UNIVERSITAS INDONESIA

ISTIA
UNIVERSITE D'ANGERS

IMPLEMENTASI PROSES DAN ALAT PERBAIKAN MUTU DENGAN PENDEKATAN LEAN DAN SIX SIGMA

TESIS

Diajukan sebagai salah satu syarat untuk memperoleh gelar Magister Teknik

INDRA FERIADI
0906579241

FAKULTAS TEKNIK
PROGRAM STUDI TEKNIK MESIN
DEPOK
JULI 2011

HALAMAN PERNYATAAN ORISINALITAS

Tesis ini adalah hasil karya saya sendiri,

dan semua sumber baik yang dikutip maupun dirujuk

telah saya nyatakan dengan benar.

Nama	:	Indra Feriadi
NPM	:	0906579241
Tanda Tangan	:	
Tanggal	:	11 Juli 2011

HALAMAN PENGESAHAN

Tesis ini diajukan oleh

Nama	:	Indra Feriadi
NPM	:	0906579241
Program Studi	:	Teknik Mesin
Judul	:	Implementasi proses dan alat perbaikan mutu dengan pendekatan Lean dan Six Sigma

Telah berhasil dipertahankan di hadapan Dewan Penguji dan diterima sebagai bagian persyaratan yang diperlukan untuk memperoleh gelar Magister Teknik pada Program Studi Teknik Mesin, Fakultas Teknik, Universitas Indonesia.

DEWAN PENGUJI

Pembimbing	:	Prof. Abdessamad Kobi
Penguji	:	Dr. Delphine Lalane
Penguji	:	Dr. Sebastien Lahaye
Penguji	:	Prof. Abdessamad Kobi

Ditetapkan di : Angers – Perancis
Tanggal : 11 Juli 2011

Mengetahui,
Ka. Departemen Teknik Mesin
Fakultas Teknik – Universitas Indonesia

Dr. Ir. Harinaldi. M. Eng

KATA PENGANTAR

Puji syukur saya panjatkan kepada Tuhan Yang Maha Esa, karena atas berkat dan rahmat-Nya, saya dapat menyelesaikan tesis ini. Penulisan tesis ini dilakukan dalam rangka memenuhi salah satu syarat untuk mencapai gelar ganda (Double Degree) Magister Teknik Program Studi Teknik Mesin pada Fakultas Teknik Universitas Indonesia dan Master 2 System Engineering and Project Management pada ISTIA – Universite d'Angers, Perancis.

Saya menyadari bahwa, tanpa bantuan dan bimbingan dari berbagai pihak, dari masa perkuliahan sampai pada penyusunan tesis ini, sangatlah sulit bagi saya untuk menyelesaikan tesis ini. Oleh karena itu, saya mengucapkan terima kasih kepada:

1. Prof. Abdessamad Kobi selaku dosen pembimbing yang telah menyediakan waktu, tenaga, dan pikiran untuk mengarahkan saya dalam penyusunan tesis ini.
2. Orang tua dan keluarga saya yang telah memberikan bantuan dukungan material dan moral.
3. Sahabat DDIP Angers yang telah banyak membantu saya dalam menyelesaikan tesis ini.

Akhir kata, saya berharap Tuhan Yang Maha Esa berkenan membalas segala kebaikan semua pihak yang telah membantu. Semoga tesis ini membawa manfaat bagi pengembangan ilmu.

Angers, 11 Juli 2011

Penulis

HALAMAN PERNYATAAN PERSETUJUAN PUBLIKASI TUGAS AKHIR UNTUK KEPENTINGAN AKADEMIS

Sebagai civitas akademik Universitas Indonesia, Saya yang bertanda tangan dibawah ini :

Nama	: Indra Feriadi
NPM	: 0906579241
Program studi	: Teknik Mesin
Departemen	: Teknik Mesin
Jenis karya	: Tesis

Demi pengembangan ilmu pengetahuan, menyetujui untuk memberikan kepada Universitas Indonesia hak bebas royalti non eksklusif (non-exclusive royalty-free right) atas karya saya yang berjudul : **Implementasi proses dan alat perbaikan mutu dengan pendekatan Lean dan Six Sigma** beserta perangkat yang ada (jika diperlukan). Dengan hak bebas royalti nonekslusif ini Univesitas Indonesia berhak menyimpan, mengalihmedia/formatkan. Mengolah dalam bentuk pangkalan data (database), merawat dan mempublikasikan tugas akhir saya tanpa meminta izin dari saya selama tetap mencantumkan nama saya sebagai penulis/pencipta dan sebagai pemilik hak cipta.

Demikian pernyataan ini saya buat dengan sebenarnya

Dibuat di : Angers
Pada tanggal : 11 Juli 2011

Yang menyatakan

(Indra Feriadi)

ABSTRAK

Nama : Indra Feriadi
Program Studi : Teknik Mesin
Judul : Implementasi proses dan alat perbaikan mutu dalam pendekatan Lean dan Six Sigma

Studi ini bertujuan untuk mengidentifikasi implementasi dari proses dan alat dari proyek perbaikan mutu. Menyediakan fase-fase beserta kegiatannya untuk menjalankan sebuah proyek perbaikan mutu. Studi ini juga menyajikan jenis-jenis alat dan teknik yang digunakan untuk mencapai tujuan dalam setiap tahapan proyek.

Studi ini mencatat bahwa berbagai jenis pendekatan manajemen mutu memiliki kesamaan dalam langkah proses dan alat yang digunakan dalam setiap proses. Terdapat empat langkah umum dalam sebuah proyek perbaikan, yaitu: 1. Identifikasi dan penetapan sebuah proyek perbaikan, 2. Mendiagnosa penyebab masalah, 3. Menghilangkan penyebab masalah, 4. Mempertahankan pencapaian dari hasil perbaikan. Disamping itu didapatkan juga bahwa sebuah alat sangat mungkin untuk dipakai di dalam lebih dari satu tahap atau proses.

Kata kunci:
Perbaikan mutu, implementasi proyek, alat dan teknik, Lean Six Sigma.

ABSTRACT

Name : Indra Feriadi

Study Program : Mechanical Engineering

Title : Implementation of quality improvement process and tools in Lean and Six Sigma approach.

This paper attempts to identify the implementation of process steps and tools in a quality improvement project. It provides phases and its activities to perform a project of quality improvement process. It also present kinds of tools and techniques are used to achieved goals in every steps of project.

This study note that various quality management approaches has a similarity in process steps and tools. There are four general steps in an improvement project. Those are identify and establish an improvement project; diagnose the cause of problems; remedy the cause of problem; and Hold the gains. It also provides most commonly tools applied in quality and a process improvement project.The application of a tool in more than one phase into a project is very possible.

Key Word: Quality improvement, project implementation, tools and techniques, Lean Six Sigma.

DAFTAR ISI

DAFTAR TABEL

DAFTAR GAMBAR

DAFTAR LAMPIRAN

CHAPTER 1
INTRODUCTION

1.1 Background

As business competition gets tougher, there is much pressure on product development, manufacturing, and service organization to become more productive and efficient. Developers need to create innovative products in less time, even though the products may be very complex. Manufacturing organization feel growing pressure to improve quality while decreasing cost and increasing production volumes with fewer resources. Service organization must reduce cycle times and improve customer satisfaction.

Many organizations, especially large organizations, have been proved being able to improve product quality and productivity at low cost by adopting varies of quality initiative or management approaches. As a quality management, Total Quality Managements, Six Sigma, Design for Six Sigma, Lean, and Lean Six Sigma can be seen to have brought many positive elements to continuous improvement. Large multinational firms such as General Electric, Honeywell, Motorola, and Toyota proved the value of those approaches by devoting substantial amounts of resources (people, time and money) and creating new infrastructure.

This study addresses the understanding of continuous improvement approach mentioned above. Especially about process steps and tools and techniques have been applied in a quality initiative project in order to improve quality and productivity in a business process.

1.2 Problem Statement

As mentioned above, many industries have been successfully implemented quality management approaches, especially in many large corporations. However, the question is how do they implement these quality improvement projects? From this question, the problems are bringing out into questions as follow:

1. What are the process steps in a quality improvement project?
2. What kind of tools and technique has been applied in process steps of project?

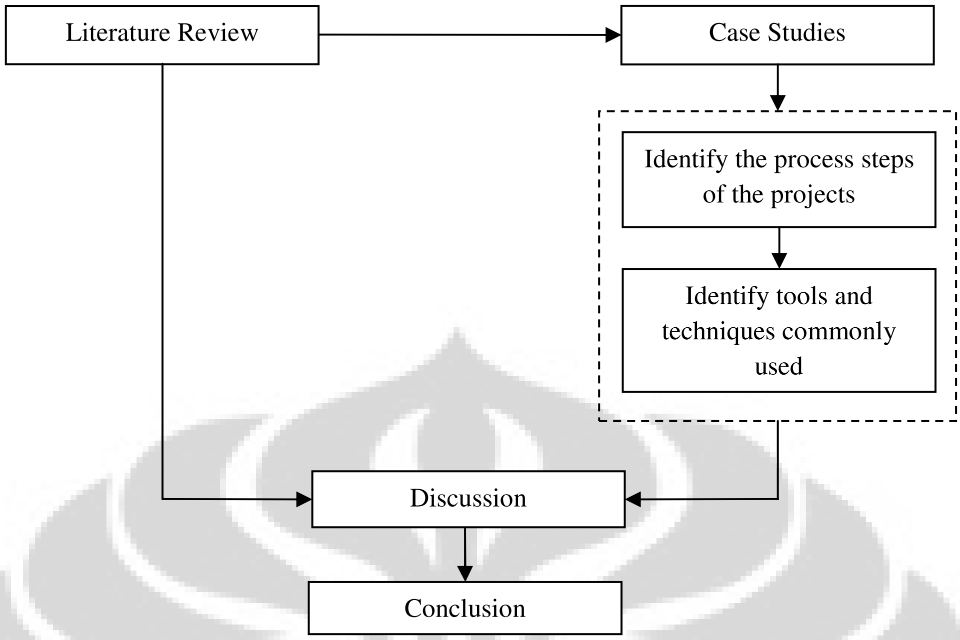
1.3 Objective and Scope

The objective is to find out how the quality improvement approach project was implemented and what kinds of tools and technique mostly used. The scope of this study focused on a review of process steps and application of tools and techniques in every phase of a quality improvement projects.

Through this study, it expected that can giving a comprehensive understanding of an implementation of quality improvement project and the application of tools and techniques in order to perform every stage of the project.

1.4 Methodology

This study conducted based on following steps. First stage of study is a literature review to understanding process steps and tools used in every steps of that quality improvement project. Journals, research articles, and thesis are used to find data and information about the application of quality management approach such as Six Sigma, Design for Six Sigma, Lean Manufacturing, and Lean Six Sigma. In the secondary steps perform a study of improvement projects from several industrial case studies. The goal of this step is to get a comprehensive understanding of a project implementation. The last step of this study is to identify the application of tools and techniques were commonly used in those projects. The flow of this method can see in the following scheme.


Literature Review
Case Studies
Identify the process steps of the projects
Identify tools and techniques commonly used
Discussion
Conclusion

CHAPTER 2
LITERATURE REVIEW

2.1 Six Sigma

2.1.1 What is Six Sigma?

History of Six Sigma

Six Sigma as recognised today was developed at Motorola through the efforts of Bill Smith, a reliability engineer. In the early and mid-1980s with Chairman Bob Galvin, they decided that the traditional quality levels -- measuring defects in thousands of opportunities -- didn't provide enough granularities. Instead, they wanted to measure the defects per million opportunities. Motorola developed this new standard and created the methodology and needed 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. Since then, hundreds of companies around the world have adopted Six Sigma as a way of doing business (www.isixsigma.com). According Black and Revere (2006), the real turning point in Six Sigma's popularity came through the work of Jack Welch, the then CEO of General Electric in 1995. Welch had observed the success experienced through Bill Smith's approach and intensely championed and led the Six Sigma methodology in GE (M.P.J. Pepper and T.A. Spedding, 2010).

Definition of Six Sigma

Six Sigma can be define as a statistical measure of the performance of a process or a product, a *goal* that reaches near perfection for performance improvement, and also as a *system of management* to achieve lasting business leadership and world-class performance (Pande and Holpp, 2002).

As a statistical measure, it can describe how much variation exists in a set of data, a group of items, or a process. The sigma measure is looking at how well you are meeting customer requirements. The sigma measure was developed to help focus measures on the paying customers of a business, and provide a consistent way to measure and to compare different processes (Pande and Holpp, 2002). Six Sigma implies 3.4 defects or mistakes or errors or failures per million opportunities (see Table 2.1). Here *Sigma* is a term used to represent the variation about the average of a process. The focus of 'Six Sigma' is not on counting the defects in processes, but the *number of opportunities* within a process that could result in defects (Antony *et al*., 2006).

Table 2.1 Sigma Level

Sigma Level	**Defect per Million Opportunity (DPMO)**
6	3.4
5	233
4	6,210
3	66,807
2	308,537
1	690,000

The goal of Six Sigma is to help people and processes aim high in aspiring to deliver defect-free products and services. Six Sigma recognizes that there's always some potential for defects, even in the best run processes or best-built product. But at 99.9997 percent performance, Six Sigma sets a performance target where defects in many processes and products are almost nonexistent (Pande and Holpp, 2002).

As a management system, Six Sigma is not owned by senior leaders or driven by middle management. The ideas, solutions, process discoveries, and improvements that arise from Six Sigma take place at the front lines of the organization. Six Sigma companies are striving to put more responsibility into the hands of the people who work directly with customers. In short, Six Sigma is a system that combines both strong leadership and grassroots energy and involvement.

In addition, the benefits of Six Sigma are not just financial. Through Six Sigma, people find that better understanding of customers, clearer processes, meaningful measures, and powerful improvement tools make their work more effective, less chaotic, and often more rewarding (Pande and Holpp, 2002).

The Benefits of Six Sigma

Pande *et al.* (2000) define several benefits of Six Sigma as follow:

- Generates sustained success.
- Sets a goal performance everyone.
- Enhances value to customers.
- Accelerates the rates of improvement.
- Promotes learning and “cross-pollination”.
- Executes strategic changes.

As examples, Table 2.2 shows the benefits and savings from Six Sigma in manufacturing.

Table 2.2 Reported benefits and savings from Six Sigma in manufacturing sector

Company/project	Metric/measures	Benefit/savings
Motorola (1992)	In-process defect levels	150 times reduction
Raytheon/aircraft integration systems	Depot maintenance inspection time	Reduced 88% as measured in days
GE/Railcar leasing business	Turnaround time at repair shops	62% reduction
Allied signal (Honeywell)/laminates plant in South Carolina	Capacity Cycle time Inventory On-time delivery	Up 50% Down 50% Down 50% Increased to near 100%
Allied signal (Honeywell)/bendix IQ brake pads	Concept-to-shipment cycle time	Reduced from 18 months to 8 months
Hughes aircraft's missiles systems group/wave soldering operations	Quality/productivity	Improved 1,000%/improved 500%
General electric	Financial	$2 billion in 1999
Motorola (1999)	Financial	$15 billion over 11 years
Dow chemical/rail delivery project	Financial	Savings of $2.45 million in capital expenditures
DuPont/Yerkes plant in New York (2000)	Financial	Savings of more than $25 million
Telefonica de espana (2001)	Financial	Savings and increases in revenue 30 million euro in the first 10 months
Texas instruments	Financial	$ 600 million
Johnson and Johnson	Financial	$ 500 million
Honeywell	Financial	$1.2 billion

Source: Young HK and Frank T. A, 2006

2.1.2 DMAIC Model and Infrastructure

DMAIC Model

When applied for performance improvement of an existing product, process, or service, the Define-Measure-Analyze-Improve-Control, or DMAIC model is used. The process and tools or techniques in DMAIC model is summarized in table 2.3.

Table 2.3 DMAIC process and tools (Pyzdek & Keller, 2010)

Six Sigma Phase	Key process	Tools and techniques
Define	Define the goals of the improvement activity, and incorporate into a Project Charter. Obtain sponsorship and assemble team.	Project Charter, VOC tools (surveys, focus group, letter, comment cards), Process map, QFD, SIPOC, Benchmarking, Project planning and management tools, Pareto analysis
Measure	Measure the existing system. Establish valid and reliable metrics to help monitor progress toward the goal(s) defined at the previous step. Establish current process baseline performance using metric.	Measurement system analysis (MSA), Process behaviour chart, Exploratory data analysis, Descriptive statistics, Run chart, Pareto analysis
Analyze	Analyze the system to identify ways to eliminate the gap between the current performance of the system or process and the desired goal. Use exploratory and descriptive data analysis to help you understand the data. Use statistical tools to guide the analysis.	Cause-effect diagrams, Tree diagram, Brainstorming, Process behaviour charts, Process maps, Design of Experiments, Enumerative statistics, Inferential statistic, Simulation
Improve	Improve the system. Be creative in finding new ways to do things better, cheaper, or faster. Use project management and other planning and management tools to implement the new approach. Use statistical methods to validate the improvement.	Force field diagrams, FMEA, 7M tools, Project planning and management tools, Prototype and pilot studies, Simulations
Control	Control the new system. Institutionalize the improved system by modifying compensation and incentive systems, policies, procedures, MRP, budgets, operating instructions and other management systems. You may wish to utilize standardization such as ISO 9000 to ensure that	SPC, FMEA, ISO 900× Change budgets, bid models, cost estimating models, Reporting system

	documentation is correct. Use statistical tools to monitor stability of the new systems.	

DMAIC Framework

The DMAIC structure provides a useful framework for creating a “gated process” for project control, as shown in figure 2.1. Criteria for completing a particular phase are defined and projects reviewed to determine if all of the criteria have been met before the next phase is begun. If all criteria have been satisfied, the gate (e.g., define) is “closed” (Pyzdek & Keller, 2010).

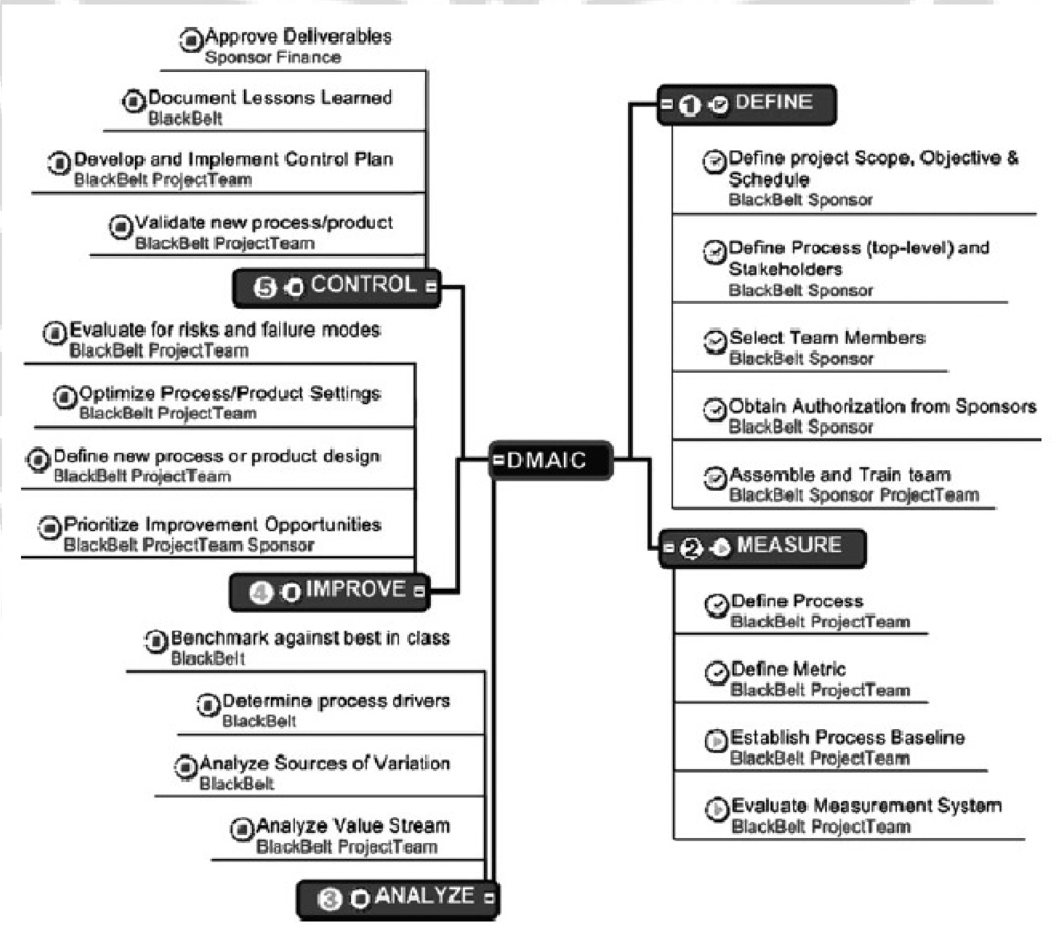


Figure 2.1 DMAIC Framework

The Six Sigma Infrastructure

Six Sigma possesses an infrastructure that effectively translates the CEO's agenda into a customer-centric set of projects chosen to maximize shareholder value, and provides effective management and monitoring of results versus plan, see figure 2.2 (George, 2003).

Starting at the top…

- The Corporate Champions are armed with the CEO and P&L manager's agenda for financial performance and shareholder value increase.
- These strategic goals are translated to an operational agenda by the Business Unit Champions (sometimes called Deployment Champions) who report to the P&L managers. These unit Champions are trained in the methods of identifying key value streams and prioritizing projects based on Net Present Value (their potential contribution to shareholder value). The P&L manager has the ultimate authority for value stream identification and project selection, since his or her commitment to the process is essential for success.

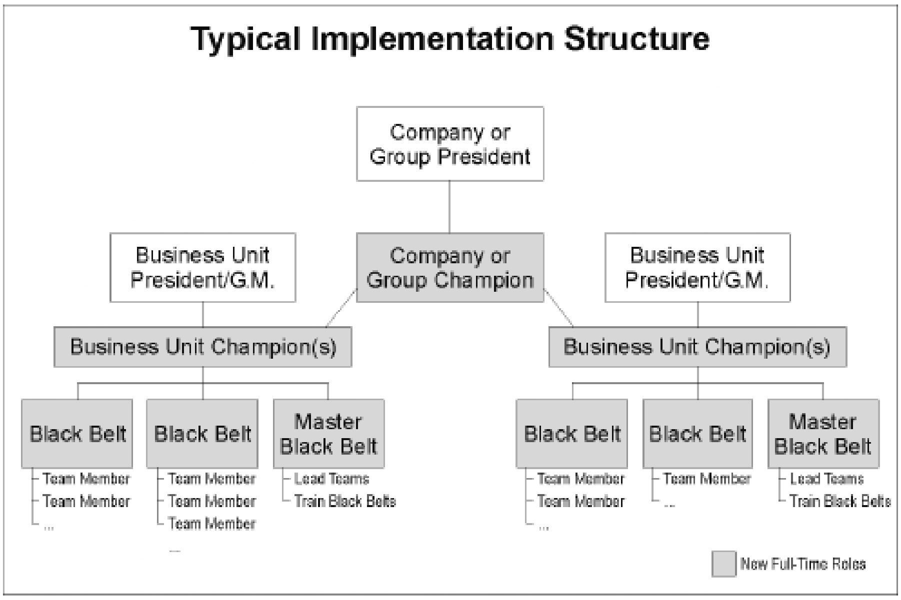


Figure 2.2 Six Sigma Infrastructure

- The customer Critical to Quality issues and the Time Traps within the key value stream are developed into projects and then prioritized. These projects (to execute cost reductions, quality improvements, etc.) are then executed by the Black Belts who have been trained in the tools and team leadership skills of Lean Six Sigma.

- Project Sponsors (who are or report to the P&L manager) own the process that is to be improved by a specific project. They have the specific authority to implement improvements and have ultimate long-term accountability for ensuring that the improvements and financial benefits stick.
- Champions are assigned full time to improvement activities, the Green Belts who support Black Belt projects are generally part time, and have received less training.

2.2 Design for Six Sigma

2.2.1 What is Design for Six Sigma?

DFSS is an improvement system used to develop new processes or products at Six Sigma quality levels. It also can be employed if a current process requires more than just incremental improvement. It is executed by Six Sigma Green Belts and Six Sigma Black Belts, and overseen by Six Sigma Master Black Belts (www.isixsigma.com).

Design for Six Sigma (DFSS) could also define as a Six Sigma strategy working on early stages of the process life cycle. It is not a strategy to improve a current process with no fundamental change in process structure. It will start at the very beginning of the process life cycle and utilize the most powerful tools and methods known today for developing optimized designs (Kai Yang, Basem S. El-Haik, 2009). Furthermore, the authors described that DFSS is a systematic approach to drastically improve the designed product in terms of its customer value, quality, reliability, and cost. It is very closely related to the product development process. A good DFSS approach is the right way of implementation of Six Sigma into the product development process.

The major objective of DFSS is to "design it right the first time" to avoid painful downstream experiences. The term "Six Sigma" in the context of DFSS can be defined as the level at which design vulnerabilities are not effective or minimal. The objective of the DFSS when adopted upfront is to "design it right the first time" by anticipating the effect of design vulnerabilities. This requires that companies be provided by the analytical means to achieve this noble objective and sustain it.

Benefits of DFSS

The research of Air Academy Associates found that there are some of the major points stemming of DFSS, those are (www.airacad.com):

- DFSS has provided at least a one sigma gain in quality at launch over previous designs. This is a major improvement, although many companies believe that if they are not at six sigma capability at launch, DFSS is a failure. What other methodology can make that kind of gain and claim? If a company has one, they ought to be using it.
- DFSS should decrease time to market by at least 25%. A conservative interval estimate is a 25%-40% reduction in time to market.
- Cost savings due to total resources utilized, which is highly correlated to time, is in the 20%-40% range. Note that this is only resource savings—there are other savings as well, e.g., the savings due to a 30-fold reduction (from, say, 4 sigma to 5 sigma) in defects.

According to Beth Hendricks, DFSS can be used for (www.isixsigma.com):

- Designing and developing a new design with predictable functional performance.
- Implementing major changes to an existing design when variation associated with continuous improvement efforts have reached a point of diminishing returns and an innovative redesign effort is required.
- Indicated by system-wide changes.
- Reducing common cause variation.
- Achieving quantum "breakthrough" design improvements.

2.2.2 DFSS Project Phases and tools

DFSS can be accomplished using any one of many methodologies. There are several acronyms used to describe the stage of a DFSS project, such as DMADC, ICOV, and IDOV. Generally there are not very much difference among them, except for some variations in the organization of the tools that might emphasize certain sections of the work, is customized to fit the culture and lingo of the company, or be changed to differentiate one consulting firm from another (Roland R. Cavanagh *et al*, 2005). Those acronyms are described as follow.

1. DMADV

DMADV, the most common acronym in use today, was first coined by General Electric to describe their vision of the steps needed to accomplish a Six Sigma design. DMADV stands for Define, Measure, Analyze, Design, and Verify. At the broadest level, it means identifying and clarifying what will be worked on, deciding how it will be measured, analyzing the situation, detailing the design, and testing and deploying the new process, product, or service (Roland R. Cavanagh *et al*, 2005). DMADV process and tools could be seen in table 2.4.

Table 2.4 DMADV project phases and tools

DMADV Phase	Key Process	Tools and Techniques
Define	• Identify specific or broad problems/ opportunities. • Define results – focused goals & change vision. • Clarify process scope & current customer requirements.	Project Charter, CTQ, SIPOC diagram, Kano analysis, Conjoint analysis, QFD.
Measure	• Measure performance to customer requirements. • Gather data on overall process efficiency	Benchmarking Capability performance
Analyze	• Identify "best practices". • Assess process design – Value/non-value adding. – Bottlenecks/disconnects – Alternate paths • Refine customer requirements.	TRIZ or Inventive Problem Solving Process Simulation

Design	• Design new process – Challenge assumptions – Apply creativity – Workflow principles • Test & implement new process, organization structures, systems.	Advanced Idea Generation Pugh Matrix Design of Experiments Failure Modes and Effects Analysis
Verify	• Establish measures & review to maintain performance. • Take action as needed to correct problems in process.	Process documentation and monitoring Response Planning Process Management

2. IDOV

IDOV is a four-phase process that consists of Identify, Design, Optimize and Validate. These four phases parallel the four phases of the traditional Six Sigma improvement methodology, MAIC - Measure, Analyze, Improve and Control. IDOV is one popular methodology for designing products and services to meet Six Sigma standards (www.isixsigma.com). Table 2.5 shows the IDOV process and tools.

3. ICOV

Design for Six Sigma ICOV has the following four phases: Identify requirements, Characterize the design, Optimize the design, and Verify the design (Kai Yang, Basem S. El-Haik, 2009). The process and tools in each step are shown in table 2.6.

Table 2.5 IDOV project phases and tools

IDOV Phase	Key Process	Tools and Techniques
Identify	It begins the process with a formal tie of design to the voice of the customer (VOC). This phase involves developing a team and team charter, gathering VOC data, performing competitive analysis, and developing CTSs.	QFD , FMEA , SIPOC, IPDS (Integrated Product Delivery System), Target Costing, Benchmarking
Design	Identifying functional requirements, developing alternative concepts, evaluating alternatives and selecting a best-fit concept, deploying CTSs, and predicting sigma capability.	Smart simple design, Risk assessment, FMEA , Engineering analysis, Materials selection software, Simulation, DOE , Systems engineering, Analysis tools
Optimize	The optimize phase requires use of process capability information and a statistical approach to tolerance. Developing detailed design elements, predicting performance, and optimizing design are activities within this phase.	Manufacturing database and flowback tools; Design for manufacturability; Process capability models; Robust design; Monte Carlo Methods; Tolerancing; Six Sigma tools
Validate	Testing and validating the design. As increased testing using formal tools occurs, feedback of requirements should be shared with production operations and sourcing, and future operations and design improvements should be noted.	Accelerated testing; Reliability engineering; FMEA; Disciplined New Product Introduction (NPI)

Table 2.6 ICOV project phases and tools

ICOV Phase	Key Process	Tools and Techniques
Identify requirements	Identify requirements, this phase includes two stages: idea creation and voice of the customer and business	Market/customer research; QFD; Kano analysis; Risk analysis
Characterize the design	Characterize the design, translate customer requirements (CTSs) to product/process functional requirements, generate design alternatives, and evaluate design alternatives.	TRIZ, QFD, Axiomatic design, Robust design, Design for X, DFMEA and PFMEA (design and performance failure mode–effect analysis) Design review, CAD/CAE, Simulation, Process management
Optimize the design	Optimize the design, an optimized design entity with all functional requirements released at the Six Sigma performance level.	Design/simulation tools; Design of experiment; Taguchi method; parameter design; tolerance design; Reliability-based design; Robustness assessment
Verify the design	Verify the design; consist of pilot test and refining, validation and process control, and full commercial rollout and handover to new process owner.	Process capability modelling; DOE; Reliability testing; Poka-yoke; errorproofing; Confidence analysis; Process control plan; Training

2.3 Lean Manufacturing

2.3.1 What is Lean Manufacturing?

History of Lean

Lean manufacturing concepts were used by some other very famous manufacturing system before Toyota did it. Ford automobile manufacturers used similar concepts to manufacture their model T automobile. Henry Ford's idea about continuous assembly lines, and flow systems are considered as very important concepts of lean manufacturing even today.

The next step of this manufacturing revolution began in Japan, with Toyota family, when they shifted from textile equipment manufacturing to Automobile manufacturing. By late 1940's Japan industry was collapsed and economy was badly affected by the World War II. They faced many problems such as limited sources of raw materials, labor movements, and limited capital availability. Therefore they could not compete on the overseas markets.

Challenged by these demands Toyota gave the task of making a system which will stand in these conditions to Taichii Ohno. Ohno with his collegue Shingo created a manufacturing system for next three decades, which is known as Toyota Production System (TPS). The roots of this system were clearly linked to the Ford's system. This manufacturing method got the influence of the Quality movements in USA. Especially thinking of people like Juran and Deming influenced the Toyota production system. Starting from mid 1940s to 1970s Toyota production systems was developed continuously. By this time TPS was doing very well (www.leanmanufacturingconcepts.com).

Definition of Lean

Lean manufacturing or lean production, often simply, "Lean", is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for (www.en.wikipedia.org).

The core idea is to maximize customer value while minimizing waste. Simply, lean means creating more value for customers with fewer resources. A lean organization understands customer value and focuses its key processes to continuously increase it. The ultimate goal is to provide perfect value to the customer through a perfect value creation process that has zero waste (www.lean.org)

Lean Manufacturing Objectives

Lean manufacturing objectives and principles are adapted from the Toyota production system and over the years have been enhanced by lean practitioners such as Jim Womack, Dr. Schoenberger, and numerous corporations and non-profit organizations such as Lean Aerospace Initiative at MIT, Lean Enterprise Institute, and others. The basic business objective of a manufacturing corporation is long-term profitability because it is essential to the continued existence of any corporation.

Lean manufacturing helps a company stay competitive by serving its customers better and continuously reducing costs. Lean gives customers the product variety they want, in the quantity they want, and without paying extra for a small-lot size. Lean makes a company flexible enough so that customer demands for change can be accommodated quickly, using lean techniques such as small-lot production. (Adi Choudri, 2002)

2.3.2 The Lean Philosophy and Principles

Lean Philosophy

One of the cornerstones of the lean philosophy is waste elimination. The survival of an organization, whether profit or non-profit, manufacturing or service oriented, may ultimately depend on its ability to systematically and continuously eliminate waste and add value to its products from its customers' perspective.

Interestingly, lean practices in their simplest form are founded on common sense, and most of them are not even proprietary to any company. The business objective of lean is to make high-quality products at a lower cost with speed and agility (Adi Choudri, 2002). There are several categories of waste that are addressed by lean theory, the most general being: Overproduction, unnecessary inventory, transport, process, activity resulting from rejected product, waiting, unnecessary motion. These activities add cost and do not cause a product to be transformed into a more complete product, from the customer's vantage point. They are non-value-added activities, as they add no value from the customer's point of view (Bill Careira, 2005).

Lean Principles

A powerful antidote to *Muda* (waste) is Lean Thinking or Lean Principle. It provides a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone request them, and perform them more and more effectively. In sort, Lean Thinking is Lean because it provide a way to do more and more with less and less – less human effort, less equipment, less time, and less space – while coming closer and closer to providing customers with exactly what they want. Lean Thinking also provides a way to make work more satisfying by providing immediate feedback on efforts to convert *muda* into value (http://www.lean.org/WhatsLean/Principles.cfm).

There are five steps of lean principle for guiding the implementation of lean technique, as follow:

1. *Value*. Specify value from the standpoint of the end customer.
2. *Value Stream*. Identify all the steps in the value stream for each product family, eliminating whenever possible those steps that do not create value.
3. *Flow*. Make the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer.
4. *Pull Planning*. As flow is introduced, let customers pull value from the next upstream activity.

5. *Perfection*. As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

2.3.3 Wastes

The lean philosophy is waste elimination. There are seven types of waste are known in Lean Manufacturing: Over-production, Waiting time, Transportation, Processing, Inventory, motion, and Defects (Kenneth W. Dailey, 2003).

- *Over-Production Waste* is produce more than is needed, faster than needed or before needed. Example: Unit which were produced in anticipation of future demand are often scrapped due to configuration changes.
- *Wait Time Waste* is the idle time that occurs when co-dependents events are not fully synchronized. Example: An operator arrives at a work station only to find he must wait because someone else is using the equipment for production.
- *Transportation Waste* is any material movement that does not directly support immediate production. Example: Production units are moved off the production floor to a parking area in order to gather a “Full Lot” for a batch operation.
- *Processing Waste* is a redundant effort (production or communication) which adds no value to a product or service. Example: Time spent manufacturing product features which are transparent to the customer or which the customer would be unwilling to pay for.
- *Inventory Waste* is any supply in excess of process requirement necessary to produce goods or services in a Just-in-Time manner. Example: Large purchases of raw material which must be stored while production catches up.
- *Motion Waste* is any movement of people which does not contribute added value to the product or service. Example: It is not uncommon to see operators make multiple trips to the tool crib at the beginning of a job. A

Lack of proper organization and communication is in fact the cause for many types of waste.

- *Defect Waste* is a repair or rework of a product or service to fulfil customer requirements as well as scrap waste resulting from materials deemed to be un-repairable or un-reworkable.

2.3.4 Lean Implementation Strategies and Tools

Lean Manufacturing Implementation Strategies

The goal is to apply the strategy, using the diagnostic tools to eliminate the seven wastes. There are four strategies to implement Lean manufacturing, which are: 1. synchronizing supply to customer, externally, 2. synchronizes production, internally, 3. create flow, and 4. establish pull-demand systems (Lonnie Wilson, 2010). The following process and tools are applied in Lean manufacturing Strategies.

1. Synchronize Supply to Customer, Externally

   To synchronize externally is to supply the product to our customer at their needed demand rate, normalized to our production schedule. We want to supply all of the customer needs but we do not want to overproduce and create excess inventory. These tools allow this balance to be achieved.

   The following Lean tools are used: Takt time Calculation, Cycle, Buffer, and Safety Stocks, and Levelling of Model Mixes or Products.

   Wastes reduced: Over-production

2. Synchronize Production, Internally

   To synchronize production internally is to divide the necessary work in processing steps such that each processing step takes the same time. The ideal is that all processing steps perform at a cycle time equal to *takt* time.

   Tools used:

   - *Balancing* is done by completing the Basic Time Study and then designing the work at each work station to be the same. Normally, some accommodation is made for OEE (Overall Equipment Effectiveness) to account for production losses caused by availability issues, quality dropout, and cycle-time losses. The end result of balancing should be work stations that are synchronized.

- Standard Work is the technique used to review the performance, including the cycle time of a production process, production cell, or a production work station. It is a key tool in evaluating and assisting the production process to achieve synchronized production.

Wastes reduced: Waiting is the key waste removed, and while inventory is often reduced, the goal is one-piece flow.

3. Create Flow

The concept of flow is such that we do not want the production units to stop, except for value-added work. The flow concept has both overall measures and local measures. The local measure would be cycle time. That is the increment of time between consecutive production units. If work is done, one piece at a time, it is also the processing time at the work station. The overall measure of flow is production lead time. It is the overall time it takes for a unit to complete the entire production process. In every case, if we can reduce cycle time or if we can reduce lead time, we will make process improvements.

Tools Used:

- Minimum lot sizes with the ideal being one-piece flow.
- Cells and other techniques to close-couple process to achieve short transportation distances and one-piece flow.
- SMED (Single Minute Exchange of Dies, quick changeovers) to reduce changeover times and the needed inventory to sustain production.
- *Jidoka*
- Problem solving by all, for the elimination of defects and to achieve process improvements. The goal should be Rapid Response PDCA (Plan-Do-Check-Act).

- CIP (Continuous Improvement Philosophy) and *Kaizen* to organize the problem-solving activities.
- 5 Whys is the key problem-solving tool used.
- Reduction of variation is a key tool used in inventory reduction.
- OEE is a key metric to use in prioritizing if quality yield, availability, or cycle time performances must be addressed to achieve and increase flow rates.
- Availability improvements through the use of TPM (Total Productive Maintenance).

Wastes Reduced: Transportation, Waiting, Overproduction, Defect, Inventory, Movement, Excess processing.

4. Establish Pull-Demand Systems

Pull systems have two characteristics. First, they have a fixed inventory, so the cycle stock, plus the buffer and safety stocks need to be determined. Second, they are activated when product is removed and this signals the upstream process to produce—no signal, no production. All *kanban* systems provide this function. However, for some simple systems such as pull systems within a close coupled cell, for example, the most effective pull signal often is the "*kanban* space". The perfect pull system is "take one, make one".

Tools Used: *Kanban,* JIT (Just in Time).

Wastes Reduced: Overproduction, Inventory.

2.4 Lean Management

2.4.1 Lean Production requires Lean Management

According to Thomas L.J and Karen R.J (1996), the majority of companies still clinging to mass production methods do so for several reasons as follows:

1. The setup of a lean production system requires assistance and time. A Company that is not thinking in the direction of long-term growth will not have the patience to preserve until the new system is firmly in place.
2. The process of transforming a company from mass to lean requires many physical procedural changes, often accompanied by major upheavals in company structure and processes.
3. The metamorphosis into leanness undergone by mass production company must be desired, decided upon, and driven by its leader. If the CEO, president, or owners are unaware of or uncommitted to lean management, lean production is not likely to happen.

Lean management invites vertical, horizontal, and diagonal bands of cross-functional coordination and cooperation – and never isolation. Lean management helps a company realign its pathway of authority so that leaders and managers are expected to contribute their skills within the context of teams. It aligns company functions to compete not against each other but against the firm’s competitors, and also against its most difficult adversary – organizational inertia.

2.4.2 Lean Management System

George A. Shinkle *et al* (2004) stated that in Lean Management Systems, lean means utilizing people, material, and assets to achieve the optimum value of the total business system to generate maximum customer value in minimum time and at the minimum cost. Further, they also described that fully integrated Lean Management Systems (LMS) are use the minimum people, time, and money to manage processes and accomplish tasks while communicating with, involving, and motivating the people throughout the organization. The LMS process allows for the endless reduction of waste in every aspect and process in the organization. It causes an acknowledgement that waste exists, that waste is not acceptable, and that waste must be removed from the system.

According to them, a Lean Management Systems include:

- Lean plans – resulting in a clear strategic direction.

- Lean management processes – resulting in a documented management system and clear management processes.
- Lean business processes – resulting in lean flow, waste reduction in process, and continuous improvement.
- Lean implementation - resulting in lean flow, waste reduction in process to approve, communicate, and control the flow of people, money, material, project, and activities – ensuring that strategies are implemented and goals are achieved.

The foundation for LMS is that organizations must be focused on creating value for their customer and their stakeholders, and that anything that is not adding value is waste. LMS focus organizations on this value-creation premise. LMS leverage the tools of lean system thinking, strategic planning, process reengineering, and team alignment to reduce waste in the five fundamental value-creating paths that are Leadership, Marketing, Development, Production, and People. It can be seen in figure 2.3.

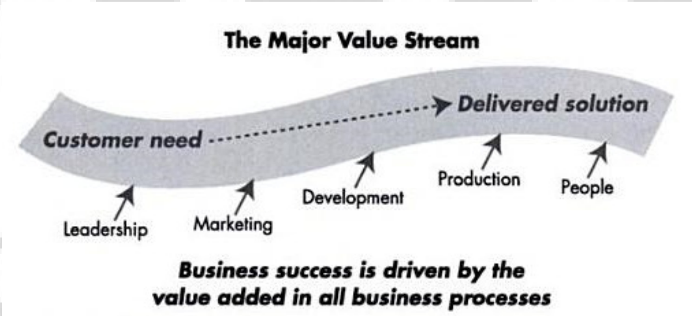


Figure 2.3 The Key Value-Creating Paths Supporting the Major Value Stream

These five fundamental value-creating paths support the overall value stream of the organization – delivering a solution that meets the customers' needs. The purpose of LMS is to create management operating system that focus on the detailed processes shown in figure below.

Figure 2.4 The Organization Creates Value Utilizing Many Processes that include Planning and Managing.

The fundamental building blocks and the key lean business principles of LMS to drive organizational change or meet specific challenges are shown in figure below.

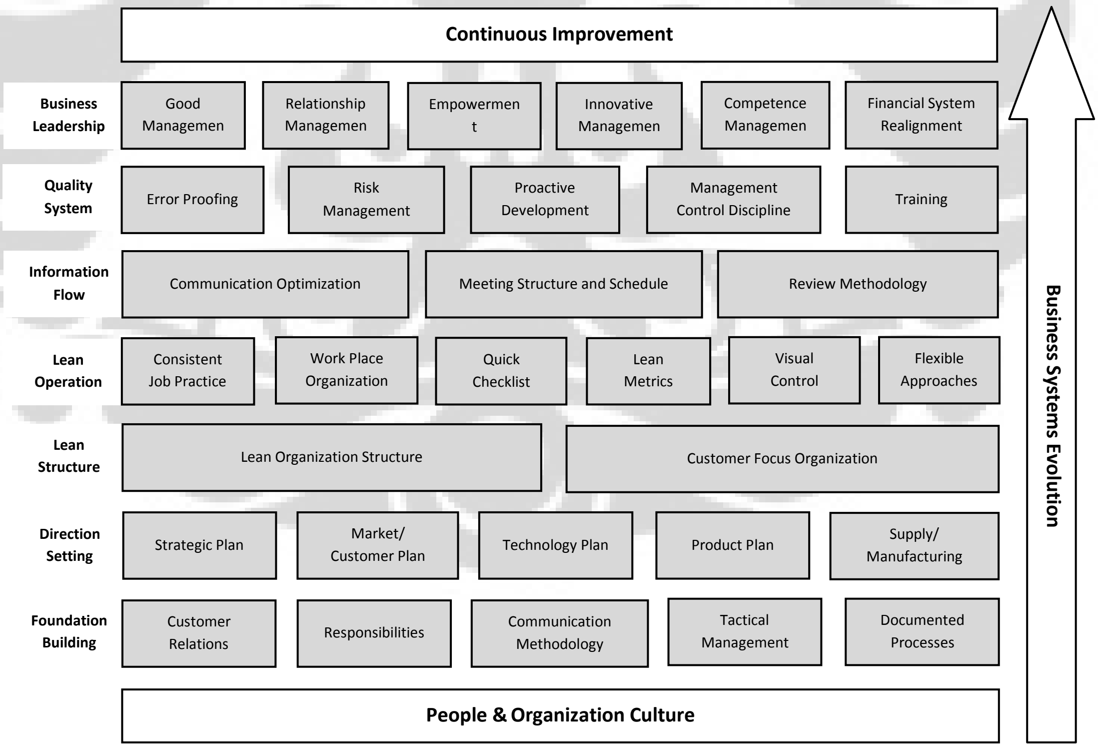


Figure 2.5 Business System Building in a Lean Management System

2.5 Lean Six Sigma

The merging of lean operation principles with other Six Sigma methods is called lean Six Sigma. Lean Six Sigma is a methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed and invested capital. The fusion of Lean and Six Sigma is required because Lean cannot bring a process under statistical control and Six Sigma alone cannot dramatically improve process speed or reduce invested capital (George, 2002). According Breyfogle, in a system that combines the two philosophies, Lean creates the standard and Six Sigma investigates and resolves any variation from the standard.

2.5.1 The similarities and the differences between Lean and Six Sigma

Lean and Six Sigma Similarities

The phrase "lean Six Sigma" is used to describe the integration of lean and Six Sigma philosophies. Six Sigma complements lean philosophy in as much as providing the tools and know-how to tackle specific problems that are identified along the lean journey: "Lean eliminates 'noise' and establishes a standard". Six sigma focuses project work on the identified variation from the proposed standard, which in itself does not entirely focus on the customer requirements; instead it is sometimes a cost-reduction exercise that can lose sight of the customer if not implemented alongside lean. Similarities can again be drawn between lean and Six Sigma, and the need for a culture of continuous improvement operating at all levels within an organisation (M.P.J. Pepper and T.A. Spedding, 2009).

Lean and Six Sigma are both customer-focused process improvement methodologies. As can see in Table below, both Lean and Six Sigma uncover similar issues (Helen Bevan *et al*).

Table 2.7 A comparison of common problems identified by Lean and Six Sigma

Lean	Six Sigma
Lack of customer focus Lack of staff empowerment Untidy, inefficient work spaces Suboptimal maintenance practices Lack of cross-training Excess inventory Lack of visible controls Suboptimal processes Time traps Outdated processes and metrics	Lack of customer focus Inadequate measurement systems Suboptimal processes Defect opportunities Outdated processes and metrics Lack of ownership of processes

Lean and Six Sigma differences

Nave (2002) has summarised the differences between the two approaches, see table 2.8 and 2.9. Nave argues that it is the organisational culture that makes the difference about which method is appropriate and that many methods appear similar when their secondary effects are considered.

Table 2.8 Differences of Six Sigma and Lean

Methodology	Lean	Six Sigma
Theory	Reduce waste	Reduce variation
Application guidelines	Identify value Identify value stream Flow Pull Perfection	Define Measure Analyse Improve Control
Focus	Flow	Problem
Assumptions	Waste removal will improve performance. Many small improvements are better than systems analysis.	A problem exists Figures and numbers are valued. System output improves if variation in all processes is reduced.
Primary effect	Reduced flow time	Uniform process output
Secondary effects	Less waste Fast throughput Less inventory New accounting system Flow metrics	Less variation Uniform output Less inventory Variation metrics

	Improved quality	Improved quality
Criticisms	Statistical or system analysis not valued	System interaction not considered. Processes improved independently.

Table 2.9 A comparison of the commonly used tools of Lean and Six Sigma

Area	Lean	Six Sigma
Process mapping	Value Stream Mapping	SIPOC Swim-lane diagrams Detailed process maps
Voice of the customer	5 Whys Statistical Process Control (SPC) Takt time Overall Equipment Efficiency (OEE)	Statistical Process Control (SPC) Process capability Applied statistics Cause and Effect diagram Pareto Charts
Process improvement	Process redesign 5S TPM Visual controls	Process redesign

2.5.2 The advantages of integrating Lean and Six Sigma

Lean needs Six Sigma and Six Sigma needs Lean because the reasons in table 2.10. A combination of both can provide the philosophy and the effective tools to solve problems and create rapid transformational improvement at lower cost. Potentially, this could increase productivity, improve quality, reduce costs, improve speed, create a safer environment for patients and staff and exceed customer expectations. It illustrated in figure 2.6.

Table 2.10 Why Lean and Six Sigma need each other (George, 2003)

Lean needs Six Sigma because	Six Sigma needs Lean because:
Lean does not explicitly prescribe the project set up and roles needed to achieve and sustain results.	It identifies waste. Six Sigma sub-optimises processes (Lean applies a systems approach).
It provides a set of tools to understand problems and sources of variation.	It improves process speed/cycle time.
Lean does not recognise the impact of variation.	It includes methods for rapid action (Kaizen).
Lean is not as strong in the measure and analyse stages of DMAIC.	Six Sigma qualities are approached faster if lean eliminates non value-added steps.

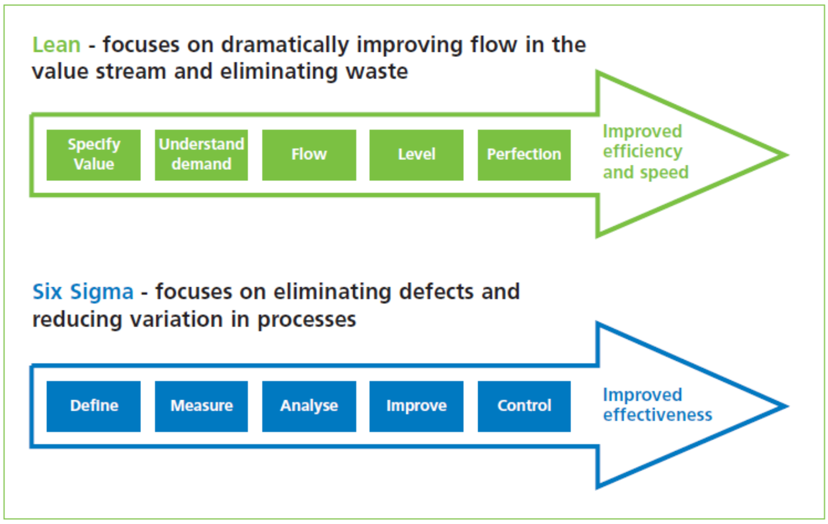


Figure 2.6 Integrating the two improvement approaches (Juran Institute)

Following the benefits could be achieved through Lean Six Sigma approach (Stephan Lunau, 2005):

- Increasing quality – customer loyalty and realizing greater turnover levels
- Cost reductions – greater competitive potential
- Higher process speed – less stock
- Greater customer loyalty – realization of new business fields

2.5.3 Integrating Lean and Six Sigma

Typically, Lean Six Sigma refers to integrating lean techniques into the DMAIC process to form synergic and complementary problem-solving and improvement perspectives. Since the DMAIC approach is split into five phases (define, measure, analyze, improve, and control), lean techniques are integrated into these five phases instead of being executed in parallel: hence the term *Lean six-sigma* (Basem El Haik, 2006).

Lean techniques can be utilized at various phases of the DMAIC process to work in conjunction with DMAIC tools. Proper selection of lean tools at each DMAIC phase is critical to successful project application. Table 2.11 presents suggested examples of lean concepts and tools that can be utilized in various phases of LSS approach (Basem El Haik, 2006).

Table 2.11 Lean Tools Selected in Various DMAIC Phases

Define	**Measure**	**Analyze**	**Improve**	**Control**
Value stream mapping	Lead time Takt time Inventory turns	Work analyses Flow analysis Scheduling	SMED JIT/Kanban Line balance	Visual controls Standard work Kaizen

As shown in Table 2.11, value stream mapping (VSM) is a key lean tool that aids the define phase of DMAIC. VSM provides a high-level graphical and time-based representation of process structure and flow. The process CTQs and variables defined can also be located in the current-state VSM. Problem-solving and improvement efforts will be assessed using the VSM and should be reflected in the future-state VSM.

In the measure phase, several lean measures, such as lead time, takt time, and throughput, can be used to guide improvement and benchmarking efforts. More business measures, such as inventory turns and on-time delivery rates, can also be used.

In the DMAIC analyze phase, lean techniques are focused on analyzing the process structure, configuration, and flow logic. This is achieved through the use of several lean techniques, such as work analyses, flow analysis, and scheduling. These analyses provide insight as to what needs to be changed in the process structure and operating procedures to reduce waste and streamline flow.

The role of lean techniques is further leveraged in the improve phase of DMAIC, where several lean techniques can be applied to improve the current state VSM lean measures. The focus is on cutting or reducing all types of waste in time, material, and effort. Several tools, such as SMED, JIT/Kanban, and work balancing, can be used to achieve these objectives.

In the control DMAIC phase, several lean tools can be used to sustain improved performance and to implement control and monitoring plans successfully. Examples include Kaizen, work standards, and visual controls.

2.6 Tools and Techniques in the Quality Improvement Process

The methodology of the continuous improvement programmes such as Six Sigma, Lean Six Sigma, or Lean manufacturing, each organisation and programme team will certainly need to use a selection or tools and techniques in their implementation process (Ron Basu, 2009).

In general, tools and techniques can be broadly defined as the practical methods and skills applied to specific activities to enable improvement. A specific tool has a defined role and a technique may comprise the application of several such tools. Dale and McQuater (1998) have suggested the following definition of tools and techniques (Ron Basu, 2009).

- A single tool may be described as a device which has a clear role and defined application. It is often narrow in its focus and can be and is usually used on its own. For instances of tools: Cause and Effect Diagram, Pareto Analysis, Relationship Diagram, Control Chart, Histogram, and Flow Chart.
- A technique, on the other hand, has a wider application than a tool. There is also a need for a greater intellectual thought process and more skill,

knowledge, understanding and training in order to use them effectively. A technique may even be viewed as a collection of tools. Examples of techniques: Statistical Process Control, Benchmarking, Quality Function Deployment, Failure Mode and Effects Analysis, Design of Experiments, and Self-assessment.

The tools and techniques commonly used in quality improvement methods such as Six Sigma, Design for Six Sigma, Lean Six Sigma, or Lean manufacturing can be seen in Appendix C.

Summary

From review of those several approaches in quality and process improvement, it seen there were similarity of characters among them, mainly in project phases or process steps. According to Juran Institute, the process of quality improvement divided into six steps as follow (Juran Institute, 1999):

1. Identify a project
2. Establish a project
3. Diagnose the cause
4. Remedy the cause
5. Hold the gains
6. Replicate the results and nominate s new projects

Using Juran's process steps as a frame to categorized four approach of quality improvement methods, it could summarize in table 2.12.

Table 2.12 Quality improvement process steps

Juran Institute	Six Sigma	DFSS	Lean Manufacturing	Lean Six Sigma
Identify & Establish a project	Define Measure	Identify	Specify value	Define Measure
Diagnose the cause	Analyze	Design	Value stream	Analyze
Remedy the cause	Improve	Optimize	Flow	Improve
Hold the gains	Control	Verify	Full	Control

CHAPTER 3
CASE STUDIES OF QUALITY IMPROVEMENT PROCESS

Due to the purpose of this study is to identify the application of tools and techniques in quality and process improvement, so we took cases from non specific industry. Several types of industry, such as automotive, electronic, and also three cases of service business are selected in this study. Those are consisting of three cases each of Six Sigma, Design for Six Sigma, Lean manufacturing, and Lean Six Sigma approach. Totally, there are twelve cases. The cases were selected with a criteria that those cases should include the all phases of the improvement project. The following cases serve as an object of study.

3.1 The Six Sigma Case Studies

3.1.1 Case Study 1: Process improvement of Coke Moisture at Tata Steel using the ASPIRE DMAIC approach (Antony *et al*, 2006)

Project Background

With a turnover of approximately $2.5 billion, Tata Steel is Asia's first and India's largest integrated private sector steel company. Over the years, it has consistently overcome the challenges of a highly competitive global economy and has, 'committed to become a supplier of choice by delighting its customers with service and products.

Until 2002, Tata Steel was following a modular framework that used numerous tools and techniques to bring about process improvements in a contextual fashion but lacked a systemic approach. In order to address this issue and provide an integrated framework, Aspirational Initiatives to Retain Excellence (ASPIRE) program was conceived in June 2002. ASPIRE program was started with Six Sigma methodology, taking some of the pilot projects.

The coke moisture project was one of the pilot projects of Six Sigma initiative of the company. The success of the project was very critical for Six Sigma deployment in Tata Steel as well as for the improvement in the process of coke moisture control.

Project Goals

The goal was taken as to get the coke moisture value consistently below 3.5%, with more than 50% reduction in the standard deviation.

Project Implementation

Phase	Steps	Tools & Techniques
Define	1. Identify the customer(s) and the critical to quality (CTQ) requirement The project started with a very strong voice of customer (VOC), which in turn was directly linked with the corporate strategic objective. One critical strategic objective of the company was 'cost reduction' and cost of hot metal produced from blast furnaces was one of the most important components of the cost of steel. The project started with this VOC and naturally the CTQ identified was "moisture % in coke". 2. Create the project charter. The typical components of project charter were then worked out as follows: Business case, problem statement, goal statement, project team, scope, and financial opportunity. 3. Develop a high-level process map	· CTQ Tree · Project Charter · SIPOC diagram
Measure	1. Confirm/refine the project output Y (CTQ) Collect data of coke moisture in the last four years and displaying it in a chart. 2. Define performance goals or standards Measurement of coke moisture is carried out every shift in a laboratory by recording the loss in weight of the sample during testing. 3. Calibrate the measurement system Since this measurement system is not automated, the team performed an Gage R&R study to validate the measurement system and found out that the repeatability and reproducibility of the system are within the limits	· Histogram · Data collection plan · Gage R&R
Analyze	1. Measure the capability of the existing process. The USL of coke moisture was defined as 3.5% considering the 'VOC' from blast furnaces. As the distribution of the coke moisture data is not normal. 2. Calculate the sigma level. In the case of coke moisture, the defect percentage has been 44.5% (i.e., DPMO = 445,000), which corresponds to a baseline sigma level of 1.6. 3. Identify possible problems Perform brainstorming to identify the problem at Batteries 8 and 9, and analyze it with a "failure modes and effects analysis". 4. Identify and verify critical problems The problem was discussed on the subject and all operational and other factors that impact the moisture level in coke were identified. After a detailed analysis, three critical parameters were shortlisted.	· Capability process · DPMO calculation · Brainstorming · Failure Mode Effect Analysis (FMEA)

Improve	1. Identify solution alternatives. Identify the optimal combinations of parameters for getting lower average value and standard deviation of the coke moisture. The team decided to go for a three-level DOE 2. Select the best solution and the relationships between Xs and Ys Develop the standard deviation of coke moisture as a function of the quenching time, the drain-out time, and the crack opening time. 3. Implementation plan Develop three possible two-way contour plots to find out the optimal combination of the parameters, which would result in the lowest coke moisture. Combining all the above observations, it was concluded that the lowest coke moisture could be achieved for the following values of the parameters: Quenching time: 75 sec; Drain-out time: 180 sec; Crack opening time: 65 sec.	· Design of Experiment (DoE)
Control	1. Develop control plan. Develop control chart (I and MR chart) to monitor coke moisture results. 2. Determine improved process capability. Monitoring sigma level of coke moisture based on shift wise coke moisture values. 3. Implement process control The parameters levels are maintained in the two-level automation system and no manual intervention (to change the parameter levels) is allowed any more.	· Control chart · Process capability

Results

The distribution of coke moisture values was improved significantly. Only 3.3% of coke moisture values were falling above 3.5%, as per the requirements of blast furnaces, whereas in previous case it was 44.5%. Sigma level increase from 2.2 to 3.4.

3.1.2 Case study 2: Quality improvement of Eye Tracer Cutting Machine at United Tractor Pandu Engineering Inc. Using Six Sigma Approach (Hidayatno and Afriansyah, 2004)

Project Background

PT United Tractors Pandu Engineering (UTE) was established in 1983, to meet the increasing demands of Indonesia's industries development. They are engaged in manufacturing heavy equipment, such as dump trucks, heavy equipment transportation, original components and attachments and mining support.

One of the problems that exist and are directly related to the product produced by PT. United Tractors Pandu Engineering is a problem of defective semi-finished products generated by the Materials Preparation (MP) line and will be processed on fabrication (welding) line as the internal customer. The high rate of return on semi-finished products reaches 50% of the total units in each type of products (particularly frame products). It is necessary to serve as a focus of concern.

Based on observations, one of the causes of the high failure costs are caused by various factors such as high rates of return on intermediate products, waste material, waste of time, the number of rework and products fail. All factors were dominated by a main cause of defects in the process of cutting plate on the Eye Tracer machine.

Project Goals

To increase sigma level of cutting process at Eye Tracer machine to 3.5 Sigma.

Project Implementation

Phase	Steps	Tools & Techniques
Define	1. Create Project Charter The typical components of project charter were then worked out as follows: Business case, problem statement, goal statement, project team, scope, and milestone. 2. Mapping the existing process Mapping the cutting process of plate using SIPOC diagram. 3. Identify customer requirements Identify the customer (fabrication line) requirements using CTQ tree.	· Project Charter · SIPOC diagram · CTQ Tree
Measure	1. Performance Measurement Standards Develop the standard of measuring characteristics. 2. Determine Sigma level of process From the results of data collection as much as 10,437 units of the five machines ET owned by the Materials Preparation line, known that the value of sigma level is 3. It indicates that still occurs around 66,800 defects in a million opportunities. 3. Collection of existing data. Collect data of cost and time in order to analyze in the next phase.	· Data collection plan · DPMO calculation

Analyze	1. Make a priority to overcome the problem Calculate failure cost to prioritize problem that have to solve. It found that the numbers of defects are dominated by chip defect. 2. Identify possible causes of problems Search the cause of the chip and then made efforts to eliminate defective repair of this type.	· Pareto diagram · Cause and Effect diagram
Improve	1. Identify solution alternatives Develop ideas systematically to create solutions alternatives to eliminate defects at machines. 2. Analyzing solution Analyzing the solutions alternatives using House of Quality from QFD to linkage the problems with the solutions. Make solving priorities that would be implemented. 3. Implementing the solution Replacing table, create product standard, maintenance schedule, standard of cutting process, standard of machine operation.	· Three Diagram · QFD · SOP
Control	1. Develop control plan Develop a check list of activities, check sheet of defect, sigma level calculation, and control chart. 2. Implement process control Involving operator to record data of defect and make control documentation.	· Check sheet · Control chart · DPMO calculation

Results

It expected that the sigma level increase to 3.5 Sigma.

3.1.3 Case study 3: Improve Machining Process Capability by Using Six Sigma (Ray and Das, 2011)

Project Background

This Six-Sigma project was implemented in an automotive manufacturing plant in India. This particular project was undertaken in the machining shop for the part crank case. The company was facing higher rejection at the honing operation of crankcase machining, seriously affecting the process yield. As a result the company was incurring loss at the current production rate apart from resulting customer dissatisfaction due to delay in on-time delivery of machined crank cases for further operation. A Six- Sigma project was, therefore, created that specifically focused on resolving the rejection of crankcase at honing operation.

Project Goals

Reduce operational scrap of crankcase by improving the process capability of bore size.

Project Implementation

Phase	Steps	Tools & Techniques
Define	1. Define the project boundary. Identify process which will be improved to reduce the defect rate with appropriate scope and boundaries. The high-level process mapping helps to define the project boundary (start and end), can identify where to collect data and clarify the scope. It also identifies the resources required to carry out the project / improvement.	· SIPOC diagram
	2. Identify and define Critical to Quality (CTQ) Based on the above objective and process definition, the CTQ for the project is selected. By measuring and monitoring the CTQ, the process quality and control can be ensured. In this project, the CTQ selected is the bore size with the specification of (111.257 - 111.277 mm).	· CTQ tree
	3. Define project charter. Define a project charter which states the project description, objectives, scope, potential benefits, team members, schedule and support required.	· Project charter

Measure	1. Formulate data collection plan and identification of stratification factors Conduct a brainstorming session to formulate a data collection plan for the process by involving personnel from QA, Production, Maintenance, Safety and Design. 2. Validate the measurement uncertainty of the current measurement system. Validate the measurement system with present 2 inspectors are measuring the bore size. Study the contribution of measurement system variation in the form of repeatability and reproducibility present in the process. Conduct the Gauge R and R study by selecting parts at random and measured by two inspectors. The study results were analyzed by the ANOVA method. 3. Collection of existing data. Collect data from the current process to estimate sigma level of bore size. Based on the data collection plan, 30 crankcases were manufactured and measured for bore size. 4. Analysis data for Sigma Level calculation. The data was analyzed by Minitab software and the result indicates that the crankcases produced in are affected by the presence of assignable causes affecting the process average. 5. Initial process analysis. The crankcases produced in the machine depict the process problem for the CTQ bore size, unidentifiable assignable causes affecting process average and with the initial sigma level of 2.32.	· Brainstorming · Gauge R&R. · ANOVA · Data collection plan · DPMO calculation
Analyze	1. Identification of suspected stratification factors and causes. Conduct a brainstorming session to identify the stratification factors and causes which are potential for bore size variation. The causes thus identified are presented in the form of a Tree diagram. The data of bore size collected at the measure phase was analyzed to identify the difference of bore size from bore-to-bore (1 to 6). The data was analyzed by one-way ANOVA. 2. Collect data on *x*'s and *y* together and establish the relation between them. Investigate all the suspected causes for their presence in the process by observing them in the workplace. The results of the investigation are summarized in Gemba Study.	· Brainstorming · Tree diagram · One-way ANOVA · Gemba study

Improve	1. Identification of Factor and Levels. A design of experiment technique was employed to identify the optimum setting of the KPIVs. The factors and the corresponding levels be considered in the experiment and summarized in a table. 2. Planning and conduct of experiments. The experiment was conducted by using full factorial experimentation techniques, in which all main effects and two factor interactions were considered. The experiments were conducted after randomizing the trial runs and the results from each experiment were documented. The experimental data were summarized to calculate. 3. Analysis of results. The data were subjected to the analysis using analysis of variance ANOVA methodology. 4. Identification of optimum setting The honing process parameters were set as per the optimum combination of the significant KPIVs and 8 crankcases were manufactured and measure for bore size for each of the 6 bores. 5. Trial run and sigma-level calculation. The process was set by using a new honing tool and as well as by using an used honing tool, which is almost at the end of its life, as it is a known fact that as the life of the honing tool reduces, it affect the process capability. The results of the process capability studies are given in a chart. The summary of the improvement thus achieved in improving process capability is given in a table of sigma level.	· DoE · ANOVA · Process capability · DPMO calculation
Control	1. Documenting the optimum process. All root causes identified during Analysis phase and their optimum condition as identified in the Improve phase are documented in the manufacturing process control plan document. 2. Implementing process control plan Process control plan is implemented in the system to make the changes irreversible.	· Control plan · Process capability

Results

The results of the improvement thus achieved in improving process capability of bore size of crank case are:

- Sigma level increases from 2.32 become 5.27 for new tool and 3.65 for used tool.
- The project also saves Rs. 10 million per annum at the rated production.
- The honing tool there will be no rejection of crankcase due to bore size problem anymore.

3.2 Case Study of Design for Six Sigma

3.2.1 Case Study 4: Develop Software to Track Drug Side Effects (www.isixsigma.com)

Project Background

A pharmaceutical company, Medistar, applied DFSS tools to develop a new pharmacovigilance system (captures and analyzes observed drug side effects) in association with the launch of a new drug. Such a system is necessary since after its market launch a drug is exposed to a much larger population than in the clinical studies conducted during the drug development. This can lead to a change in the known safety profile of a drug. Medistar recognized the need for an updated system using newer technology. Under the old system a physician manually completed a registration form and mailed it to the respective field service agent who then transferred the information manually into yet another system. The information regarding the adverse effect was then forwarded to the pharmacovigilance team. This process was slow, cumbersome and could take several days – too long given the potential consequences of an unidentified risk.

With the launch of the new drug Medistar wanted to play it safe – every side effect should be immediately identified and addressed. From capturing all relevant patient data to the medical director making a decision, all major process steps and influence factors were in the process-scope of the project.

Project Goals

Develop a new system to capture and analyze observed drug side effects more quickly.

Project Implementation

Phase	Steps	Tools & Techniques

Identify	1. Develop a team. The project sponsor, the medical director of Medistar and the project manager agreed on a team with representatives from the IT department and pharmacovigilance organization. 2. Identify the system needs and what business processes it needed to address. The goal was to understand the process, its internal and external customers and their requirements before developing the system. Therefore, the team developed a high-level process map using SIPOC (suppliers, inputs, process, output, customers). The developers of the SIPOC map recognized that not every adverse event would necessarily entail a counter measure. 3. Comprehensive voice of the customer (VOC) data collection. The team interviewed representatives from the pharmacovigilance teams, the medical director and the chief executive officer of the company. The team translated those requirements into measurable CTQs (critical to quality), which served as the basis for defining key performance indicators (KPIs) for the new pharmacovigilance process. The translation of customer needs into CTQs and their prioritization was done using quality function deployment (QFD). All CTQs were summarized with target values and tolerances in a design scorecard. This was used throughout the project to measure and document the system performance.	· SIPOC diagram · CTQ Tree · QFD
Design	1. Create a detailed process of the should-be process. This showed detailed process steps and responsibilities as well as first requirements with regards to the new pharmacovigilance system. 2. Defining the user requirement specifications. Using process map the team started defining the user requirement specifications (USR) for the system. In a workshop with previously interviewed customers URS were identified and – in order to ensure that all previously identified CTQs were considered – a QFD 2 matrix was used to map and prioritize the URS against the CTQs. The main priorities from a user perspective were a user-friendly input mask and the ability to automatically create summaries and detailed reports. 3. Development of functional specifications. Development of functional specifications in accordance to the previously described system requirements. The team opted for the application of QFD 3, as this could guarantee traceability of the requirements. The team began to define service level requirements for the future maintenance and support organization of the pharmacovigilance system.	· Process Map · CTQ Tree · QFD · QFD

Optimize	The optimize phase was typical for a software development project. It included a detailed adaptation of the software according to the customer needs and the establishment of necessary testing and validation procedures. For the description of test cases the previously created QFD 3 was helpful and provided an overview of system requirements and functional specifications.	Testing & Validation
Verify	1. Develop a dashboard to monitor the process performance. Based on previously defined CTQs key performance indicators (KPIs) were defined – how often they had to be calculated, by whom, and to whom they had to be reported. 2. Trained on the new system and the old pharmacovigilance system was shutdown. The transition from the old system to the new went well and was in place prior to Medistar launching the new drug.	· Dashboard · KPIs

Result

After only two months, the head of pharmacovigilance proudly presented new data that reflected that not only had no major events regarding the new drug been reported, but that the process and the IT system also functioned as desired.

3.2.2 Case Study 5: Creating a Recruiting Process: DFSS for Process Design (isixsigma.com)

Project Background

A pharmaceutical company applied selected DFSS tools to develop a new recruiting process for sales representatives. Tools and activities are described along the IDOV phases, which served as a guiding roadmap through this process design project.

The following case study illustrates how a pharmaceutical company applied selected DFSS (Design for Six Sigma) tools to develop a new recruiting process for sales representatives. Tools and activities are described along the IDOV (Identify, Design, Optimize, Verify) phases, which served as a guiding roadmap through this process design project.

The need to completely redesign the recruiting process resulted from two weaknesses in the existing process. First, with an average of 60 days to fill a vacant sales representative position, it simply took too long. Second, due to a growing market in the upcoming three years, an increase of the sales force by 10 percent was planned, and the company wanted to organize its hiring process to make it as effective and efficient as possible.

Project Implementation

Phase	Steps	Tools & Techniques
Identify	1. Develop a team Under the project lead of a human resources (HR) associate, a team with representatives from sales and HR was established. Additionally, a steering committee with members from the same departments and from IT and Controlling was set up. They would meet at the end of each IDOV phase to review the project progress and to make go or no-go decisions for the next phase. 2. Conduct a voice of the customer (VOC) data collection. Twenty district managers and four HR representatives who had all been involved in at least one recruiting process in the past were interviewed. The main questions to determine the customer needs, their relative importance and measurable CTQs. The results from this internal VOC were structured via quality function deployment (QFD).	· VOC · CTQ · QFD
Design	1. Conducted a functional analysis. In a process design, functions are the high-level process steps. Developing functions enabled the team to define the necessary steps of the recruiting process without immediately having to think about solutions, detailed concepts or a detailed process design. 2. Analyze the process steps. The team used a function tree. This allowed for a definition of the process on levels 1 and 2. In order to determine those functions that would contribute most to meet the customer requirements, the team used the QFD 2	· Tree Diagram · QFD
Optimize	1. Detailed process design. Using a deployment flow chart, detailed process steps, roles and responsibilities for the previously prioritized level 2 processes were defined Furthermore, detailed design elements in the categories of information systems, human resources and templates and tools, as well as supplier quality were developed for the same five prioritized processes steps. 2. Conducted a risk analysis for the new process. It performed by using the failure mode and effects analysis (FMEA) approach. The objective was to identify potential failure modes and their potential causes upfront so that appropriate mitigation actions could be determined	· Process Mapping · Detailed Design Elements · FMEA

Verify	The DFSS team piloted the implementation of the new recruiting process in three regions and collected new data for the CTQs. They also gathered and analyzed information with regard to the highest prioritized failure modes from the FMEA. In doing this, they wanted to validate what the critical process steps were that had to be controlled as leading indicators of the desired (lagging) process performance. Based on the pilot experiences, the team made final modifications of the process. Among others, they decided to have the contract already prepared before the second interview date (even if that meant that up to three contracts had to be created in case three candidates were still left). All critical process steps, leading and lagging indicators, and a reaction plan were summarized in a process management chart	· Process management chart (PDCA)

Results

After this successful completion of the pilot phase, the team handed the new process over to the process owner, in this case the head of HR. She was responsible for the implementation of the process in Europe. Six months later the first results of the implementation could be measured, and they fully met the expectations of all stakeholders.

3.2.3 Case Study 6: Product Development at Prestolite Electric Using DFSS (www.airacad.com)

Project Description

Reduction in M125 starter EOL line rejects due to low power below 7.6Kw. Identify and specify critical design variables related to control low power failures.

Problem Description

Production experiencing 9.04% End of Line Reject of M125 starter for power output below 7.6Kw. It resulting in lost sales of approximately $780,000 annually.

Project Implementation

Phase	Steps	Tools & Techniques

Identify	Identify product features contributing to starter motor end of line output power. 3 groups of low and high power units were swapped to identify factors to be studies which contribute to the low power issue. · Motors can successfully be rebuilt –assembly damage can be identified. · 2/3 units showed armature and frame interactions–3rd unit showed dramatic variation in performance due to Comm. diameter 1mm undersize. · Further analysis shows frame swap has impact in studies · 4 out of 5 units rebuilt passed testing (Loose shunt field fasteners) · Control study completed 12 frame assemblies measured for pole piece radius and position	· IPO diagram · QFD · Process Scorecard
Design	Frame Design Analysis · Component features affecting air gap confirmed. · Completed Tolerance stack-up analysis and defined air gap at 0.8mm MAX. · New dimensions for assembled part established and checking fixture designed to verify max pole variation 0.38mm across pole face. Validate design significant characteristics and verify impact of process variation	· DoE
Optimize	Optimization run confirms design intent and process shift in mean Team identified 3 options through use of selection matrix · Implement new pole piece in assemblies' complete validation run with larger lot of frames components that meet the design requirement. 0.8mm max air gap. · Complete a confirmation run with sorted components	· Process Capability
Verify	88 starter built with new pole piece sorted for pole variation between 0.38mm MAX all 100% pass rate no low power at 8.127KW average output power 76.2% above 8Kw. Team Completed a weighted selection matrix.	· Pugh Matrix

3.3 Case study of Lean Manufacturing

3.3.1 Case Study 7: The QED Motors Company (Lonnie Wilson, 2010)

Project Background

The QED Motors Company had been making motors for over 30 years. They had a plant in California and had just constructed this new facility in Mexico to take advantage of the low-cost Mexican labor. Their plan had been to run the two plants in parallel for three to six months while the Mexican plant came up to speed, and then shut down the California facility. It had now been over 15 months and the Mexican plant had just that month achieved the design capacity of 3500 motors per month.

To meet the demand mentioned above, the plant was working seven days versus a business plan of five days, and still had a number of production problems. The largest problems were:

- Low on-time delivery, only 76 percent
- 14 percent scrap rate
- Seven days productions lead time.

Project goals

- Improve line capacity so the plant could provide demand on a five-day basis.
- Make a 50 percent reduction in lead time.
- Implement a make-to-stock, pull system, operating at *takt*.
- Reduce line rejects by 50 percent.
- Increase on-time delivery to over 95 percent.

Project Implementation

Phase	Steps	Tools & Techniques
Specify value	Synchronize Supply to Customer, Externally · Calculate Takt time *Takt* = (22 – 2.5)∗60/165 = 7.09 minutes. It was based on two shifts each lasting 11 hours. Each shift included 1.25 hours of meal and rest breaks. Production was 3550 units per month—with 21.5 days/mo = 165 motors/day. · Calculate processing time The processing time for the ten models was relatively straightforward to calculate and it made model-mix leveling easy. All models of small stators take one particular time, while all models of large stators take a longer time. · To size the buffer and safety stocks For buffer and safety stock combined, team decided to have two weeks for all weekly pickups and three days for all daily pickups. For cycle stock, uses the pick-up volume, as a starting point.	· Value stream mapping · Takt time calculation · Cycle, Buffer, and Safety Stocks

Value stream	Synchronize Production, Internally · Defining the Work Perform time study based on data in the first phase to identify each processing step time of large and small stator cycle times compared to the takt time. Then converted to a balancing chart to show operation with a line that is balanced with 50 percent large stators and 50 percent small stators. · Evaluation of the Balance Chart. As team evaluates this line balance chart, they can see there is lots of waiting and that the process stations are not well balanced. However, the critical problem is the bottleneck of the CNC lathe. Not only is it a bottleneck but the cycle time exceeds *takt*. This shows clearly why a great deal of overtime is required. It is obvious that to meet customer demand we will need to improve the cycle time at the CNC lathe. · Reduce the Lathe Cycle Time A unique holding jig was required for eight of the ten models.	· Basic Time study · Line balance chart
Flow	Create Flow · Creating the future state value stream map · Implement Kaizen technique	· Value stream mapping · Single Minute Exchange of Dies · Heijunka
Pull	Establish Pull-Demand Systems · Implementing the pull systems · Display several process to reduce transportation and make better use of the floor space.	· Kanban · Spaghetti Diagram

3.3.2 Case Study 8: Reduce Lead-time in Bravo Line using Lean Manufacturing (Lonnie Wilson, 2010)

Problem

The problem was stated as: “The line cannot meet the demand of 10,000 units per week. It is well laid out, has a cycle time that should easily meet demand in a five-day work week, but it consistently need to work overtime. It has gotten so bad that have even had to put the utility line into service on occasion, effectively working an eighth day, just to meet regular demand. Quality is extremely good; a process with Six Sigma yield, but it just cannot meet demand.” The problems also related with production times and missed shipments.

Project implementation

Phase	Steps	Tools & Techniques
Specify value	Synchronize Supply to Customer, Externally Demand was 10,000 units per week and the normal workweek was five days. Available time was 24 hours per day, less a 30-minute lunch and two ten-minute breaks during each of the three shifts, so we needed to produce 2000 units in 21.5 hours or generate a 39-second *takt* (21.5 × 3600/2000 = 38.7). Checked the standard work combination table and it listed the cycle time as 28 seconds, but the line balancing studies appeared to be balanced to 25 seconds.	Takt time calculation
Value stream	Synchronize Production, Internally The Basic Time and Balancing Studies. Team had made an effort to balance the cycle times to 25 seconds. Problems had occurred at two cells. As a result of these problems, the work procedures had been modified but the balance chart and planning numbers had never been updated. Team completed the three-part evaluation—waiting time, station-to-station balance check, and bottleneck analysis—of the balancing chart. The work (from the time study) for Cell 1 was 207 seconds and the work for Cell 2 was 105 seconds. Consequently, for a 39-second *takt*: · At Cell 1 we needed 207/39 = 5.3, or six stations · At Cell 2 we needed 105/39 = 2.7, or three stations The team need to redesign the work stations.	Basic Time Study Balancing Study
Flow	Create Flow · Working to destroy batchs. To destroy batches, implement one-piece flow in place of the 50 unit batches. The conveyor eliminated the need to pass 50 unit trays from station to station. To better connect the cells, use the *kanban* cart operator to transfer the small boxes from Cell 1 to a makeshift storehouse we created in front of Cell 2. · Establishing Jidoka	One-piece flow Kanban cart Jidoka
Pull	Establish Pull-Demand Systems *Kanban* system provided a good pull system within each cell, but we had no pull signal from the storehouse. Team had enough information to design a good *heijunka* board with a make-to-stock system.	Kanban Heijunka

Results

- Lead time of cell No.1, first piece reduced to 97%.
- Lead time of cell No.2, first piece reduced to 99%.
- Total shipment lead time reduced to 81%.

3.3.3 Case Study 9: Implementing Lean Manufacturing in Zeta Cell (Lonnie Wilson, 2010)

Problem

The background to this is that we were hired for our problem-solving abilities—in this case, to solve a problem with a controller that was produced on the Zeta Cell. The controller was used to guide a robot and would occasionally stick in the "full speed ahead mode," causing the robot to consequently crash into a wall or the production line. This was not only undesirable, it was dangerous.

The other problems also exist at this cell, the workers, who were grossly underworked, would leave the cell without warning. Inventory would build up in front of their station and then the operator would return, concentrate on the work for a while, and the inventory would move further down the process. At times, if inventory build-ups were too large—that is, they ran out of space—a worker might leave his station to assist in the work-off of the inventory at his colleague's workstation. In short, it was a inefficient operation typical of non-Lean production facilities.

Project Implementation

Phase	Steps	Tools & Techniques
Specify value	Synchronizing the Supply to the Customer, Externally Perform a *takt* calculation. Since they have a 9.5-hour shift with 50 minutes for lunch and breaks, the *takt* was 39 seconds to produce the 800-unit weekly shipment for client.	· *Takt* calculation
Value stream	Synchronizing Production, Internally Completed a time study and a balancing study. The time study showed they had 157 seconds of work. At a *takt* of 39 seconds, that would be 4.02 operators at 100 percent OEE.	· Time study · Balancing study · OEE
Flow	Creating flow Cut the cell size dramatically. Using a new table design, created a cell using less than 40 percent of the space of the ten-person cell. Moved the press and anchored it.	· Cell system · TPM
Pull	Establishing Pull-Demand Systems Set up four piece space *kanbans* at each work station. Workers were trained to stop producing if the *kanban* location was full. Work instructions were modified to match the work stations.	· Kanban · Stand

Results

- First piece Lead Time reduced to 97%
- Batch Lead Time reduced to 58%
- Space utilization reduced to 62%
- Operators per cell reduced to 50% reduction
- Labour costs/unit reduced to 79% reduction

3.4 Case Study of Lean Six Sigma

3.4.1 Case Study 10: Reducing mold changing time by implementing Lean Six Sigma (Lee and Wei, 2009)

Project Background

This case study analyzed a PCB manufacturer located in Shenzhen, China. The company was founded in 1997 and currently employs about 1600 workers. This company produces semi-finished multi-layer PCB products for computer manufacturers in China and Taiwan.

ICT uses an electrical probe to test a PCB, checking for shorts, opens, resistance, capacitance and other basic quantities which will show whether the assembly was correctly fabricated. It is performed with a bed of nails type test fixture and specialist test equipment. Changing the mold is necessary if different types of PCBs are going to be tested. However, the mold changes required for this testing process were extremely time consuming, and caused bottlenecks in the PCB manufacturing process which substantially reduced the ICT efficiency and affected the delivery schedule. Consequently, the quality management council of the company deemed an improvement to the mold changing process at the ICT station as necessary.

Project Goals

Using five phases DMAIC of Six Sigma Management combined with Lean Production with the objectives are:

- To discover the critical factors that cause variation and waste in the ICT mold change process.
- To reduce the mold changing time in In-circuit testing (ICT) process.

Project Implementation

Phase	Steps	Tools & Techniques
Define	1. Create project charter Describe the problem, project objective, scope, schedule and milestones, organization and critical performance indicators 2. Identify the customer(s) and the critical to quality (CTQ) requirement	· Project Charter · CTQ Tree
Measure	1. Mapping the current process Mapping the current process to Illustrate the target process for identifying input variables (*X*s), output variables (*Y*s), relationships between *X*s and *Y*s, and all value-added and NVA process steps. Simultaneously, the team discussed and listed all input variables during brainstorming sessions and by constructing a fishbone/cause and effect diagram. Each input variable was characterized into the following categories: controlled, uncontrolled, SOP. 2. Analyze value-added and NVA activities in the process Using Time Value Chart, the team identified which NVA operation accounted for the greatest portion and discussed what factors affected the time measured by the ICT tester. They found that numerous points on a pin board probably indicated a significant factor. The project team then listed the factors and tested them for statistical significance. 3. Prioritize input variables in the process mapping To prioritize input variables in the process mapping, the team employed a Cause & Effect Matrix. The team thought that the room for improvement should be considered in implementing the project.	· Process mapping · Brainstorming · Cause and effect diagram · Time value chart · Cause and Effect Matrix

Analyze	1. Noise variable verification The project team first examined whether the four KPIVs significantly affect the mold changing time but doubted whether noise factors such as operators and work stations would potentially influence the mold changing time. The effects of different operators and work stations on the mold changing time were studied by using MINITAB software. The *p* value calculated by ANOVA and Correlation analysis revealed whether these two variables (operators and work stations) were significant factors. 2. Key point variable analysis and verification. The project team then examined how the varying number of broken ICT connectors, irregular points on fixtures and irregular points on a pin board correlated with the mold changing time. The ANOVA were performed to test the hypotheses and all statistical verification results The statistical analysis indicated that the three KPIVs significantly influenced the mold changing time. The project team decided that the information regarding fixture storage location should also be listed in the KPIV list.	· ANOVA analysis · Correlation Analysis · ANOVA
Improve	1. Analyze failure modes and potential causes The four critical variables were input into a FMEA form to analyze their failure modes and potential causes and then used to draft the corresponding improvement and prevention actions. 2. Draft the corresponding improvement and prevention actions Re-designed the procedures for removing the ICT connectors, set up a strict control plan to ensure that the fixtures were well maintained and followed a proper frequency, reassess the 5S approach and Total Productive Maintenance (TPM) also employed, redesign the testing fixtures, established a fixture management information system. 3. Implement improvement and prevention actions.	· FMEA · SOP · Five S · TPM · SMED/Quick Changeover
Control	Established a plan for controlling all critical input and output variables	· Control plan

Results

After making all the improvements, the project team then tested their effects on the performance, and the results are:

- The average mold changing time was reduced from 39.23 to 19.44 min in 3 months from March, 2007 to June, 2007.
- The performance exceeded the project objective of 25min.

- The original 66.77% production utilization rate of the ICT station gradually increased to 92.71% within 3 months.
- The fixture search time was reduced significantly from an average of 4.73 to 1.53min.
- Additionally, the erroneous pin problem was decreased from 72 to 11.5% within 3 months and to 1.8% within 6 months.
- The company was able to produce an additional 22 500 pieces of PCB each day after the improvements.

3.4.2 Case Study 11: Implementing the Lean Sigma framework in an Indian SME (Kumar, *et al*., 2006)

Project Background

The die-casting unit under study was established in 1978 with 150 employees, which comes under the category of SME as per the classification given by Indian Trade Industry. The organization is engaged in designing and manufacturing various types of precision machined components using pressure and gravity die-casting processes. The main customers of the company are ordinance factories, the automobile industry, and textile machine manufacturers. The company manufactures around 250 000 units of die casting products per year to cater for the needs of its customers.

In the last six years, demand for their product became high due to globalization and the boom in the automobile sector. In order to meet the customers' demand, production of automobile accessories was given top priority, irrespective of the quality of product. The management was able to meet the customer demands by putting the quality of product at risk. This resulted in a number of customer complaints from different parts of the country.

This intimidating situation led management to ponder over redeploying the quality initiatives taken at the beginning. As most of the customer complaints were related to crack propagation in the final die-casting product (resulting in improper functioning of the automobile engine), management formed a team to identify the root cause of problems. Moreover, there was a constant increase in in-process inventory, machine downtime, idle time at different workstations, and there was also concern about the health and safety issues of the employees as the average number of accidents on the shop floor were increasing each year.

Project Goals

Identify the root cause of problem and reduce the defects occur in the product (crack propagation in the automobile accessories).

Project Implementation

Phase	Steps	Tools & Techniques
Define	1. Conduct management initiatives. An emergency meeting conducted by top level management with operators, engineers and senior managers of different departments to discuss the restructuring required in the current practices for enhancing the market share and customer satisfaction. A cross-functional team was formed consisting of the operators, engineers from production, quality, and marketing department, and senior managers. This team spent many hours on the shop floor observing, in order to collect data and understand the different processes associated with the die-casting unit. 2. Identify critical to quality (CTQ) characteristics based on the voice of customer (VOC) input (Problem Definition). Conduct a number of brainstorming sessions to identify critical to quality (CTQ) characteristics based on the voice of customer (VOC) input. In the meeting the problem of the die-casting unit, the size of the problem, the impact of the problem, etc. 3. Develop the current state map. Develop a current state map in order to have an insight into the current state of the die-casting unit, which gives a closer look at the process so that opportunities for improvement can be identified. The movement of materials through different processes/facilities during manufacturing is shown in the current state map.	· Project charter · Brainstorming · CTQ Tree · Value Stream mapping

Measure	1. Collecting data of defective products. The team was divided into small groups to monitor the defects occurring in each process involved in the manufacturing of die-casting product. The team had been collecting data of defective products for the last 2 years and had identified the critical processes where maximum defects were occurring, but no action was taken. In order to validate the historic data, the team members decided to collect the data of defective product for the following 6 days of production from their respective work stations. 2. Analyzing the collected data. The collected data was analyzed and it was found to match with the historic data, showing that the maximum numbers of defects were coming from the die-casting machine, de-burring operation (MC2), and chamfering and threading operation (MC3). 3. Determine a performance standard based on customer requirements. Establish a data collection plan to focus on the project output and also to carry out the standard setting exercise for the same. A Gauge repeatability and reproducibility (Gauge R&R) study was conducted to identify the sources of variation in the measurement system and to determine whether it was accurate or not. What the customers want is a sound casting with measurable characteristics, such as the density of the casting. Therefore the ultimate goal of the team was to increase casting density.	· Data collection plan · Gage R&R
Analyze	1. Determine the defects. Determine defects and identify the significant process parameters causing the defect. Illustrates the percentage contribution of internal and external defects in the process using Pareto diagram. 2. Determine the root causes of defects and identify the significant process parameters causing the defect. Uses a cause and effect diagram to have a clear picture of the process parameters affecting the density of casting. The cause and effect diagram shows that the most important process parameters that affect the casting density are: piston velocity at first stage, piston velocity at second stage, metal temperature, filling time and hydraulic pressure.	· Pareto diagram · Brainstorming · Cause and effect diagram

Improve	1. Identify the significant process parameters. Carry out a designed experiment to identify the significant process parameters affecting the casting density. Once the optimum settings of process parameters were identified, the team members decided to implement 5S system and total productive maintenance (TPM). 2. Validate the results obtained. Validate the results obtained from the improve phase by perform a confirmatory experiment using the optimal setting of process parameters. This resulted in an increase of casting density by over 12%. 3. Implement improvement action. Implement the 5S system in order to organise the work environment, standardise the work flow and assign clear ownership of processes to employees, and help in increasing the productivity by reducing idle time of some processes. Iimplement TPM to maintain the machine, collection and analysis data of Overall Equipment Effectiveness, and involve operator to achieve zero defects, zero breakdown, and zero accidents.	· DoE · Confirmatory test · Five S · TPM
Control	1. Standardization of the optimal process parameters. To improved results sustained, From time to time, control charts are plotted, to check that the product is meeting the desired specification. The die-casting process has been improved by optimizing the critical process parameters. 2. Perform a mistake proofing exercise. Reduce the number of defects occurring in the process by performing a mistake proofing exercise.	· Control charts · Mistake proofing

Results

The savings generated by the organization by achieving improvements in aforementioned areas are as follows:

- The decrease in machine downtime from 1% to 6% helped in increasing the OPE and OEE. This resulted in estimated savings of over $40 000 per year.
- Work in process inventory reduced by over 25% and resulted in estimated savings of over $33 000 per year.
- Standard housekeeping procedures helped to reduce the number of accidents at work place significantly. This reduced the amount of compensation the management needed to pay to injured employees (around $20 000 on average per year).

3.4.3 Case Study 12: Lean Six Sigma Application in a Local Government (Furterer and Elshennawy, 2005)

Project Background

The authors applied Lean Six Sigma tools and principles to the financial administration processes in a local governmental entity. These tools streamlined the processes and reduced the time to complete the financial processes.

The finance director identified the need to streamline the financial processes. The finance clerk complained of needing additional staff and not being able to complete her work. Vendor payments were frequently late, resulting in vendors constantly calling the finance department requesting payment. The revenue receipts were frequently held in the finance department for over a week before processing and depositing. The estimated current payroll processing time ranged from 13–70 hours, with a mean time of 40 hours. Employees frequently complained about payroll paycheck errors. The monthly reconciliations were not performed on a regular basis. Adjustment journal entries were frequently made months after the error should have been discovered.

Project Goals

A successful implementation of the Lean Six Sigma problem-solving approach and Quality and Lean tools will be measured by the reduction of process inefficiencies, the reduction of the time it takes to process the financial transactions, and the assignment of appropriate staffing levels to handle the workload. No quantitative or qualitative measures of process or quality characteristics exist for any of the financial processes.

Project Implementation

Phase	Steps	Tools & Techniques
Define	1. Define process improvement need The Finance Director identified the need to streamline the financial processes, and was the project champion. 2. Identify department goals, project scope, objectives and project plan The Team Quality Facilitator, the Process Analyst, and the Consulting Manager interviewed the Finance personnel to understand the financial department goals, the project scope and objectives. Form process improvement team A process improvement team was formed, consisting of the Finance Director, the Finance Clerk, and a Team Quality Facilitator that performed the role of a Black Belt, a Process Analyst and a Consulting Manager.	· Project charter · CTQ · SIPOC diagram

Measure	1. Profile current state Mapping the current state processes using process flow chart analysis. These flow charts identified the steps involved in the Finance Department activities related to the financial processes. 2. Identify problems that contribute to process inefficiencies and errors The project team used the process flow charts and a brainstorming session to identify process problems, such as, inefficient sorting and filing of purchase orders and invoices. 3. Identify root causes of problems Identify root causes related to people (such as lack of training, and skills), methods (lack of standardized procedures), information technology (Information system human factors and processing flow was confusing and inefficient), and hardware (broken and inefficient printers) by using Cause and Effect analysis.	· Process flow chart · Brainstorming · Cause & Effect diagram
Analyze	1. Analyse gaps from best practice Identify gaps comparing the current state processes to best practice financial processes. Using Pareto Analysis to understand the vendor purchase patterns to potentially streamline the number of vendors across city departments. Identify non-valued added activities, especially related to unnecessary work and rework. Perform an analysis of reported financial information system problems using Pareto Analysis and Statistical Process Control Charts to identify employee training and knowledge gaps with respect to the financial and administrative information system. 2. Identify improvement opportunities and develop an improvement plan Identify improvement opportunities that grouped as Lean categories: standardized processes and procedures, good housekeeping, Kanban and visual control, waste identification and elimination, and one-piece flow. 3. Perform a cost–benefit analysis We identified potential costs and benefits of each proposed improvement to determine if the estimated benefits are greater than the costs to implement. Most of the costs were related to training, and the resources needed to implement and document the standardized procedures.	· Benchmarking · Pareto diagram · SPC · Cost-Benefit Analysis

Improve	1. Implement improvement solutions Implement leant tools: standardized processes and procedures, good housekeeping, Kanban and visual control, waste identification and elimination, and one-piece flow. 2. Measure impact of the improvements Measure the impact of the improvements after the majority of the improvement opportunities were implemented for each financial process 3. Documenting procedures and training employees on the improved procedures	· Standardized Work · SOP · Five S · Kanban · Visual Control · One-piece flow
Control	1. Design and implement process performance measures. 2. Implement a continuous process improvement approach to always improve.	Mistake proofing Control plan Process capability Control chart Standard Work

Results

Through implementing a Lean Six Sigma programme, the city's Finance Department was able to reduce significantly the time to process payroll, purchasing and accounts payable, accounts receivable and monthly reconciliation, which are:

- Payroll processing time was reduced by 60%.
- Purchasing and accounts payable processing time was reduced by 40%.
- Accounts Receivable processing time was reduced by 90%.
- Monthly reconciliation processing time was reduced by 87%.

CHAPTER 4
PROCESS AND TOOLS APPLICATION IN CASE STUDIES

This chapter present summarizes of process and tools that are used by twelve cases of project improvement in previous part. It will showing the list of process steps and tools that used in three projects categorize, that are Six Sigma, Design for Six Sigma, and Lean Six Sigma. It also indicates the usage of tools and techniques in each phase of the project.

4.1 Process Steps

Comparison between literature and case study, see Appendix A, shows that the process steps of quality improvement almost similar. The differences were just on the number of activities in the the process. However, the substances of the activities were the same.

4.2 Application of Tools and Techniques

Identification of the tools usage in every stage of quality or process improvement projects from 12 case studies using the method with the following steps:

1. Identify tools and techniques in cases and make a list of them that used in each stage.
2. Develop a matrix table of the tool to calculate how much it was used at every stage of projects (see Appendix B).
3. Assess the level of tools application using table in step 2 and shows it in a table with giving symbols (☺,😐,☹, X) to indicate its level. Symbol (☺) indicates that the tool is frequently used, symbol (😐) indicates that the tool is occasionally used, symbol (☹) indicates that the tool is rarely used, and symbol (X) indicates that the tool is never used.

This part also discuss about the overall application of tools in the twelve cases.

4.2.1 The Tools and Techniques are applied in Six Sigma Projects

a. Tools and techniques in Six Sigma case studies
There are three projects are taken as examples to identify the application of quality improvement tools in Six Sigma project, which are mentioned as case study 1,2, and 3 (CS1, CS2, CS3). From the three cases, it can summarize in table 4.1. The application of tools is divided into five phases of project; those are Define, Measure, Analyze, Improve, and Control.
From the table 4.1, it seen that their using similar several tools in define phase.. In the next four phases, it found that the tools and techniques utilization in each

phase shows the differences, in number and type. Generally, CS1 and CS2 perform the project using thirteen tools, and CS3 used seventeen tools.

Table 4.1 List of tools and techniques in Six Sigma case studies

Phase	CS1	CS2	CS3
Define	· CTQ Tree · Project Charter · SIPOC diagram	· Project Charter · SIPOC diagram · CTQ Tree	· SIPOC diagram · CTQ tree · Project charter
Measure	· Histogram · Data collection plan · Gage R&R	· Data collection plan · DPMO calculation	· Brainstorming · Gauge R&R. · ANOVA · Data collection plan · DPMO calculation
Analyze	· Capability process · DPMO calculation · Brainstorming · Failure Mode Effect Analysis (FMEA)	· Pareto diagram · Cause and Effect diagram	· Brainstorming · Tree diagram · One-way ANOVA
Improve	· Design of Experiment (DoE)	· Three Diagram · QFD · SOP	· DoE · ANOVA · Process capability · DPMO calculation
Control	· Control chart · Process capability	· Check sheet · Control chart · DPMO calculation	· Control plan · Process capability

b. Tools and techniques are applied in each phase of Six Sigma project

Further, we calculate the number of utilization tools and techniques to identify what tools are mostly used. To make it, firstly make a matrix of the tool utilization (see appendix B1). Then, based on it, we could identify which tools are mostly used. A table 4.2 showing tools were commonly used in each phase of three cases.

From the table 4.2, we can see that in define phase, all cases using the similar tools, those are CTQ Tree, Project Charter, and SIPOC diagram. This may imply that those tools are commonly used in that phase. In measure phase, data collection plan, Gauge R&R, and DPMO calculation were generally used. Brainstorming technique is generally used in analyze phase. In improve phase, DoE is a technique that mostly used. It practiced by 2 cases. Control chart is a tools mostly used in control phase, those are used by two cases. The table also showing that several tools are applied in three phases. For example, process capability tool is used in analyze, improve, and control phase.

Table 4.2 List of tools and techniques in the each phase of Six Sigma project

Tools & Techniques	Define	Measure	Analyze	Improve	Control
1. CTQ Tree	☺	X	X	X	X
2. Project Charter	☺	X	X	X	X
3. SIPOC diagram	☺	X	X	X	X
4. Histogram	X	☹	X	X	X
5. Data collection plan	X	☺	X	X	X
6. Gage R&R	X	😐	X	X	X
7. DPMO calculation	X	😐	☹	☹	☹
8. Brainstorming	X	☹	😐	X	X
9. ANOVA	X	☹	☹	☹	X
10. Process Capability	X	X	☹	☹	☹
11. FMEA	X	X	☹	X	X
12. Pareto diagram	X	X	☹	X	X
13. Cause and Effect diagram	X	X	☹	X	X
14. Tree diagram	X	X	☹	☹	X
15. DoE	X	X	X	😐	X
16. QFD	X	X	X	☹	X
17. SOP	X	X	X	☹	X
18. Control chart	X	X	X	X	😐
19. Check sheet	X	X	X	X	☹
20. Control Plan	X	X	X	X	☹

Frequently used (☺); occasionally used (😐); rarely used (☹); Never used (x)

This may imply that the tools could be used in more than one phase in a project. According to the table, we also see that in analyze-improve-control phase, they used tools almost totally difference. Table 4.3 shows the resume of tools and techniques application in each phase of Six Sigma project.

Table 4.3 Tools and techniques application in each phase of Six Sigma project

Define	Measure	Analyze	Improve	Control
1. CTQ Tree 2. Project Charter 3. SIPOC diagram	1. Histogram 2. Data collection plan 3. Gage R&R 4. DPMO calculation 5. Brainstorming 6. ANOVA	1. DPMO calculation 2. Brainstorming 3. ANOVA 4. Process Capability 5. FMEA 6. Pareto diagram 7. Cause and Effect diagram 8. Tree diagram	1. DPMO calculation 2. ANOVA 3. Process Capability 4. Tree diagram 5. DoE 6. QFD 7. SOP	1. DPMO calculation 2. Process Capability 3. Control chart 4. Check sheet 5. Control Plan

4.2.2 The Tools and Techniques are applied in Design for Six Sigma Projects

a. Tools and techniques in Design for Six Sigma case studies

From the three cases (CS4, CS5, CS6) of Design for Six Sigma project, it could be summarize in table 4.4. The application of tools is divided into four phases of project; those are Identify, Design, Optimize, and Verify/Validate.

The table shows that CS1 uses nine tools, CS2 perform the project using ten tools, and CS3 used six tools. From that table also, it seen that they use several tools are similar in Define phase. For instance, CTQ tree was used by CS4 and CS5, and all cases used QFD. The table also indicates that the use of tools in every stage of project does not always the similar. We can see in table above, they used difference tools in design, optimize, and verify phase.

Table 4.4 List of tools and techniques in Design for Six Sigma case studies

Phase	CS4	CS5	CS6
Identify	· SIPOC diagram · CTQ Tree · QFD	· VOC · CTQ · QFD	· IPO diagram · QFD · Process Scorecard
Design	· Process Map · CTQ Tree · QFD	· Tree Diagram · QFD	· DoE ·
Optimize	· Testing & Validation	· Process Mapping · Detailed Design Elements · FMEA	· Process Capability
Verify/ Validate	· Dashboard · KPIs	· Process management chart (PDCA)	· Pugh Matrix

b. Tools and techniques are applied in each phase of Design for Six Sigma projects

To see which tools are mostly used in these three cases, further, we can calculate the number of utilization tools and techniques based on table in Appendix B2. The table 4.5 showing tools were commonly used in each phases of DFSS three cases.

From the table 4.5, we can see that in identify phase, QFD was mostly used. Then it followed by CTQ tree. This tool also used in design phase. So, there are two tools were generally used in this stage. In design phase, QFD, also was typically practiced. These may imply that QFD are commonly used in both phases. In the further phase, optimize and verify, there is no tool was used in similar.

Table 4.5 List of tools and techniques in the each phase of DFSS project

Tools & Techniques	Identify	Design	Optimize	Verify
1. SIPOC diagram	☹	X	X	X
2. CTQ Tree	😐	☹	X	X
3. QFD	☺	😐	X	X
4. VOC	☹	X	X	X
5. IPO diagram	☹	X	X	X
6. Process Scorecard	☹	X	X	X
7. Process Mapping	X	☹	☹	X
8. Tree Diagram	X	☹	X	X
9. DoE	X	☹	X	X
10. Testing & Validation	X	X	☹	X
11. Detailed Design Elements	X	X	☹	X
12. FMEA	X	X	☹	X
13. Process Capability	X	X	X	☹
14. Dashboard	X	X	X	☹
15. Process management chart (PDCA)	X	X	X	☹
16. Pugh Matrix	X	X	X	☹

Frequently used (☺); occasionally used (😐); rarely used (☹); Never used (x)

Table 4.6 shows the resume of tools and techniques application in each phase of Design for Six Sigma project.

Table 4.6 Tools and techniques application in each phase
Design of Six Sigma project

Identify	Design	Optimize	Verify
1. SIPOC diagram 2. CTQ Tree 3. QFD 4. VOC 5. IPO diagram 6. Process Scorecard	1. CTQ Tree 2. QFD 3. Process Mapping 4. Tree Diagram 5. DoE	1. Process Mapping 2. Testing & Validation 3. Detailed Design Elements 4. FMEA	1. Process Capability 2. Dashboard 3. Process management chart (PDCA) 4. Pugh Matrix

4.2.3 The Tools and Techniques are applied in Lean Manufacturing Projects

a. Tools and techniques in Lean Manufacturing case studies

From the three cases (CS7, CS8, CS9) of Lean Manufacturing project, it could be summarize in table 4.7. The application of tools is divided into four phases of project; those are Specify value, Value stream, Flow, and Pull.

Table 4.7 List of tools and techniques in case study of Lean Manufacturing

Phase	CS7	CS8	CS9
Specify value	· Value stream mapping · Takt time calculation	· Takt time calculation	· *Takt* calculation
Value stream	· Time study	· Time Study · OEE	· Time study · OEE
Flow	· Value stream mapping · Single Minute Exchange of Dies · Heijunka	· One-piece flow · Jidoka	· Cell system · TPM
Pull	· Kanban · Spaghetti Diagram	· Kanban · Heijunka	· Kanban

The table shows that CS7 uses nine tools, CS8 perform the project using ten tools, and CS9 used six tools. It also seen that they use several tools are similar almost in all phase, except flow stage. For instance, takt time calculation practiced in first stage, basic time study and balancing study in second stage.

b. Tools and techniques are applied in each phase of Lean projects

To identify which tools are mostly used in these three cases, further, we can calculate the number of utilization tools and techniques based on table in Appendix B3. The table 4.8 showing tools were commonly used in each phases of Lean manufacturing cases.

As seen in table 4.8, in first phase (specify value), takt time calculation is frequently used. This could mean that such a tool, typically used in this phase. As well as the value stream stage, the projects also use similar tools such as basic time, time study, and OEE tools to create value stream of their processes. This also can be interpreted that those tools generally practiced in this phase. In third stage, flow, they applied difference tools. In the last phase, Pull, all cases also using the same tools, that is Kanban. It could be concluded that Kanban is commonly tool are used in the pull stage.

Table 4.9 shows the resume of tools and techniques application in each phase of Lean manufacturing project.

Table 4.8 List of tools and techniques in the each phase of Lean project

Tools & Techniques	Specify value	Value stream	Flow	Pull
1. Value stream mapping	☹	X	X	X
2. Takt time calculation	☺	X	X	X
3. Basic Time study	X	☺	X	X
4. OEE	X	😐	X	X
5. SMED	X	X	☹	
6. Heijunka	X	X	☹	☹
7. One-piece flow	X	X	☹	X
8. Cell system	X	X	☹	X
9. Jidoka	X	X	☹	X
10. TPM	X	X	😐	X
11. Kanban	X	X	X	☺
12. Spaghetti Diagram	X	X	X	☹

Frequently used (☺); occasionally used (😐); rarely used (☹); Never used (x)

Table 4.9 Tools and techniques application in each phase of Lean manufacturing project

Specify value	Value stream	Flow	Pull
1. Value stream mapping 2. Takt time calculation	1. Basic Time study 2. OEE	1. SMED 2. Heijunka 3. One-piece flow 4. Cell system 5. Jidoka 6. TPM	1. Heijunka 2. Kanban 3. Spaghetti Diagram

4.2.4 The Tools and Techniques Applied in Lean Six Sigma Projects

a. Tools and techniques in Lean Six Sigma case studies

From the three cases of Lean Six Sigma projects, it can be summarize in table 4.10. The application of tools is divided into five phases of project; those are Define, Measure, Analyze, Improve, and Control.

Generally, CS10 applied fifteen tools included five lean tools. CS11 also perform the project using fifteen tools which are four among them are Lean tools. CS3 practiced twenty tools include six lean tools. From the table 4.10, it seen that their using similar tools in define phase. In the next phases, it found that the tools and techniques utilization in each phase shows the differences, except in improve phase, there are several tools relatively are the same.

Table 4.10 List of tools and techniques practiced in case study of Lean Six Sigma

Phase	CS10	CS11	CS12
Define	· Project Charter · CTQ Tree	· Project charter · Brainstorming · CTQ Tree · Value Stream mapping	· Project charter · CTQ · SIPOC diagram
Measure	· Process mapping · Brainstorming · Cause and effect diagram · Time value chart · Cause and Effect Matrix	· Data collection plan · Gage R&R	· Process flow chart · Brainstorming · Cause & Effect diagram
Analyze	· ANOVA analysis · Correlation Analysis	· Pareto diagram · Brainstorming · Cause and effect diagram	· Benchmarking · Pareto diagram · SPC
Improve	· FMEA · SOP · Five S · TPM · SMED/Quick Changeover	· DoE · Five S · TPM	· Standardized Work · SOP · Five S · Kanban · Visual Control · One-piece flow
Control	· Control plan	· Control charts · Mistake proofing	· Mistake proofing · Control plan · Process capability · Control chart · Standard Work

b. Tools and techniques are applied in each phase of Design for Six Sigma projects

To identify which tools are mostly used in these three cases, we can calculate the number of application of tools and techniques based on table in Appendix B4. The table 4.11 showing tools are commonly used in each phases of Lean manufacturing cases.

From the table 4.11, we can see that in define phase, two tools such as CTQ Tree and Project Charter were frequently used. This may imply that those tools are commonly used in this stage. In measure phase, Brainstorming and cause and effect diagram are occasionally used. In analyze phase, the tool mostly used is Pareto diagram. In improve stage; two Lean tools, Five S and TPM, are commonly used. It used by two cases. In the last phase, control, control plan, control chart, and mistake proofing are three tools were used in common, which used by two cases. Mistake proofing is a one of Lean tools.

Table 4.12 shows the resume of tools and techniques application in each phase of Lean Six Sigma project.

4.3 Application of Tools and Techniques in all quality improvement projects

Using Juran's quality improvement process, and refers to table 4.12 and table in Appendix B5-B6, then we make a matrix map of tools application on 12 cases, as seen in table 4.13. From the table, we can summarize which tools are most widely used in each steps of project improvement. Tools selected from its application frequency, which are frequently and occasionally used. See table 4.14.

Table 4.11 List of tools and techniques in the each phase of Lean Six Sigma project

Tools & Techniques	Define	Measure	Analyze	Improve	Control
1. Project Charter	☺	X	X	X	X
2. CTQ Tree	☺	X	X	X	X
3. Brainstorming	☹	😐	☹	X	X
4. SIPOC diagram	☹	X	X	X	X
5. Value Stream mapping	☹	X	X	X	X
6. Process mapping	X	☹	X	X	X
7. Cause and effect diagram	X	😐	☹	X	X
8. Time value chart	X	☹	X	X	X
9. Cause and Effect Matrix	X	☹	X	X	X
10. Data collection plan	X	☹	X	X	X
11. Gage R&R	X	☹	X	X	X
12. Process flow chart	X	☹	X	X	X
13. ANOVA	X	X	☹	X	X
14. Correlation Analysis	X	X	☹	X	X
15. Pareto diagram	X	X	😐	X	X
16. Benchmarking	X	X	☹	X	X
17. SPC	X	X	☹	X	X
18. DoE	X	X	X	☹	X
19. FMEA	X	X	X	☹	X
20. SOP	X	X	X	😐	X
21. Five S	X	X	X	☺	X
22. TPM	X	X	X	😐	X
23. SMED/ Quick Changeover	X	X	X	☹	X
24. Standardized Work	X	X	X	☹	☹
25. Kanban	X	X	X	☹	X
26. Visual Control	X	X	X	☹	X
27. One-piece flow	X	X	X	☹	X
28. Control plan	X	X	X	X	😐
29. Control charts	X	X	X	X	😐

30. Mistake proofing	X	X	X	X	😐
31. Process capability	X	X	X	X	☹

Frequently used (☺); occasionally used (😐); rarely used (☹); Never used (x)

Table 4.12 Tools and techniques application in each phase of Lean Six Sigma project

Define	Measure	Analyze	Improve	Control
1. Project Charter 2. CTQ Tree 3. Brainstorming 4. SIPOC diagram 5. Value Stream mapping	1. Brainstorming 2. Process mapping 3. Cause and effect diagram 4. Time value chart 5. Cause and Effect Matrix 6. Data collection plan 7. Gage R&R 8. Process flow chart	1. Brainstorming 2. Cause and effect diagram 3. ANOVA 4. Correlation Analysis 5. Pareto diagram 6. Benchmarking 7. SPC	1. DoE 2. FMEA 3. SOP 4. Five S 5. TPM 6. SMED/ Quick Changeover 7. Standardized Work 8. Kanban 9. Visual Control 10. One-piece flow	1. Standardized Work 2. Control plan 3. Control charts 4. Mistake proofing 5. Process capability

Table 4.13 Application of Tools and Techniques in all quality improvement projects

Quality improvement tools	Quality Improvement Steps			
	Identify & Establish a project	Diagnose the cause	Remedy the cause	Hold the gains
1. ANOVA	☹	X	X	X
2. Benchmarking	X	☹	X	X
3. Brainstorming	😐	😐	X	X
4. Cause and effect diagram	😐	😐	X	X
5. Cause and Effect Matrix	☹	X	X	X
6. Check Sheet	X	X	X	☹
7. Control charts	X	X	X	☺
8. Control plan	X	X	X	😐
9. Correlation Analysis	X	☹	X	X
10. CTQ Tree	☺	X	X	X
11. Data collection plan	☺	X	X	X
12. DoE	X	☹	😐	X
13. DPMO calculation	😐	☹	☹	☹
14. FMEA	X	☹	😐	X
15. Gage R&R	☺	X	X	X
16. Histogram	☹	X	X	X

17. IPO diagram	☹	X	X	X
18. Pareto diagram	X	😐	X	X
19. Process capability	X	☹	😐	😐
20. Process flow chart	☹	X	X	X
21. Process mapping	☹	☹	☹	X
22. Process Scorecard	☹	X	X	X
23. Project Charter	☺	X	X	X
24. QFD	😐	😐	☹	X
25. SIPOC diagram	☺	X	X	X
26. SPC	X	☹	X	X
27. Time value chart	☹	X	X	X
28. Tree diagram	X	😐	☹	X
LEAN TOOLS				
1. Basic Time study	X	😐	X	X
2. Cell system	X	X	☹	X
3. Five S	X	X	😐	X
4. Heijunka	X	X	😐	X
5. Jidoka	X	X	☹	X
6. Kanban	X	X	☺	X
7. Mistake proofing	X	X	X	😐
8. OEE	X	😐	X	X
9. One-piece flow	X	X	☹	X
10. SMED/ Quick Changeover	X	X	😐	X
11. Spaghetti Diagram	X	X	☹	X
12. Standardized Work	X	X	☹	☹
13. Takt time calculation	😐	X	X	X
14. TPM	X	X	☺	X
15. Value Stream mapping	☹	X	X	X
16. Visual Control	X	X	X	☹

Frequently used (☺); occasionally used (😐); rarely used (☹); Never used (X)

Table 4.14 The most widely used tools in quality improvement project

Identify & establish a project	Diagnose the cause	Remedy the cause	Hold the gains
1. Brainstorming 2. Cause and effect diagram 3. CTQ Tree 4. Data collection plan 5. DPMO calculation 6. Gage R&R 7. Project Charter 8. QFD 9. Takt time calculation	1. Brainstorming 2. Cause and effect diagram 3. Pareto diagram 4. QFD 5. Tree diagram 6. Basic Time study 7. OEE	1. DoE 2. FMEA 3. Process capability 4. Five S 5. Heijunka 6. Kanban 7. SMED/ Quick Changeover 8. TPM	1. Control charts 2. Control plan 3. Process capability 4. Mistake proofing

CHAPTER 5
CONCLUSION

The main goal of this study is to find out the project implementation and its tools and technique of a quality and process improvement project. For this purpose, it studied several literatures and took twelve examples or case studies of quality improvement approach such as Six Sigma, Design for Six Sigma, Lean Manufacturing, and Lean Six Sigma. Here are some important things that can be withdrawn from the study.

The initial stage of this project, literature review, it provided phases and its activities to perform a project of quality and process improvement. It also present kinds of tools and techniques are used to achieved goals in every steps of project. It contributes to enhance an understanding to carry out a project with several quality and management approach such as Lean and Six Sigma. In this stage was also found that generally, there are four stage or process steps to conduct a project of quality and process improvement (see page 32).

The secondary stage, case studies, it describes several applications of quality and process improvement approaches and its tools in vary types of companies. This provides a comprehensive understanding of the implementation of methods to solve the problems related to quality and process in specific situations.

In the third stage of project, discussion of tools application, it was found several phases of project using tools in common. Following the most commonly tools applied in quality and process improvement projects.

- In the first stage of a project, identify and establish an improvement project, there were nine tools and techniques commonly used, those are: Brainstorming, Cause and effect diagram, CTQ Tree, Data collection plan, DPMO calculation, Gage R&R, Project Charter, QFD, and takt time calculation.
- In the second stage, diagnose the cause of problems, eight tools mostly used such as Brainstorming, Cause and effect diagram, Pareto diagram, QFD, Tree diagram, Balancing Study, Basic Time study, and OEE.
- In the third stage, remedy the cause of problem generally using quality tools like DoE, FMEA, Process capability, and also could uses Lean tools such as Five S, Heijunka, Kanban, SMED/ Quick Changeover, and TPM.
- In the last stage, keep the quality and process that resulted from the improvement, several tools broadly used that are control charts, control plan, process capability, and mistake proofing.
- This study also found that the application of a tool in more than one phase into a project is very possible.

There was limitation faced during conduct this study. The difficulty was to find project examples which have a complete cycle of project phase. It was spends a lot of time to search books, articles, or journal.

The benefit of this study is enhancing the understanding of an implementation of quality improvement project and the application of tools and techniques in order to perform every stage of the project. The common tools was resulted from this study also possible used as a consideration to select tools that will be used in a project.

The conclusion mentioned before need more justification. It because this study used few cases and was not focused on specific industry and problem. So for the future work, it proposes to conduct a similar study which much more cases and focused on specific industry or case of quality improvement problem.

REFERENCES

Books and Journals

Adi Choudri, 2002, Manufacturing Handbook of Best Practices: An Innovation, Productivity, and Quality Focus, edited by Jack B. ReVelle, CRC Press LLC, Florida

Akhmad Hidayatno, Bahrun Afriansyah, 2004, Quality Improvement of Eye Tracer Cutting Machine at United Tractor Pandu Engineering Inc. Using Six Sigma Approach, Journal of Technology, Volume 2: Industrial Engineering, June 2004, Indonesia.

Bill Careira, 2005, Lean manufacturing That Works: Powerful Tools for Dramatically Reducing Waste and Maximizing Profits, American Management Association, New York.

Basem El Haik, Raid Al-Aomar, 2006, Simulation-Based Lean Six Sigma and Design for Six-Sigma, John Wiley & Sons, Inc, Ney Jersey

George A. Shinkle *et al*. 2004, Transforming strategy into success: how to implement a lean management system, Productivity Press, New York.

Helen Bevan et al, Lean Six Sigma: Some Basic Concepts, NHS Institute for Innovation and Improvement.

Jiju Antony, Ricardo Bañuelas, Ashok Kumar, 2006, World Class Applications of Six Sigma, Elsevier Ltd, Oxford.

Kai Yang, Basem S. El-Haik, 2009, Design for Six Sigma: A Roadmap for Product Development, Second Edition, McGraw-Hill Companies, Inc.

Kenneth W. Dailey, 2003, Lean Manufacturing Pocket Handbook.

Kuo-Liang Lee, and Chun-Chin Wei, 2009, Reducing Mold Changing Time by Implementing Lean Six Sigma, Quality and Reliability Engineering International, John Wiley & Sons, Ltd.

Lonnie Wilson, 2010, How to Implement Lean Manufacturing, McGraw-Hill Companies, Inc.

Michael L. George, 2002, Combining Six Sigma Quality with Lean Production Speed, McGraw-Hill Companies, Inc.

Juran Institute, 1999, Juran's Quality Handbook, Fifth edition, McGraw-Hill Companies, Inc.

M. Kumar, J. Antony, R.K. Singh, M.K. Tiwari, D. Perry, Implementing the Lean Sigma Framework in an Indian SME: a Case Study, Journal of Production Planning & Control, Vol. 17, No. 4, June 2006.

M.P.J. Pepper and T.A. Spedding, 2010, The Evolution of Lean Six Sigma, International Journal of Quality & Reliability Management, Vol. 27 No. 2, 2010.

Pete Pande and Larry Holpp, 2002, What is Six Sigma? McGraw-Hill, USA

Roland R. Cavanagh, Robert P. Neuman, Peter S. Pande, 2005, What is design for Six Sigma, McGraw-Hill Companies, Inc.

Ron Basu, 2009, Implementing Six Sigma and Lean: A Practical Guide to Tools and Techniques, Elsevier.

Sanjit Ray, Prasun Das, Improve Machining Process Capability by Using Six Sigma, International Journal for Quality research, Volume X, No. X, 2011.

Thomas Pyzdek, Paul A. Keller, 2010, The Six Sigma Handbook: A Complete Guide for Green Belts, Black Belts, and Managers at All Levels, Third Edition, McGraw-Hill Companies, Inc.

Thomas Lindsay Jackson, Karen R. Jones, 1996, Implementing a lean management system, Productivity Press, Potland.

Young HK and Frank T. A, 2006, Benefits, Obstacles, and Future of Six Sigma Approach, Journal Elsevier Ltd.

Internet

www.isixsigma.com

www.airacad.com

www.leanmanufaturingconcepts.com

www.lean.org

www.en.wikipedia.com

Appendix A: The Process Steps of Case Studies

Appendix A1: Comparison the process steps between Literature and Case Studies of Six Sigma

Phase	Literature	Case 1	Case 2	Case 3
Define	1. Define project scope, objective, & schedule 2. Define process and stakeholders 3. Select team members 4. Obtain Authorization from sponsor 5. Assemble & train team	4. Identify the customer(s) and the critical to quality (CTQ) requirement 5. Create the project charter 6. Develop a high-level process map	4. Create Project Charter 5. Mapping the existing process 6. Identify customer requirements	4. Define the project boundary. 5. Identify and define Critical to Quality (CTQ) 6. Defined project charter.
Measure	1. Define process 2. Define metric 3. Establish process baseline 4. Evaluate measurement system	4. Confirm/refine the project output Y (CTQ) 5. Define performance goals or standards 6. Calibrate the measurement system	4. Performance Measurement Standards 5. Determine Sigma level of process	6. Formulate data collection plan and identification of stratification factors 7. Validate the measurement uncertainty of the current measurement system. 8. Collection of existing data. 9. Analysis data for Sigma Level calculation. 10. Initial process analysis.
Analyze	1. Benchmar against best in class 2. Determine process drivers 3. Analyze source of variation 4. Analyze value stream	1. Measure the capability of the existing process 2. Calculate the sigma level 3. Identify possible problems 4. Identify and verify critical problems	3. Make a priority to overcome the problem 4. Identify possible causes of problems	3. Identification of suspected stratification factors and causes. 4. Collect data on *x*'s and *y* together and establish the relation between them.
Improve	1. Evaluate for risk and failure modes 2. Optimize process/product setting 3. Define new process or product design 4. Prioritize improvement opportunities	4. Identify solution alternatives 5. Select the best solution and the relationships between Xs and Ys 6. Implementation plan	4. Identify solution alternatives 5. Analyzing solution 6. Implementing the solution	6. Identification of Factor and Levels. 7. Planning and conduct of experiments. 8. Analysis of results. 9. Identification of optimum setting 10. Trial run and sigma-level calculation.
Control	1. Approves deliverables 2. Document lesson learned 3. Develop and implement control plan 4. Validate new process/product	4. Develop control plan 5. Determine improved process capability 6. Implement process control	3. Develop control plan 4. Implement process control	3. Documenting the optimum process. 4. Implementing process control plan

Appendix A2: Comparison the process steps between Literature and Case Studies of Design for Six Sigma

Phase	Literature	Case 3	Case 4	Case 5
Identify	1. Developing a team and team charter, 2. Gathering VOC data, 3. Performing competitive analysis, 4. Developing CTSs.	1. Develop a team 2. Identify the system needs and what business processes it needed to address 3. Comprehensive voice of the customer (VOC) data collection	1. Develop a team 2. Conduct a voice of the customer (VOC) data collection	1. Develop a team 2. Identify product features
Design	1. Identifying functional requirements 2. developing alternative concepts, 3. Evaluating alternatives and selecting a best-fit concept, 4. Deploying CTQ, and predicting sigma capability.	1. Create a detailed process of the should-be process 2. Defining the user requirement specifications 3. Development of functional specifications	1. Conducted a functional analysis 2. Analyze the process steps	1. Frame Design Analysis 2. Validate design significant characteristics and verify impact of process variation
Optimize	1. Developing detailed design elements, 2. predicting performance, 3. Optimizing design	Establishment of necessary testing and validation procedures	1. Detailed process design 2. Conducted a risk analysis for the new process	Optimization run confirms design
Verify	Testing and validating the design	1. Develop a dashboard to monitor the process performance 2. Trained on the new system	1. Implementation trial 2. made final modifications of the process	Peform a weighted selection matrix

Appendix A3: Comparison the process steps between Literature and Case Studies of Lean Six Sigma

Phase	Literature	Case 10	Case 11	Case 12
Define	1. Define project scope, objective, & schedule 2. Define process and stakeholders 3. Select team members 4. Obtain Authorization from sponsor 5. Assemble & train team	1. Create project charter 2. Identify the customer(s) and the critical to quality (CTQ) requirement	1. Conduct management initiatives 2. Identify critical to quality (CTQ) characteristics based on the voice of customer (VOC) input (Problem Definition 3. Develop the current state map	1. Define process improvement need 2. Identify department goals, project scope, objectives and project plan 3. Form process improvement team
Measure	1. Define process 2. Define metric 3. Establish process baseline 4. Evaluate measurement system	1. Mapping the current process 2. Analyze value-added and NVA activities in the process 3. Prioritize input variables in the process mapping	1. Collecting data of defective products. 2. Analyzing the collected data 3. Determine a performance standard based on customer requirements	1. Profile current state 2. Identify problems that contribute to process inefficiencies and errors 3. Identify root causes of problems
Analyze	1. Benchmark against best in class 2. Determine process drivers 3. Analyze source of variation 4. Analyze value stream	1. Noise variable verification 2. Key point variable analysis and verification	1. Determine the defects 2. Determine the root causes of defects and identify the significant process parameters causing the defect	1. Analyse gaps from best practice 2. Identify improvement opportunities and develop an improvement plan 3. Perform a cost–benefit analysis
Improve	1. Evaluate for risk and failure modes 2. Optimize process/product setting 3. Define new process or product design 4. Prioritize improvement opportunities	1. Analyze failure modes and potential causes 2. Draft the corresponding improvement and prevention actions 3. Implement improvement and prevention actions.	1. Identify the significant process parameters 2. Validate the results obtained 3. Implement improvement action	1. Implement improvement solutions 2. Measure impact of the improvements 3. Documenting procedures and training employees on the improved procedures
Control	1. Approves deliverables 2. Document lesson learned 3. Develop and implement control plan 4. Validate new process/product	Established a plan for controlling all critical input and output variables	1. Standardization of the optimal process parameters 2. Perform a mistake proofing exercise	1. Design and implement process performance measures 2. Implement a continuous process improvement approach to always improve

Appendix B: The Data of Tools and Techniques Application in Case Studies

Appendix B1: The data of tools and techniques application in Six Sigma case studies

Tools & Techniques	Phase															Nr of usage
	Define			Measure			Analyze			Improve			Control			
	CS 1	CS 2	CS 3	CS 1	CS 2	CS 3	CS 1	CS 2	CS 3	CS 1	CS 2	CS 3	CS 1	CS 2	CS 3	
21. CTQ Tree	V	V	V													3
22. Project Charter	V	V	V													3
23. SIPOC diagram	V	V	V													3
24. Histogram				V												1
25. Data collection plan				V	V	V										3
26. Gage R&R				V		V										2
27. DPMO calculation					V	V	V					V		V		5
28. Brainstorming						V	V		V							3
29. ANOVA						V			V			V				3
30. Process Capability							V					V			V	3
31. FMEA							V									1
32. Pareto diagram								V								1
33. Cause and Effect diagram								V								1
34. Tree diagram									V		V					2
35. DoE										V		V				2
36. QFD											V					1
37. SOP											V					1
38. Control chart													V	V		2
39. Check sheet														V		1
40. Control Plan															V	1

Appendix B2: The data of tools and techniques application in DFSS case studies

Tools & Techniques	Phase												Number of usage
	Identify			Design			Optimize			Verify			
	CS4	CS5	CS6	CS4	CS5	CS6	CS4	CS5	C6	CS4	CS5	CS6	
SIPOC diagram	v												1
CTQ Tree	v	v		v									3
QFD	v	v	v	v	v								5
VOC		v											1
IPO diagram			v										1
Process Scorecard			v										1
Process Mapping				v				v					2
Tree Diagram					v								1
DoE						v							1
Testing & Validation							v						1
Detailed Design Elements								v					1
FMEA								v					1
Process Capability									v				1
Dashboard										v			1
KPIs										v			1
Process management chart (PDCA)											v		1
Pugh Matrix												v	1

Appendix B3: The data of tools and techniques application in Lean case studies

Tools & Techniques	Phase												Number of usage
	Specify value			Value stream			Flow			Pull			
	CS7	CS8	CS9	CS7	CS8	CS9	CS7	CS8	CS9	CS7	CS8	CS9	
Value stream mapping	v												1
Takt time calculation	v	v	v										3
Basic Time study				v	v	v							3
Balancing Study				v	v	v							3
OEE					v	v							2
SMED							v						1
Heijunka							v				v		2
One-piece flow								v					1
Cell system									v				1
Jidoka								v					1
TPM								v	v				2
Kanban										v	v	v	3
Spaghetti Diagram										v			1

Appendix B4: Data of tools and techniques application in Lean Six Sigma case studies

Tools & Techniques	Phase															Nr of usage
	Define			Measure			Analyze			Improve			Control			
	CS10	CS11	CS12	CS10	CS11	CS12	CS10	CS11	CS12	CS10	CS11	CS12	CS10	CS11	CS12	
Project Charter	v	v	v													3
CTQ Tree	v	v	v													3
Brainstorming		v		v		v		v								4
SIPOC diagram			v													1
Value Stream mapping		v														1
Process mapping				v												1
Cause and effect diagram				v		v		v								3
Time value chart				v												1
Cause and Effect Matrix				v												1
Data collection plan					v											1
Gage R&R					v											1
Process flow chart						v										1
ANOVA							v									1
Correlation Analysis							v									1
Pareto diagram								v	v							2
Benchmarking									v							1
SPC									v							1
DoE											v					1
FMEA										v						1
SOP										v		v				2
Five S										v	v	v				3
TPM										v	v					2
SMED/ Quick Changeover										v						1
Standardized Work												v				1
Kanban												v				1
Visual Control												v				1
One-piece flow												v				1
Control plan													v		v	2
Control charts														v	v	2
Mistake proofing														v	v	2
Process capability															v	1
Standard Work															v	1

Appendix B5: Overall tools and techniques of Six Sigma are applied in all case studies

Tools & Techniques	Case Study									Nr
	1	2	3	4	5	6	10	11	12	
1. ANOVA			v				v			2
2. Benchmarking									v	1
3. Brainstorming	v	v	v				v	v	v	6
4. Cause and effect diagram		v					v	v	v	4
5. Cause and Effect Matrix							v			1
6. Check Sheet		v								1
7. Control charts	v	v						v	v	4
8. Control plan			v				v		v	3
9. Correlation Analysis							v			1
10. CTQ Tree	v	v	v	v	v		v	v	v	8
11. Data collection plan	v	v	v					v		4
12. DoE	v		v			v		v		4
13. DPMO calculation	v	v	v							3
14. FMEA	v				v		v			3
15. Gage R&R	v		v					v		3
16. Histogram	v									1
17. IPO diagram						v				1
18. Pareto diagram		v						v	v	3
19. Process capability	v		v			v			v	4
20. Process flow chart									v	1
21. Process mapping					v	v	v			3
22. Process Scorecard						v				1
23. Project Charter	v	v	v				v	v	v	6
24. QFD		v		v	v	v				4
25. SIPOC diagram	v	v	v	v					v	5
26. SPC									v	1
27. Time value chart							v			1
28. Tree diagram		v	v		v					3

Appendix B6: Overall tools and techniques of Lean are applied in all case studies

Tools & Tehniques	Case Study						Nr
	7	8	9	10	11	12	
1. Balancing Study	v	v	v				3
2. Basic Time study	v	v	v				3
3. Cell system			v				1
4. Five S				v	v	v	3
5. Heijunka	v	v					2
6. Jidoka		v					1
7. Kanban	v	v	v			v	4
8. Mistake proofing					v	v	2
9. OEE		v	v				2
10. One-piece flow		v				v	2
11. SMED/ Quick Changeover	v			v		v	3
12. Spaghetti Diagram	v						1
13. Standardized Work						v	1
14. Takt time calculation	v	v	v				3
15. TPM		v	v	v	v		4
16. Value Stream mapping	v				v		2
17. Visual Control						v	1

Appendix C: Tools and Techniques

1. Benchmarking

Definition

Benchmarking is a continuous and systematic process for comparing your own efficiency in terms of productivity, quality and best practices with those companies and organisations that represent excellence. Dale (1999) suggests three main types of formal benchmarking:

- Internal benchmarking: involves benchmarking between the same groups of companies so that best practices are shared across the corporate business.
- Competitive benchmarking: relates to a comparison with direct competitors to gather data on 'best in class' performance and practices.
- Functional benchmarking: a comparison of specific process in different industries to obtain information on 'best in school' performance and practices.

Application

A benchmarking process seeks to provide knowledge in a number of areas including:

1. What are the potential opportunities for improvement in our products or processes?
2. Who the 'best in class' industry leaders in our competitive market are?
3. How is our performance comparing with those of industry leaders?

The above three objectives could be provided respectively by internal, competitive and functional benchmarking. The application areas usually depend on the type of benchmarking. Internal benchmarking is widely used by a multi-national business with a number of subsidiaries in different countries or a national business which operates with some kind of branch structure of divisions. The object of functional benchmarking is to identify the best practice wherever it may be found. The purpose is to benchmarking a part of the business which displays a logical similarity even in different industries.

Basic steps

1. *Identify what to benchmark:* Identifying what to benchmark is influenced by the knowledge of your own business.
2. *Plan the benchmarking process* : The preparation and planning should include:
a. Forming a team with their roles and responsibilities.
b. Selecting the measures of performance for the selected activity for benchmarking.
c. Method of data collection.
d. Defining the scope and time line for the exercise.
3. *Identify benchmarking partners:* The participating units will vary depending on the type of benchmarking.
4. *Collect data:* The purpose of the fourth stage is to supply the information needed for the analysis.
5. *Analyse data:* A comparative analysis of the validated data is carried out to identify gaps.
6. *Implement and improve plan:* Develop action plan of closing the gap which the analysis stage has identified.
7. *Review and repeat:* More often than not, a benchmarking exercise is a continuous process. This should be conducted on a regular basis by sharing the results with benchmarking partners.

2. Brainstorming

Definition

Brainstorming is an improvement tool for a team to generate, creatively and efficiently, a high volume of ideas on any topic by encouraging free thinking. There are a few variations on the brainstorming process, of which two methods are more frequently used. First is the structured method (known as the '"round robin") where each member is asked to put forward an idea. The other technique is unstructured and is known as "free-wheeling", in which ideas are produced and expressed by anyone at any time.

Application

Brainstorming is employed when the solution to a problem cannot be found by quantitative or logical tools. It works best by stimulating the synergy of a group. One member's thoughts trigger the idea of another participant, and so on. It is often used as a first step to open up ideas and explore options, and these are then followed up by appropriate quality management tools and techniques. It has the advantage of getting every member involved, avoiding a possible scenario where just a few people dominate the whole group. There are some simple ground rules or codes of conduct to observe:

- Agree to a time limit with the group
- Accept all ideas as given and do not interpret or abbreviate
- Do not evaluate ideas during the brainstorming process.
- Encourage quantity rather than quality of ideas.
- Discourage the role of an expert
- Keep ideas expressed in just a few words
- Emphasise causes and symptoms as opposed to solutions
- Write clearly and ensure the ideas are visible to everyone
- Have fun!

Basic steps

1. Clearly state the focused problem selected for the brainstorming session.
2. Form a group and select a facilitator, agree on a time limit and remind members of the ground rules.
3. Decide whether a structured approach or a free-wheeling basis will be used. For a larger group, a structured approach will allow everyone to get a turn and subsequently this could be switched to the free-wheeling method.
4. Write clearly on a flip chart or a board any ideas as they are suggested. The facilitator will motivate and encourage participants by prompting them, ' What else? '
5. Review the clarity of the written list of ideas, allow them to settle and discard any duplication.
6. Apply filters to reduce the list. Typical filters could include cost, quality, time and risk.
7. Ensure that everyone concurs with the shortlist of ideas.

   Brainstorming is a very useful tool for generating ideas in a group. Follow the ground rules with particular emphasis on two points:

1. Do not dominate the group
2. Set a time limit of, say, half an hour for the entire session.

3. Cause and Effect Diagram

Definition

The Cause and Effect Diagram is a graphical representation of potential causes for a given effect. Since it was first used by Ishikawa, this type of illustration is also known as an Ishikawa diagram. In addition, it is often referred to as a 'fishbone' diagram due to its skeletal appearance. The purpose of the diagram is to assist in brainstorming and enabling a team to identify and graphically display, in increasing detail, the root causes of a problem.

Application

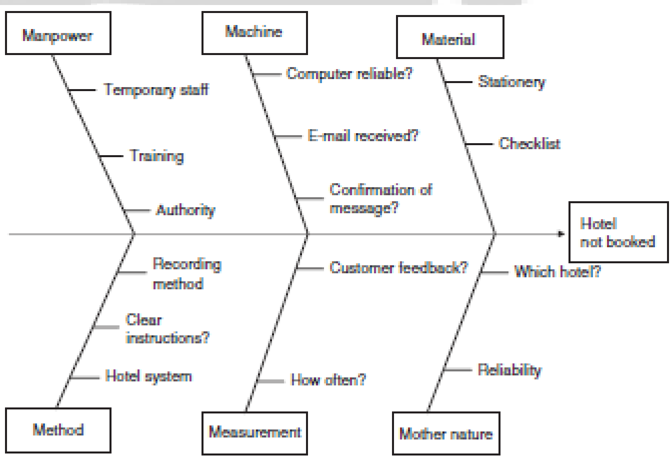
The Cause and Effect Diagram is arguably the most commonly used of all quality improvement tools. The "effect" is a specific problem and is considered to constitute the head of the diagram. The potential causes and sub-causes of the problem form the bone structure of the skeletal fish. They are typically used both during the measurement and analysis phase of the project. The main bone structure or branches typically consist of the self-explanatory '6Ms': Machine, Manpower, Material, Method, Measurement, and Mother Nature (Environment).

Basic steps

1. Select the most appropriate cause and effect format.
2. Define with clarity and write the key effect of the problem in a box to the right-hand side of the diagram.
3. Draw a horizontal line from the left-hand side of the box. Draw main branches (fishbone) of the diagram after agreeing the main categories of causes.
4. Brainstorm for each category the potential sub-causes affecting the category.
5. List the sub-causes of each category in a flipchart.
6. Rank the sub-causes in order of importance by a group consensus (or multi-voting) and select up to six top sub-causes for each category.
7. Construct the diagram by posting the top sub-causes in each category. These are the 'root causes'.
8. Decide upon further Dispersion Analysis or gather additional data needed to confirm the root causes.
9. Develop solutions and improvement plans.

Worked-out examples

The following example is taken from Basu and Wright. Consider the situation where customers of a large international travel agency sometimes find that when they arrive at their destination, the hotel has no knowledge of their booking.



4. Check Sheet

Definition

The check sheet is a simple and convenient recording method of collecting and determining the occurrence of events. These sheets or forms allow a team to systematically record and compile data from observations so that trends can be shown clearly.

Application

The check sheets are very easy to apply and are used to record non-conforming data and events including:

- The breakdown of machinery
- Non-value added activities in a process
- Mistake or defects recording in a process or a problem.

The forms are prepared in advance of recording the data by the operatives being affected by the problem. It makes patterns in the data clearer, based on facts, from a simple process that can be applied to any performance area.

Basic steps

1. Agree on the type of data to be recorded. The data could relate to the number of defects and type of defects and apply to equipment, the operator, process, department, shift, etc.
2. Decide which characteristics and items are to be checked.
3. Determine the type of check sheet to use, e.g. tabular form, defect position or tally chart.
4. Design the form to allow the data to be recorded in a flexible and meaningful way.
5. Decide who will collect data, over which period and from what sources.
6. Record the data on check sheets and analyse data.

Worked-out examples

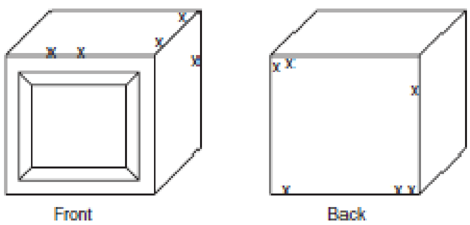
The design of check sheets is highly flexible but they can be grouped into three main categories: tabular form, defect position and tally charts. Figure …. shows an example of a check sheet in a tabular form. Figure … shows an example of a check sheet where defects positions are marked on the drawing of a product. Figure below shows an example of a check sheet.

Check items	Week number							
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	etc.
Incorrect brand specification								
Incorrect print								
Density								
Ink smudging								
Mis-registration								

Example of check sheet in tabular form.

Mistakes	Check sheet for: Typing February 03				
	Week 1	Week 2	Week 3	Week 4	Total
Centring	11	1111	11	1111	13
Spelling	1111 1	1111	11	111	15
Punctuation	1111 1111 11	1111 1111 1111 1	111	1111	35
Missed paragraph	11	1	1	111	7
Wrong page number	1	1	11	1	5

Example of a check sheet.



Example of a check sheet to illustrate defect positions

5. Control charts

Definition

A Control Chart consists of a graph with time on the horizontal axis and an individual measurement (such as mean or range) on the vertical axis. A Control Chart is a basic graphical tool of Statistical Process Control for determining whether a process is stable and also for distinguishing usual (or common) variability from unusual (special assignable) causes.

Three control limits are drawn: the central line (CL), the lower control limit (LCL) and the upper control limit (UCL). The points above the UCL or below the LCL indicate a special cause. If no signals occur the process is assumed to be under control, i.e. only common causes of variation are present.

Application

Control Charts can be used for examining a historical set of data and also for current data. The current control based on current data underpins a feedback control loop in the process. There are many good reasons why Control Charts have been applied successfully in both quality control and improvement initiatives.

Basic steps

1. Choose the quality characteristic to be charted.
2. Establish the type of Control Chart to ascertain whether it is a variable chart or an attribute chart.
3. Choose the subgroup or sample size.
4. Decide on a system of collecting data.
5. Calculate the mean and standard deviation and then calculate the control limits.
6. Plot the data and control limits on a Control Chart and interpret results.

Worked-out example

The following example illustrates the construction of variable Control Charts based on the data of packing cartons of a morning shift.

Table …. Packing cartons in a morning shift

Reading number	Measurements				Average	Standard deviation	Range
1	25.1	25.5	25.0	25.1	25.175	0.222	0.50
2	24.8	25.2	25.1	24.9	25.000	0.183	0.40
3	25.1	25.2	25.2	25.2	25.175	0.050	0.10
4	25.1	25.4	24.8	25.0	25.075	0.250	0.60
5	25.2	24.7	24.9	25.3	25.025	0.275	0.60
6	25.2	25.2	25.0	25.1	25.125	0.096	0.20
7	25.2	25.2	25.2	25.3	25.225	0.050	0.10
8	25.2	25.1	25.3	25.0	25.150	0.129	0.30
9	24.9	25.1	25.2	24.8	25.000	0.183	0.40
10	25.1	25.1	25.3	25.4	25.225	0.150	0.30
Average					25.118	0.159	0.35

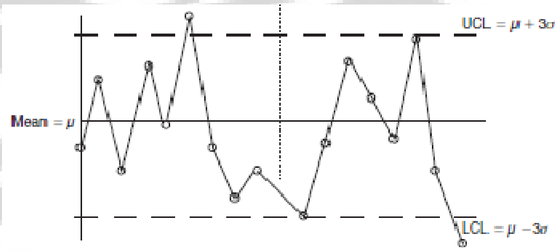


Figure Control Chart.

Control Charts are useful to identify data and their causes outside the control limits. However, nothing will change just because you charted it. You need to do something and eliminate the causes.

6. CTQ Tree

Definition

Critical to Quality (CTQ) is a term widely used within the field of Six Sigma activities to describe the key output characteristics of a process. An example may be an element of a design or an attribute of a service that is critical in the eyes of the customer. A CTQ tree helps the team to derive the more specific behavioural requirements of the customer from his general needs.

Application

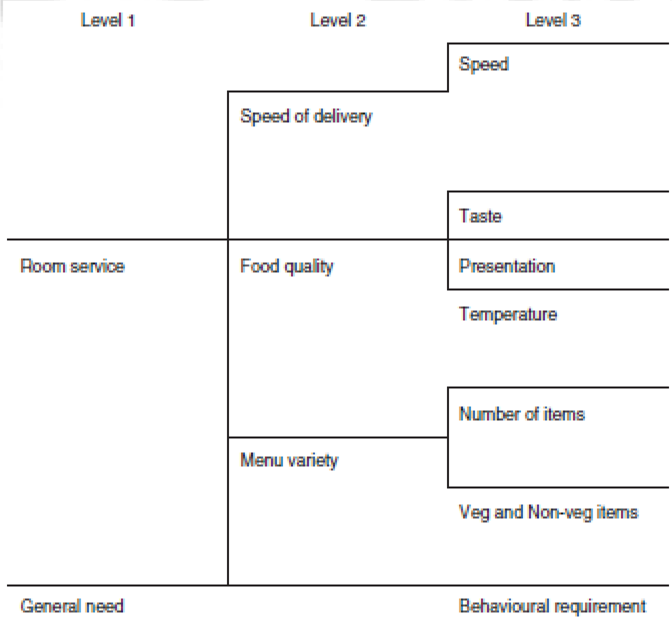
A CTQ tree is a useful tool during the data collection stage (Define) of an improvement project. Once the project team has established who their customers are, the team should then move towards determining the customer needs and requirements. The need of a customer is the output of a process. Requirements are the characteristics to determine whether the customer is happy with the output delivered. These constitute what is CTQ and a CTQ tree helps to identify these CTQs in a systematic way.

Basic steps

1. Identify the customer.
2. Identify customers' general needs in Level 1.
3. Identify the first set of requirements for that need in Level 2.
4. Drill down to Level 3 if necessary to identify the specific behavioural requirements of the customer.
5. Validate the requirements with the customer. The process of validation could be one-to-one interviews, surveys or focus groups depending on the CTQ.

Worked-out example

Figure below shows a worked-out example of a CTQ tree for room service in a hotel.



A CTQ tree is a simple but powerful tool for capturing the details of customer requirements and we recommend its use at the very early stage of a Six Sigma project.

7. Data collection plan

Data collection is a term used to describe a process of preparing and collecting data - for example as part of a process improvement or similar project. The purpose of data collection is to obtain information to keep on record, to make decisions about important issues, to pass information on to others. Primarily, data is collected to provide information regarding a specific topic.

Data collection usually takes place early on in an improvement project, and is often formalised through a data collection plan which often contains the following activity.

1. Pre collection activity – Agree goals, target data, definitions, methods
2. Collection – data collection
3. Present Findings – usually involves some form of sorting analysis and/or presentation.

Prior to any data collection, pre-collection activity is one of the most crucial steps in the process. It is often discovered too late that the value of their interview information is discounted as a consequence of poor sampling of both questions and informants and poor elicitation techniques. After pre-collection activity is fully completed, data collection in the field, whether by interviewing or other methods, can be carried out in a structured, systematic and scientific way.

A formal data collection process is necessary as it ensures that data gathered is both defined and accurate and that subsequent decisions based on arguments embodied in the findings are valid. The process provides both a baseline from which to measure from and in certain cases a target on what to improve.

Types of data collection:

- 1-By mail questionnaires
- 2-By personal interview.

Other main types of collection include census, sample survey, and administrative by-product and each with their respective advantages and disadvantages. A census refers to data collection about everyone or everything in a group or population and has advantages, such as accuracy and detail and disadvantages, such as cost and time. A sample survey is a data collection method that includes only part of the total population and has advantages, such as cost and time and disadvantages, such as accuracy and detail. Administrative by-product data is collected as a by product of an organization's day-to-day operations and has advantages, such as accuracy, time simplicity and disadvantages, such as no flexibility and lack of control.

8. Design of Experiment

Definition

DOE is a series of techniques that involves the identification and control of parameters or variables (termed 'factors') that have a potential impact on the output (termed 'response') of a process with the aim of optimising the design or the process. The experiment usually involves the selection of two or more values (termed 'levels') of these variables and then running the process at these levels. Each experimental run is termed as a 'trial'.

There are a number of methods of experimentation in DOE, of which the most commonly applied ones are:

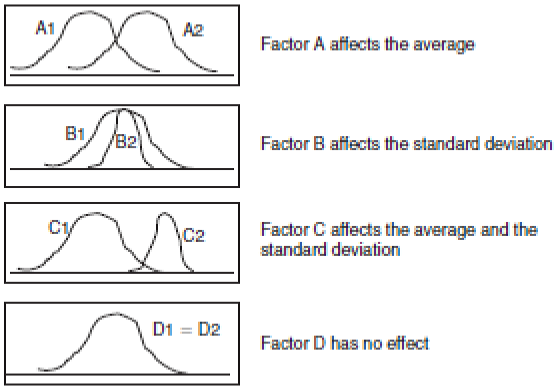
- Trial and error method, involves the step-by-step approach of changing one factor at a time, using the experience of the experimenter. This approach is easy to use and understand, but it is inefficient and time consuming.
- Full factorial method, considers all combinations of the factors to find the best combination. This method is useful for a lower number of factors.
- Fractional factorial method, applied when the number of variables or values is high. Typically for seven factors at two levels. This method changes several factors at the same time in a systematic way to ensure the reliability of results.

Application

DOE is an advanced technique which can be applied to both the design of a new product or process or to the redesign of the existing design or process. The technique is most effective for higher levels of variables and values. The application areas include:

- Product design and process design
- Minimum variation of a system performance
- Reduction of losses in a production line
- Achieving reproducibility of best system performance in manufacture

  DOE identifies types of factors.



Basic steps

The steps of a DOE would vary in detail depending on the methods of experimentation. The following basic steps have been simplified to describe the process of orthogonal arrays of the fractional factorial design.

1. Define the project
2. Develop an IPO diagram
3. Select the factors to be optimised
4. Design the orthogonal array
5. Choose the levels of control factors and the sample size.
6. Carry out the experiment
7. Analyse the data and confirm the results
8. Close the project

9. DPMO calculation

In process improvement efforts, defects per million opportunities or DPMO (or nonconformities per million opportunities (NPMO)) is a measure of process performance. It is defined as

$$DPMO = \frac{1,000,000 \times \text{number of defects}}{\text{number of units} \times \text{number of opportunities per unit}}$$

A defect is defined as a nonconformance of a quality characteristic (e.g., strength, width, response time) to its specification. DPMO is stated in opportunities per million units for convenience: Processes that are considered highly-capable (e.g., processes of Six Sigma quality) are those that experience only a handful of defects per million units produced (or services provided).

Note that DPMO differs from reporting defective parts per million (PPM) in that it comprehends the possibility that a unit under inspection may be found to have multiple defects of the same type or may have multiple types of defects. Identifying specific opportunities for defects (and therefore how to count and categorize defects) is an art, but generally organizations consider the following when defining the number of opportunities per unit:

- Knowledge of the process under study
- Industry standards
- When studying multiple types of defects, knowledge of the relative importance of each defect type in determining customer satisfaction
- The time, effort, and cost to count and categorize defects in process output

10.FMEA

Definition

FMEA is a systematic and analytical quality planning technique at the product, design, process and service stages assessing what potentially could go wrong and thereby aiding faulty diagnosis. The objective is to classify all possible failures according to their effect measured in terms of severity, occurrence and detection and then find solutions to eliminate or minimise them.

Application

There are five basic areas where FMEA can be applied. These are Concept, Design, Equipment, Process and Service.

- *Concept:* FMEA can be used to analyse a product, system or its components in the conceptual stage of the design.
- *Design:* FMEA is applied to analyse a product before the mass production of the product starts.
- *Equipment:* FMEA can also be used to analyse an equipment before it is procured.
- *Process:* With regard to process, FMEA is applied to analyse the manufacturing, assembly and packaging processes.
- *Service:* FMEA can also be applied to test industry processes for failure prior to their release to market.

Basic steps

FMEA involves a 12-step process.

1. Form a team and flow chart the relevant details of the product, process or service that is selected for analysis.
2. Assign each component of the system as a unique identifier.
3. List all the functions each component of the system performs.
4. Identify potential failure modes for each function listed in Step 3. (A failure mode is a short statement of how a function may fail to be performed.)
5. The next step describes the effects of each failure mode, especially the effects perceived by the user.
6. The causes of each failure mode are then examined and summarised.
7. Current controls to detect a potential failure mode are identified and assessed.
8. Determine the severity of the potential hazard of the failure to personnel or system in a scale of 1 to 10.
9. Estimate the relative likelihood of occurrence of each failure, ranging from highly unlikely (1) to most likely (10).
10. Estimate the ease with which the failure may be detected. A scale of 1 to 10 is used.
11. Determine a risk priority number (RPN) for each failure, which is the product of the numbers estimated in Steps 7, 8 and 9. The potential failure modes in descending order of RPN should be the focus of the improvement action to minimise the risk of failure.
12. The recommendations and corrective actions that have been put in place to eliminate or reduce failures are monitored for continuous improvement.

FMEA facilitates the relative weighting of a potential failure before the action is committed at a conceptual or an early stage of an operation.

11. ANOVA Gage R&R

Definition

ANOVA Gauge R&R (or ANOVA gauge repeatability and reproducibility) is a measurement systems analysis technique that uses analysis of variance (ANOVA) random effects model to assess a measurement system.

The evaluation of a measurement system is *not* limited to gauges (or gages) but to all types of measuring instruments, test methods, and other measurement systems.

Purpose

ANOVA gauge R&R measures the amount of variability induced in measurements by the measurement system itself, and compares it to the total variability observed to determine the viability of the measurement system. There are several factors affecting a measurement system, including:

- Measuring instruments, the gauge or instrument itself and all mounting blocks, supports, fixtures, load cells, etc. The machine's ease of use, sloppiness among mating parts, and, "zero" blocks are examples of sources of variation in the measurement system. In systems making electrical measurements, sources of variation include electrical noise and analog-to-digital converter resolution.
- Operators (people), the ability and/or discipline of a person to follow the written or verbal instructions.
- Test methods, how the devices are set up, the test fixtures, how the data is recorded, etc.
- Specification, the measurement is reported against a specification or a reference value. The range or the engineering tolerance does not affect the measurement, but is an important factor in evaluating the viability of the measurement system.
- Parts or specimens (what is being measured), some items are easier to be measured than others. A measurement system may be good for measuring steel block length but not for measuring rubber pieces, for example.

There are two important aspects of a Gauge R&R:

- Repeatability: The variation in measurements taken by a single person or instrument on the same item and under the same conditions.
- Reproducibility: The variability induced by the operators. It is the variation induced when different operators (or different laboratories) measure the same part.

12.Histogram

Definition

A histogram is a graphical representation of recorded values in a data set according to frequency of occurrence. It is a bar chart of numerical variables giving a graphical representation of how the data is distributed.

Applications

The histogram is used extensively in both statistical analysis and data presentation.

A histogram displays the distribution of data and thus reveals the amount of variation within a process. There are a number of theoretical models for various shapes of distribution of which the most common one is the normal or Ganssion distribution.

There are several advantages of applying histograms in continuous improvement projects including:

- It displays large amounts of data that are difficult to interpret in tabular form.
- It illustrates quickly the underlying distribution data revealing the central tendency and variability of a data set.

Basic steps

1. Collect at least 50–125 data points for establishing a representative pattern.
2. Subtract the smallest individual value from the largest in the data set.
3. Divide this range by 5, 7, 9 or 11 depending on the number of data points. As a rough guide take the square root of the total number of data points and round it to the nearest integer. For example, for 50 data points divide the range by 7 and 125 data points by 11.
4. The resultant value determines the interval of the sample. It should be rounded up for convenience.
5. Calculate the number of data points in each group or class.
6. Plot the histogram with the intervals in the x -axis and the frequency of occurrence on the y -axis.
7. Clearly label the histogram.
8. Interpret the histogram related to centring, variation and shape (distribution).

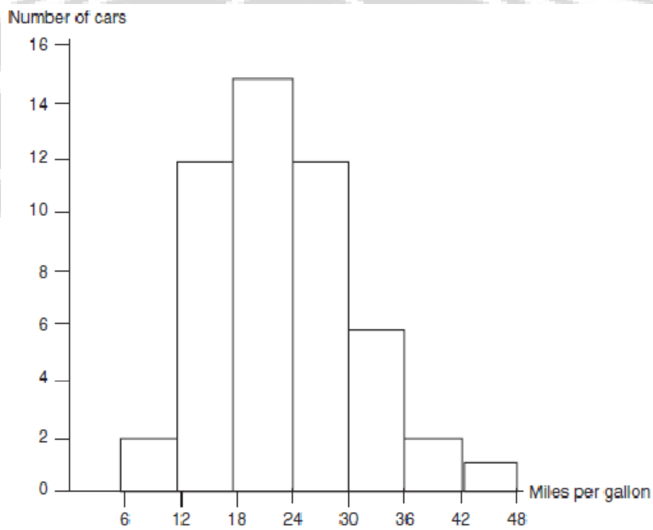


Figure of a Histogram

13.IPO diagram

Definition

An Input-Process-Output (IPO) diagram, also known as a general process diagram, provides a visual representation of a process by defining a process and demonstrating the relationships between input and output elements. The input and output variables are known as 'factors' and 'responses', respectively.

Application

Whether we are performing a service or manufacturing a product or completing a task, an IPO diagram is very useful to define a process as an activity that transforms inputs in order to generate corresponding outputs.

An IPO diagram is very often the starting point of a Six Sigma or similar improvement project. This high level mapping of the processes is then followed by Flow Diagrams, Process Mapping and Design of Experiments (DOE) to understand fully the process and related sub-processes. It is necessary to develop an IPO diagram to determine the factors and responses before carrying out a DOE exercise.

Basic steps

1. In building an IPO diagram we first choose a process.
2. Next we define the outputs or responses. They are also called 'quality characteristics' or critical to quality (CTQ) or *y* -variables. They are usually defined from a customer perspective.
3. We then define the input factors which will be required to make the process valuable to the customer.
4. Draw the IPO diagram with incoming arrows for inputs and outgoing arrows for outputs (See Figure below).

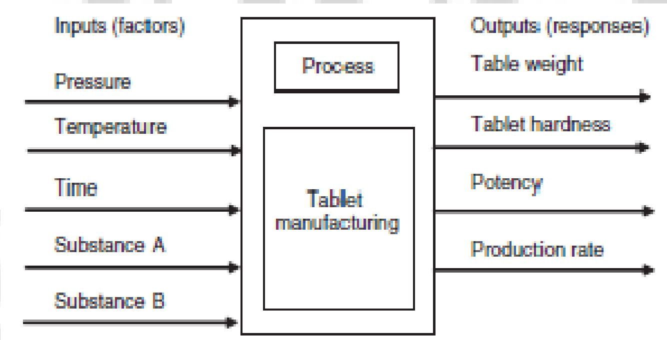


Figure an IPO diagram.

Worked-out example

Figure above shows an example of an IPO diagram of a tablet manufacturing process in a pharmaceutical company.

An IPO diagram is a simple tool to define a process and focus on its key variables. This is closely linked with a Cause and Effect diagram and DOE. We recommend the extensive use of IPO diagrams.

14.Pareto diagram

Definition

A Pareto Chart is a special form of bar chart that rank orders the bars from highest to lowest in order to prioritise problems of any nature. It is known as 'Pareto' after a nineteenth century Italian economist Wilfredo Pareto who observed that 80% of the effects are caused by 20% of the causes: 'the 80/20 rule'.

Applications

Pareto Charts are applied to analyse the priorities of problems of all types, e.g. sales, production, stock, defects, sickness, accident occurrences, etc. The improvement efforts are directed to priority areas that will have the greatest impact. There are usually two variants in the application of Pareto Charts. The first type is the standard chart where bar charts are presented in descending order. The second type is also known as the 'ABC Analysis'.

Basic steps

The following steps apply for the preparation of a Pareto Chart.

1. Identify the general problem (e.g. IC Board Defects) and its causes (e.g. Soldering, Etching, Moulding, Cracking, and other).
2. Select a standard unit of measurement (e.g. Frequency of Defects or Money Loss) for a chosen time period.
3. Collect data for each of the causes in terms of the chosen unit of measurement.
4. Plot the Pareto Chart with causes along the x -axis and the unit of measurement along the y -axis. The causes are charted in descending order of values from left to right.
5. Analyse the graph and decide on the priority for improvement.

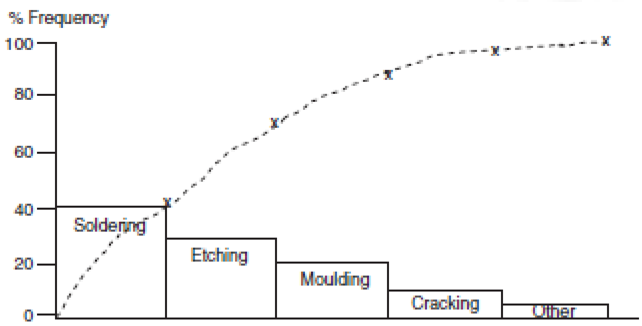
Worked-out examples

The following example of a Pareto Chart is taken from Schmidt et al. (1999). The major defects identified during the manufacture of Integrated Circuit Boards for a given period were given in table below.

Table major defects identified during the manufacture of Integrated Circuit Boards

Causes	Frequency	% Frequency
Soldering	60	40
Etching	40	27
Moulding	30	20
Cracking	15	10
Other	5	3
Total	150	100

We plot the causes along the x -axis and frequencies along the y -axis as shown in Figure below.



Pareto Charts are extremely useful in optimising efforts and 'going for gold'. They have the twin advantages of being both easy to understand and to apply. Thus we highly recommend the use of Pareto Charts for all quality improvement projects.

15.Process capability

Definition

Process Capability is the statistically measured inherent reproducibility of the output (product) turned out by a process. A commonly used measure of process capability is given by the capability index (C_p):

$$C_p = \frac{USL - LSL}{6\sigma}$$

Where USL and LSL are upper and lower specification limits and σ is the standard deviation. The C_p index measures the potential or inherent capability of process. The C_{pk} index measures the realised process capability relative to the actual operation and is defined as

$$C_{pk} = \text{minimum}\left(\frac{\mu - LSL}{3\sigma}, \frac{USL - \mu}{3\sigma}\right)$$

If $C_{pk} > 1$, we declare that the process is capable, and if $C_{pk} < 1$, then we declare that the process is incapable. C_{pk} is a more practical measure of capability than C_p.

Application

A customer requires that specifications are given in terms of a target value, a LSL and USL. They are the ‘ tolerances ’ of the specification. The process capability index determines the reliability of these tolerances to be delivered by the process used by the supplier.

The process capability information serves many purposes including:

- Selection of competing processes or equipment that best satisfies the specification.
- Predicting the extent of variability that processes could exhibit to establish realistic specification limits.
- Testing the theories of cause and effect during quality improvement programmes.

  Motorola introduced the concept of Six Sigma as a statistical way of measuring total customer satisfaction. Given that the process is a Six Sigma process, we know that USL - LSL = 6 σ + 6 σ + 12 σ. Hence

$$C_p = \left(\frac{USL - LSL}{6\sigma} = \frac{12\sigma}{6\sigma}\right) = 2.0$$

Another metric, DPMO (defects per million opportunities), is also used to assess the performance of a process. DPMO is represented by the proportion of area outside the specification limit multiplied by one million. For example, if 3.5% of the area is outside specification limits, then

$$DPMO = 1{,}000{,}000 \times \frac{3.5}{100} = 35{,}000$$

The three metrics DPMO, C_p and C_{pk} all given numerical values that indicate how well a process is doing with respect to these specification limits.

Basic steps

1. Using a stable Control Chart, determine the process grand average (χ), the average (R) and process standard deviation (s).
2. Determine the USL and the LSL based upon customer requirements.
3. For a stable process, assume that the values of the sample mean and standard deviation are the same as the corresponding values of the population, i.e. $\sigma = s$ and $\mu = \chi$.
4. Calculate the process capability indices C_p and C_{pk} by using the formulae:

$$C_p = \frac{USL - LSL}{6\sigma} \qquad C_{pk} = \text{Minimum}\left(\frac{\mu - LSL}{3\sigma}, \frac{USL - \mu}{3\sigma}\right)$$

Figure below ilustrates three states of the potential process capability for $C_p < 1$, $C_p = 1$ and $C_p > 1$.

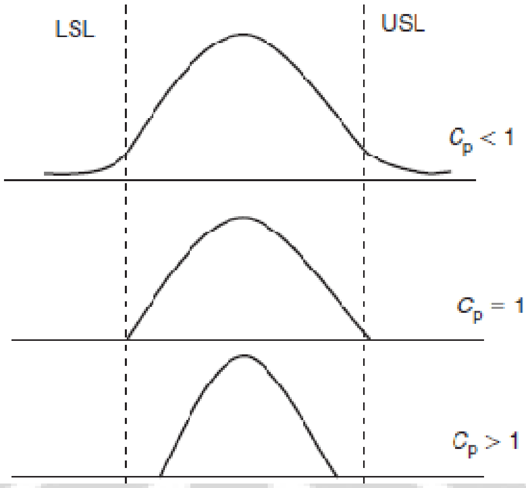


Figure a Process Capability.

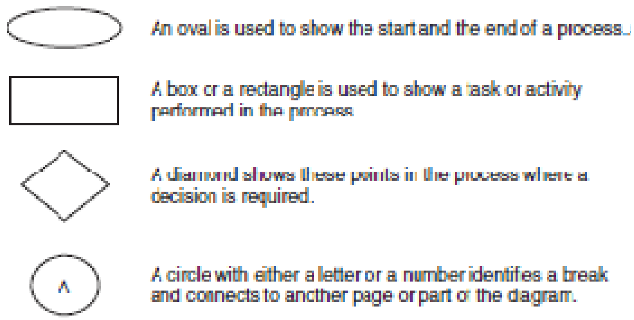
Process Capability is a useful tool in determining whether a process can deliver the customer specifications.

16.Process flow chart

Definition

A Flow Diagram (also called a Flow Chart) is a visual representation of all major steps in a process. It helps a team to understand a process better by identifying the actual flow or sequence of events in a process that any product or service follows.

There are variations of a Flow Diagram depending on the details required in an application. The type of Flow Diagram is a top level mapping of the general process flow and uses four standard symbols in figure beside.

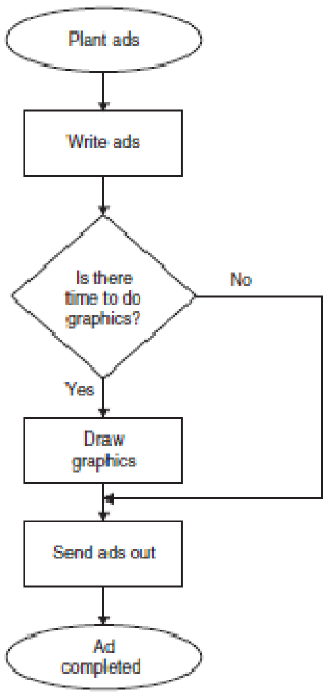


Application

A Flow Diagram can be applied to any type of process, to anything from the development of a product to the steps in making a sale or servicing a product. It allows a team to come to a consensus regarding the steps of the process and to identify critical and problem areas for improvement. In addition, it serves as an excellent training aid to understand the complete process.

Basic steps

1. Select the process and determine the scope or boundaries of the process:
   a. Clearly define where the process understudy starts and ends.
   b. Agree the level of detail to be shown on the Flow Diagram.
2. Brainstorm a list of major activities and determine the steps in the process.
3. Arrange the steps in the order they are carried out. Unless you are developing a new process, sequence what actually is and not what should be.
4. Draw the Flow Diagram using the appropriate symbols.
5. There are a number of good practices when charting a process including:
   a. Use Post-it™ notes so that you can move them around in a large process.
   b. For a large scale process, start by charting only the major steps or activities.
   c. Come back to develop further details for major steps if necessary.
   d. Consider Process Mapping to apply to a larger process.



Worked-out example

Figure above shows an example of a Flow Diagram to illustrate an advertising process.

17.Process mapping

Definition

Process Mapping is a tool to represent a process by a diagram containing a series of linked tasks or activities which produce an output. It is a further development of a Flow Diagram by using computer software so that the user can link quickly the activities and drill down to gain a more detailed picture.

Application

With the advent of well supported software, Process Mapping is becoming a way of life for analysing a process or an organisation. A process map does not use symbols like a Flow Process Chart or a Flow Diagram. Only boxes and arrows are used and different colours are often applied to identify types of activities (e.g. non-value added or value added). There are several benefits of applying Process Mapping including the following. Process Mapping means that the team:

- Can clarify what is happening within an organisation
- Can simulate what should be happening
- Can show a process at various levels of detail
- Can allocate ownership of each activity and promote teamwork
- Can reflect the end-to-end process and its visibility
- Can add resources, costs, volumes and duration to build up sophisticated cost models
- Can identify how the performance of this process can be measured.

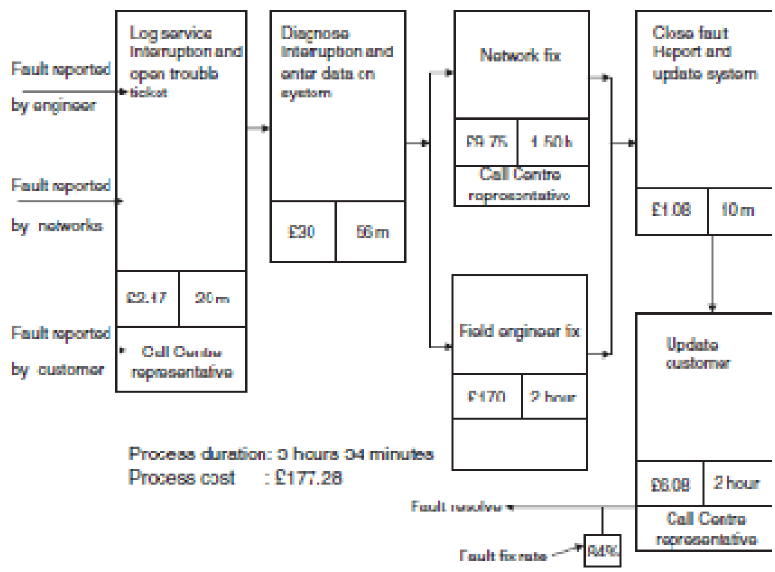
Basic steps

1. Decide on the organisation, function or process for analysis.
2. Agree higher level functions and their relationships.
3. Agree on input, process and output for each activity.
4. Construct a process diagram for selected functions.
5. Validate the process diagram with stakeholders.
6. Add resources, costs, volumes and duration if required.
7. Apply a 'what-if' analysis and simulation to achieve sustainable process improvement.

Worked-out example

A high level process map is shown in Figure….

Process Mapping has become a very useful computer aided tool for process improvement. However, it should be used for process mapping's sake. Process maps do not – in isolation – change individual behaviour.



F

Figure a Process Mapping

18.Project Charter

Definition

A Project Charter is a working document for defining the terms of reference of each Six Sigma project. The charter can make a successful project by specifying necessary resources and boundaries that will in turn ensure success. The necessary elements of a Project Charter include:

- *Project Title:* It is important to use a descriptive title that will allow others to quickly identify the project.
- *Project Type:* Whether it is for quality improvement, increasing revenue or reducing cost.
- *Project Description:* A clear description of the problem, the opportunity and the goal.
- *Project Purpose:* Why you are carrying out this project.
- *Project Scope:* Project dimensions, what is included and not included.
- *Project Objectives:* Target performance improvement in measurable terms.
- *Project Team:* Sponsor, Team Leader, and Team Members. It is important to identify Black Belts and Green Belts within the team.
- *Customers and CTQs:* Both internal and external customers and CTQs specific to each customer.
- *Cost Benefits:* A draft business case of savings expected and the cost required completing the project.
- *Timing:* Anticipated project start date and end date.

Application

A Project Charter is the formalised starting point in the Six Sigma methodology. It takes place in the Define stage of DMAIC. It recommend that larger (e.g. over $1 million savings) projects of a Six Sigma programme which is usually led by a Black Belt should have a Project Charter. A Project Charter can also be useful in a multi-discipline, medium sized project. A Project Charter should be used as a working document that is updated as the project evolves. The version control of the charter is therefore very important.

Basic steps

1. Select the project by taking into account the following criteria:
   a. Not capital intensive
   b. Achievable in 6 months
   c. High probability of success
   d. Good fit with Six Sigma techniques
   e. Clearly linked to real business need
   f. Historical and current data accessible.
2. Identify the customers and their specific CTQ requirements by a SIPOC diagram.
3. Estimate an order of magnitude figures for the costs and savings for the project.
4. Obtain top management support and sponsorship.
5. Select the project team with clear leadership and ownership for delivery.
6. Develop the Project Charter following a defined template.
7. Obtain the approval of the sponsor.
8. Review and update the charter with the necessary version control as the project progresses.

19.QFD

Definition

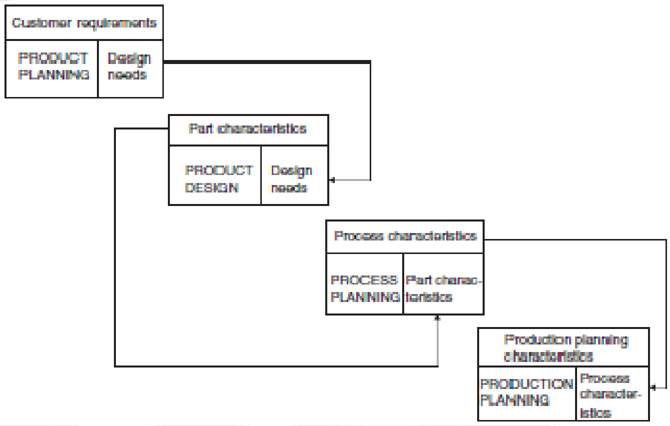
QFD is a technique that is used for converting the needs of customers and consumers into design requirements and follows the concept that the 'voice of the customer' drives all the company operations. QFD is used to build in quality in the early stage of a new product development and helps to avoid downstream production and product delivery problems. In its simplest form, QFD involves a matrix in which customer requirements are rows and design requirements are columns.

Application

In congruence with Figure beside, QFD is applied to deliver customer needs through four planning phases:

- Product Planning
- Product Design and Development
- Process Planning and Development
- Production Planning and Delivery

The application of the QFD technique has achieved remarkable results to incorporate the 'voice of customers' into all stages of the design, manufacture, delivery and support of product and services.



QFD approach

Basic steps

1. *List customer requirements:* The list of customer requirements includes the major elements of customer needs related to a specific product or process.
2. *List design elements:* These design elements that relate to customer requirements are building materials and specifications.
3. *Demonstrate relationship between customer requirements and design elements:* A diagram can be used to show these relationships..
4. *Identify the co-relations between design elements:* Positive or negative scores are assigned depending on whether the design elements are positively or negatively co-related.
5. *Assess the competitiveness of customer requirements:* This is an assessment of how your product compares with those of the competitors. A five point scale is used.
6. *Prioritise customer requirements:* 'Customer importance' is a subjective assessment, using a 10 point scale, of how critical a particular customer's requirement is. A focus group of customers usually assigns the rating.
7. *Prioritise technical requirements:* Technical requirements are prioritised by assessing difficulty level, target value, absolute weight and relative weight.
8. *Final assessment:* The percentage weight factor for each of the absolute and relative weights is then computed. The technical elements with a higher share of relative weight are identified as key design requirements.

20.Run Chart

Definition

A Run Chart is a graphical tool to allow a team to study observed data for trends over a specified period of time. It is basically a simple line graph of x - and y -axes.

Application

A Run Chart has a wide range of applications to detect trends, variation or cycles. It allows a team to compare performances of a process before and after the implementation of the solution. The application areas include sales analysis, forecasting, and performance reporting and seasonality analysis.

Basic steps

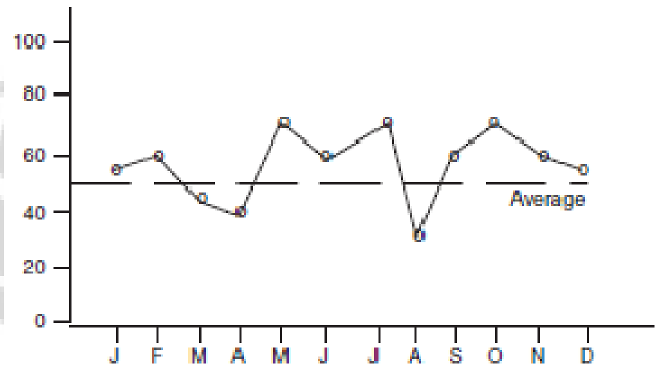
1. Select the parameter and time period for measurement.
2. Collect data (generally 10–20 data points) to identify meaningful trends:
   a. x -axis for time or sequence cycle (horizontal)
   b. y -axis for the variable parameter that you are measuring (vertical).
3. Plot the data in a line graph along the x - and y -axis.
4. Interpret the chart. If there are no obvious trends then calculate the average value of the data points and draw a horizontal line at the average value.

Worked-out example

The following table shows the operational efficiency (%) of a packaging machine:

x	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
y	55	60	45	40	65	60	65	30	60	65	60	55

The Run Chart for the above data is shown in figure below.



Example of a Run Chart.

Due to the fact that it could be seen as encompassing simplicity to a fault, a danger in using a Run Chart is the inclination to interpret every variation as significant. For any statistically significant result, Control Charts or Regression Analysis should be more appropriate. It recommends the use of a Run Chart for detecting a visual trend only and identifying areas of further analysis.

21.Scatter Diagram

Definition

A Scatter Diagram is a plot of points to study and identify the possible relationship between two variables, characteristics or factors. The knowledge provided by a Scatter Diagram can be enhanced more accurately by Regression Analysis.

Application

A Scatter Diagram is used, as an initial step before Regression Analysis, to show in simple terms if the variables are associated (a linear pattern) or unrelated (non-linear random pattern). Analysis should investigate the scatter of the plotted points and if some linear or non-linear relationship exists between two variables. In this the Scatter Diagram is very useful for diagnosis and problem solving.

Basic steps

1. Collect paired samples of data (at least 10) of two variables that may be related.
2. Draw the x - and y -axes of the diagram.
3. Plot the data points on the diagram.
4. If some values are repeated, circle those points depending on the number of times they are repeated.
5. Interpret the results. The Scatter Diagram does not predict cause and effect relationships. It can, however, indicate a possible positive or negative correlation or no correlation between two variables.

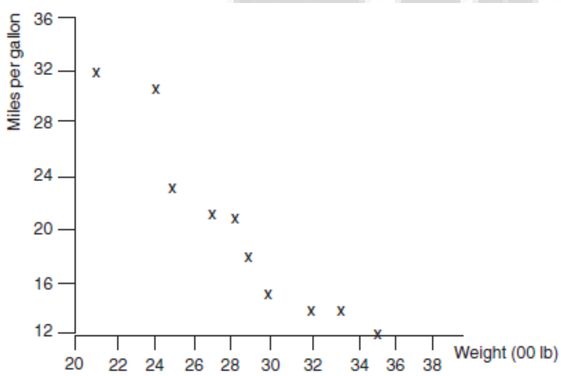
Worked-out example

Table 5.3 shows a set of paired data points of two variables.

Table .... A set of paired data points of two variables

Observations	Weight (lb)	Miles per gallon (mpg)
1	3000	18
2	2800	21
3	2100	32
4	2900	17
5	2400	31
6	3300	14
7	2700	21
8	3500	12
9	2500	23
10	3200	14

We plot the above data with weight as the x -axis (cause) and mpg as the y -axis (effect), as an example of a Scatter Diagram, as shown in Figure ... . It appears that a negative correlation exists between two variables, because when one variable (weight) gets bigger than the other variable (mpg) becomes smaller.



Example of a Scatter Diagram

22.SIPOC diagram

Definition

SIPOC is a high level map of a process to view how a company goes about satisfying a particular customer requirement in the overall supply chain.

SIPOC stands for:

- *Supplier:* The person or company that provides the input to the process (e.g. raw materials, labour, machinery, information, etc.). The supplier may be both external and internal to the company.
- *Input:* The materials, labour, machinery, information, etc. required for the process.
- *Process:* The internal steps necessary to transform the input to output.
- *Output:* The product (both goods and services) being delivered to the customer.
- *Customer:* The receiver of the product. The customer could be the next step of the process or a person or organisation.

Application

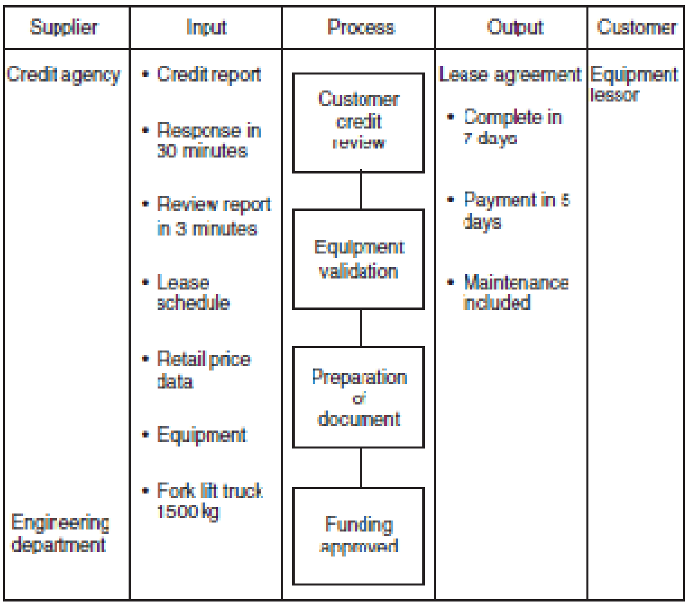
A SIPOC diagram is usually applied during the data collection of a project or at the 'Define' stage of DMAIC in a Six Sigma programme. However, its impact is utilised throughout the project life cycle. SIPOC not only shows the interrelationships of the elements in a supply chain, but also CTQ indicators such as 'delivered in 7 days.

Basic steps

1. Select the process for the SIPOC diagram and identify CTQ parameters.
2. Determine the input requirements.
3. Identify the suppliers for each of the input elements.
4. Define the output and validate CTQ parameters.
5. Identify the customers.
6. Draw the SIPOC process diagram.
7. Retain the diagram for the rest of the improvement project.

Worked-out example

Figure beside shows a SIPOC diagram for a company that leases equipment.



SIPOC is a useful tool to identify the customer, stakeholders and CTQs of a process before the development of a Project Charter. However it is not an essential tool and a process can be analysed at a high level by an IPO or a Flow Diagram.

23.Statistical Process Control (SPC)

Definition

In simple terms, SPC is the control or management of the process through the use of statistical methods and tools. SPC is about control, capability and improvement and comprises some basic statistics, (e.g. measures of control tendency and measures of dispersion), some tools for data collection (e.g. control charts) and analysis (e.g. process capability).

Application

SPC has four main areas of application:

- To achieve process stability.
- To provide guidance on how the process may be improved by the reduction of variation.
- To assess the performance of a process.
- To provide information to assist with management decision making.

The application of SPC is potentially extensive, ranging from high volume 'metal cutting' operations to non-manufacturing situations including services and commerce.

Basic steps

The objective of SPC is to record the 'voice of the process' , remove or reduce ' special ' and ' common ' causes of variation to the pursuit of continuous improvement. In this context the process means the whole combination of people, equipment, information, input materials, methods and environment that work together to produce output.

The basic steps of a SPC technique are:

- Collect data to a plan and plot the data on a graph such as a control chart or a line graph.
- Use the collected data to calculate control limits to determine whether the process is in a state of statistical control.
- Identify and rectify the 'special causes' of variation to stabilise the process.
- Assess the 'capability' of the process.
- Reduce, as much as possible, the 'common causes' of variation so that the output from the process is centred around a target value.

This is an iterative process in pursuit of continuous improvement. A great deal of effort is required to stabilise the process to be in statistical control, and a great deal more to reduce the common causes of variation.

Benefits

The major benefits of SPC include:

- The quantitative and statistical foundation of SPC provided the distinction between the TQM approach (outside Japan) of the 1970s and the success of Six Sigma in the 1990s.
- SPC is an effective feedback system that links process outcomes with process outputs leading to continuous improvement.
- The fundamental principle of SPC (i.e. variation from common causes should be left to chance, but special causes of variation should be eliminated) is also a cornerstone of less quantitative approaches of continuous improvement.
- SPC can act as a focal point of a training and company-wide change programme.

24.Time and motion study

Definition

A time and motion study (or time-motion study) is a business efficiency technique combining the Time Study work with the Motion Study work. It is a major part of scientific management.

Time standards can be used to investigate the difference between actual and standard performance and take appropriate action where necessary. It can also be used to facilitate job design as a basis for comparing different work methods, introducing sound production controls, designing an efficient workplace layout, and balancing between work schedules and available manpower. Other benefits include budgetary control, development of incentive plans, and ensuring that quality specifications are met.

Time study developed in the direction of establishing standard times, while motion study evolved into a technique for improving work methods.

Time study is a direct and continuous observation of a task, using a timekeeping device (e.g., decimal minute stopwatch, computer-assisted electronic stopwatch, and videotape camera) to record the time taken to accomplish a task and it is often used when:

- There are repetitive work cycles of short to long duration,
- Wide variety of dissimilar work is performed, or
- Process control elements constitute a part of the cycle.

Purpose

The main objective of a time and motion study is to determine reliable time standards for the efficient and effective management of operations. Through the establishment of reliable and accurate time standards, companies can better define their capacity or output, thus increasing the efficiency of equipment and obtaining optimum utilisation of the workforce.

Direct time study procedure

Following is the procedure developed by Mikell Groover for a direct time study:

1. Define and document the standard method.
2. Divide the task into work elements.

   Steps 1 and 2 These two steps are primary steps conducted prior to actual timing. They familiarise the analyst with the task and allow the analyst to attempt to improve the work procedure before defining the standard time.
3. Time the work elements to obtain the observed time for the task.
4. Evaluate the worker's pace relative to standard performance (performance rating), to determine the normal time.

   Note that steps 3 and 4 are accomplished simultaneously. During these steps, several different work cycles are timed, and each cycle performance is rated independently. Finally, the values collected at these steps are averaged to get the normalised time.
5. Apply an allowance to the normal time to compute the standard time. The allowance factors that are needed in the work are then added to compute the standard time for the task.

25.Five S

Definition

Five S is a tool for improving the housekeeping of an operation, developed in Japan, where the five Ss represent five Japanese words all beginning with “s”:

- *Seiri (Organisation):* Separate what is essential from what is not.
- *Seiton (Neatness)* : Sort and arrange the required items in an orderly manner and in a clearly marked space.
- *Seiso (Cleaning):* Keep the workstation and the surrounding area clean and tidy.
- *Seiketson (Standardisation):* Clean the equipment according to laid down standards.
- *Shitsuke (Discipline):* Follow the established procedure.

Application

The Five S method is a structured sequential programme to improve workplace organisation and standardisation. Five S improves the safety, efficiency and the orderliness of the process and establishes a sense of ownership within the team. Five S is used in organisations engaged in Lean Sigma, Just-in-Time (JIT), Total Productive Maintenance (TPM) and Total Quality Management (TQM). This principle is widely applicable not just for the shop floor, but for the office too. As an additional bonus there are benefits to be found in environmental and safety factors due to the resulting reduced clutter. Quality is improved by better organisation and productivity is increased due to the decreased time spent in searching for the right tool or material at the workstation. As the Five S programme focuses on attaining visual order and visual control, it is a key component of Visual Factory Management.

Basic steps

1. *Seiri*: The initial step in the Five S programme is to eliminate excess materials and equipment lying around in the workplace. These non-essential items are clearly identified by ‘ red-tagging ’ .
2. *Seiton*: The second step is to organise, arrange and identify useful items in a work area to ensure their effective retrieval. The storage area, cabinets and shelves are all labelled properly. The objective of this step is, as the old mantra says, ‘ a place for everything and everything in its place ’ .
3. *Seiso*: This third action point is sometimes known as ‘ sweep ’ or ‘ scrub ’ . It includes down-to-basics activities such as painting equipment after cleaning, painting walls and floors in bright colours and carrying out a regular cleaning programme.
4. *Seiketson*: The fourth point encourages workers to simplify and standardise the process to ensure that the first three steps continue to be effective. Some of the related activities include establishing cleaning procedures, colour coding containers, assigning responsibilities and using posters.
5. *Shitsuke*: The fifth step is to make Five S a way of life. Spreading the message and enhancing the practice naturally involves people and cultural issues.
6. The final step is to continue training and maintaining the standards of Five S.

Five S is a simple tool and should be considered for the housekeeping and visual control of all types of work area, whether they are in manufacturing or service.

26.Heijunka (Production Levelling)

Definition

Production levelling, also known as production smoothing or – by its Japanese original term – heijunka, is a technique for reducing the *muda* waste and vital to the development of production efficiency in the Toyota Production System and Lean Manufacturing. The general idea is to produce intermediate goods at a constant rate, to allow further processing to be carried out at a constant and predictable rate.

Ideally production can easily be leveled where demand is constant but in the real world where actual customer demand appears to fluctuate two approaches have been adopted in lean: Demand leveling and production leveling through flexible production.

On a production line, as in any process, fluctuations in performance increase waste. This is because equipment, workers, inventory and all other elements required for production must always be prepared for peak production. This is a cost of flexibility. If a later process varies its withdrawal of parts in terms of timing and quality, the range of these fluctuations will increase as they move up the line towards the earlier processes. This is known as demand amplification.

To prevent fluctuations in production, even in outside affiliates, it is important to try to keep fluctuation in the final assembly line to zero. Toyota's final assembly line never assembles the same automobile model in a batch. Production is leveled by making first one model, then another model, then yet another. In production leveling, batches are made as small as possible in contrast to traditional mass production, where bigger is considered better. When the final assembly process assembles cars in small batches, then the earlier processes, such as the press operation, have to follow the same approach.

Implementation

1. Implement Green stream/Red stream or Fixed sequence, fixed volume to establish the entry and exit criteria for products from these streams and establish the supporting disciplines in the support services. The cycle established will produce Every Product Every Cycle (EPEC). This is a specific form of Fixed Repeating Schedule. Green stream products are those with predictable demand, Red stream products are high value unpredictable demand products.
2. Faster fixed sequence with fixed volume keep the streams the same but use the now established familiarity with the streams to maximise learning and improve speed of production (economies of repetition). This will allow the shortening of the EPEC cycle so that the plant is now producing every product every 2 weeks instead of month and then later on repeating every week. This may require support services to speed up as well.
3. Fixed sequence with unfixed volume keep the stream sequences the same but now phase in allowing actual sales to influence volumes within those sequences. This affects inbound componentry as well as support services. This is a more generalised form of Fixed Repeating Schedule.
4. Unfixed sequence with fixed volume the stream sequences, and EPEC, can now be gradually flexed but move to small fixed batch sizes to make this more manageable.
5. Unfixed sequence with unfixed volume finally move to true single piece flow and pull by reducing batch sizes until they reach one.

27.Jidoka (Autonomation)

Definition

Autonomation describes a feature of machine design to effect the principle of jidoka used in the Toyota Production System (TPS) and Lean manufacturing. It may be described as "intelligent automation" or "automation with a human touch." This type of automation implements some supervisory functions rather than production functions. At Toyota this usually means that if an abnormal situation arises the machine stops and the worker will stop the production line. Autonomation prevents the production of defective products, eliminates overproduction and focuses attention on understanding the problem and ensuring that it never recurs. It is a quality control process that applies the following four principles:

1. Detect the abnormality.
2. Stop.
3. Fix or correct the immediate condition.
4. Investigate the root cause and install a countermeasure.

Purpose and implementation

The purpose of autonomation is that it makes possible the rapid or immediate address, identification and correction of mistakes that occur in a process. Autonomation relieves the worker of the need to continuously judge whether the operation of the machine is normal; their efforts are now only engaged when there is a problem alerted by the machine. As well as making the work more interesting this is a necessary step if the worker is to be asked later to supervise several machines.

For instance rather than waiting until the end of a production line to inspect a finished product, autonomation may be employed at early steps in the process to reduce the amount of work that is added to a defective product. A worker who is self-inspecting their own work, or source-inspecting the work produced immediately before their work station is encouraged to stop the line when a defect is found. This detection is the first step in Jidoka. A machine performing the same defect detection process is engaged in autonomation.

Once the line is stopped a supervisor or person designated to help correct problems gives immediate attention to the problem the worker or machine has discovered. To complete Jidoka, not only is the defect corrected in the product where discovered, but the process is evaluated and changed to remove the possibility of making the same mistake again. One solution to the problems can be to insert a "mistake-proofing" device somewhere in the production line. Such a device is known as Poka-Yoke.

28.Kanban

Definition

Kanban literally means ‘card’. It is usually a printed card in a transparent plastic cover that contains specific information regarding part number and quantity. It is a means of pulling parts and products through the manufacturing or logistics sequence as needed. It is therefore sometimes referred to as the ‘pull system’.

Application

Following the Japanese examples, Kanban is accepted as a way of maximising efficiency by reducing both cost and inventory. The key components of a Kanban system are: Kanban cards, Standard containers or bins, Workstations, usually a machine or a worktable, and Input and output areas.

The input and output areas exist side by side for each workstation on the shop floor. The Kanban cards are attached to standard containers. These cards are used to withdraw additional parts from the preceding workstation to replace the ones that are used. When a full container reaches the last downstream workstation, the card is switched to an empty container. This empty container and the card are then sent to the first workstation signalling that more parts are needed for its operation.

Basic steps

1. Select the operation for the Kanban system and decide whether a single or dual card system will be applied.
2. Determine the number of Kanban containers to set the amount of authorised inventory. Use the following formula:

$$\text{Number of containers} = \frac{\text{Demand in lead time} + \text{Safety stock}}{\text{Size of container}}$$

3. Design and procure the standardised containers and Kanban cards.
4. Develop and implement the workstation layout. Carry out a pilot run.
5. Train operators and activate the Kanban system by following some basic rules:
   - Each container must have a Kanban card.
   - Each container must contain the exact quantity stated on the card.
   - The containers are pulled only when needed by the next downstream station.
   - No defective parts are sent.
6. Review the process regularly and aim to reduce the number of Kanbans and the time period.

Benefits

1. Kanban enables only small inventory through the plant and pulling only when needed thus allowing only a small quantity of faulty or delayed material.
2. Kanban minimises the negative aspects of inventory management including obsolescence, occupied space, working capital, increased material hand ling and poor quality.
3. Kanban uses standardised containers conducive to efficient material handling and lower costs.
4. It aims to create work sites that can respond to changes quickly empowering the operators to exercise their initiatives.
5. It facilitates the re-engineering of the process and works in harmony with JIT techniques.

29.Mistake proofing

Definition

Mistake Proofing is an improvement tool to prevent errors being converted into defects. It comprises two main activities: preventing the occurrence of a defect and detecting the defect itself. Mistake Proofing is also known as Poka-Yoke. The concept was developed by Shigeo Shingo and the term ' poka-yoke ' comes from the Japanese words ' poka ' (inadvertent mistake) and ' yoke ' (prevent).

Application

Mistake Proofing is applied in fundamental areas. Although Poka-Yoke was devised as a component of Shingo's 'Zero Quality Control' for Toyota production lines, it is very easy to understand and grounded in basic common sense. The process of Mistake Proofing is simply paying careful attention to every activity in the process and then placing appropriate checks at each step of the process. Mistake Proofing emphasises the detection and correction of mistakes at the Design stage before they become defects. This is then followed by checking. It is achieved by 100% inspection while the work is in progress by the operator and not by the quality inspectors. This inspection is an integral part of the work process.

There are abundance of examples of simple devices related to Mistake Proofing in our everyday surroundings including limit switches, colour coding of cables, error detection alarms, a level crossing gate and many more.

Basic steps

1. Perform Shingo's "source inspection" at the Design stage. In other words, identify possible errors that might occur in spite of preventive actions.
2. Ensure 100% inspection by the operator to detect that an error is either taking place or is imminent.
3. Provide immediate feedback for corrective action. There are three basic actions in order of preference:
    - *Control:* An action that self-corrects the error, e.g. spell checker.
    - *Shutdown:* A device that shuts down the process when an error occurs, e.g. a limit switch.
    - *Warning:* Alerts the operator that some error is imminent, e.g. alarm.

Worked-out example

Consider the situation leading to the development of a level crossing. This is a place where cars and trains are crossing paths and the chances of accidents are very high. The possible errors that might occur would relate to car drivers, who might be thinking one thing or another or distracted while driving (source inspection). Both the level crossing operator and the car driver should ensure safety features while the work is in progress (judgement inspection). In order to prevent drivers from making mistakes when a train is approaching, traffic lights were installed to alert the driver to stop (warning). The lights might not be completely effective, so a gate was installed when a train was coming (shutdown or regulatory function). The operation of the gate was controlled automatically as the train was approaching (control). With the above Mistake Proofing devices in place, an accident can only occur if either the control and regulatory measures are malfunctioning or the driver drives around the gate.

30.SMED/ Quick Changeover

Definition

SMED or Single Minute Exchange of Dies is name of the approach used for reducing output and quality losses due to changeovers and setups. 'Single Minute' means that necessary setup time is counted on a single digit.

Application

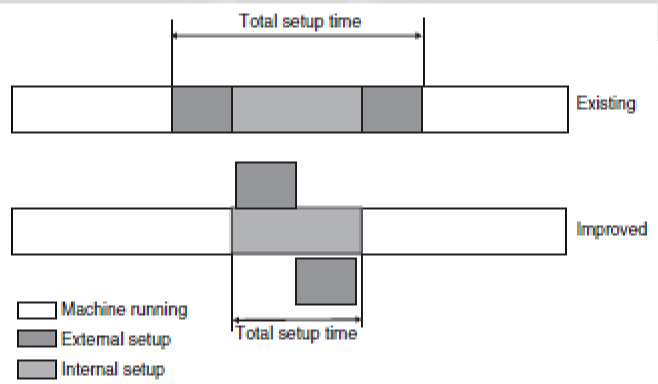
This method has been developed in Japan by Shigeo Shingo (1985) and has proven its effectiveness in many manufacturing operations by reducing the changeover times of packaging machines from hours to minutes. The primary application area of SMED is the reduction of setup times in production lines. This process enables operators to analyse and find out themselves why the changeovers take so long and how this time can be reduced. In many cases, changeover and setup times can be condensed to less than 10 minutes, so that the changeover time can be expressed with one single digit, and it is therefore called ' SMED ' .

Basic steps

1. Study and measure the operations of the production line to discriminate:
   - Internal setup, the operation that must be done while machine is stopped.
   - External setup, the operation that possibly can be done while the machine is still running.
2. Suppress non-value added operations and convert internal setup operating into external setup. The data from OEE and the preparations of prerequisites are reviewed to achieve results.
3. The next stage is to simplify the design of the machine, especially fillings and tightening mechanisms.
4. Balance the work content of the line and ensure teamwork. For example, in one automatic insertion machine, one operator sets up on the machine front while the other operator feeds components on the other side.
5. Minimise trials and controls. Use of Mistake Proofing or Poka-Yoke enables the standard way to be carried out each time.

Worked-out example

Consider the setup time reduction of a packing machine. The internal and external setup times have been measured. As shown in figure below , the total setup time is reduced by overlapping external setup times on the internal setup time.



31.Overall Equipment Effectiveness (OEE)

Definition

OEE is a hierarchy of metrics which evaluates and indicates how effectively a manufacturing operation is utilized. The results are stated in a generic form which allows comparison between manufacturing units in differing industries. It is not however an absolute measure and is best used to identify scope for process performance improvement, and how to get the improvement. If for example the cycle time is reduced, the OEE can also reduce, even though more product is produced for less resource. OEE measurement is also commonly used as a key performance indicator (KPI) in conjunction with lean manufacturing efforts to provide an indicator of success.

In addition to the above measures, there are three underlying metrics that provide understanding as to why and where the OEE gaps exist.

The measurements are described below:

- Availability: The portion of the OEE Metric represents the percentage of scheduled time that the operation is available to operate. Often referred to as Uptime. Availability = Available Time / Scheduled Time.
- Performance: The portion of the OEE Metric represents the speed at which the Work Center runs as a percentage of its designed speed. Performance = (Parts Produced x Ideal Cycle Time) / Available Time.
- Quality: The portion of the OEE Metric represents the Good Units produced as a percentage of the Total Units Started. Commonly referred to as First Pass Yield (FPY). Quality = Good Units / Units Started.

Calculations for OEE

OEE breaks the performance of a manufacturing unit into three separate but measurable components: Availability, Performance, and Quality. Each component points to an aspect of the process that can be targeted for improvement. OEE may be applied to any individual Work Center, or rolled up to Department or Plant levels. This tool also allows for drilling down for very specific analysis, such as a particular Part Number, Shift, or any of several other parameters. It is unlikely that any manufacturing process can run at 100% OEE. Many manufacturers benchmark their industry to set a challenging target; 85% is not uncommon.

OEE = Availability x Performance x Quality

Example:

A given Work Centre experiences...

Availability of 86.7%

The Work Centre Performance is 93.0%.

Work Centre Quality is 95.0%.

OEE = 86.7% Availability x 93.0% Performance x 95.0% Quality = 76.6%

32.Takt time calculation

Definition

Takt time, derived from the German word Taktzeit which translates to *cycle time*, sets the pace for industrial manufacturing lines. For example, in automobile manufacturing, cars are assembled on a line, and are moved on to the next station after a certain time - the takt time. The time needed to complete work on each station has to be less than the takt time in order for the product to be completed within the allotted time. Takt time concept aims to match the pace of production with customer demand.

Takt time can be first determined with the formula: $T = \frac{T_a}{T_d}$

Where

T = Takt time, e.g. [minutes of work / unit produced]

T_a = Net time available to work, e.g. [minutes of work / day]

T_d = Time demand (customer demand), e.g. [units required / day]

Net available time is the amount of time available for work to be done. This excludes break times and any expected stoppage time (for example scheduled maintenance, team briefings, etc.).

Example:

If there is a total of 8 hours (or 480 minutes) in a shift (gross time) less 30 minutes lunch, 30 minutes for breaks (2 × 15 mins), 10 minutes for a team briefing and 10 minutes for basic maintenance checks, then the net *Available Time to Work* = 480 - 30 - 30 - 10 - 10 = 400 minutes. If customer demand was, say, 400 units a day and one shift was being run, then the line would be required to spend a maximum of one minute to make a part in order to be able to keep up with Customer Demand.

Application

Takt time is calculated on virtually every task in a business environment. It is used in manufacturing (casting of parts, drilling holes or preparing a workplace for another task), control tasks (testing of parts or adjusting machinery) or in administration (answering standard inquiries or call center operation). It is, however, most common in production lines that move a product along a line of stations that each perform a set of predefined tasks.

Benefits

Once a takt system is implemented there are a number of benefits:

- The product moves along a line, so bottlenecks (stations that need more time than planned) are easily identified when the product does not move on in time.
- Correspondingly, stations that don't operate reliably (suffer frequent breakdown, etc.) are easily identified.
- The takt leaves only a certain amount of time to perform the actual value added work. Therefore there is a strong motivation to get rid of all non value-adding tasks (like machine set-up, gathering of tools, transporting products, etc.)
- Workers and machines perform sets of similar tasks, so they don't have to adapt to new processes every day, increasing their productivity.
- As all products are "stuck" in the line and cannot leave it, they cannot be "lost" somewhere on the shop floor.

33.Total Productive Maintenance

TPM is a maintenance process developed for improving productivity by making processes more reliable and less wasteful. Original goal of total productive management: "Continuously improve all operational conditions, within a production system; by stimulating the daily awareness of all employees.

TPM has basically 3 goals - Zero Product Defects, Zero Equipment Unplanned Failures and Zero Accidents. It sets out to achieve these goals by Gap Analysis of previous historical records of Product Defects, Equipment Failures and Accidents.

TPM identifies the 7 losses (types of waste) or *muda*, namely set-up and initial adjustment time, equipment breakdown time, idling and minor losses, speed (cycle time) losses, start-up quality losses, and in process quality losses, and then works systematically to eliminate them by making improvements (kaizen).

PM has 8 pillars of activity, each being set to achieve a "zero" target. These 8 pillars are the following: focused improvement; autonomous maintenance; planned maintenance; training and education; early-phase management; quality maintenance; office TPM; and safety, health, and environment.

The Pillars & their details

1. Focused improvement - Continuously even small steps of improvement: a) Efficient Equipment Utilisation b) Efficient Worker Utilisation c) Efficient Material & Energy Utilisation.
2. Planned Maintenance - It focusses on Increasing Availability of Equipments & reducing Breakdown of Machines.
3. Initial Control - To establish the system to launch the production of new product & new equipment in a minimum run up time.
4. Education & Training - Formation of Autonomous workers who have skill & technique for autonomous maintenance.
5. Autonomous Maintenance - It means "Maintaining one's equipment by oneself".
6. Quality Maintenance - Quality Maintenance is establishment of machine conditions that will not allow the occurrence of defects & control of such conditions is requored to sustain Zero Defect.
7. Office TPM - To make an efficient working office that eliminate losses.
8. Safety, Hygiene & Environment - The main role of SHE (Safety, Hygiene & Environment) is to create Safe & healthy work place where accidents do not occur, uncover & improve hazardous areas & do activities that preserve environment.

TPM success measurement

A set of performance metrics which is considered to fit well in a lean manufacturing/TPM environment is overall equipment effectiveness (OEE).

34. Value Stream mapping

Definition

Value Stream Mapping (VSM) is a visual illustration of all activities required to bring a product through the main flow, from raw material to the stage of reaching the customer. Mapping out the activities in a production process with cycle times, down times, in-process inventory and information flow paths helps us to visualise the current state of the process and guides us to the future improved state.

Application

VSM is an essential tool of Lean Manufacturing in identifying non-value added activities at a high level of the total process. According to Womack and Jones (1996) , the initial objective of creating a Value Stream Map is to identify every action required to make a specific product. Thus the initial step is to group these activities into three categories:

1. Those which actually create value for the customer.
2. Those which do not create value but are currently necessary (type one Muda).
3. Those which create no value as perceived by the customer (type two Muda).

Once the third set has been eliminated, attention is focused on the remaining non-value creating activities. This is achieved through making the value flow at the pull of the customer. VSM is closely linked with the analytical tool of Process Mapping. Having established improvement opportunities at a high level by VSM, a detailed analysis of the specific areas of the process is effective with Process Mapping.

Basic steps

1. The first step of VSM is to select the product or process for improvement.
2. Each component of production from the source to the point of delivery is then identified.
3. The entire supply chain of the product or process (e.g. through order entry, purchasing, manufacturing, packaging and shipping) is mapped sequentially.
4. The quantitative data of each activity (e.g. storage time, delay, distance travelled, process time and process rate) are then recorded.
5. Each component (i.e. activity) of production or process is evaluated to determine the extent to which it adds value to product quality and production efficiency.
6. These activities are then categorised as:
    - Value added
    - Necessary non-value added
    - Unnecessary non-value added.
7. Areas of further analysis and improvement are then identified clearly.

Worked-out example

The following example is adapted from Womack and Jones (1996, pp. 38–43). Consider a case containing eight cans of cola at a Tesco store. Figure … shows a Value Stream Map of cola, from the mining of Bauxite (the source of aluminium of the cans) to the user's home. The quantitative data related to the activities in the value stream are summarised in Table …. .

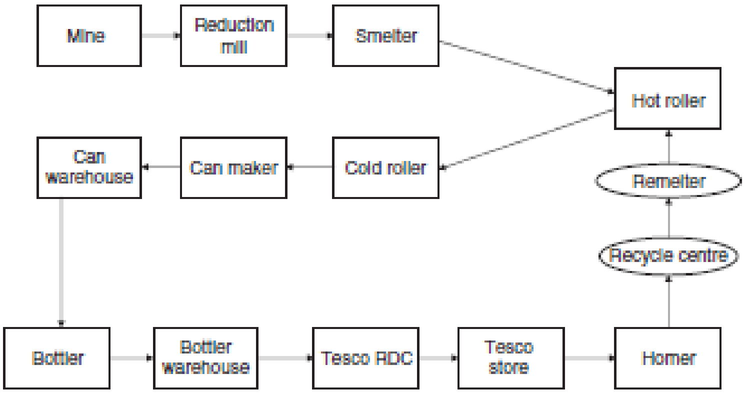


Figure of Value Stream for Cola Cans.

Table of Quantitative data of Cola Cans

	Incoming storage	Process time	Finished storage	Process rate	Cumulative days
Mine	0	20 minutes	2 weeks	1000 tonnes/ hour	319
Reduction mill	2 weeks	30 minutes	2 weeks	–	305
Smelter	3 months	2 hours	2 weeks	–	277
Hot rolling mill	2 weeks	1 minute	4 weeks	10 feet/ minute	173
Cold rolling mill	2 weeks	<1 minute	4 weeks	2100 feet/ minute	131
Can maker	2 weeks	1 minute	4 weeks	2000 feet/ minute	89
Bottler	4 days	1 minute	5 weeks	1500 feet/ minute	47
Tesco RDC	0	0	3 days	–	8
Tesco store	0	0	2 days	–	5
Home storage	3 days	5 minutes	–	–	3
Totals	5 months	3 hours	6 months	–	319

35. Visual Control

Definition

Visual control is a technique employed in many places and contexts whereby control of an activity or process is made easier or more effective by deliberate use of visual signals. These signals can be of many forms, from different coloured clothing for different teams, to focusing measures upon the size of the problem and not the size of the activity, to kanban and heijunka boxes and many other diverse examples. Visual controls are means, devices, or mechanisms that are designed to manage or control the operations (processes) so as to meet the following purposes:

- Make the problems, abnormalities, or deviation from standards visible to everyone and thus corrective action can be taken immediately,
- Display the operating or progress status in an easy to see format.
- Provide instruction.
- Convey information.
- Provide immediate feedback to people.

Application

There are two types of application in visual controls, displays and controls.

- A visual display relates information and data to employees in the area. For example, charts showing the monthly revenues of the company or a graphic depicting a certain type of quality issue that group members should be aware of.
- A visual control is intended to actually control or guide the action of the group members. Examples of controls are readily apparent in society: stop signs, handicap parking signs, no smoking signs, etc.

Implementation

There are two types of visual control implementation items, analog and actual.

- Examples of actual items that can be implemented through visual control are items that are designed to designate a location/position for each item, indicate quantity including inventory levels, distinguish items from each other and specify form.
- Analog items that can be implemented through visual control are seen in the following examples: colors, shapes, symbols, characters, numbers, graphs, electronic lights, sound, touch, smell, taste, etc.

Common examples of Visual Control

- Tape Manual beside the Appliances: Often we are looking for the instructional manual for a specific home appliance or hand tool. Taping manual beside the appliance so that it can be found easily.
- Print Instruction inside the Cover of Washing Machine: Printing short operating instruction and safety concerns inside the cover of home appliance allows users to easily find the instruction and prevent from inappropriate use of the appliance.
- Use Tools Organizer to Organize Tools: Tools organizer helps to organize the small tools. It can eliminate the need of searching for tools when needed. It can also prevent tools from wearing out and rusty.