma commonly used in Six Sigma is high level process map or known as SIPOC diagram. However, there is another type of process map that can provide important outlook to project team on the current process. It is called as "As Is" process map.

"As-Is" process map define the current process in an organization, it visualizes the current state of the process in order to calrify exactly how the organization works today. The "As-Is" process map can show which process as a source of particular non conformities. Example of "As-Is" process map presented by Prashar (2014) is shown in Figure 2.8.

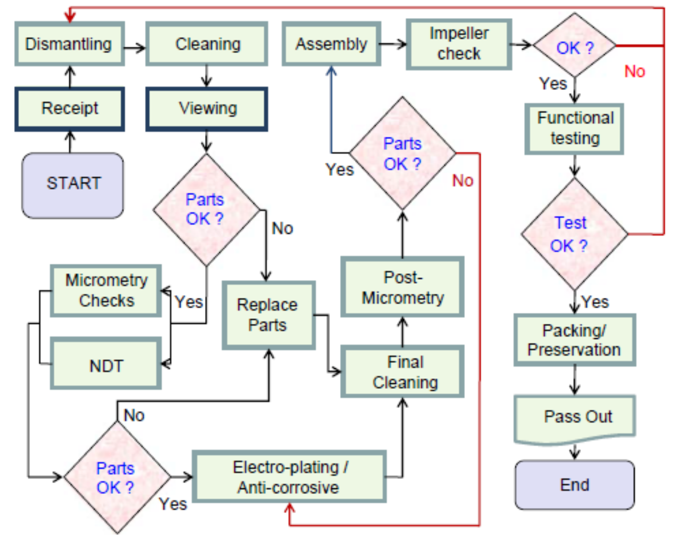


Figure 2.8. Example of "As-Is" Process Map (Prashar, 2014)

e. Pareto Diagram

Pareto diagram is originally based on the extensive studies of the wealth distribution in Europe by Alfredo Pareto (1948-1923). The result of unequal distribution of wealth (few people with lot of money and many people with few money) as part of economic theory. Dr. Joseph Juran later on recognized this concept as a universal tool that can be used in many problems and fields. Pareto diagrams are used to identify the most important problems. Example of Pareto diagram presented by Arthur (2007) is shown in Figure 2.9.

Tague (2005) stated the conditions suitable to use Paret chart are as follows:

i. Analyze data about the frequency of problems or causes in a process.
ii. If there are many problems or causes that are wanted to be focused on the most significant outcome.
iii. Analyze broad causes by looking at their specific components.
iv. Communicating with others about the data.

A Pareto diagram is a graph that ranks elaborates the data classifications in descending order from the left to the right. The horizontal scale shows the type of failure and the vertical scale shows the percentage of the failure. Pareto dan be distinguished from histograms in which the horizontal scale of Pareto is categorical whereas the scale for the histogram is numerical (Besterfield, 1994). Pareto diagram is used to determine the most important problems. Usually, 80% of the total results from 20% of the items. Besterfield (1994) elaborates the steps on constructing a Pareto diagram as follows:

1. Determine the method of classifying data: by problem, cause, type of non conformity and so forth.
2. Decide if monetary unit or frequency is to be used to rank the charcteristics.
3. Collect data for appropriate time interval.
4. Summarize the data and rank order categorization from largest to smallest.
5. Compute the cumulative percentage if it is to be used.
6. Construct the diagram and find the vital few.

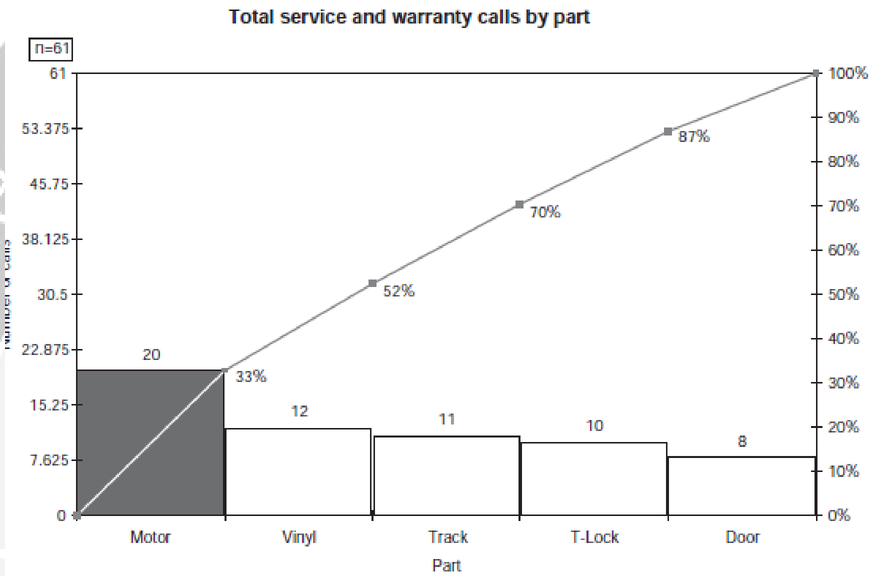


Figure 2.9. Example of Pareto Diagram (Arthur, 2007)

f. Measurement System Analysis (MSA)

MSA is a tool to check the measurement system to comply with existing standards. The data to be processed must be valid so that required a measurement system analysis. A good measurement system has small measurement errors. A good measurement system should be accurate and precise. Accuracy includes linearity, bias, and stability. Precision includes repeatability and reproducibility. Pyzdek and Keller (2009) defines the following terms:

i. Accuracy is the conformity of measurement result with current standards. In other words, items measured are correctly categorized.
ii. Repeatability is the variation in measurement obtained with one measurement instrument when used several times by one appraiser on the same conditions.

iii. Reproducibility is the variation in the average of the measurements made by different appraisers using the same measuring instrument when measuring the identical characteristic on the same part.

MSA is distinguished by the type of data, MSA for varible data and attribute data. MSA for variable data is Gage R & R. The MSA for attribute data is the Attibute Agreement Analysis (ARR). A good measurement system has high percentage of accuracy, repeatability, and reproducibility. The level can also be analyzed using kappa coefficient, fleiss kappa is used to compare more two appraisers while cohen kappa is used to compare only two appraisers. A statistics test can be performed to evaluate current MSA using Z-test, the p-value is compared with significance level. If p-value is smaller than significance level, then kappa coefficient is high, which means the measurement system has high accuracy, reproducibility, and reliability.

The value of Kappa coefficient is explained by Fleiss (1981) as the agreement between appraiser with appraiser or appraiser with standard. The Kappa coefficient range from -1 to 1. The value intepretaion is explained by Minitab (2014) are as follows:

i. When Kappa = 1, perfect agreement exists.
ii. When Kappa = 0, agreement is the same as would be expected by chance
iii. When Kappa < 0, agreement is weaker than expected by chance

Automotive Industry Action Group (AIAG) suggests that the preferable Kappa value is minimum 0.75, but it is preferable to achieve larger Kappa value to 0.90. MSA evaluates measurement within appraisers (repeatability), appraiser vs standard (accuracy), between appraisers (reproductibility), all appraisers vs standard (accuracy).

g. Control Chart

Control chart visualizes the variations that occur in central tendency used to monitor quality, it is the basis for process capability analysis. There are two types of control chart based on its quality characteristics such as control chart for variable data and control chart for attribute data. Control chart for variable data consists of c-chart and n-p chart. While control chart for attribute data depends on the attribute data which is nonconforming or nonconformities. Both of this terms are explained by Besterfield (1994):

i. Nonconformity is the degradation of quality characteristic from its intended level or state that occurs with severe effect in which a product or service does not meet a specification requirement. The term is similar to defect, expect the term defect is used to express usage and functionality of product, while nonconformity is to express the conformace to specification.

ii. Nonconforming is used to describe a unit of product or service that contains at least one nonconformity. The term is similar to defective, exceopt the term defective is used to express usage or functionality.

Based on nonconformity units and nonconfirming untis, Besterfield (1994) presents when to use various attribute charts such as np-chart, c-chart, p-chart, or c-chart as shown in Table 2.6.

Table 2.6. When to Use Various Attribute Charts (Besterfield, 1994)

		Attribute Chart	
		Nonconforming Units	**Nonconformities**
Sample Size	**Constant**	np	C (n=1)
	Constant or Varies	p	u

Np-chart and p chart is used for nonconforming units, while c-chart and u chart is used for nonconformity. It is emphasized by Besterfield (1994) that u-chart can be used both for constant and varies sample size to control number of defect per unit. Example of u-chart presented by Besterfield (2012) is shown in Figure 2.10.

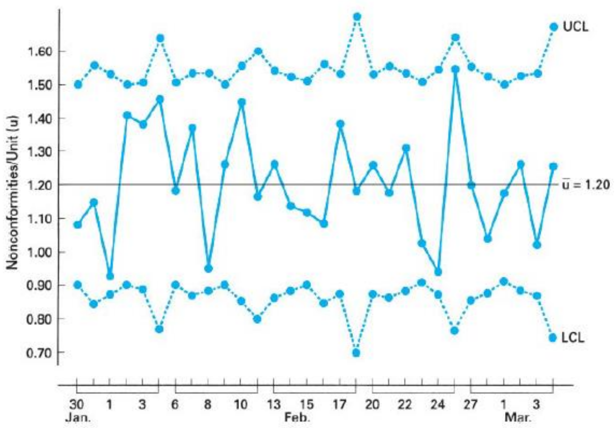


Figure 2.10. Example of U-chart (Besterfield, 2012)

U-chart consists of centre line (CL), lower control limit (LCL), upper control limit (UCL). Center line is the mean of defect per unit. Two other horizontal lines are called as upper control milit (UCL) and lower control limit (LCL). It is hoped that the data falls within the UCL and LCL. If the data falls outside the control limit, it is assumed that the process is out of control and an investigation is needed to find and eliminate the causes. The formula to calculate CL, UCL, and LCL are as follows:

$$CL = \bar{u} \tag{2.12}$$

$$LCL = \bar{u} - 3\sqrt{\frac{\bar{u}}{n_i}} \tag{2.13}$$

$$UCL = \bar{u} + 3\sqrt{\frac{\bar{u}}{ni}} \tag{2.14}$$

$$\bar{u} = \frac{\sum c_i}{\sum n_i} \tag{2.15}$$

Where u is number of nonconformities per unit, n is sample size, c_i is total nonconformities, and $\bar{u}$ is average number of nonconformities per unit.

h. Cause-Effect Diagram (Fishbone Diagram)

Cause-effect diagram, also known as fishbone diagram is picture composed of lines and symbols to represent the meaningful relationships between an effect with its causes. It is developed by Dr. Kaoru Ishikhawa in 1943. The diagram enables the study on the bad effect and take action to correct the causes. On the other hand, the diagram also enables the study of good effect and learn from the positive causes. The effect is the characteristics with numerous root cause needed to be improved.

Causes are usually broken down into major causes of work methods, materials, measurement, people, and environment. Each major causes is further subdivided into minor causes (Besterfield, 1994). The fishbone diagram is useful in:

i. Analyzing te actual condition for the purpose of product or service quality improvement, more efficient use of resources, and reduced costs.
ii. Elimination of conditions causing nonconforming product and customer complaints.
iii. Standardization of existing and proposed operations.

iv. Education and training of personnel in decision-making and corrective-action activities.

Besterfield (1994) outlines the first step taken in constructing fishbone diagram is the project team to identify the effect or quality problem. Then determining the major causes, followed by minor causes. The points are gathered through team member brainstorming sessions. Brainstorming is an idea-generating technique that is well-suited in the construction of fishbone diagram. Once the diagram is completed, the fishbone diagram needs to be evaluated to determine the most likely causes, in this case using PFMEA can enhanced major causes quantified in RPN value. Example of fishbone diagram presented by Bass (2007) is shown in Figure 2.11.

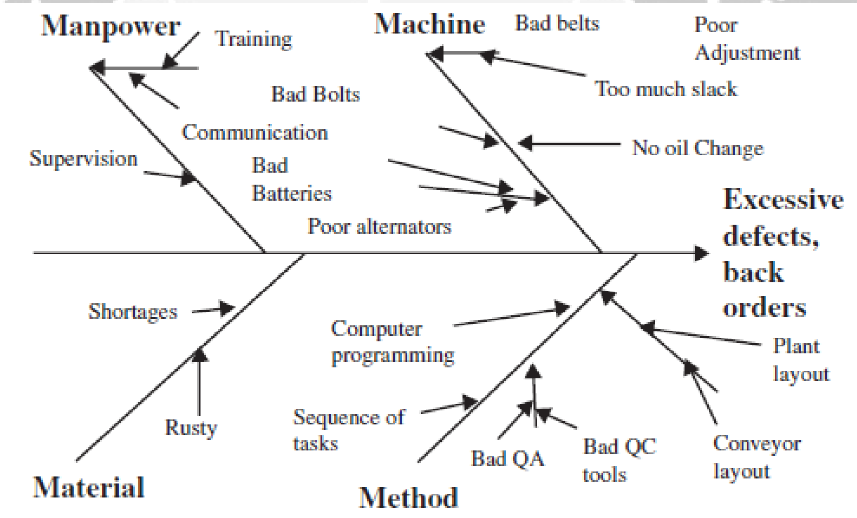


Figure 2.11. Example of Fishbone Diagram (Bass, 2007)

i. Process Failure and Mode Effect Analysis (PFMEA)

Failure and Mode Effect Analysis (FMEA) is an engineering realibility tool that helps engineer to reduce or eliminate potential failure modes based on identification of potential failures in the process or design. FMEA defines the the following elements:

i. Effect and severity of the failure modes
ii. Causes and occurrence of the failure modes
iii. Current control for failure modes detection
iv. Recommendation or solution to overcome failure modes

FMEA is powerful because it quantifies and prioritize the risks associated with the failure modes (Stamatis, 2014). It is very important to organization to improve and gain superior competitive advantage by having faster development time, reduction of overall cost, improved quality of product or service. There are four common classes of FMEA according to Morris (2011) such as:

i. System FMEA (SFMEA) which focuses on the interactions among systems might fail.
ii. Design FMEA (DFMEA) which focuses on how product design might fail.
iii. Process FMEA (PFMEA) which focuses on how processes that make product might fail.
iv. Machinery FMEA (MFMEA) which focuses on how machinery that perform processes might fail.

The PFMEA is used in this case study to reduce the potential causes of failure modes in the production system. PFMEA enables project team to analyze manufacturing or assembly that focuses on input of the process, while DFMEA is used for analyzing on development phase to enhance design (Yang and El-Haik, 2003). PFMEA is a living document that should be reviewed and managed on a continuous basis. The layout of PFMEA document is shown in Table 2.7.

Table 2.7. Layout of PFMEA Document

Process Description	Potential Failure Mode	Potential Effect of Failure	SEV	Potential Causes	OCC	Current Control Prevention	DET	RPN	Recommended Action

There are no standard or universal cirteria for ranking any FMEA. However, Stamatis (2014) defines the typical rating for ranking any PFMEA shown in Table 2.8. through Table 2.10. The steps to implement PFMEA are as follows:

1. Identify the scope and process stage.
2. Indentify the potential failure mode. Failure mode focuses on how the function can fail. According to Stamatis (2014), There are six minimum failures for each function such as: no function (product does not work), degradation (the function fails over time), intermittent (the function sometimes work and sometimes does not), partial (the function does not work at full cycle), unintended (the function acts in a suprising manner).
3. Identify the potential failure effects. Effect is a description of what will happen to user if the system fails.

4. Identify severity (SEV). Severity is the subjective measurement on indicating the effect of failure mode to user or customer. The rating is given from 1-10, the higher the value the worst the effect of failure towards user or customer. Severity value rating is shown in Table 2.8.

Table 2.8. PFMEA Severity (Stamatis, 2014)

Effect	Description	Rating
None	No effect noticed by customer. The failure will not have any effect on the customer.	1
Very minor	Very minor disruption to production line. A very small portion of the product may have to be reworked. Defect noticed by discriminating customers.	2
Minor	Minor disruption to production line. A small portion (much < 5%) of product may have to be reworked online. Process up, but minor annoyances exist.	3
Very low	Very low disruption to production line. A moderate portion (< 10%) of very low product may have to be reworked online. Process up, but minor annoyances exist.	4
Low	Low disruption to production line. A moderate portion (< 15%) of product may have to be reworked online. Process up, but some minor annoyances exist.	5
Moderate	Moderate disruption to production line. A moderate portion (> 20%) of product may have to be scrapped. Process up, but some inconveniences exist.	6
High	Major disruption to production line. A portion (> 30%) of product may have to be scrapped. Process may be stopped. Customer dissatisfied.	7
Very High	Major disruption to production line. Close to 100% of product may have to be scrapped. Process unreliable. Customer very dissatisfied.	8
Very High	May endanger operator or equipment. Severely affects safe process operation and/or involves noncompliance with government regulations. Failure will occur with warning.	9
Hazard with no warning	May endanger operator or equipment. Severely affects safe process operation and/or involves noncompliance with government regulations. Failure occurs without warning.	10

4. Determine the potential cause of failure mode. It is an indication of process weakness, common ways to determine causes are brainstorming, 5 whys, fishbone diagram, and fault tree analysis (FTA).

5. Determine the probability of occurrence (OCC). The rating is given from 1-10, the higher the value the higher the probability of failure and its associated cause to take place. Occurrence value rating is shown in Table 2.9.

Table 2.9. PFMEA Occurrence (Stamatis, 2014)

Occurrence	Description	Frequency	Rating
Remote	Failure is very unlikely. No failures associated with similar processes	<1 in 1,500,000	1
Low	Few failures. Isolated failures associated with the processes	1 in 150,000	2
		1 in 15,000	3
Moderate	Occasional failures associated with similar processes but no in major proportions	1 in 2000	4
		1 in 400	5
		1 in 80	6
High	Repeated failures. Similar processes have often failed	1 in 20	7
		1 in 8	8
Very High	Process failure is almost inevitable	1 in 3	9
		> 1 in 2	10

6. Determine current prevention controls. The planning to avoid the cause happening or reduce the rate of occurrence.
7. Determine detection value (DET). Detection is a subjective judgement on the design control to detect the potential failure modes and potential causes. The rating is given from 1-10, the higher the value the more effective the current detection or prevention of potential cause of subsequent failure mode. Detection value rating is shown in Table 2.10. In order to achieve lower ranking, a detection system must be improved by verification and validation.

Table 2.10. PFMEA Detection (Stamatis, 2014)

Effect	Description	Rating
Almost certain	Process control will almost certainly detect or prevent the potential cause of subsequent failure mode	1
Very high	Very high chance process control will detect or prevent the potential cause of subsequent failure mode	2
High	High chance the process control will detect or prevent the potential cause of subsequent failure mode	3
Moderately high	Moderately high chance the process control will detect or prevent the potential cause of subsequent failure mode	4
Moderate	Moderate chance the process control will detect or prevent the potential cause of subsequent failure mode	5
Low	Low chance the process control will detect or prevent the potential cause of subsequent failure mode	6
Very low	Very low chance the process control will detect or prevent the potential cause of subsequent failure mode	7

Table 2.10. (Cont'd)

Remote	Remote chance the process control will detect or prevent the potential cause of subsequent failure mode	8
Very remote	Very remote chance the process control will detect or prevent the potential cause of subsequent failure mode	9
Very uncertain	There is no process control, or control will not or can not detect the potential cause of subsequent failure mode	10

8. Calculate risk priority number (RPN). The RPN is the product of severity (SEV), occurrence (OCC), and detection (DET). Every root cause has its own RPN value, the value is often used to determine the priority for operational improvement in PFMEA.
9. Propose or recommend action plans to overcome the failure modes. There can be more than one action plan. The objective is to reduce the modes with high severity and occurrence.
10. Analyze PFMEA after implementation process to recognize the improvement effect on reducing failure modes.

j. Work Instruction

Work instruction is a written procedures which provide step by step directions on how to perform a task. It is one of job aids tools, which requires workers to perform tasks with numerous steps. Work instruction can help reducing worker's reliance on skill and memory to perform task, assist worker in decision making and help to ensure a given task is perform consistently (Rooney et al., 2002).

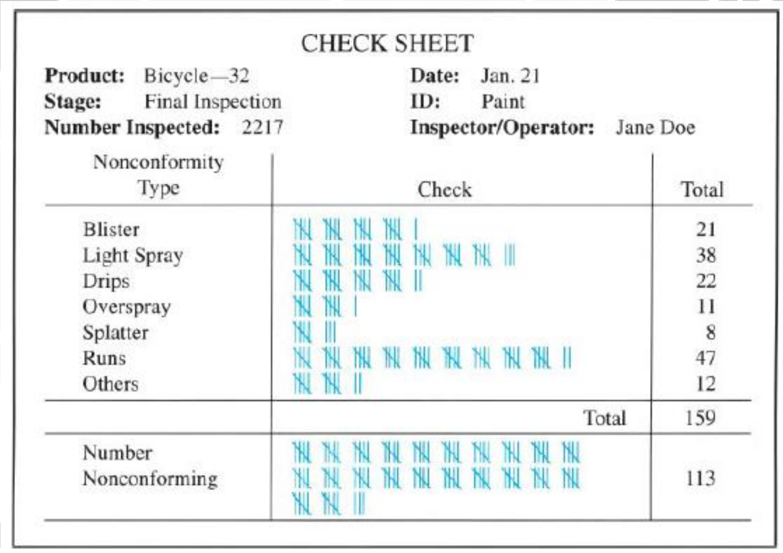
The work instruction must be consice, easy to understand, contains visual aid to ease the understanding of workers. Providing work instruction nearby where it should be used is also important, if the are current area is not possible, work instruction can be placed in centralized area. Rooney et al. (2002) states the principles to increase work procedure effectiveness as follows:

i. Select a procedure style or format that is useable, familiar and best communicates with worker.
ii. Ensure the procedure is accurate and complete to maintain credibility and sustainbale to be used in the workplace.
iii. Include several detail in each procedure, this can be done by including warning, cautions, and other critical parameters for workers at all level of expertise.

iv. Use simple and consice language such as active voice, complete language, and simple sentences to reduce the potential for errors.

k. Checksheet

Checksheet is one of seven quality tools that ensures the data are collected careufully and accurately by operating personnel (Yang and El-Haik, 2003). Data should be collected easily to be used and analyzed. When measurement data become too discrete for statistical process control (SPC), checksheet is used to monitor the system (Pyzdek and Keller, 2009). As addition, the checksheet form must be designed to show location that enables management team to find the source of the nonconformities. Example of checksheet presented by Besterfield (2012) is shown in Figure 2.12.



CHECK SHEET

Product: Bicycle—32 **Date:** Jan. 21
Stage: Final Inspection **ID:** Paint
Number Inspected: 2217 **Inspector/Operator:** Jane Doe

Nonconformity Type	Check	Total
Blister		21
Light Spray		38
Drips		22
Overspray		11
Splatter		8
Runs		47
Others		12
	Total	159
Number Nonconforming		113

Figure 2.12. Example of Checksheet (Besterfield, 2012)

l. Operator Training

Training is a process for providing required skills to the employee for doing the job effectively and develop skill to a desired standards by institution or organization. Operator training is conducted to educate operator on how to do work, recognize quality issue, operate machine safely, and consult if they have problem at work (Anjoran, 2016). Employee training is not only restricted to new operators. Von Bodelschwigh and Pausch (2003) describe the training of an experienced operator on a machine that he owns, reaches working plateau.

A research conducted by Aalmo (2014) on operator performance improvement through training shows an improvement in completion time, reduction in variability, provide support for learning-curve, and trainee respond rapidly to instructions. As addition, the effects of training stated by Jacobs (2006) are as follows:

i. The time required to complete a given task or unit of a product will decrease each time the task is undertaken.
ii. The time taken will decrease at a decreasing rate.
iii. The reduction of time taken will follow a predictable pattern.

m. Andon Systems

The word Andon means paper lantern in Japanese and is a system which provides visual feedback to the plant floor (Zidel, 2006). It indicates status of particular line for help and assistance whenever it is needed. The Andon consists of several buttons and chords. Common Andon light consists of three colors, green Andon indicates a normal machine operation, yellow Andon indicates the worker needs assistance and a possible delay in the station, a red Andon indicates a stop of machine and requires immediate response from team such as supervisor or team leader to investigate and apply corrective actions.

Lean manufacturing refers Andon to any visual management tools that show the status of the plant floor. The signal is visible and very easy to understand. Today, more sophisticated visual displays are often used in the Andon system. Andon is an effective communication tool that provide information to plant floor, encourage immediate response towards defects, highlight downtime, safety problems, and increasing worker to improve their performance in producing product as specified (Ragnmark and Westin, 2015).

n. Hypothesis Testing

Hypothesis is a value judgement and current opinion about the population. Lean Six Sigma is closely related with variation and central tendencies, in which project team might want to prove that the averages or variation are the same or different (Arthur, 2007). This is why hypothesis testing involves two hypotheses to be evaluated. The same or queal result would be called as null hypothesis (H_0). Then, based on the analysis, we want either to accept or reject the null hypothesis. The rejection of H_0 depends on the value of α and significance level. P-value is the minimum significance level to reject the H_0. The smaller the p-value, the higher the confidence would reject H_0. There are two types of error from decision-making procedure:

i. Error type I (α) is to reject the correct null hypothesis (H_0).
ii. Error type II (β) is to unable to reject the wrong null hypothesis (H_0).

Pyzdek and Keller (2009) outlines the four general steps in hypothesis testing:

1. Formulating a hypothesis about the population
2. Collecting a sample of observation from the population
3. Calculating statistics based on the sample
4. Either accept or reject the hypothesis based on predetermined acceptance criterion.

Hypothesis testing can be done with one-tail and two-tail. Hypothesis testing is categorized as one-tail if alternative hypothesis involves a statement of more than or less than. When it involves a statement 'not equal to' is a two-tail. Bass (2007) explains several hypothesis types such as:

i. Testing for Population Mean with Known Variance

   Mean with known variance and normally distributed, for one population can be calculated with equation 2.15.

$$Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}} \quad (2.16)$$

   Mean with known variance, for two populations can be calculated with equation 2.16.

$$Z = \frac{\bar{X}_1 - \bar{X}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1{}^2}{n_1} + \frac{\sigma_2{}^2}{n_2}}} \quad (2.17)$$

   Where $\bar{X}$ is sample mean, μ is population mean , σ is population standard deviation, *n* is sample size.

ii. Hypothesis Testing about Proportion

   Hypothesis testing can be applied to sample proportions. Control limit theorem is used. The distribution of the mean can be calculated with equation 2.17.

$$Z = \frac{\bar{p} - p}{\sqrt{\frac{p.q}{n}}} \quad (2.18)$$

   Where $\bar{p}$ is sample proportion, *p* is the population proportion, *n* is the sample size, and *q = 1 – p.*

iii. Hypothesis Testing about Variance

Distribution of variance follows a chi-square distribution. The formula for single variance is shown in equation 2.18.

$$X^2 = \frac{(n-1)S^2}{\sigma^2} \tag{2.19}$$

Where σ^2 is the population variance, S^2 is the sample variance, and *n* is the sample size.

iv. Hypothesis Testing about Mean (T-test)

The population is distributed normally with unknown variance. T-test consists of two types, test for one population and test for two populations. The variance is assumed equal (if sample 1 and sample 2 are almost the same) or unequal. The calculation can be performed by using equation 2.19.

$$t = \frac{\bar{X}_1 - \bar{X}_2 - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{2.20}$$

Interpretation of p-value in 2-sample t Minitab software:

1. P-value ≤ α: The difference between the means is statistically significant (Reject H_0)
2. P-value > α: The difference between the means is not statistically significant (Fail to reject H_0)