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AN OVERVIEW ON SIX SIGMA: QUALITY IMPROVEMENT PROGRAM

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Abstract**—Six Sigma is a smarter way to manage business or department. It is a vision of quality that equates with only 3.4 defects for million opportunities for each product or service transactions, Strives for perfection. We believe that defects free product can be in any organization implementing six sigma. In this paper, we presented an overview of the process which explains how six sigma increase the overall quality improvement task into a series of project management stages: Define, Measure, Analyses, Innovation, Improve and Control. We will describe dependence of six sigma on Normal Distribution theory and also process capability. It gives a small note on the assumptions made in six sigma methodology of problem solving and the key elements involved .A brief view on Defects Per Million Opportunities (DPMO) Analysis is given.**

Ultimate objectives of the methodology to solve problems, improve the quality, profitability and customers satisfaction. Like quality management in general six sigma has penetrated into most sectors of today's business world. Six Sigma is the tool through which we can improve the Quality and profitability by removing the cause of defects and variability in manufacturing and business processes. Six Sigma is perhaps the most widely-accepted initiative by all a broad range of organizations. The DMAIC (Define – Measure-Analyze-Improve-Control) approach is followed here to solve the problem of management. The DMADV (Define – Measure– Analyze – Design – Verify) is used in product design improvement. Both of these procedures are developed in the classic Plan – Do – Check – Act (PDCA) cycle.

This paper seeks to synthesize the literature, with an emphasis on establishing its relationship to quality management theories and topics for future research. In doing so, there is an attempt to answer the fundamental questions: (1) what is six sigma? (2) What are its impacts on operational performance? (3) What is its role in quality management?

Keywords- Six Sigma; Quality Improvement; DMAIC; DMADV; PDCA;

INTRODUCTION

The main objective of any business is to make profit. For increasing the profit, the selling price should increase and/or the manufacturing cost should come down. Since the price is decided by the competition in the market, hence the only the way to increase the profit is to cut down the manufacturing cost which can be achieved only through continuous improvement in the company's operation. Six sigma quality programs provide an overall framework for continuous improvement in the process of an organization. Six sigma uses facts, data and root cause to solve problems.

Six Sigma was invented at Motorola in the 1980s The invention was motivated by the high cost of poor quality discovered at Motorola Like many companies at that time, it was as high as 15% to 20% of the sales revenue. Due to that cause large portion of product fail to meet customer requirement which led to scrap, rework and other services. Six Sigma was started in Motorola by engineer Bill smith in order to address the company's chronic problems of meeting customer expectations in a cost effective manner. Within improvement projects quality problems were systematically analyses at the front end of the process & continued throughout the manufacturing process using four phases (Measure, Analyses, Improve, and Control).Statistically, Six Sigma refers to a process in which the range between the mean of a process quality measurement and the nearest specification limit is at least six times the standard deviation of the process. [1]

The traditional quality management approaches, including Statistical Quality Control (SQC), Zero Defects and Total Quality Management (TQM), have been key players for many years, while Six Sigma is one of the more recent quality improvement initiatives to gain popularity and acceptance in many industries across the globe. Six Sigma differs from other quality programs in its top-down drive in its rigorous methodology that demands detailed analysis, fact-based decisions, and a control plan to ensure on going quality control of a process. Many companies including GE, Honeywell, Sony, Caterpillar, and Johnson Controls have adopted Six Sigma and obtained substantial benefits. Six sigma background stretches back eighty plus years, from management science concepts developed in the United States to Japanese management breakthroughs to "TOTAL QUALITY" efforts in 1970s and 1980s. But the real impacts can be seen in the waves of change and positive results sweeping such companies as GE, MOTOROLA, JOHNSON &JOHNSON and AMERICAN EXPRESS. Six Sigma is a long-term commitment. It won't work well without full commitment from upper management. Six Sigma changes the way a company thinks by teaching fact-based decision making to all levels. [2]

WHAT IS SIX SIGMA

Six sigma is defined a customer oriented, structured, systematic, proactive and quantitative company wide approach for continuous improvement of manufacturing, services, engineering, suppliers and other business process. It is a statistical measure of the performance of a process or a product. It measures the degree to which the process deviates from the goals and then takes efforts to improve the process to achieve total customer satisfaction.

Six sigma efforts target three main areas:

- Improving customer satisfaction.
- Reducing cycle time.
- Reducing defects.

Three key characteristics separates six sigma from quality programs of the past:

- Six Sigma is a customer focused.
- Six sigma projects produce major returns on investments.
- Six sigma changes how management operates.

The very first definition of Six Sigma is that it is a defect rate metric, specifically, it means 3.4 DPMO.

TABLE I SIX SIGMA PROCESS

Sigma Level	Defects Per Million Opportunities	Rate o Improven
1 σ	690,000	1 time
2 σ	308,000	**2** time
3 σ	66,800	5 time
4 σ	6,210	11 time
5 σ	230	27 time
6 σ	3.4	68 time

This is actually the origin of the name Six Sigma. Statisticians have used the Greek letter Sigma to refer to standard deviation. Six Sigma is simply six standard deviations. What it truly means is that a process is highly capable that customer specifications are actually six standard deviations away from the process center (see Fig. 1).

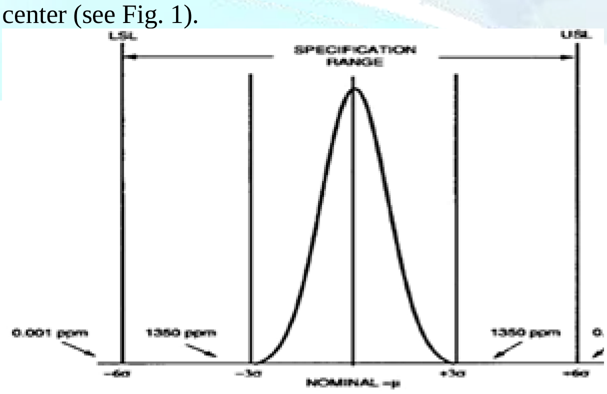

Fig.1. Six Sigma as a defect rate matrix

Since a product will only be considered defective if it is produced outside of customer specifications, a process with such a high capability will almost produce no defect.

The mathematical calculation of 3.4 DPMO is based on two assumptions: the process output follows a normal distribution, and the process mean may shift up to 1.5 standard deviations in the long term. In the extreme situations when the process mean has shifted 1.5 standard deviations one way or the other, the most number of defects the process will produce can be calculated as $P(Z > 4.5) + P(Z > 7.5)$ Since $P(Z>7.5)$ is virtually zero, Six Sigma is technically $P(Z > 4.5)$, which is 3.4 per million (see Fig. 2). [3]

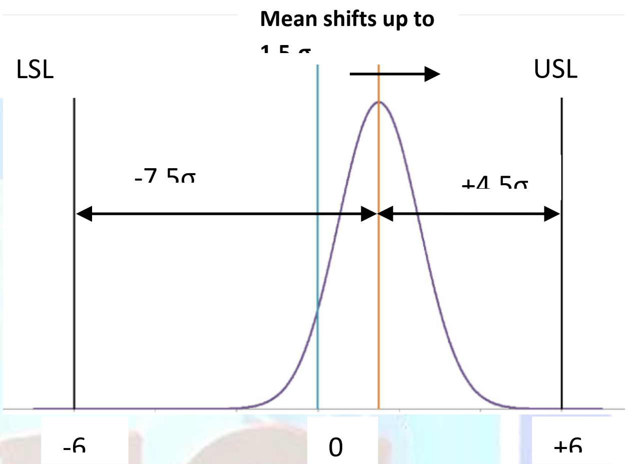

Fig.2. Calculating defect per million opportunities for six sigma

Six Sigma equates 3.4 defects for every million parts made or process transactions carried out. This quality equates to 99.99966% defect free products or transactions.

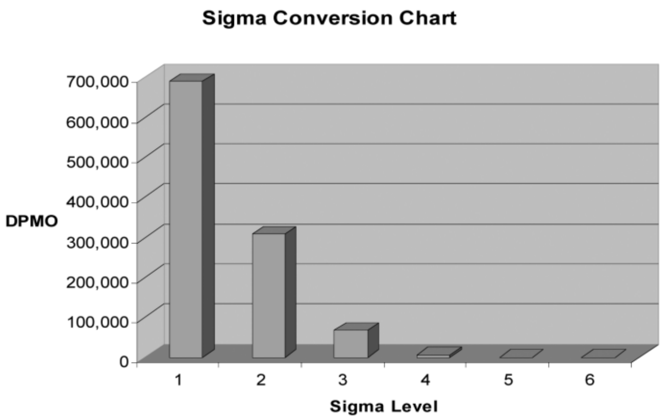

Fig.3. Diagram of six sigma conversion

High quality standards do make sense but the cost required to pursue such high standards have to be balanced with benefits gained. The six sigma processes exposes the root causes and then focuses on the improvements to achieve the highest level of quality at acceptable cost. This is essential to achieve and maintain a competitive advantage and high levels of customer satisfaction and loyalty.

When we say that a process is at six sigma level, such a process is normally yield two instances of non-conformances out of every million opportunities for non-conformances, provided there is no shift in the process average. The same will yield 3.4 instances of non-conformances out of every million opportunities with an expected of 1.5 sigma in the process average. This is considered to be best-in-class quality.

METHODOLOGY OF SIX SIGMA

Six Sigma has been defined as the statistical unit of measurement, a sigma that measures the capability of the process to achieve a defect free performance. Six Sigma has the ability to produce products and services with only 3.4 defects per million, which is a world class performance. Six Sigma has also been described as a high performance data driven approach in analyzing the root causes of business problems and solving them [4]. Six Sigma has two key methodologies:-

DMAIC Methodology and DMADV Methodology, both inspired by Deming's Plan-Do-Check-Act Cycle.

- DMAIC is used to improve an existing business process.
- DMADV is used to create new product or process design.

DMAIC (Define-Measure-Analyze-Improve-Control)

The basic DMAIC methodology consists of the following five steps:

- Define process improvement goals that are consistent with customer demands and the enterprise strategy.
- Measure key aspects of the current process and collect relevant data.
- Analyze the data to verify cause-and-effect relationships. Determine what the relationships are, and attempt to ensure that all factors have been considered.
- Improve or optimize the process based upon data analysis using techniques like Design of Experiments.
- Control to ensure that any deviations from target are corrected before they result in defects. Set up pilot runs to establish process capability, move on to production, set up control mechanisms and continuously monitor the process. [5]

TABLE II KEY TOOLS OF DMAIC METHODOLOGY

Objective: DEFINE the Opportunity.	**Objective**: MEASURE current performance.	**Objective**: ANALYZE the root causes of problems.	**Objective**: IMPROVE the process to eliminate root causes.	**Objective**: CONTROL the process to sustain the gains.
Key Define Tools: ➢ Cost of Poor Quality (COPQ) ➢ Voice of the Stakeholder (VOS) ➢ Project Charter ➢ As-Is Process Map(s) ➢ Primary Metric (Y)	**Key Measure Tools**: ➢ Critical to Quality Requirements (CTQs) ➢ Sample Plan ➢ Capability Analysis ➢ Failure Modes and Effect Analysis (FMEA)	**Key Analyze Tools**: ➢ Histograms, Boxplots, Multi-Vari Charts, etc. ➢ Hypothesis Tests ➢ Regression Analysis	**Key Improve Tools**: ➢ Solution Selection Matrix ➢ To-Be Process Map(s)	**Key Control Tools**: ➢ Control Charts ➢ Contingency and/or Action Plan(s)

DMADV (Define-Measure-Analyze-Design-Verify)

The basic DMADV methodology consists of the following five steps:

- Define design goals that are consistent with customer demands and the enterprise strategy.
- Measure and identify CTQs (characteristics that are Critical To Quality), product capabilities, production process capability, and risks.
- Analyze to develop and design alternatives, create a high-level design and evaluate design capability to select the best design.
- Design details, optimize the design, and plan for design verification. This phase may require simulations.
- Verify the design, set up pilot runs, and implement the production process. [6]

TABLE III KEY TOOLS OF DMADV METHODOLOGY

Objective: DEFINE the project goals.	**Objective:** MEASURE the customer needs and specifications.	**Objective:** ANALYZE the process options to meet the customer needs.	**Objective:** DESIGN the process to need the customer needs.	**Objective:** VERIFY the design performance.
Key Define Tools: ➢ Project management tools ➢ Project selection ➢ Bench marking ➢ C & E matric ➢ Survey	**Key Measure Tools**: ➢ Brain storming ➢ FMEA screening ➢ Bench marking transfer ➢ QFD ➢ Process Map	**Key Analyze Tools**: ➢ FMEA ➢ Reliability ➢ Pareto analysis ➢ Gap analysis ➢ Risk analysis	**Key Design Tools**: ➢ Work design ➢ Robust design ➢ Machine design ➢ Engineering design ➢ Specification design	**Key Verify Tools**: ➢ Reliability test ➢ FMEA ➢ Simulation ➢ Control plan

SIX SIGMA STRATEGIES, TOOLS, TECHNIQUES, AND PRINCIPLES

Six sigma is a systematic, data-driven approach using define, measure, analysis, improve, and control (DMAIC) process and utilizing design for six sigma method (DFSS). The fundamental principle of six sigma is to 'take an organization to an improved level of sigma capability through the rigorous application of statistical tools and techniques'. It generally applies to problems common to production. Table-I summarizes six sigma strategies, tools, techniques, and principles. [7]

TABLE IV STRATEGIES, TOOLS, TECHNIQUES & PRINCIPLES

Strategies and Principles	Tools and Techniques
Project management	Statistical process control
Data-based decision making	Process capability analysis
Knowledge discovery	Measurement system analysis
Process control planning	Design of experiments
Data c tools and techniques	Robust design
Variability reduction	Quality function deployment
Belt system	Failure mode and effects analysis
DMAIC process	Regression analysis
Change management tools	Analysis of means and variances Hypothesis testing Root cause analysis Process mapping

QUALITY APPROACHES AND MODELS

Six Sigma –

Six Sigma revolves around a few key concepts given in table below. [8]

TABLE V KEY CONCEPTS

Keys	Details
Critical to Quality	Attributes most important to the customer.
Defect	Failing to deliver what the customer wants.
Process Capability	What your process can deliver.
Variation	What the customer sees and feels.
Stable Operations	Ensuring consistent, predictable processes to improve.
Design for Six Sigma	Designing to meet customer needs and process capability.

DFSS (Design for six sigma) –

DFSS is a systematic methodology utilizing tools, training and measurements to enable the organization to design products and processes that meet customer expectations and can be produced at Six Sigma quality levels. The goal of DFSS is to achieve minimum defect rates, six sigma level, and maximum possible impact during the development stage of the products. [9]

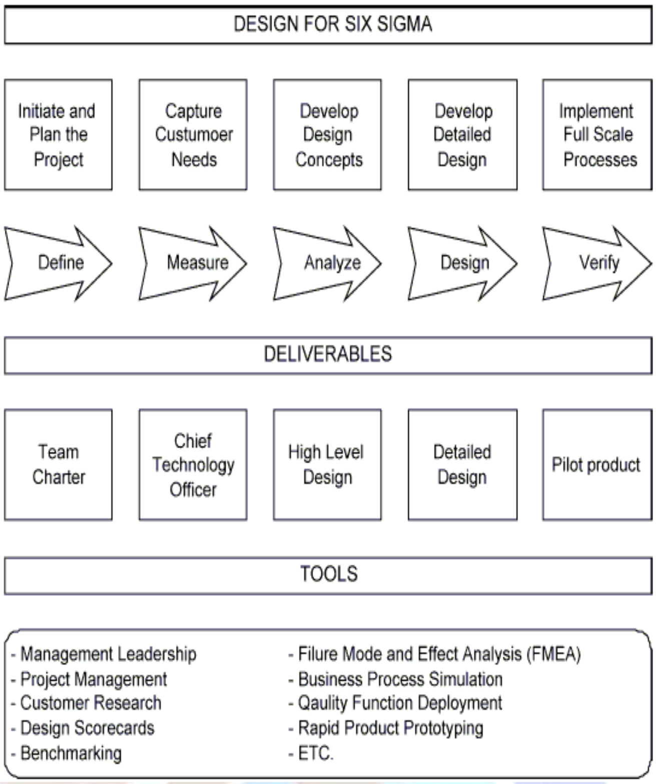

Fig. 4. Five steps DFSS process

SIX SIGMA TOOLS

Associates are exposed to various tools and terms related to quality. Below are just a few of them-

Charts and Graphs-

Usually, the first and best way to analysis measures of a process is to create a picture of the data. Charts and graphs are really nothing more than visual displays (pictures) of data. For most of us, looking at a pie chart or a line graph is a lot more meaningful and convenient than reading tables of numbers. And when you compare different segments of data—the stratification mentioned in the section on checksheets—you can make discoveries that the numbers themselves would hide.

For example, Figure 5 (a) shows an initial pie chart covering the entire company, on reasons for complaints. Figure 5 (b) and (c) show the same data broken out by region, giving you a very different picture. It's discoveries like this that help DMAIC teams both define their problems better and analyse the causes.

Charts and graphs are of various types, each offering a bit different picture of the data. A Black Belt will usually use at least a couple of these on a project. Following are some of the most commonly used types of charts and graphs.

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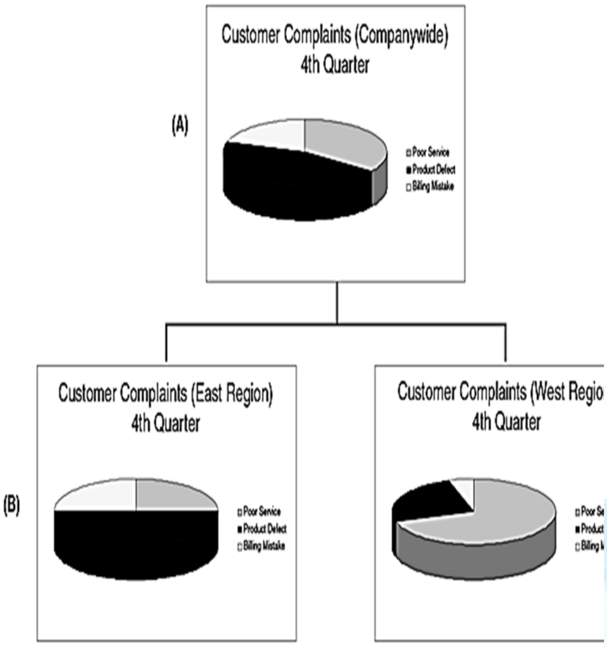

Fig. 5. Diagram of Pie Charts

Control Chart –

A control chart is simply a run chart to which two horizontal lines called control limits are added, the upper control limit and the lower control limit. Control limits are chosen statistically so that they are highly probability (greater than 0.99) that points will fall between these limits if the process is in control. **Control charts only give the signal when the process trends to go out of control and cannot determine the source of the problem. As problem-solving tools, control charts allow operators to identify quality problems in processes as they occur.**

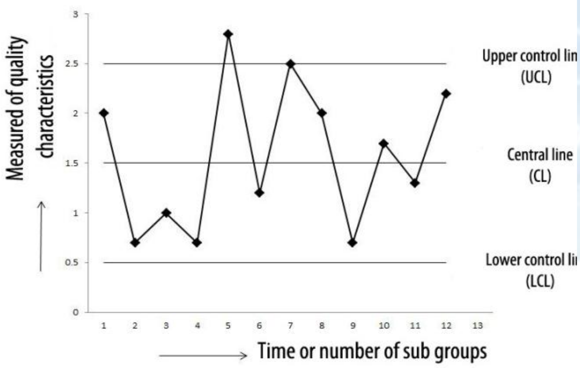

Fig. 6. The Diagram of control chart

Pareto Diagram –

Pareto analysis is a technique based on the pareto principle of "the vital few and the trivial many". The Pareto principle is also called the 80-20 rule, i.e. approximately 20 percent of a group of items, people, inventory, causes and the like accounts for approximately 80 percent of the work, effort, problems and the like. **"A Pareto diagram is a bar chart that illustrates the frequency of recurrence or the cost of a set of items. The items are shown in the descending order of importance from left to right. By highlighting the most frequent or most costly items, Pareto diagram can help a team focus its efforts."** [10]

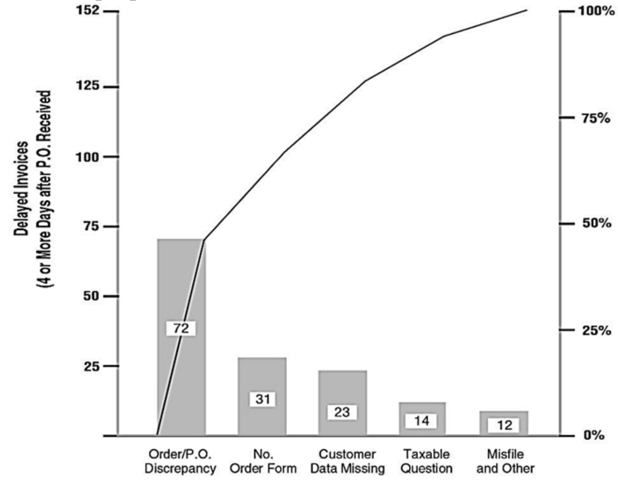

Fig. 7. Pareto diagram for shock absorber

The bar represents the defect type arranged in descending order by number of defect per category. And are plotted against Y axis .the cumulative percentage of the category is shown by the X line plotted on the right Y axis.

Cause-and-Effect or Fishbone Diagram –

.This is a diagram which gives the relationship between quality characteristic and its factors. It is a pictorial presentation in which all possible causes and their effects are displayed. A problem can be due to a variety of reasons or causes. The solution to the problem becomes similar and easier if only true causes for the problem can be identified. "**The cause and effect diagram was introduced by Kaoru Ishikawa of Japan."** It is the simple, graphical method for presenting a chain of causes and effects and for sorting out causes and organising relationships between variables. Because of its structure, it is often called **fish bone diagram**. [11]

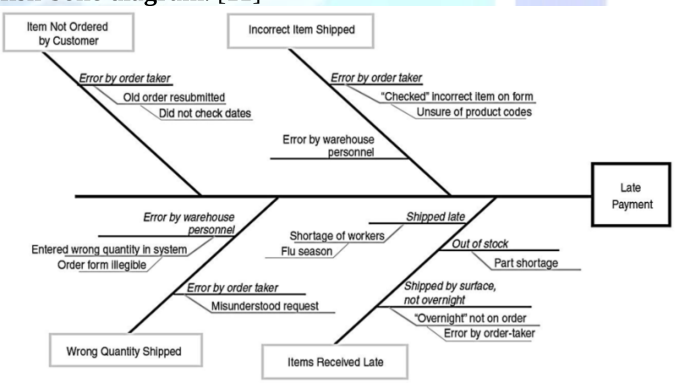

Fig. 8. Cause and Effect Diagram

Statistical Process Control –

SPC is the application of statistical techniques to determine whether the output of a process conforms to the product or service design. In SPC, control charts are used primarily to detect production of defective products or services or to indicate that the production process has changed and that products or services will deviate from their design specifications unless something is done to correct the situation.

SIPOC Diagram

SIPOC (pronounced "sye-pahk") is an acronym for Supplier, Input, Process, Output, and Customer. SIPOC is used in the Define phase of DMAIC and is often a preferred method for diagramming major business processes and identifying possible measures. The SIPOC diagram is used to show major activities, or sub processes, in a business process, along with the framework of the process, represented by the Suppliers, Inputs, Outputs, and Customers. A SIPOC diagram is used to help define the boundaries and critical elements of a process without getting into so much detail that the big picture is lost. As you can see in Figure 9, the Process part of the diagram is represented by only a few high-level activities.

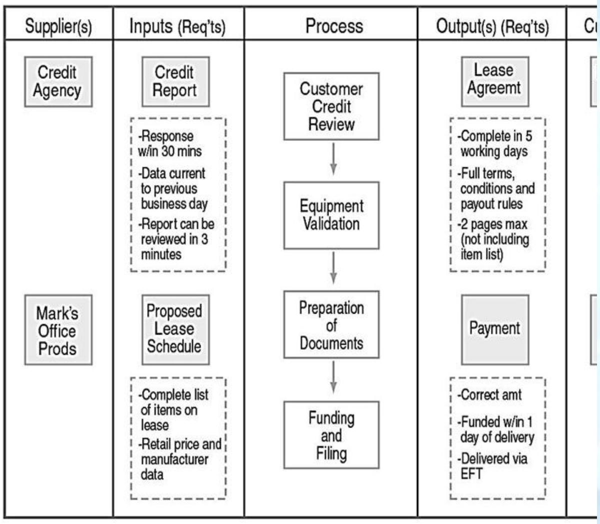

Fig. 9. Diagram of "SIPOC" Equipment Leasing Process

Tree Diagram –

A tree diagram maps out the paths and tasks necessary to complete a specific project or reach a specific goal. This technique is used to seek answers to such questions as "What sequence of tasks will address this issue?" A structure tree is used to show the links or hierarchy of the ideas brainstormed. Figure 10 shows how goals and possible solutions can be connected by using a structure tree. You might also use this approach to tie major customer needs, such as good value, to more specific requirements, such as low installation cost, low maintenance cost, and so on.

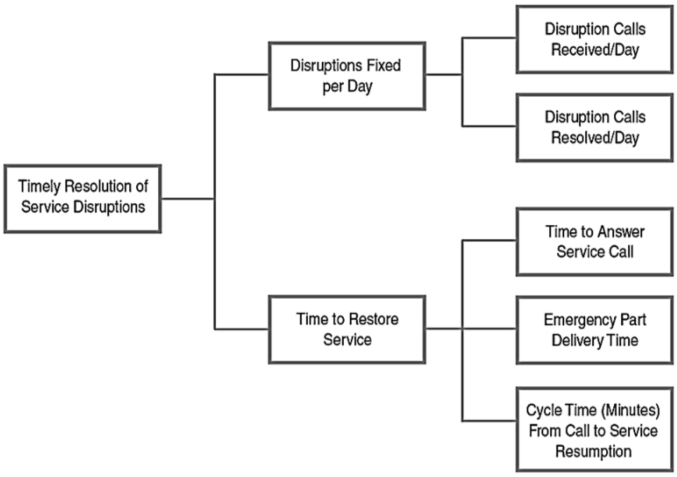

Fig. 10. Diagram of Structure Tree

Run Chart –

Monitors performance of one or more processes over time to detect trends, shifts or cycles. Allows a team to compare performance before and after implementation of a solution to measure its impact. Focuses attention on truly vital changes in the process. Pareto charts and histograms don't show you how things are changing over time. That's the job of a run, or trend, chart. Figure 11 shows the number of late pizzas per day over a month.

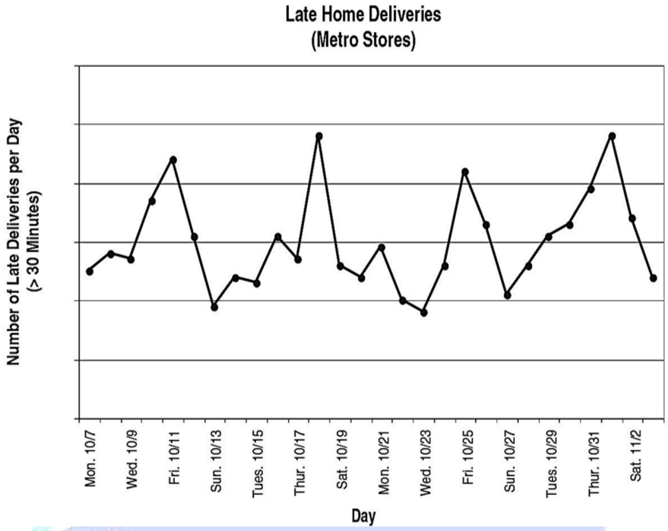

Fig.11. Diagram of Run or Trend Chart

Checksheets and Spreadsheets

Checksheets are forms used to collect and to organize data. Ideally, checksheets are designed by a Black Belt and/or team and have two key objectives:

- To ensure that the right data is captured, with all necessary facts included, such as when it happened, how many, and what customer. We call these facts stratification factors.
- To make data gathering as easy as possible for the collectors.

Checksheets can vary from simple tables and surveys to diagrams used to indicate where errors or damage occurred. Spreadsheets are the place where checksheet

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data is collected and organized. A well-designed spreadsheet makes it much easier to use the data. Figure 12 shows a spreadsheet with data taken from observing patients eating new menu items in a hospital.

MENU ITEM	Portions Ordered	Portions Consumed	Per Cons
Asparagus	477	387	8
Garlic Bits	255	12	
Chicken Nibbles	669	624	9
Ice Cream Sundae	1121	1118	9
Hot Dog Helper	235	124	5
Spinach Thermador	112	21	1
Onion Surprise	23	0	
Beef Brochette	611	544	8
TOTALS	3503	2830	8

Fig.12. Diagram of Spreadsheet

Matrix Diagram –

Matrix diagram are "spreadsheets" that graphically display relationships between ideas and activities in such a way as to provide logical connecting points between each item. It is one of the most versatile tools in quality planning.

Flow Chart-

A flowchart is used to show details of a process, including tasks and procedures, alternative paths, decision points, and rework loops. A flowchart can be depicted as an "as-is" map showing a process as it currently works or as a "should-be" map showing how it ought to work. The level of detail will vary, depending on the objective. Many Black Belts now use software to draw their flowcharts but often start with a bunch of stickies on a wall. (See Figure 13)

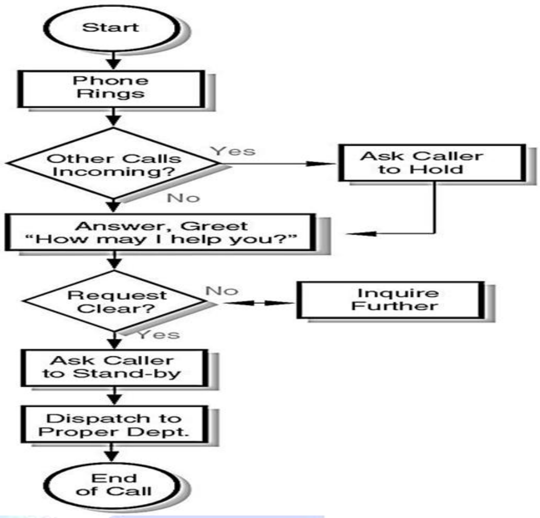

Fig.13. Diagram of Flowchart or Process Map

Scatter Diagram –

Scatter diagrams are used to determine whether relationship really exists between two process two process characteristics and the direction of the relationship. **A scatter diagram graphically illustrates the relationship between variables, typically based on quantitative data.** They reveal bi-variate relationships, which are relationships between pairs of variables, such as number of defects per batch against changes in the speed of production line, or production time per unit against hours of training. [12]

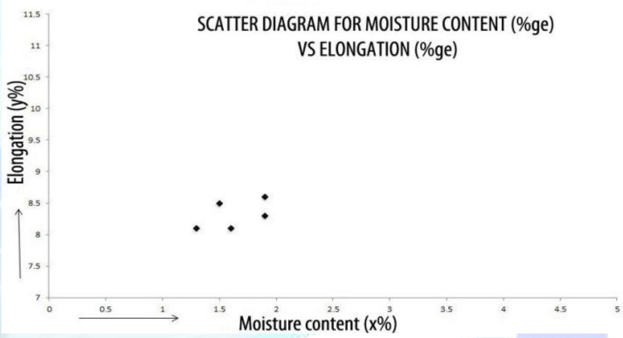

Fig. 14. Scatter Diagram

Histrogram-

A histogram, another type of bar chart, shows the distribution or variation of data over a range: size, age, cost, length of time, weight, and so on. (A Pareto chart, by contrast, slices data by category.) For instance, we know that a big chunk of our pizza deliveries are late, but we do not know how late—or even how early— they arrive. So, over several days or weeks, you could measure the time in minutes it takes to deliver pizzas to customers and then plot that data (see Figure 15). In analysing histograms, you can look for the shape of the bars or the curve, the width of the spread, or range, from top to bottom, or the number of "humps" in the bars. If you plot customer requirements on a histogram, you can quickly see how much of what you do is meeting—or not meeting—

customers' needs. how much of what you do is meeting—or not meeting—customers' needs.

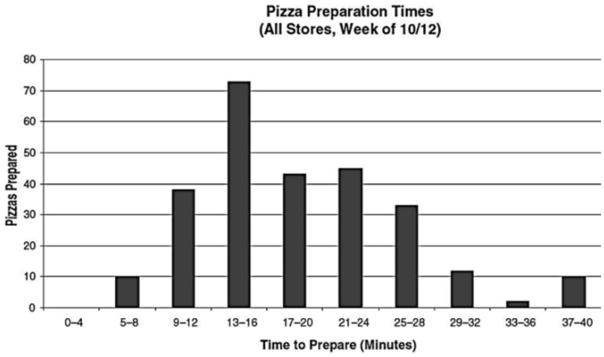

Fig.15. Diagram of Histogram

SUCCESSFUL SIX SIGMA IMPLEMENTATION

The following elements are absolutely essential to successful implementation of Six Sigma:

Antony and Banuelas (2002) and Banuelas Coronado and Antony (2002) presented the key ingredients for the effective introduction and implementation of six sigma in UK manufacturing and services organizations as the following-

- Management commitment and involvement.
- Understanding of six sigma methodology, tools, and techniques.
- Linking six sigma to business strategy.
- Linking six sigma to customers.
- Project selection, reviews and tracking.
- Organizational infrastructure.
- Cultural change.
- Project management skills.
- Liking six sigma to suppliers.
- Training.
- Linking six sigma to human resources.

Johnson and Swishier (2003) provided useful implementation tips for successful six sigma applications as:

- Sustained and visible management commitment.
- Continuing Education and training of managers and participants.
- Setting clear expectations and selecting project leaders carefully for leadership skills.
- Picking and selecting strategically important projects.

Starbird (2002) argued that six sigma processes is part of a management system to achieve business excellence in organizations and presented keys to six sigma success as:

- Start process management: identify core processes, customer needs, and measures.
- Drive performance through reporting: Leaders must maintain and report opportunity lists, status of active projects/resources, and results from finished projects.
- Integrate championing of active projects: Select and charter projects and require updates during existing staff meetings.
- Consistent and visible leadership involvement.
- A measurement system to track progress, providing accountability for the initiative.
- Internal and external benchmarking of the organization's products, services, and processes. You must find out where you really are.
- Setting challenging stretch goals that focus your employees on changing the process, not just tweaking it.
- Educating and informing every member of your organization about the Six Sigma methodology.
- Developing the infrastructure to support change throughout your organization.
- Working to create a "cause," not just a business success.

APPLICATION OF SIX SIGMA

Manufacturing Sector –

Motorola was the first organization to use the term six sigma in the 1980s as part of its quality performance measurement and improvement program. Six sigma has since been successfully applied in other manufacturing organizations such as General Electric, Boeing, DuPont, Toshiba, Seagate, Allied Signal, Kodak, Honeywell, Texas Instruments, Sony, etc. The reported benefits and savings are composed and presented from investigating various literatures in six sigma (Weiner, 2004; de Feo and Bar-El, 2002; Antony and Banuelas, 2002; Buss and Ivey, 2001; McClusky, 2000). Table 3 summarizes the organizations, projects, benefits, improvements, and savings by implementing the six sigma process.

Financial Sector –

In recent years, finance and credit department are pressured to reduce cash collection cycle time and variation in collection performance to remain competitive. Typical six sigma projects in financial institutions include improving accuracy of allocation of cash to reduce bank charges, automatic payments, improving accuracy of reporting, reducing documentary credits defects, reducing check collection defects, and reducing variation in collector performance (Doran, 2003).

Bank of America (BOA) is one of the pioneers in adopting and implementing six sigma concepts to streamline operations, attract and retain customers, and create competitiveness over credit unions. It has hundreds of six sigma projects in areas of cross-selling, deposits, and problem resolution. BOA reported a 10.4% increase in customer satisfaction and 24% decrease in customer problems after implementing six sigma (Roberts, 2004). American Express applied six sigma principles to improve external vendor processes, and eliminate non-received renewal credit cards. The result showed an improved sigma level of 0.3 in each case (Bolt et al., 2000). Other financial institutions including, GE Capital Corp., JP Morgan Chase, and SunTrust Banks are using six sigma to focus on and improve customer requirements and satisfaction (Roberts, 2004).

Healthcare Sector –

Six sigma principles and the healthcare sector are very well matched because of the healthcare nature of zero tolerance for mistakes and potential for reducing medical errors. Some of the successfully implemented six sigma projects include improving timely and accurate claims reimbursement (Lazarus and Butler, 2001), streamlining the process of healthcare delivery (Ettinger, 2001), and reducing the inventory of surgical equipment and related costs (Revere and Black, 2003). The radiology film library at the University of Texas MD Anderson Cancer Center also adopted six sigma and improved service activities greatly (Benedetto, 2003). Also in the same institution's outpatient CT exam lab, patient preparation times were reduced from 45 min to less than 5 min in many cases and there was a 45% increase in examinations with no additional machines or shifts (Elsberry, 2000).

Engineering And Construction Sector –

In 2002, Bechtel Corporation, one of the largest engineering and construction companies in the world, reported savings of $200 million with an investment of $30 million in its six sigma program to identify and prevent rework and defects in everything from design to construction to on-time delivery of employee payroll (Eckhouse 2004). For example, six sigma was implemented to streamline the process of neutralizing chemical agents, and in a national telecommunications project to help optimize the management of cost and schedules (Moreton, 2003).

Research And Development Sector –

The objectives of implementing six sigma in R&D organizations are to reduce cost, increase speed to market, and improve R&D processes. To measure the effectiveness of six sigma, organizations need to focus on data driven reviews, improved project success rate, and integration of R&D into regular work processes. One survey noted that as of 2003 only 37% of the respondents had formally implemented six sigma principles in their R&D organization (Johnson and Swisher, 2003). Rajagopalan et al. (2004) reported that the development and manufacturing of the new prototype at W.R. Grace (Refining Industry) was cut to 8–9 months from 11–12 months by implementing the DFSS process. Fig. 2 shows the conceptual benefits and improvement of implementing six sigma in R&D projects.

FUTURE OF SIX SIGMA

Six sigma is likely to remain as one of the key initiatives to improve the management process than just being remembered as one of the fads (Johnson and Swisher, 2003). The primary focus should be on improving overall management performance, not just pinpointing and counting defects. Researchers and practitioners are trying to integrate six sigma with other existing innovative management practices that have been around to make six sigma method even more attractive to different organizations that might have not started or fully implemented the six sigma method. Integrating and comparing principles and characteristics of six sigma with Total Quality Management (Revere and Black, 2003), (Hammer and Goding, 2001), Human Resource Functions (Wyper and Harrison, 2000), Lean Production (Antony et al., 2003), ISO 9000 (Catherwood, 2002), ISO 9001 (Dalgleish, 2003), and the capability maturity model (Murugappan and Keeni, 2003) are all part of the quality community's effort to maximize the positive effect of the six sigma method.

In my opinion, six sigma will be around as long as the projects yield measurable or quantifiable bottom-line results in monetary or financial terms. When six sigma projects stop yielding bottom-line results, it might disappear. I also feel that while six sigma will evolve in the forthcoming years, there are some core elements or principles within six sigma that will be maintained, irrespective of the "next big thing". One of the real dangers of six sigma is to do with the capability of black belts (the so-called technical experts) who tackle challenging projects in organisations. We cannot simply assume that all black belts are equally good and their capabilities vary enormously across industries (manufacturing or service), depending a great deal on the certifying body. Another danger is the attitude of many senior managers in organisations that six sigma is "an instant pudding" solving all their ever-lasting problems.

I also believe that the six sigma toolkit will continue to add new tools, especially from other disciplines such as healthcare, finance, sales and marketing. Having a core set of tools and techniques is an advantage of six sigma that brings speed to fix problems and its ease of accessibility to black belts and green belts.

I would like to raise the point that six sigma does provide an effective means for deploying and implementing statistical thinking (Snee, 1990; 2002) which is based on the following three rudimentary principles:

- All work occurs in a system of interconnected processes.
- Variation exists in all processes.
- Understanding and analysing the variation are keys to success.

Statistical thinking can also be defined as thought processes, which recognise that variation is all around us and present in everything we do. All work is a series of interconnected processes, and identifying, characterising, quantifying, controlling and reducing variation provide opportunities for improvement (Snee, 1990). The above principles of statistical thinking within six sigma are robust and therefore it is fair to say that six sigma will continue to grow in the forthcoming years. In other words, statistical thinking may be used to create a culture that should be deeply embedded in every employee within any organisation embarking on six sigma programs.

However the total package may change in the evolutionary process. It is important to remember that six sigma has a better record than total quality management (TQM) and business process re-engineering (BPR), since its inception in the mid-late 1980s. The ever-changing need to improve will no doubt create needs to improve the existing six sigma methodology and hence develop better products and provide better services in the future. As a final note, the author believes that companies implementing or contemplating embarking on six sigma programs should not view it as an advertising banner for promotional purposes.

The following are some of the limitations of six sigma which create opportunities for future research:

- The challenge of having quality data available, especially in processes where no data is available to begin with (sometimes this task could take the largest proportion of the project time).
- In some cases, there is frustration as the solutions driven by the data are expensive and only a small part of the solution is implemented at the end.
- The right selection and prioritisation of projects is one of the critical success factors of a six sigma program. The prioritisation of projects in many organisations is still based on pure subjective judgement. Very few powerful tools are available for prioritising projects and this should be major thrust for research in the future.
- The statistical definition of six sigma is 3.4 defects or failures per million opportunities. In service processes, a defect may be defined as anything which does not meet customer needs or expectations. It would be illogical to assume that all defects are equally good when we calculate the sigma capability level of a process. For instance, a defect in a hospital could be a wrong admission procedure, lack of training required by a staff member, misbehaviour of staff members, unwillingness to help patients when they have specific queries, etc.
- The calculation of defect rates or error rates is based on the assumption of normality. The calculation of defect rates for non-normal situations is not yet properly addressed in the current literature of six sigma.
- Due to dynamic market demands, the critical-to-quality characteristics (CTQs) of today would not necessarily be meaningful tomorrow. All CTQs should be critically examined at all times and refined as necessary (Goh, 2002).
- Very little research has been done on the optimisation of multiple CTQs in six sigma projects.
- Assumption of 1.5 sigma shift for all service processes does not make much sense. This particular issue should be the major thrust for future research, as a small shift in sigma could lead to erroneous defect calculations.
- Non-standardisation procedures in the certification process of black belts and green belts are another limitation. This means not all black belts or green belts are equally capable. Research has shown that the skills and expertise developed by black belts are inconsistent across companies and are dependent to a great extent on the certifying body. For more information on this aspect, readers are advised to refer to Hoerl (2001). Black belts believe they know all the practical aspects of advanced quality improvement methods such as design of experiments, robust design, response surface methodology, statistical process control and reliability, when in fact they have barely scratched the surface.
- Six sigma can easily digress into a bureaucratic exercise if the focus is on such things as the number of trained black belts and green belts, number of projects completed, etc. instead of bottom-line savings.
- There is an overselling of six sigma by too many consulting firms. Many of them claim expertise in six sigma when they barely understand the tools and techniques and the six sigma roadmap. The relationship between cost of poor quality (COPQ) and process sigma quality level requires more justification.
- The linkage between six sigma and organisational culture and learning is not addressed properly in the existing literature.

CONCLUSION

The term “sigma” is used to designate the distribution or the spread about the mean of any process. Sigma measures the capability of the process to perform defect-free work. A defect is anything that results in customer dissatisfaction. For a business process, the sigma value is a metric that indicates how well that process is performing. Higher sigma level indicates less likelihood of producing defects and hence better performance.

Six sigma is a performance standard to achieve operational excellence. With six sigma, the common measurement index is “defects-per-unit” where a unit can be virtually anything-a component, piece of material, administrative form etc. Conceptually, six sigma is defined as achieving a defect level of 3.4 ppm or better. Operationally, six sigma is defined a staying within half the expected range around the target. The approach aims at continuous improvement in all the process within the organisation. This works on the belief that quality is free, in that the more we work towards zero-defect production, the more return on investment we will have. The advantages of six sigma approaches are reduction in defects/rejections, cycle time, work in progress etc. and increase in product Quality &Reliability, customer satisfaction, productivity etc. leading ultimately to excellent business results.

The purpose of this paper has been to review the effect of six sigma as a tool to improve quality and profitability. Six Sigma is generally described as a metric, a mindset & a methodology for strategic management and process improvement. Six Sigma provides an effective mechanism to focus on customer requirements, through improvement of process quality. The Six Sigma Approach is customer-driven. For a business the Sigma Capability is a metric that indicates how well the process is being performed. The Six Sigma Approach is also data-driven. It focuses on reducing process variation, centering the process and on optimizing the process. Various approaches to six sigma have been applied to increase the overall performance of different business sectors. Effective six sigma principles and practices are more likely to succeed by refining the organizational culture continuously.

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