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New Product Development Cycle Time Reduction of Industrial Chains Using Six Sigma Methodology

A Project Report

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This is to certify that Mr. G RAJKUMAR (R.No.02ME41), Final Year B.E. Mechanical Engineering student of Kumaraguru College of Technology, Coimbatore undertook a project work titled "NEW PRODUCT DEVELOPMENT CYCLE TIME REDUCTION OF INDUSTRIAL CHAINS USING SIX SIGMA METHODOLOGY" in our Organization from 05.01.2006 to 05.04.2006.

During this period his Character and conduct were good.

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ABSTRACT

Customer satisfaction is the key for the success of each and every business. All the innovations and changes done in the product are to satisfy the customer. M/s L.G.B. is one of the leading chains manufacturing company which manufactures chains almost to all industrial applications. It includes Steel mills, Cement industries, Oil refineries, etc.

One of the important factors, which are required to meet the competition, is to meet the due date of delivery of chains. The company has started a new type of chain for one of its client. In this project work, an attempt has been made to reduce the cycle reduction of the new chain using six-sigma approach with the experiences that the company has gained over a period of time in manufacturing the other chains. The concept of DMAIC is employed for reducing the cycle time reduction of chains.

The SIPOC analysis and CTQ tree technique have been employed to define the problems that are affecting the due date delivery. The product development flow chart, lead-time calculations and stratification of data are employed to measure the factors that are affecting the delivery time of the new chain. Flow charts, cause and effect diagrams, FMEA and Pareto charts are used to analyze the problem and to prioritize the factors that are to be focused immediately for reducing the cycle time. The solutions are identified and implemented to reduce the cycle time to 75 days. The sigma level has improved from 0.22 to 1.92 (expected). Finally control methods are implemented in preventing the occurrence of the causes in future.

During this process, various statistical tools have been applied at the relevant places for arriving at decisions. The improvement activities are suggested to the company for implementation. The detailed work is presented in this report.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

σ	Population Standard Deviation
μ	Population Mean
σ^2	Population Variance
$\overline{Y}$	Sample Mean
S	Sample Standard Deviation
V	Sample Variance
C_p	Potential Process Capability Index
C_{pk}	Process Capability Index
$\overline{R}$	Range Mean

ABBREVIATIOS

CTQ	Critical To Quality
CTQ_y	Critical Effects
CTQ_x	Critical Causes
QFD	Quality Function Deployment
PPM	Parts Per Million
DPMO	Defects Per Million Opportunities
LSL	Lower Specification Limit
USL	Upper Specification Limit
CPU	Upper Capability Index
CPL	Lower Capability Index
DFSS	Design for Six Sigma

CHAPTER 1

INTRODUCTION

1.1 EVOLUTION OF QUALITY

During the middle ages in Europe, the skilled craftsperson served as both manufacturer and inspector. "Manufacturers" who dealt directly with the customer took considerable pride in workmanship. Quality assurance was informal; every effort was made to insure that quality was built into the final product by the people who produced it. During the middle of 18^{th} century, a French gunsmith, Honore Le Blanc, developed a system for manufacturing his product in a standard pattern using interchangeable parts. Thomas Jefferson brought the idea to the America. The use of interchangeable necessitated careful control of quality. Whereas a customized product built by a craftsperson can be tweaked and hammered to fit and work correctly, random matching of mating parts provides no such assurance. Whitney designed special machine tools and trained unskilled workers to make parts following a fixed design, which were then measured and compared to a model. Whitney needed more than 10 years to complete the project. Nonetheless, the value of concept of interchangeable parts was recognized, and it eventually leads to industrial revolution, making a quality assurance a critical component of production process.

1.1.1 Early Twentieth Century

In the early 1900s the work of Frederick.W.Taylor, often called the "father of scientific management", lead to the new philosophy of production. Taylor's philosophy was to separate the planning function from the execution function. Managers and engineers were given the task of planning, supervisors and workers took on the task of execution. By segmenting a job into specific work task and focusing on increasing efficiency, quality assurance fell into the hand of inspector. Manufacturers were able to ship good quality products, but at great cost. Defects were present, but were removed by inspection.

Eventually, production organizations created quality departments. This artificial separation of production workers from responsibility for quality assurance lead to indifference to quality amount both the workers and managers. Concluding that quality was the responsibility of quality department, many upper managers turned their attention to output quantity and efficiency. One of the leaders of second industrial revolution, Henry Ford, Sr, developed many of the fundamentals of what we now called "total quality practice" in the early 1900s. The Bell system was the leader in the early modern history of industrial quality assurance. It was created an inspection department in its western electric company in the early 1900s to support the bell operating companies. The early pioneers of quality assurance – Walter Shewhart, Harold dodge, George Edwards, and others, including W. Edwards Deming- were members of this group. The western electric group, lead by walter shedward, ushered in era of statistical quality control (SQC), the application of statistical method for controlling quality. SQC goes beyond inspection to focus on identifying and eliminating the problems that cause defects. During World war II the United States military began using statistical sampling procedures and imposing standards on suppliers.

1.1.2 Post World War II

After World War II, during the late 1940s and early 1950s, the shortage of civilian goods in the United States made production a top priority. During this time, two US consultants, Dr.Joseph Juran and Dr.W.Edward Deming, introduced statistical quality control techniques to the Japanese to aid them in their rebuilding efforts. With the support of top managers, the Japanese integrated quality throughout their organizations and developed a culture of continuous improvement. It is referred by the Japanese term Kaizen. No understanding of quality movement would be complete without mentioning the visionary W. Edwards Deming, best known for helping the Japanese Industries after the World War II. His approach was radically new and had significant impact on evolution of quality.

1.1.3 Quality Revolution

During 1950s and 1960s the US consumers bought the goods that were made in Japan without the question of quality. During 1970s higher quality foreign products entered the market which led the US consumers to take their decisions carefully. They began to notice the difference between the quality of US products and Japanese products. Particularly after the space shuttle disaster in 1986 they concentrated more towards the quality. Consumers began to value a product based on quality price and serviceability. Magazines and newspaper reviews made this task easier. One of the most influential individuals in the quality revolution was W. Edward Deming. From 1980 to 1993 Deming with his leadership and expertise helped many US companies to revolutionize their approach to quality.

In India, the quest for quality started even before the era of Thiruvalluvar who wrote the famous "Thirrukkural". Indian Statistical Institute was one among the organizations which had propagated the need for quality among the industries. Now-a-days the organizations like Confederation of Indian Industry, other non-profit organizations (Ex. Quality Circle Forum of India) etc., have taken lead to instill the interest among companies to produce quality products.

1.2 DEFINING QUALITY

Quality can be a confusing concept, partly because people view quality in relation to differing criteria based on their individual roles in a production marketing value chain. In addition, the meaning of quality continues to evolve as a quality profession grow and mature. Neither consultants nor business professionals agree on universal definitions. A study that asked managers of 86 firms in eastern United States to define quality produced several dozens of different response, including the following. Quality is

- Perfection
- Consistency
- Eliminating waste
- Speed of delivery
- Compliments with policies and procedures
- Providing a good, usable products
- Doing it right at the first time
- Delighting customers
- Total Customer service and satisfaction.

Thus, it is important to understand the various perspectives from quality is viewed in order to fully appreciate the role it plays in many parts of business organization.

1.2.1 Judgmental Perspective

One common notation of quality often used by customer, that it is a synonyms with superiority. In 1931 Walter Shewhart first defined quality as the goodness of a product. This view is referred to as the transcendent. In this sense, quality is "absolute and universal recognizable, a mark of uncompromising standards and high achievements. Excellence is abstract and subjective, however, and standards of excellence may vary considerably among the individuals. Hence, the transcendent definition is of little practical value to managers. It does not provide a mean by which quality can be measured as a basis for decision making.

1.2.2 Product Based Perspective.

Another definition of quality is that it is a function of specific, measurable variable and that difference in quality reflects difference in quality of some product attributes, such as in number of stitches per inch on a shirt or in number of cylinders in an engine. This assessment implies that higher level or amount of product characteristics are equivalent to higher quality. As a result, quality is often mistakenly assumed to be related to price; the higher the price, the higher the quality.

1.2.3 User Based Perspective

A third definition of quality is based on preassumption that quality is determined by what the customer wants. Individuals have different wants and needs, hence, different quality standards, which leads to a user based definition. Quality is defined as fitness for indented use or how well the product performs its indented function. Both Cadillac Sedan and a jeep Cherokee are fit for use, for example, but they serve different needs and groups of customers. If you want high touring vehicle with luxury amentis, then a cadalic may better satisfy your needs. If you want a vehicle for camping, fishing, a jeep might be viewed as a having a better quality.

1.2.4 Value Based Perspective

A fourth approach to define quality is based on a value. That is the relationship of usefulness to price. From this perspective, a quality product is one that is as useful as competing product and is sold at a lower price. Thus, one might purchase a generic product, rather than a brand name one, if it performs as well as the brand name product at a lower price.

1.2.5 Manufacturing Based Perspective

A fifth view of quality is manufacturing based and defined quality as a desirable outcome of engineering and manufacturing practice, or conformance to specification. Specifications are targets and tolerance determined by designer of products and service. Targets are the individual value for which production is to strive, tolerance are specified because designers recognize that it is impossible to meet target all of the time in manufacturing.

1.2.6 Integrating Perspectives on Quality.

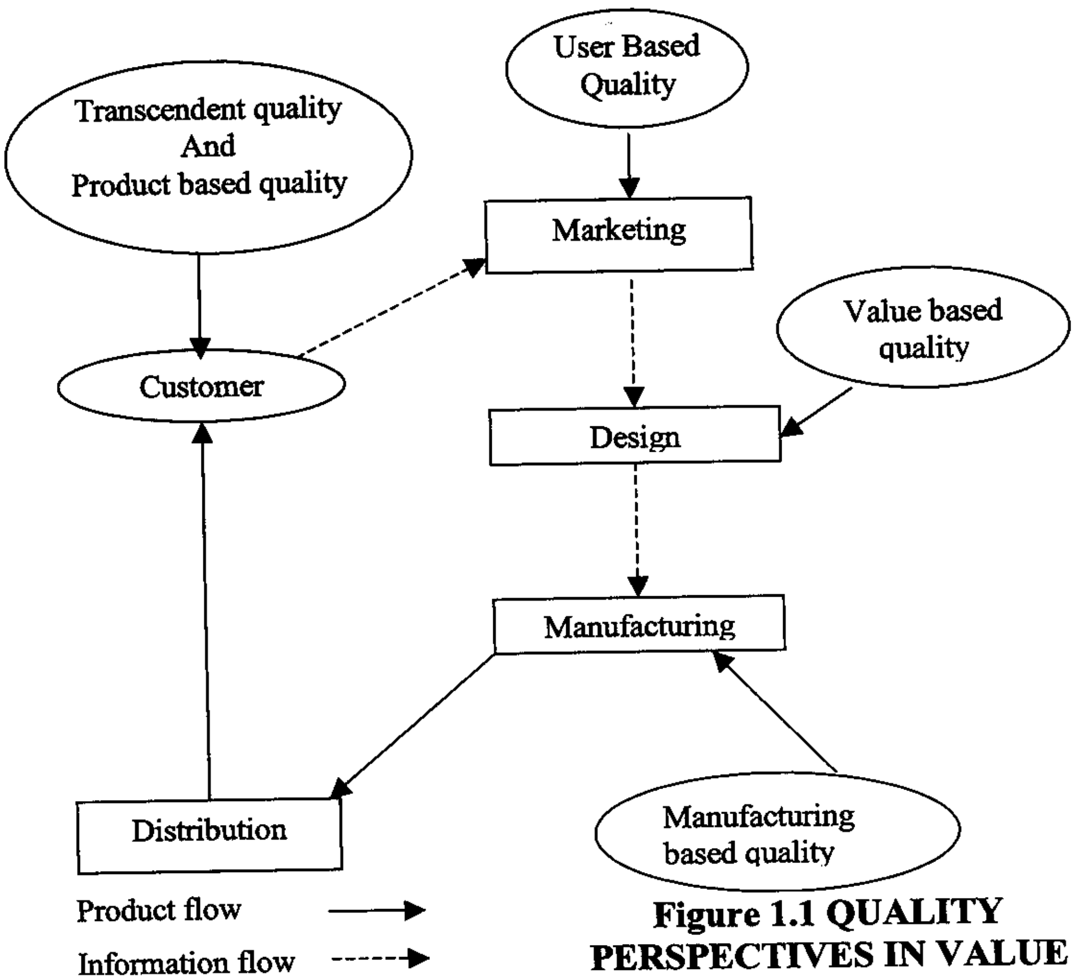


Figure 1.1 QUALITY PERSPECTIVES IN VALUE CHAIN

Although product quality should be important to all individuals throughout the value chain, how quality is viewed may dependent on one's position in the value chain, i.e. whether one is the designer, manufacturer or service provider, distributor, or customer. To understand this concept more clearly from a manufacturing perspective examine Figure 1.1.

1.3 TOTAL QUALITY MANAGEMENT

Total Quality (TQ) is a people focused management system that aims at continual increase in customer satisfaction at continually lower real cost. TQ is a total system approach and an integral part of high level strategy. It works horizontally across functions and departments, involves all employees, top to bottom, and extends backward and forward to include the supply chain and the customer chain.

Actually, the concept of TQM has been around for sometime. A. V. Feigenbaun recognized the importance of comprehensive approach to quality in 1950s and coined the term Total Quality Control. Feigenbaun observed that the quality of product and service is directly influenced by what he terms the 9Ms, Markets, Money, Management, Men and women, Motivation, Materials, Machine, Mechanism, Modern information methods, and Mounting product requirements. The Japanese adopted Feigenbaun and renamed it company wide quality control. Wayne S. Reiker listed five aspects of total quality control practiced in Japan.

- ❖ Quality emphasis extends through market analysis, design, and customer service rather than only production stages of making a product.
- ❖ Quality emphasis is directed towards operation in every department from executive to clerical personnel.
- ❖ Quality is the responsibility of the individuals and the work group, not some other group, such as inspection.
- ❖ The two types of quality characteristics as viewed by customers are those that satisfy and those that motivate. Only the later are strongly related to repeat sales and "quality" image.
- ❖ The first customer for a part of information is usually the next department in the production process.

The term total quality management was developed by the Naval air system commands to describe its Japanese style approach to quality improvement and became popular with business in the United States during 1980s.

1.3.1 Principles of Total Quality

Total quality is based on three fundamental principles.

- ❖ The focus on customers and stake holders
- ❖ Participation and team work by everyone in the organization
- ❖ A process focus supported by continuous improvement and learning

1.3.1.1 Customer and Stake holder Focus

The customer is the principle judge of quality perception of values and satisfaction are influenced by many factors throughout the customers overall purchase, ownership and service experiences. To accomplish this task, the companies efforts need to extend well beyond merely meeting specifications, reducing defects and errors, or resolving complaints. They must include both designing new products that truly delight the customers and responding rapidly to changing the customers and market demands. A company close to its customer nose what the customer wants, how the customer uses its products, and anticipates needs that customer may not even be able to express. It also continually develops new way of enhancing customer relationships. Customer focus extends beyond the customer and internal customer relationship, however. Employees and society represent important stake holders. An organization success depends on the knowledge, skills, creativity and motivation of its employees and partners. Therefore, a total quality organization must demonstrate commitment to employees, provides opportunity for development and growth, provide recognition beyond normal compensation system, share knowledge, and encourage risk taking. Viewing society as the stake holder is an attribute of world class organization. Business ethics, public health and safety, the environment, and community and professional support are necessary activities that fall under social responsibilities.

1.3.1.2 Participation and Team Work

Jospeh Juran credited Japenese managers full use of the knowledge and creativity of entire work force as one of the reasons for Japan's rapid quality achievement. When managers give employees the tools to make good decisions and freedom encouragement to make contributions, the virtually guarantee that better quality products and production process will result. Employees who are allowed to participate both individually and in teams in decision that affects their jobs and the customer can make substantial contribution to quality. This attitude represents a profound shift in the typical philosophy of senior management, the traditional view was that the work force should be "managed" or to put less formally, the workforce should leave their brain at the door. Good intentions alone are not enough to encourage employment involvement. Management's task includes formulating the system and procedures and then putting them in place to ensure that participation becomes a part of the culture.

Another important element of total quality is team work, which focus attention on customer supplier relationship and encourages the involvement of the total work force in attacking systematic problems, particularly those that cross functional boundaries.

1.3.1.3 Process Focus in Continuous Improvement

A process is a sequence of activity that is intended to achieve some result. According to AT & T, a process is how work creates value for the customer, we typically think of process in the context of production. The collection of activities and operations in transforming inputs into outputs. The common type of production process includes machining, mixing, assembling filling orders. However nearly every major activity within an organization involves a process that crosses traditional organizational boundary. For example an order fulfillment process might involve a sales person placing the order, a marketing representative entering it on the company computer system, a credit cheque by finance, picking, packing and shipping by distribution and logistics personnel, invoicing by finance, and installation by field service engineers.

Continuous improvement refers to both incremental changes, which are small and gradual, and break through, and large and rapid, improvement. These improvements may take any one of the several forms.

- ❖ Enhancing the value to the customer through new and improved products and services.
- ❖ Reducing error, defects, wastes and their related costs
- ❖ Increasing productive and effectiveness in the use of all resources
- ❖ Improving responsiveness and cycle time performance for such process as resolving customers complaints or new product introduction.

Thus, response time, quality and productive objectives should be considered together. A process focus supports continuous improvements efforts by helping to understand these synergies and to recognize the true source of problem.

1.4 QUALITY GURUS AND THEIR VIEWS

1.4.1 Deming Philosophy

Deming philosophy focuses on continual improvements in product and service quality by reducing uncertainty and variability in design, manufacturing, and service processes, driven by the leadership of Top Management. The Deming "Chain Reaction" theory is that improvement in quality lead to lower cost because they result it less rework, fewer mistakes, fewer delay and snags, and better use of time and material. The Deming chain reaction theory is summarized in Figure 1.2.

Deming philosophy underwent many changes as he himself continued to learn. In his early work in the United States, he preached his 14 points. Near the end of his life, however, he synthesized the underlying foundation of the 14 points in what he called "A System of Profound Knowledge". The Deming profound knowledge system consists of four interrelated parts.

- ❖ Appreciation for a system
- ❖ Understanding of variation
- ❖ Theory of knowledge
- ❖ Psychology

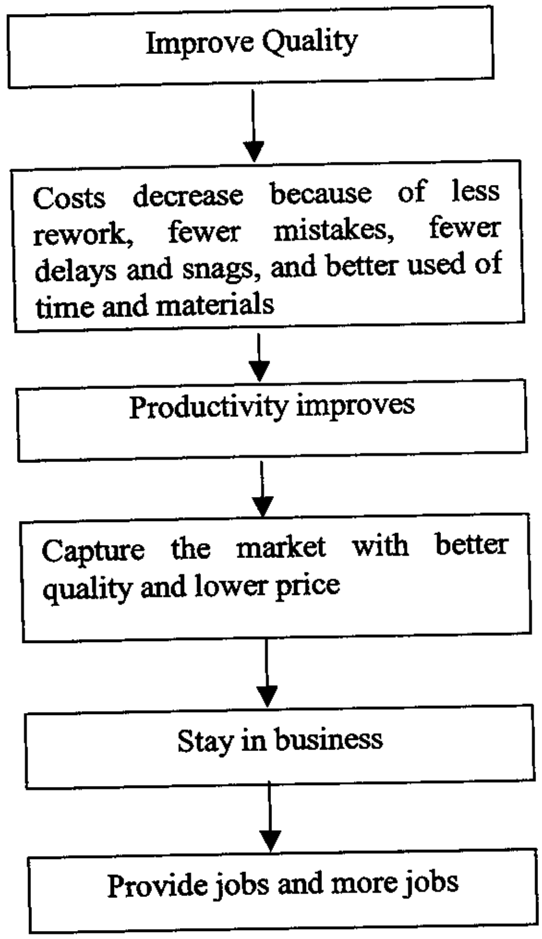


Figure 1.2 DEMING CHAIN REACTION

Deming's fourteen points

- Create a vision and demonstrate commitment
- Learn the new philosophy
- Understand inspection
- Stop making decision purely on the basis of cost
- Improve constantly and forever
- Institute training
- Institute Leadership
- Drive out fear
- Optimize the effort of teams
- Eliminate exhortation
- Eliminate numerical quotas and management by objective
- Remove barriers to pride in workmanship
- Encourage education and self improvement
- Take action

1.4.1 Juran's Philosophy

Juran proposed a simple definition of quality "Fitness for use". He spent much of his time in writing, editing and publishing of quality control hand book. This book, one of the most comprehensive quality manuals ever written, has been revised several times and continuous to be a popular reference. Like Deming, Juran taught quality principle to the Japanese in the 1950s and was principle force in their quality reorganization. Juran also echoed deming's conclusion that US business face a major crisis in quality due to the huge cost of poor quality and the loss of sales to foreign competition. Both Men felt that the solution to this crisis depends on new thinking about quality that includes all levels of the managerial hierarchy.

Unlike Deming, however, Juran did not propose a cultural change in the organization, but rather sought to improve quality by working within the system familiar to managers. Thus, his program was designed to fit into a company's current strategy business planning with minimal risk of rejection. He argued that employees at different level of an organization should be in their own languages. Juran stated that top management speaks in language of dollars, workers speak in language of things, and middle management must be able to speak both languages and translate between dollars and things. Thus, to get the top management attention, quality issue must be cast in the language they understand – dollars. Hence, Juran advocated the use of quality coast accounting and anlalysis to focus attention on quality problem. At the operational level, Juran focused on increasing conformance to specification throughout elimination of defects, supported extensively by statistical tools for analysis. Thus, his philosophy fit well into the existing management system. Juran's definition of quality suggest that it should be viewed from both external and internal perspectives, i.e. qualities related to

- Product performance that results in customer satisfaction
- Freedom from product deficiencies, which avoids customer dissatisfaction

Juran prescription focus on three major quality processes, called the Quality Triology.

- Quality planning – the process of preparing to meet quality goals

- Quality control - the process of meeting quality goals during operation
- Quality improvement – the process of breaking through to unprecedented level of performance.

1.4.2 The Crosby Philosophy

Philip. B. Crosby was corporate vice president for quality at international telephone and telegraph for fourteen years after working his way up from line inspector. He also authored several popular books. His first book, Quality is free, sold about 1 million copies and was largely responsible for bringing quality to the attention of top corporate managers in the United States. The essence of Crosby quality philosophy is embodied in what he called the "Absolutes of quality management" and the "Basic elements of Improvement". Crosby's Absolute of quality management includes the following points

- Quality means of conformance to requirements, not elegance
- There is no such things as quality problems
- There is no such things as the economics of quality
- The only performance measurement is the cost of quality
- The only performance standard is "Zero Defects"

Crosby Basic elements of improvement were determination, education and implementation. Determination means the top management must take quality improvement seriously. Everyone should understand the absolutes, which can be accomplished only through education. Finally every member of management team must understand the implementation process. Unlike Juran and Deming, Crosby approach primarily behavioral. He emphasized using management and organizational processes rather statistical techniques to change corporate culture and attitudes. Like Juran and Unlike Deming however, his approach fitwell within existing organizational structure.

!.4.4 A. V. Feigenabaun Philosophy

Feigenabaun is best known for coining the phrase Total Quality Control which he defined as "An effective system for integrating the quality development, quality maintenance and quality improvement effort of the various group in an organization. So as to enable the production and service at the most economical levels this allows full customer satisfaction. Feigenabaun is summarized in his three steps to quality

- ❖ Quality leadership
- ❖ Modern quality technology
- ❖ Organizational Commitment

1.4.5 Kaoru Ishikawua Philosophy

Ishikawua built on Feigenbaun concept on total quality and promoted greater involvement by all employees, from the top management to frontline staff, by reducing reliance on quality professionals and quality departments. He advocated collecting and analyzing factual data using simple visual tool, statistical techniques and team work as the foundation for implementing total quality. Some key elements of his philosophy are summarized here

- ❖ Quality begin with education and end with education
- ❖ The first step in quality is to know the requirement of customers
- ❖ The ideal state of quality control occurs when inspection is no longer necessary
- ❖ Remove the root causes, not the symptoms
- ❖ Quality control is the responsibility of all workers and all divisions
- ❖ Do not confuse the means with the objectives
- ❖ Put quality first and set your sight on long term profits
- ❖ Marketing is the ntrance and exit of quality
- ❖ Top management must not show anger when facts are presented by the subordinates
- ❖ 95% of problem in the company can be solved with simple tools for analysis and problem solving
- ❖ Data without dispersion information or false data

1.4.6 Genichi Taguchi

A Japenese Engineer, Genichi Taguchi – whose philosophy was strongly advocated by deming – explained the economic value of reducing variations. Taguchi maintained that the manufacturing based definition of quality as conformance to specification limit is inherently flawed. For example, suppose that the specification for some quality characteristic is 0.500 +_ 0.020. Using this definition, the actual value of the quality characteristic can fall anywhere in a range from 0.480 to 0.520. This approach assumes that the customer, either the consumer or the next department in the production process, would accept any value within the 0.480 to 0.520 range. But not be satisfied with a value outside the tolerance range. Also, this approach assumes that cost do not depends on the actual value of quality characteristic as long as it falls with in the tolerance specified. Taguchi's approach assumes that the smaller the variation about the nominal specification, the better is the quality. In turn, products are more consistent, and the total costs are less.

1.5 PROJECT OBJECTIVE

The main customers for industrial chains are Steel mills, Cement industries, food and Electronic industries. These industries have developed new technologies and production methods for improving the processes in order to get more profits. These processes required high performance chains for rapid process and process accuracy. L.G.B has developed this high performance chains through technological up gradation. They cater to the needs to these important industries by manufacturing chains to their requirement. Although they developed chains with high accuracy, they were not able to achieve customer satisfaction. This is because of the delay in development and delivery of the chains. Because of the delay they were not able to satisfy the customers and also not able to concentrate on manufacturing new products. Growth of market share and new business volumes are affected by these delays. Hence it is decided to improve the new product deliveries by reducing development cycle time. This is done with the help of the six sigma methodology which proves to be effective and more fruitful when compared with other quality methods.

CHAPTER 2

SIX SIGMA AT A GLANCE

2.1 DEFINING SIX SIGMA

Sigma is a term used in statistics to represent standard deviation, an indicator of degree of variation in a set of measurement or a process. The sigma scale of measure is perfectly correlated to such characteristics as defects-per-unit, parts-per-million defectives, and the probability of a failure. Six Sigma is a statistical concept that measures a process in terms of defects. At the Six Sigma level, there are only 3.4 defects per million opportunities. Six Sigma is also a philosophy of managing that focuses on eliminating defects through practices that emphasize understanding, measuring and improving process. Also Six Sigma is a symbol of quality.

Harry (1998) defines Six Sigma to be "a strategic initiative to boost profitability, increase market share and improve customer satisfaction through statistical tools that can lead to breakthrough quantum gains in quality."

2.1.1 Six Sigma Companies

The following Figure 2.1 shows a note of the companies which adopted Six Sigma.

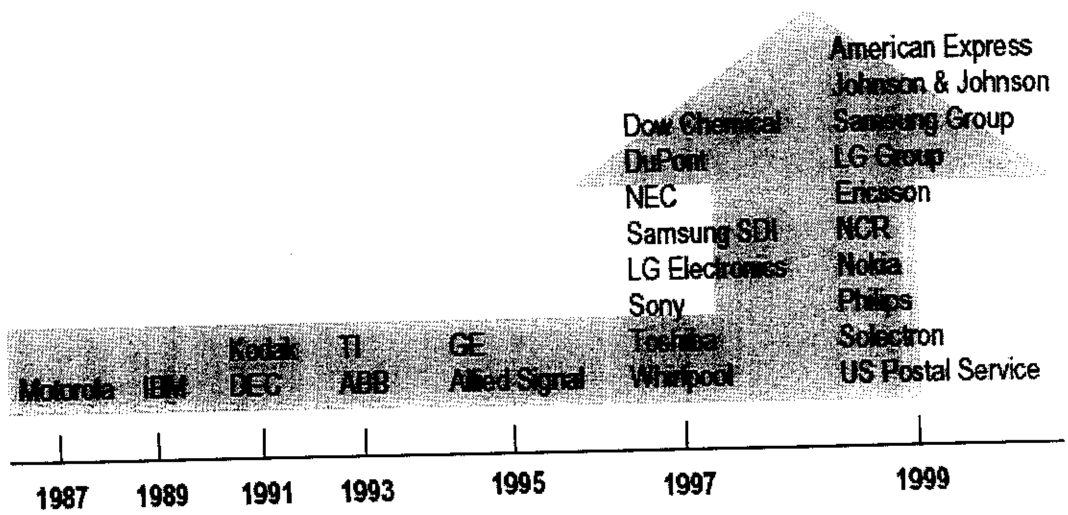


Figure 2.1 GLOBALLY WELL KNOWN SIX SIGMA COMPANIES

2.1.2 Key Concepts of Six Sigma

Six Sigma is based on a few key concepts

- Defect

A measurable characteristic of the process or its output that is not within the acceptable customer limits, i.e. not conforming to specifications. The sigma level is calculated in terms of the number of defects in ratio to the number of opportunities for defects.

- Variation

Any Quantifiable difference between a specified measurement or standard in the deviation from such measurement or standard in the output of a process. Variation in outputs can result from many causes in the functioning and management of processes.

- Process Capabilities

A statistical measurement of inherent variation for a given event in a stable process. It is usually defined as the process width divided by Six Sigma and quantified using capability index (Cp).

- Critical to Quality

It is a process of identifying the elements which are critical to quality. It is also the elements which are the most important attributes to the customer.

- Design for Six Sigma(DFSS)

Sigma (DFSS) is a rare approach to product development that focuses on delivering the right product at the right time and at right cost.

2.1.3 Actually - Six Sigma

Six Sigma uses statistics and measurements for its application, so most of the people consider it as a statistics program, it is not so. Six Sigma uses statistics tools solely for interpreting and clarifying data. The ultimate goal of implementing Six Sigma is to make companies to be as perfect as possible in their process and obtaining their best performance levels.

To achieve such a quality just statistical data is not enough a cultural change in the organization is required. Six Sigma is a rigorous approach that requires a deep commitment from the highest level of management that permeates the entire organization. Key people in the organization have to be involved in implementing Six Sigma methodology.

2.1.4 Strategy of Six Sigma

A strategy may be defined as a plan or method for obtaining some good or result. Unlike other quality initiatives, Six Sigma has a strategic concept. Aimed at not only developing management's commitment to Six Sigma but their active involvement. One of the problems with previous Quality initiatives is that the work force saw the improvement in quality is just in their improvement in hard work. The change that has to be made in the organization is not considered as a fact. The experts analyzed the reasons for quality failure and found that the reason was the lack of management support.

In Six Sigma the work first begins with management. In any organization the management is responsible for the strategy of how the work is done. As a management strategy, Six Sigma is a plan or method for obtaining the goods or results of the business. Six Sigma unlike other quality initiatives is a management philosophy. There are six essential steps for the strategic improvement in Six Sigma given by George Eckes in his book " The Six Sigma Revolution", they are

- ❖ Creation and agreement of strategic business objectives.
- ❖ Creation of core, key sub and enabling process.
- ❖ Identification of process owner.
- ❖ Creation and validation of measurement "Dash board *".
- ❖ Data collection on agreed dash boards.
- ❖ Creation of project selection criteria.

** Dash Board – A measurement technique or device*

2.2 ESSENCE OF SIX SIGMA

The essence of Six Sigma is the integration of four elements (customer, process, manpower and strategy) to provide management innovation as shown in Figure 2.2

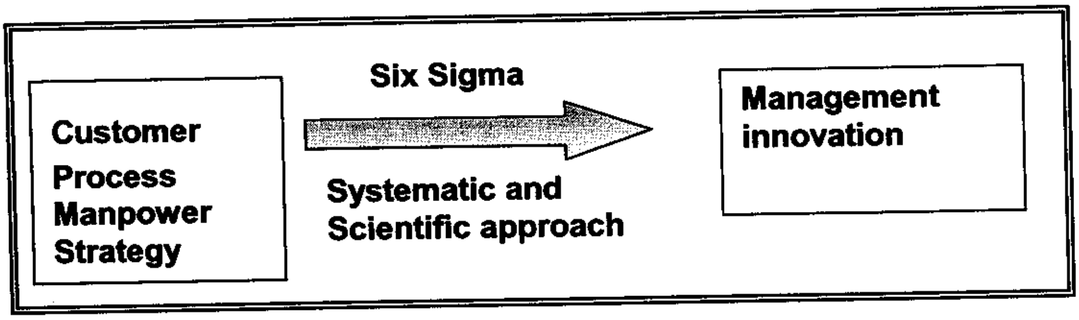


Figure 2.2 ESSENCE OF SIX SIGMA

Six Sigma provides a scientific and statistical basis for quality assessment for all processes through measurement of quality levels. This method allows us to draw comparisons among all processes, and tells how good a process is. Through this information, top-level management learns what path to follow to achieve process innovation and customer satisfaction. Second, Six Sigma provides efficient manpower cultivation and utilization. It employs a "belt system" in which the levels of mastery are classified as green belt, black belt, master black belt and champion. As a person in a company obtains certain training, he acquires a belt. Usually, a black belt is the leader of a project team and several green belts work together for the project team.

Third, there are many success stories of Six Sigma The pace of change during the last decade has been unprecedented, and the speed of change in this new millennium is perhaps faster than ever before. Most notably, the power has shifted from producer to customer. The producer-oriented industrial society is over, and the customer-oriented information society has arrived. (Park S 2003) The customer has all the rights to order, select and buy goods and services. Especially, in e-business, (Pant and Hsu, 1996) the customer has all-mighty power. Competition in quality and productivity has been ever increasing. Second-rate quality goods cannot survive anymore in the market. Six Sigma with its approaches provides flexibility in managing a business unit.

2.3 KEY PLAYERS IN SIX SIGMA

One of the best publicized aspects of the Six Sigma movement is the creation of corps of process measurement and improvement experts. The success of Six Sigma relies on the people who are responsible for implementing it. The key task to start on the Six Sigma way will be to define appropriate roles in the organization and to clarify the responsibilities of the people. Six Sigma provides some powerful techniques and tools, but success depends on the people who play the primary role and assure the central responsibilities for putting those techniques and tools for the organization.

There are basically five key players in a Six Sigma organization, they are

- Executive Leaders
- Champions
- Master Black Belt
- Black Belts
- Green Belts

2.3.1. Executive Leaders

Executive leaders are those people in the top management level. The key role of the executive leaders is to decide to do Six Sigma and to publicly endorse it throughout the organization. There are few essential aspects that help, build, and round out the foundation for successful executive leadership responsibility.

- For starters they must show the determination. They need to be the resolute in the believing that Six Sigma will succeed.
- By actively showing their confidence with rewards and incentives, company leaders inspire sustained commitment and effort from the employees.
- Executives must have a high level of integrity. By following through commitments and staying true to a stated purpose, executives should demonstrate a high standard of ethical leadership.
- The leaders must have a high patience. The Six Sigma process will take time. If it is done in rush it will jeopardize the result.
- They must share the best practices throughout the organization and with key suppliers and customers, where appropriate.
- They must act as "road block removers" when teams identify seeming barrier.

- They must periodically review the progress of various projects, and offering ideas and help.

2.3.2 Champions

A champion is a senior manager who "oversees" an improvement project. The Champions need to report to the top management about the project progress and they need to support their teams. The champion acts as advocate and defender, as mentor and coach. The champion is ultimately responsible for the Six Sigma project. They must be fully engaged in the process allotting at least 20% of their time ensuring black belts are making progression on their projects. It is the job of the champion to identify and remove obstacles so that the black belts can focus on their project. Champions responsibilities include:

- Coaching on and approving changes in direction or scope of a project.
- Finding resources for the project.
- Representing the team to the executive leaders and serving as its advocate.
- Helping to smooth out issues and overlaps that arise between team or with people outside team.
- Applying their gained knowledge of process improvement to their own management tasks.

2.3.3 Master Black Belt

The master black belt acts as the mentor, trainer and guide. The master black belt cannot be given to any person in the beginning of a Six Sigma project. It can be given only, after establishing all necessary elements, designated and trained people in their roles, started projects and garnered some results, a black belt can be upgraded to master black belt. A master black belt must be an expert in Six Sigma tools and tactics with good knowledge resource in technical and historical aspects. They focus 100% of their efforts on process improvement.

A key aspect to the master black belt role is the capability to skillfully facilitate the problem solving without actually taking over a project. A master black belt is a valuable asset for a Six Sigma initiative who collaborates the project team with upper management, coaches black belts and ultimately keeping champions focused on what's important in selecting project and implementing Six Sigma.

2.3.4 Black Belts

The black belt is the back bone of the Six Sigma culture. Black belts work full time on the selected projects. As the team leaders and project heads, black belts are central to Six Sigma success. They are trained to dig into the chronic and high impact issues and fix them with Six Sigma techniques. They relentlessly pursue the project objectives, they strive to understand the cause and effects of defects, and they develop steps to permanently eliminate them. Black belts manage risks, help to set direction and lead the way to quantum gains in product or service quality.

2.3.5 Green Belts

Green belts assist black belts in the functional area. They work on project in part time, usually in a limited and specific area. They apply Six Sigma tools to examine and solve chronic problems on projects within their regular jobs. They are the team members with enough knowledge on Six Sigma to share the tools and to transform company culture from the group ground up. Working in a complimentary fashion with the character of Executive leadership, champions and Black belts, Green belts are the "Working Bees" driving the bottom line results.

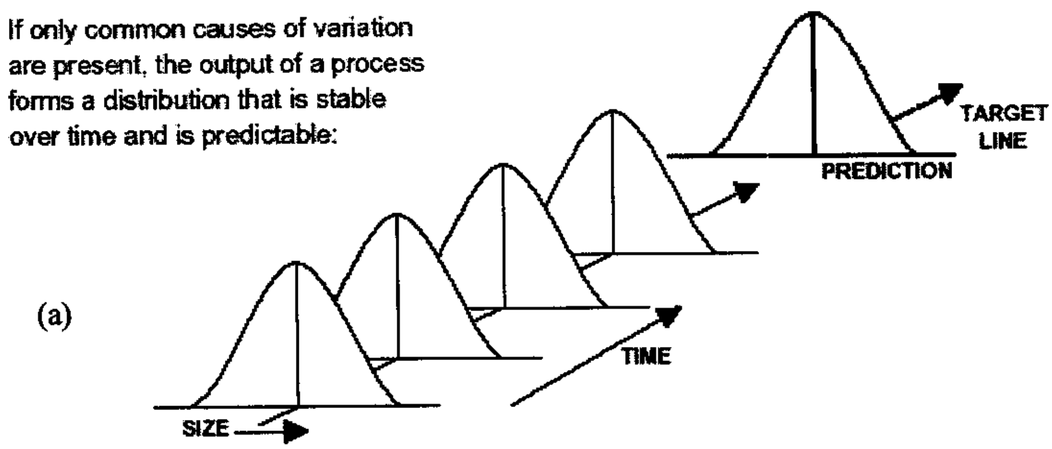
2.4 MEASUREMENT OF PROCESS PERFORMANCE

Among the dimensions of the process performance variation is the preferred measurement for process performance in Six Sigma. Cycle time and yield could have been used, but they can be covered through variation. The distribution of a characteristic in Six Sigma is usually assumed to be Normal (or Gaussian) for continuous variables, and Poissonian for discrete variables. The two parameters that determine a Normal distribution are population mean (μ) and population standard deviation (σ). The mean indicates the location of the distribution on a continuous scale, whereas the standard deviation indicates the dispersion.

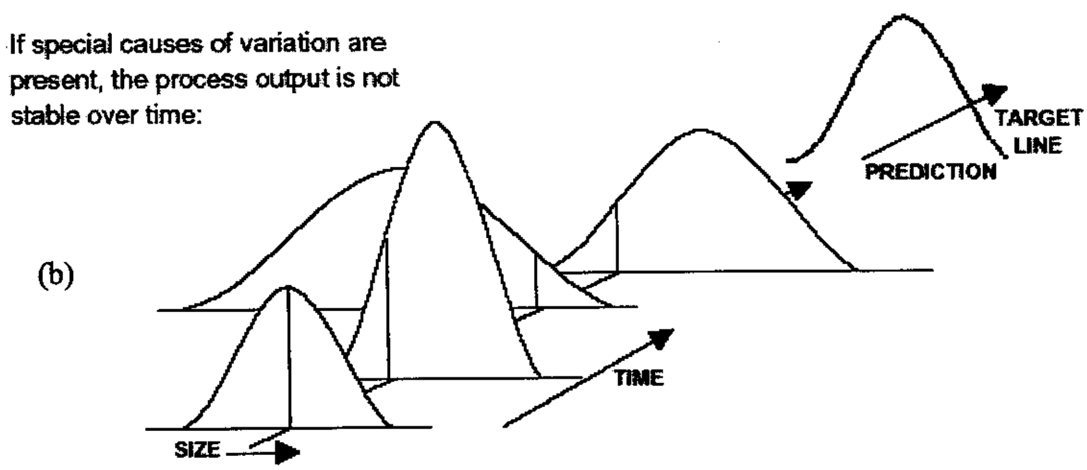
2.4.1 Variation

A company cannot manufacture all the products or do a project often up to the required characteristics. This is because of many factors like machine tool, employee, process, climatic factors and many more. This results in the variation in the specifications of the produced product or process. The cause for variation is commonly divided into two types: common causes and special causes.

Common causes refer to the sources of variation within a process that have a stable and repeatable distribution over time. This is called "in a state of statistical control". The random variation which is inherent in the process, is not easily removable unless we change the very design of the process or product, and is a common cause found everywhere. Common causes behave like a stable system of chance causes. If only common causes of variation are present and do not change, the output of a process is predictable as shown in the Figure 2.3(a).



(a)



(b)

Figure2.3 (a) &(b)VARIATION: COMMON AND SPECIAL CAUSES

Special causes as shown Figure 2.3(b), also called as assignable causes refer to any factors causing variation that are usually not present in the process. That is, when they occur they make change in the process distribution. Unless all the special causes of variation are identified and acted upon, they will continue to affect the process output in unpredictable ways. If special causes are present, the process is not stable over time.

2.4.2 Standard deviation and Normal distribution

The population parameters μ (population mean), σ (population standard deviation) and σ^2 (population variance), are usually unknown, and they are estimated by the sample statistics as follows.

$\bar{y}$ = Sample Mean = Estimate of μ

s = Sample Standard Deviation = Estimate of σ

V = Sample Variance = Estimate of σ^2

If we have a sample of size n and the characteristics are $y_1, y_2 ... y_n$, then μ, σ and σ^2 are estimated by, respectively

$$\bar{y} = \frac{y_1 + y_2 + ... + y_n}{n} \qquad \text{.............................. (2.1)}$$

$$s = \sqrt{V} \qquad \text{.............................. (2.2)}$$

$$V = \frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1} \qquad \text{.............................. (2.3)}$$

However, if we use an $\bar{X}$ &R control charts, in which there are k subgroups of size n, s can be estimated by

$$s = \frac{\bar{R}}{d_2} \qquad \text{.............................. (2.4)}$$

Where $\bar{R}$= R_i /n, and R_i is the range for each subgroup and 'd_2' is a constant value that depends on the sample size 'n'. The values of 'd_2' can be found from standard tables for control limits of various control charts. Many continuous random variables, such as the dimension of a part and the time to fill the order for a customer, follow a normal distribution. Figure 2.4 illustrates the characteristic bell shape of a normal distribution where X is the normal random variable, μ is the population mean and σ is the population standard deviation. The probability density function (PDF), f (x), of a normal distribution is

$$f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left[\frac{x-\mu}{\sigma}\right]^2} \qquad \text{.......................... (2.5)}$$

where we usually denote $X \sim N(\mu, \sigma^2)$

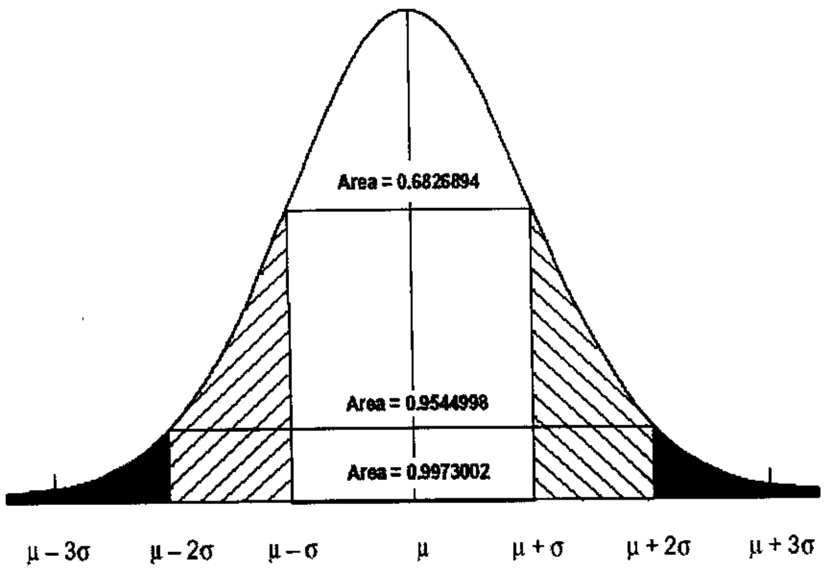


Figure 2.4 NORMAL DISTRIBUTION

When $X \sim N(\mu, \sigma^2)$, it can be converted into standard normal variable $Z \sim N(0,1)$ using the relationship of variable transformation, whose probability density function is

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} \qquad \text{.......................... (2.6)}$$

2.4.3 Defect Rate, ppm And DPMO

The defect rate, denoted by 'p', is the ratio of the number of defective items, which are out of specification to the total number of items processed (or inspected). Defect rate or fraction of defective items has been used in industry for a long time. The number of defective items out of one million inspected items is called the Parts-Per-Million (ppm) defect rate. Sometimes a ppm defect rate cannot be properly used, in particular, in the cases of service work. In this case, a Defects per Million Opportunities (DPMO) is often used. DPMO is the number of defective opportunities, which do not meet the required specification out of one million possible opportunities.

2.4.4 Sigma quality level

Specification limits are the tolerances or performance ranges that customer's demand of the products or processes they are purchasing. The specification limits are shown in Figure 2.5(a) & (b) as the two major vertical lines. The sigma quality level (in short, sigma level) is the distance from the process mean (μ) to the closer specification limit. In practice, we desire that the process mean to be kept at the target value. However, the process mean during one time period is usually different from that of another time period for various reasons. This means that the process mean constantly shifts around the target value. To address typical maximum shifts of the process mean, Motorola added the shift value ±1.5 σ to the process mean.

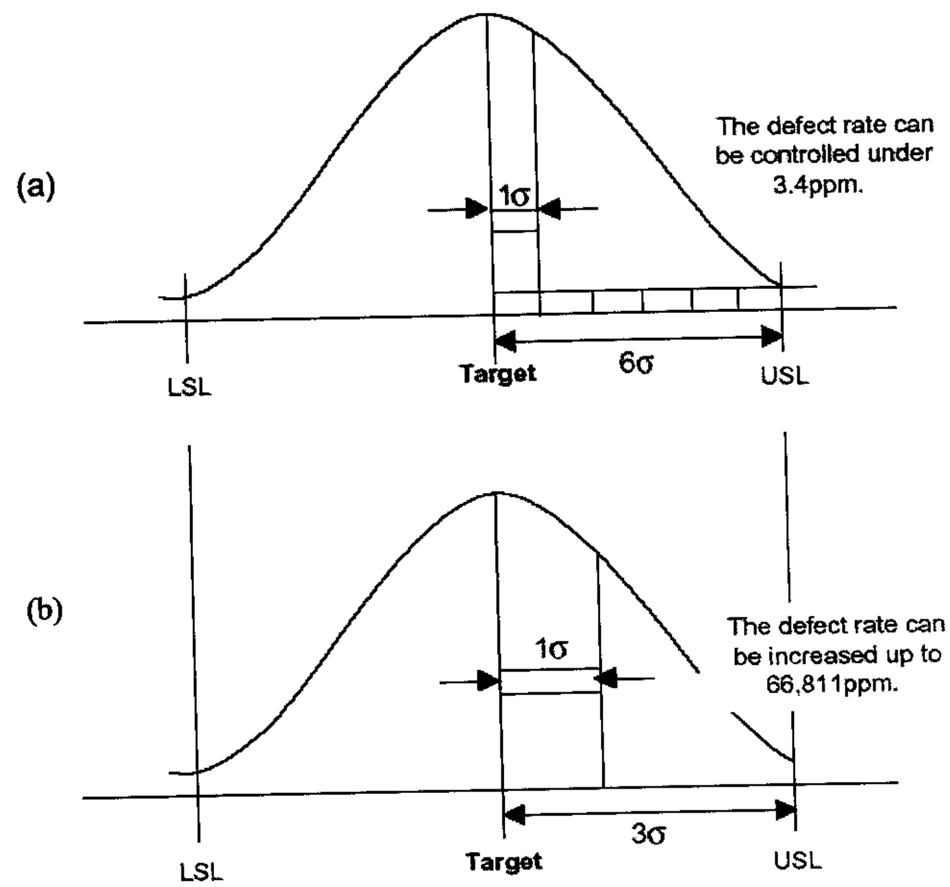


Figure 2.5 (a) & (b) SIGMA QUALITY LEVELS

2.4.5 Process Shift of 1.5 Sigma

Six Sigma actually translates to about 2 defects per billion opportunities, and 3.4 defects per million opportunities, which we normally define as 6 sigma but it really corresponds to a sigma value of 4.5. Where does this 1.5 sigma difference come from? Motorola has determined, through years of process and data collection, that processes vary and drift over time - what they call the Long-Term Dynamic Mean Variation. This variation typically falls between 1.4 and 1.6. The actual process capability of Six Sigma is shown Figure 2.6 (a).

After a process has been improved using the Six Sigma DMAIC methodology, we calculate the process standard deviation and sigma value. These are considered to be short-term values because the data only contains common cause variation. DMAIC projects and the associated collection of process data occur over a period of months, rather than years. Long-term data, on the other hand, contains common cause variation and special (or assignable) cause variation. Because short-term data does not contain this special cause variation, it will typically be of a higher process capability than the long-term data. This difference is the 1.5 sigma shift as shown Figure 2.6 (b). Given adequate process data, the most appropriate factor for the process can be determined.

In the book written by Harry and Schroeder the advantages of 1.5 sigma process shift is explained,

"By offsetting normal distribution by a 1.5 standard deviation on either side, the adjustment takes into account what happens to every process over many cycles of manufacturing. Simply put, accommodating shift and drift is our 'fudge factor,' or a way to allow for unexpected errors or movement over time. Using 1.5 sigma as a standard deviation gives us a strong advantage in improving quality not only in industrial process and designs, but in commercial processes as well. It allows us to design products and services that are relatively impervious, or 'robust,' to natural, unavoidable sources of variation in processes, components, and materials."

This shift of the mean is used when computing a process sigma level as shown in Figure 2.6(a) & (b).

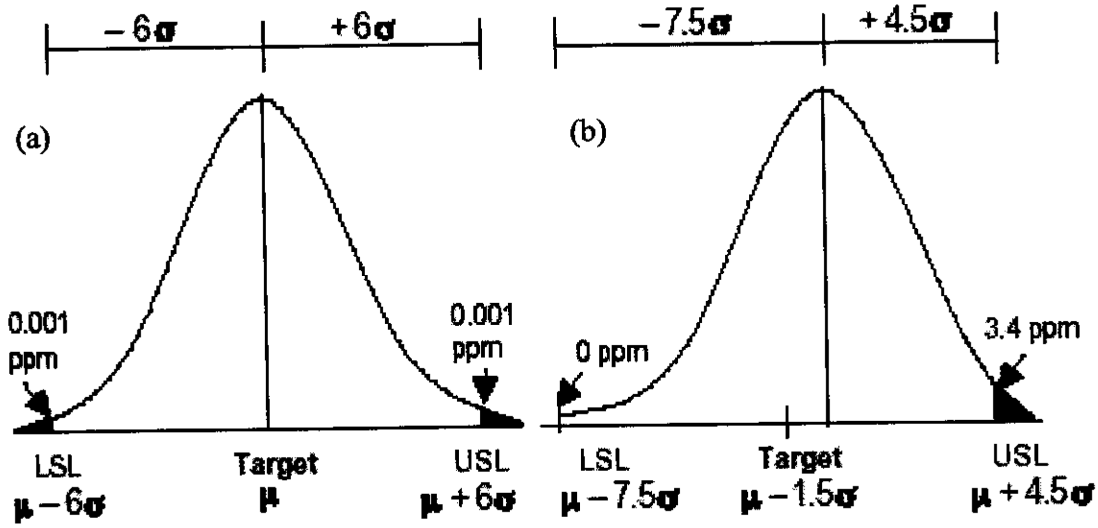


Figure 2.6(a) & (b) EFFECT OF 1.5 SIGMA SHIFT OF PROCESS MEAN WHEN 6 SIGMA QUALITY LEVELS IS ACHIEVED

2.4.6 Six Sigma Quality Levels

Table 2.1 illustrates how sigma quality levels would equate to other defect rates and organizational performances.

Table 2.1 PPM CHANGES WHEN SIGMA QUALITY LEVEL CHANGES

Sigma Quality Level	Process Mean, Fixed		Process Mean, with 1.5 σ shift	
	Non-Defect rate (%)	Defect rate (ppm)	Non-Defect rate (%)	Defect rate (ppm)
1σ	68.26894	317,311	30.2328	697,672
2σ	95.44998	45,500	69.1230	308,770
3σ	99.73002	2,700	93.3189	66,811
4σ	99.99366	63,4	99.3790	6,210
5σ	99.999943	0.57	99.97674	233
6σ	99.9999998	0.002	99.99966	3.4

2.5 CUSTOMER SATISFACTION

Customer satisfaction is one of the watchwords for company survival in this new 21st century. To create satisfied customers, the organization needs to identify customer's needs, design the production and service systems to meet those needs, and measure the results as the basis for improvement. Customer satisfaction can be achieved when all the customer requirements are met. Six Sigma emphasizes that measuring and improving processes and products must fulfill the customer requirements, and Critical-To-Quality (CTQ) characteristics are measured on a consistent basis to produce few defects in the eyes of the customer. Having identified the CTQ requirements by using Quality Function Deployment (QFD), the customer is usually asked to specify what the desired value for the characteristic is, i.e., target value, and what a defect for the characteristic is, i.e., specification limits. This vital information is utilized in Six Sigma as a basis for measuring the performance of processes. The quality cycle based on customer is shown in the Figure 2.7.

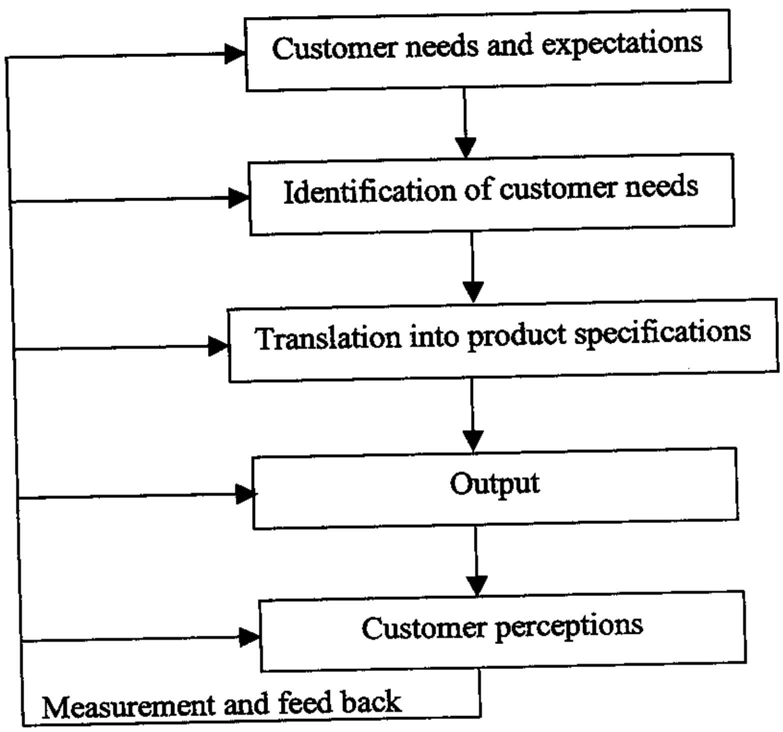


Figure 2.7 CUSTOMER DRIVEN QUALITY CYCLE

2.6 PROJECT SELECTION FOR SIX SIGMA

A useful way of classifying quality and performance – related problems that can help identify potential Six Sigma projects is by problem type. According to Kepner and Tregoe, "a problem is a deviation between what should be happening and what actually is happening that is important enough to make someone think the deviation ought to be corrected". After doing research on more than 1000 cases of quality problems, it is found that all the problems fall in one of the following five categories (given by James Evans and William Lindsay in their book "The management and Control of Quality").

- ❖ Conformance problems, which are defined by unsatisfactory performance by a well specified system.
- ❖ Unstructured performance problems, which result form unsatisfactory performance by a poorly specified system.
- ❖ Efficiency problems, which is a result form unsatisfactory performance from the standpoint of stakeholders other than customers.
- ❖ Product design problems, which involve designing new products that better satisfy the expectations of the customer.
- ❖ Process design problems, which involve designing new processes or substantially revising existing process.

While selecting a problem the factors that are to be considered are, the Probability of success, financial returns, Impact on customers, Impact on employees, Fit to strategy and competitive advantage. Also prioritizing and selecting projects using some rational criteria can contribute greater to the effectiveness of the project. Finally, Six Sigma projects should support the organization's vision and competitive strategy.

The method of solving the problem using six sigma methodology is discussed in chapter 3.

CHAPTER 3

THE SIX SIGMA APPROACH

3.1 PROBLEM SOLVING

Problem solving is the activity associated with changing the state of what is actually happening to what should be happening. The objectives of Six Sigma project focus on breakthrough improvements that add value to the organization and its customers through systematic approaches to problem solving. Successful quality and business performance improvement depends on the ability to identify and solve problems; this ability is fundamental to Six Sigma philosophy. Leaders in the quality revolution like Deming, Juran, and Crosby have proposed specific methodologies for improvement of quality revolution. The following four points are found common between them, they are

- Redefining and analyzing problem
- Generating ideas
- Evaluating and Selecting ideas
- Implementing ideas

These common points reflected in the principal problem solving methodology used by Six Sigma, the DMAIC method.

3.1.1 Defects Per Million Opportunities

The most popular metrics used in assessing Six Sigma projects, in DMAIC is defects per million opportunities (DPMO). This measurement is the average number of defects per unit observed during an average production run divided by the number of opportunities for making a defect on the product. Then the number is normalized to one million. A defect is defined as a failure to conform to requirements. Those requirements are articulated in the specification or tolerance of the products or processes. Tolerances should be determined in product or process development. They should be established in order that the products or processes may be assembled easily, and so that they can perform their required function with minimum adjustment. Properly designed specifications can reduce the DPMO.

3.2 DMAIC Method

The Six Sigma DMAIC problem solving methodology consists of Define, Measure, Analyze, Improve and Control phases. The DMAIC methodology should be used when a product or process is in existence at the company but is not meeting specification or is not performing adequately. The DMAIC process can be explained through flow chart as shown in the Figure 3.1

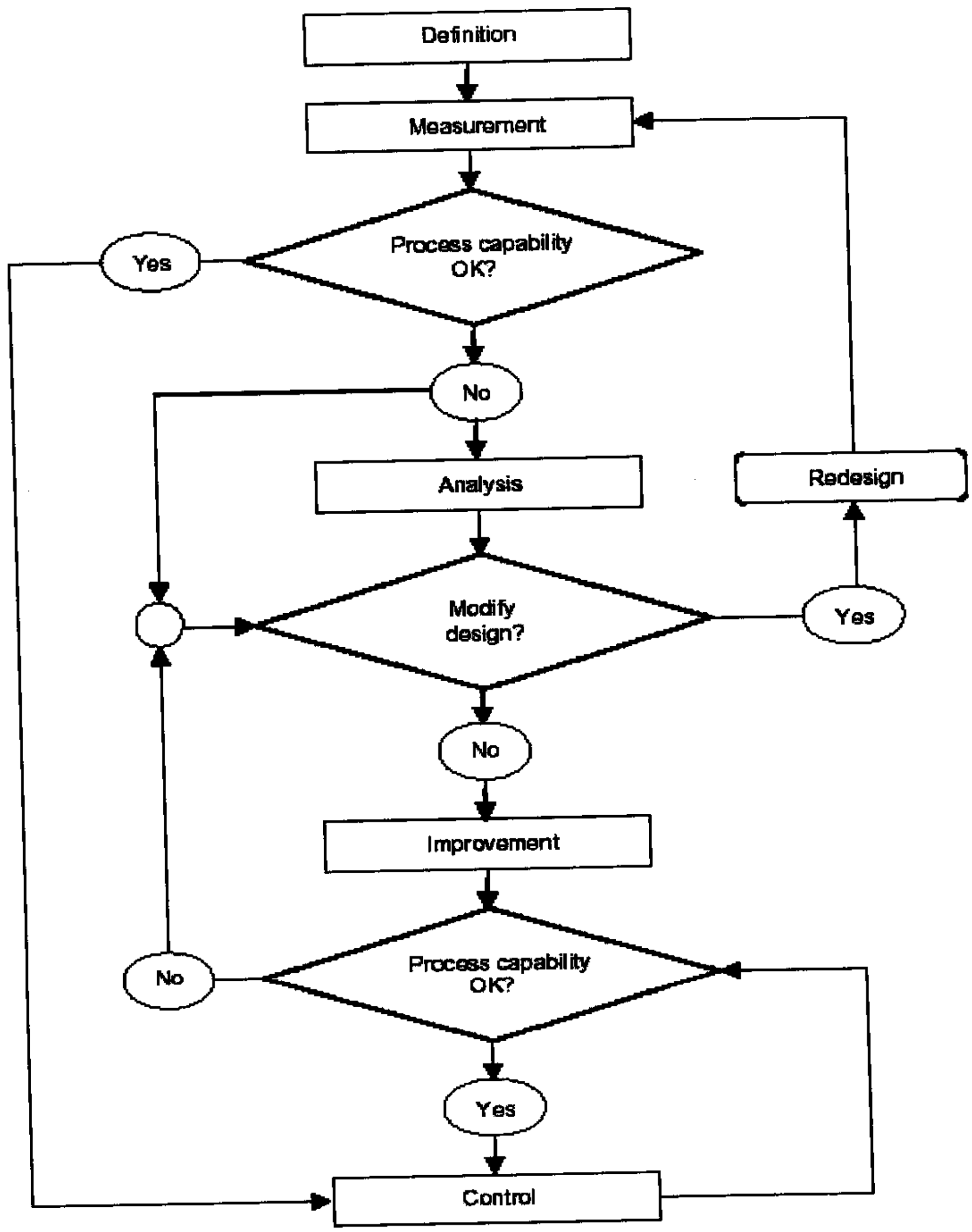


Figure 3.1 DMAIC QUALITY IMPROVEMENT PROCESS

3.2.1 Phase 1: Define

The first step after selecting a Six Sigma project is to clearly define the problem. This action is different form project selection which generally responds to symptoms of problems and usually results in a vague problem statement. The problem must be described in operational terms that facilitate further analysis. The process of drilling down more specific problem statement is sometimes called Project Scoping.

A good problem statement should also identify customers and CTQs that have the most impact on product or service performance, nature of errors or customer complaints, identifying relevant performance metrics, calculating the revenue implications of the project, and quantify the expected level of performance from a successful Six Sigma effort. The Define phase should also address management issues as what is need to be done, by whom and when.

3.2.2 Phase 2: Measure

This phase of DMAIC process focuses on how to measure the data. Data collection should not be performed blindly. Data from existing processes and practices often provide important information. The data will become meaningless unless they are well defined and understood without ambiguity.

Juran's institute suggests 10 important considerations for data collection:

- ❖ Formulate good questions that relate to the specific information needs of the project.
- ❖ Use appropriate data analysis tools and be certain that necessary data are being collected.
- ❖ Define comprehensive data collection points so that job flow suffers minimum interruption.
- ❖ Select an unbiased collector who has the easiest and most immediate access to the relevant facts.
- ❖ Understand the environment and make sure that data collectors have proper experience.
- ❖ Design simple data collection forms.
- ❖ Prepare instructions for collecting data.
- ❖ Test the data collection forms and the instructions and make sure they are filled out properly.

- Train the data collectors as to the purpose of study, what data will be used for, how to fill out the forms, and the importance of being unbiased.
- Audit the data collection process and validate results.

These guidelines can greatly improve the process of uncovering relevant facts necessary to identify and solve problems.

3.2.3. Phase 3: Analyze

A major flaw in many problem solving approaches is a lack of emphasis on rigorous analysis. The analyze phase of DMAIC focuses on why defects, errors, or excessive variation occur, which often result form one or more of the following

- A lack of knowledge about how a process works, which is particularly critical if different people perform the process.
- A lack of knowledge about how the process should work, including understanding customer expectations and the goal of the process.
- A lack of control of materials and equipment used in the process.
- Inadvertent errors in performing
- Failure to understand the capability of a process to meet specifications.
- Lack of training.
- Poor instrument calibration and testing.
- Inadequate environmental characteristics such as light, temperature, and noise.

Finding answers requires identifying the key variables that are most likely to create errors and excessive variation. These variables are called as the Root Causes. The root causes can be defined as "that condition having allowed or caused a defect to occur, which once corrected properly, permanently prevents the recurrence of the defect in the same, or subsequent, product or service generated by the process".

One useful approach for identifying the root cause is the "5 why" technique. This approach forces one to redefine a problem statement as a chain of causes and effects to identify the source of symptoms by asking why, ideally five times. The tools which can be used for identifying root causes are explained under the section 3.3.

3.2.4 Phase 4: Improve

Once the root cause of the problem is understood, the analyst or team needs to generate ideas for removing or resolving the problem and improve the performance measures and CTQs. This idea gathering phase is highly creative. The ideas should not be prejudged before evaluating them. Effective problem solvers must learn to differ judgment and develop the ability to generate a large number of ideas.

A number of tools to facilitate idea generation can be used. Brainstorming (Section 3.3.1), a useful problem-solving procedure for generating ideas was proposed by Alex Osborn. With brainstorming, no criticism is permitted, and people are encouraged to generate a large number of ideas through combination and enhancement of existing ideas. After a set of ideas have been proposed, it is necessary to evaluate them and select the promising. This process includes confirming that the proposed solution will positively impact the key process variables and CTQs.

To implement a solution effectively, responsibility must be assigned to a person or a group who will follow through on what must be done, where it will be done, and how it will be done. Project management techniques are helpful in implementation planning.

3.2.5. Phase 5: Control

The control phase focuses on how to maintain the improvements, which includes putting tools in place to ensure that the key variables remain within the maximum acceptable ranges under the modified process. These improvements might include establishing the new standards and procedures, training the work force, and institute controls to make sure that improvements do not die over time.

3.3 SIX SIGMA TOOLS

The overall Six Sigma methodology is implemented by using a specific set of statistical tools throughout each phase. These tools are the keys to unlocking the information that will yield the answers you need to improve performance. They are focused, specific, and sequential. They address and quantify the narrowest margin of error and the broadest action plan.

In the beginning certain tools called warm-up tools are used. These warm-up tools are the basic statistics, graphical analysis and simple correlation studies. These tools help in understanding and representing the data obtained from a process. The basic statistics consists of finding the mean, median and mode for obtained data. The graphical analysis is done using Histogram (bar chart). Distribution, Variance and Dispersion are the key terms used to do graphical analysis. Correlation is the degree to which two variables are related, measured in terms of a correlation coefficient.

3.3.1 Brainstorming

Brainstorming is a method for generating ideas. Participants focus on a problem or an opportunity and come up with as many ideas as possible and push the ideas as far as possible. During brainstorming, there is no criticism or discussion of any ideas; the point is to generate ideas and expand thinking about the problem or opportunity. As participants mention their ideas, somebody records the ideas on a board or a flip chart. Participants can build on each other's ideas. Then after brainstorming, the team can analyze the results and explore the best ideas. Brainstorming is also a valuable tool for probing during the Analyze phase and for generating ideas during the Improve phase.

3.3.2 Cause and Effect Diagram

The Cause & Effect (CE) diagram, also sometimes called the 'fishbone' diagram, is a tool for discovering all the possible causes for a particular effect. The effect being examined is normally some troublesome aspect of product or service quality, such as 'a machined part not to specification', 'delivery times varying too widely', 'excessive number of bugs in software under development', and so on, but the effect may also relate to internal processes such as 'high rate of team failures'.

The major purpose of the CE Diagram is to act as a first step in problem solving by generating a comprehensive list of possible causes. It can lead to immediate identification of major causes and point to the potential remedial actions or, failing this, it may indicate the best potential areas for further exploration and analysis. At a minimum, preparing a CE Diagram will lead to greater understanding of the problem. An example of Cause and Effect diagram is shown in Figure 3.2

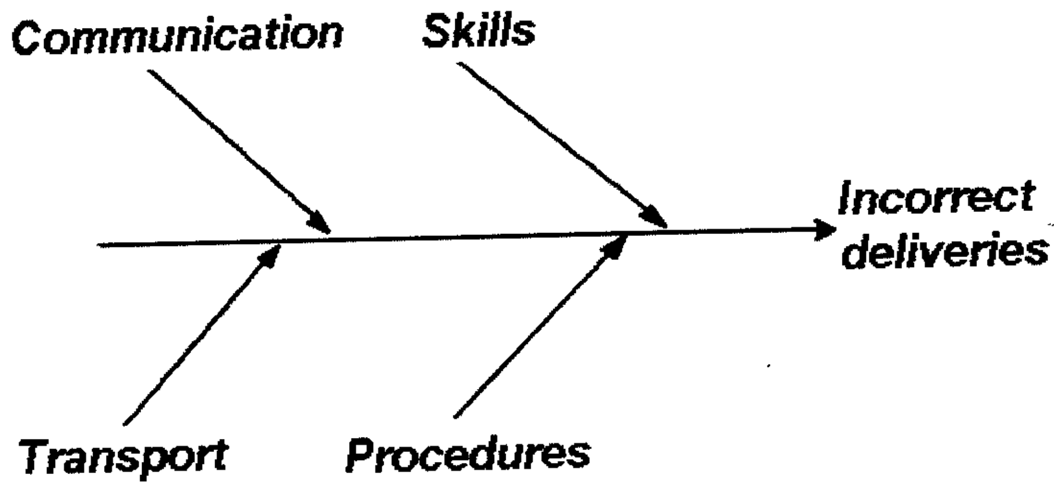


Figure 3.2 AN EXAMPLE FOR CAUSE AND EFFECT DIAGRAM

3.3.3 Pareto Chart

A Pareto diagram is a simple bar chart that ranks related measures in decreasing order of occurrence. The principle was developed by Vilfredo Pareto, an Italian economist and sociologist who conducted a study in Europe in the early 1900s on wealth and poverty. He found that wealth was concentrated in the hands of the few and poverty in the hands of the many. The principle is based on the unequal distribution of things in the universe. It is the law of the "significant few versus the trivial many." The significant few things will generally make up 80% of the whole, while the trivial many will make up about 20%.

The purpose of a Pareto diagram is to separate the significant aspects of a problem from the trivial ones. By graphically separating the aspects of a problem, a team will know where to direct its improvement efforts. Reducing the largest bars identified in the diagram will do more for overall improvement than reducing the smaller ones. An example of Pareto Chart is shown in Figure 3.3

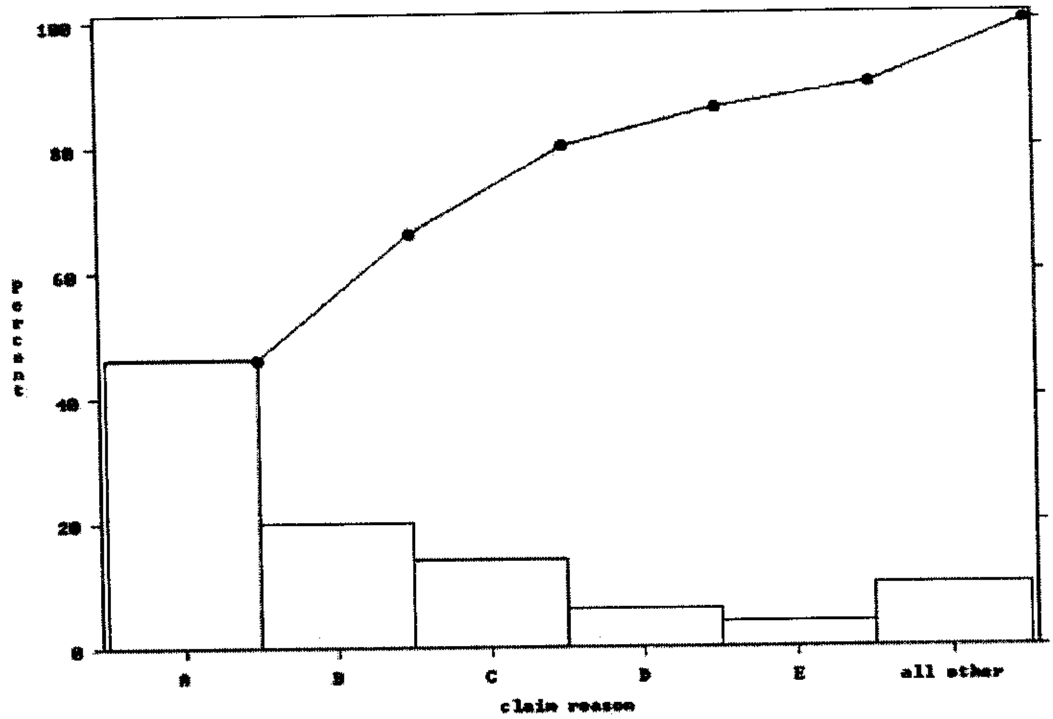


Figure 3.3 AN EXAMPLE FOR PARETO CHART

3.3.4 Histogram

It is meaningful to present data in a form that visually illustrates the frequency of occurrence of values. In the analysis phase of the Six Sigma improvement methodology, histograms are commonly applied to learn about the distribution of the data within the results Ys and the causes Xs collected in the measure phase and they are also used to obtain an under- standing of the potential for improvements.

To create a histogram when the response only "takes on" certain discrete values, a tally is simply made each time a discrete value occurs. After a number of responses are taken, the tally for the grouping of occurrences can then be plotted in histogram form. For example, Figure 3.4 shows a histogram.

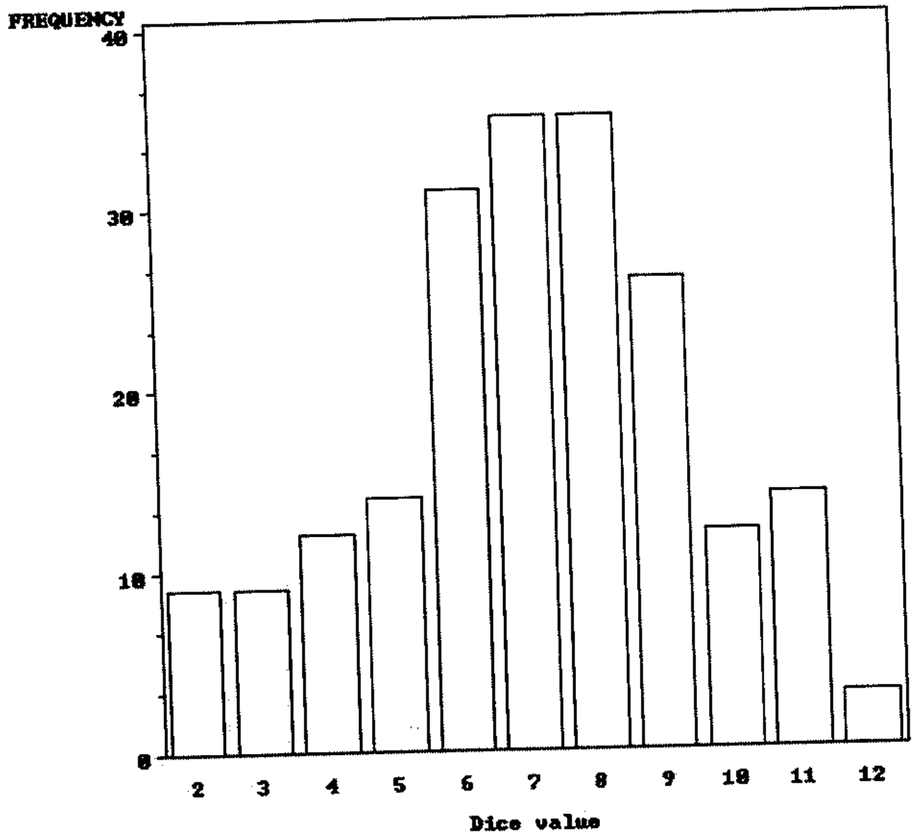


Figure 3.4 AN EXAMPLE FOR HISTOGRAM

3.3.4 Failure Mode and Effects Analysis (FMEA)

An FMEA can be described as a systemized group of activities intended to:

- Recognize and evaluate the potential failure of a product/process and its effects,
- Identify actions which could eliminate or reduce the chance of the potential failure occurring, and
- Document the process. It is complementary to the process of defining what a design or process must do to satisfy the customer.

Failure Modes and Effects Analysis (FMEA) is methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures. A crucial step is anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible. The early and consistent use of FMEAs in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEAs also capture historical information for use in future product improvement.

FMEA charts the type of defect, severity of defect, probability of occurrence, and whether or not systems are in place to properly to detect it. The FMEA then assesses a "risk Priority" number to the defect, to rate the severity and urgency of that defect. It's important to remember the possible or probable snowball effect of even a small failure mode. As defects go undetected, each defect affects at least one subsequent action. As the effects accumulate, performance is further undetermined and the associated risk priority increases. An example of FMEA chart is shown in Table 3.1

Table 3.1 AN EXAMPLE FOR FMEA CHART

FMEA type (design or process):					Project name/description:							Date (Orig.):				
Responsibility:							Prepared by:					Date (Rev.):				
Core team:												Date (Key):				
Design FMEA (Item/ Function) Process FMEA (Function/ Require.)	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Controls	Detec	RPN	Recommended Actions	Responsibility and Target Completion Date	Actions Taken	Sev	Occ	Det	RPN

Risk Priority Numbers (RPN). The Risk Priority Number is a mathematical product of the numerical Severity, Probability, and Detection ratings:

RPN = (Severity) x (Probability) x (Detection)

The RPN is used to prioritize items than require additional quality planning or action. The ratings for Severity, Deduction and Probability are given in the Table I, II & III in appendices.

With the help of DMAIC method and quality tools the existing problem is solved and it is discussed in chapter 4.

CHAPTER 4

IMPLEMENTING SIX SIGMA FOR CYCLE TIME REDUCTION

This chapter 4 outlines the study of various issues of Six Sigma while attempting to implement it in a project of reducing the new product development cycle time in industrial chains, a problem which led to customer dissatisfaction, loss of turn over and market share.

4.1 ABOUT THE COMPANY

LGB, one of the leading industries in South India was established way back in 1937. Started with a fleet of 250 buses, LGB grew into India's leading Roller chain manufacturer. Since then we have come a long way, keeping in pace with the technological advancements and meeting our customer needs with newer & innovative solutions. Today, LGB stands proud as the premier manufacturer of both automotive and industrial chains under the popular brand name 'ROLON'.

The company has five chain manufacturing plants, all ISO 9001 certified by Underwriters Laboratories Inc., USA. Three of the manufacturing facilities along with the central functions have been registered to ISO/TS 16949 by UL, USA.

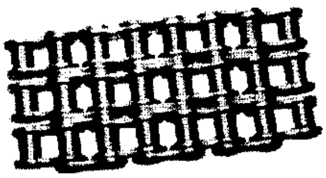
LGB is now surging ahead to become a METAL FORMING company concentrating on Hot, Warm & Cold forging, Blanking, Fine blanking & Precision machined parts

4.1.1 An Overview about Industrial Chains

Rolon Industrial chains are widely used in textile, sugar, oil & water drilling, material handling, agriculture etc. They are manufactured to different standards depending on the requirement of the customer. A few of the standards followed are ANSI, BRITISH, ANSI Heavy series & ROLON. These Industrial chains are provided with special attachments along with the chain depending on the purpose for which it is employed. The industrial chains undergo the following engineering processes to perform flawlessly and reliably for longer periods.

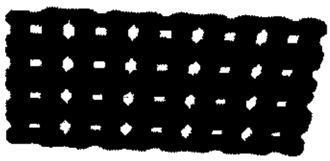
- Controlled Atmospheric heat treatment
- Shot peened parts
- Pre-Loaded Chain
- Greater Fatigue & Ultimate Tensile Strength
- Longer Wear life

A few types of industrial chains that are manufactured in the company are given in Figure 4.1.



ANSI STANDARD ROLLER ATTACHMENT

CHAINS (RIPLEX) ROLLER CHAINS WITH- K1



ANSI STANDARD ROLLER (QUADRUPLEX)

CHAINS ROLON STANDARD LEAF CHAINS

ROLLER CHAINS WITH TIMING CHAINS ATTACHMENT - M1

(ENGINE MECHANISM CHAINS)

Figure 4.1 TYPES OF INDUSTRIAL CHAINS

4.1.2 Applications

LGB offers a whole range of Oil field chains that match all the requirements of the various applications such are Mud pump drives, Engine compound, Tubular and Casing draw works input, transmission drives, Cam shafts, Low & high drum, Rotary Countershafts and Tables. Safety and reliability is of paramount importance for oil field chains and only a few chain manufacturers have the capability in manufacturing these high precision chains.

Agricultural chains are widely used in applications like harvesters, tillers & rotavators employing the latest technology in process. These chains are highly reliable and endures even under the most severe and hostile conditions. The product range includes roller, leaf, carding, bush, conveyor and stenter and also special custom – made chains for any application.

4.2 DEFINE PHASE

The Six Sigma philosophy uses data and statistical tools to systematically improve process and sustain improvements. The methodolody is a project focused approach consisting of five phases: Define, Measure, Analyze, Improve and Control.

The first step in the define phase is to clearly define the problem. It describes the problem in operational terms that facilitate further analysis. It also identifies the customers and the CTQs that have the most impact on product or service performance, describes the current level of performance or the nature of errors or customer complaints. The suppliers, inputs, outputs, processes and customers are identified with the help of the S I P O C analysis. The critical to quality factors are identified based on the needs of the customer. Based on the needs of the customer the best performance standards are benchmarked and the current process is compared with the standards. The deviation from the standards is considered for improvement which is carried out in the following phases.

4.2.1 Problem Identification

The present delivery of the new product of industrial chains to the customer is 75 days (min) and it goes upto 189 days (max). This fails to meet the customer requirement of delivery within 75 days. The reason behind the problem is the delay in new product development cycle. . This project is worked on satisfying the customer by delivering the chains within the specified time. It identifies the various critical factors that lead to delay and improve the process by eliminating the errors. This helps the company to manufacture more number of products and hence the business of the company increases. This indirectly helps the company to gain more profit and market share.

4.2.2 Project Charter

Project Title	:	Product Development Cycle time reduction of Industrial Chains using Six Sigma methodology.
Back Ground	:	Customers are not satisfied with present delivery periods [Min. 75 Days – Max. 189 Days] It leads to loss of turn over, loss of customer and market share.
Goal	:	Design and development of cycle time reduction for industrial chains <75 days
Measures	:	Cycle Time for 1) Overall product development in Days 2) Enquiry processing & product design 3) Tool Design & Development 4) Tool try out & Sample Submission
Benefits	:	❖ More business in new products ❖ More market share ❖ More Nos. of products

4.2.3 New Product Development Process Sequence:

A process is defined as the series of steps and activities that take inputs, add value, and produce an output. Since the project involves in reducing the cycle time of new product development, the various steps involved in manufacturing the product is studied and is given in Figure 4.2

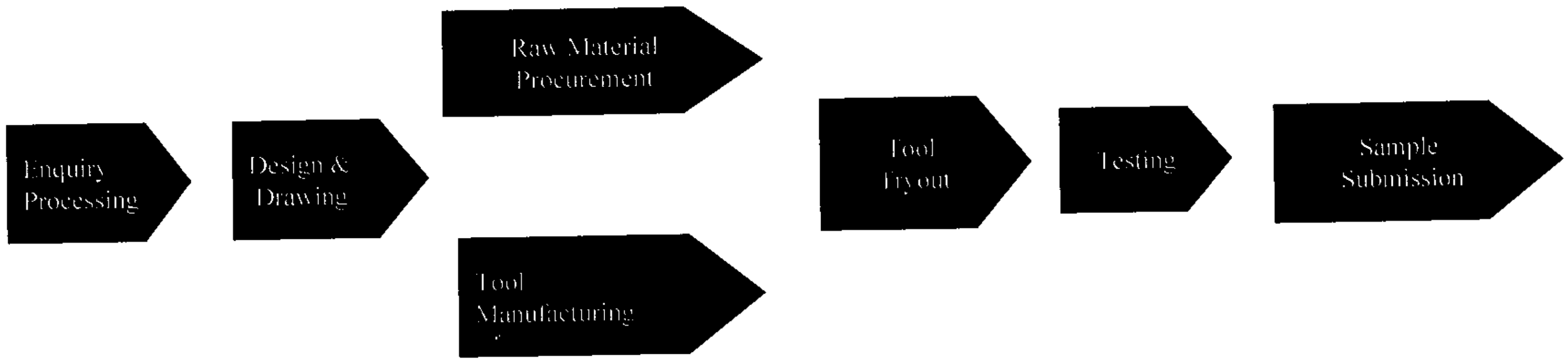


Figure 4.2 NEW PRODUCT DEVELOPMENT PROCESS SEQUENCE

4.2.4 S I P O C Analysis:

S I P O C is used to document a process at a high level and visually show the process, from suppliers, inputs to the products or services received by customers. It identifies process boundaries, the customer and suppliers of a process, process inputs supplied by the suppliers and the process outputs used by the customer, data collection needs. The Suppliers, Inputs, Process, Outputs, and Customers for the new product development are given in the Figure 4.3.

SUPPLIER	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
Marketing	Customer Enquiry Published Data	Development of New Product	Drawing & EDS	End Customer
R & D	Costing / TFC / CAD/CAM Software Design Check List		Design Review Sheet	Top Management
Purchase	Raw Material		Control Plan	R & D
Tool Room	Tools		Tool App Report	Marketing
MBD	Machine		Gauge R&R Rep	Tool Room
QAD	Inspection / Test Std		Product Tryout Report	Production
MFG	Machine / Trial Plan		HT Cycle	
Vendors	Lubrication & Packing		Design Validation Reports	
Packing				

Figure 4.3 S I P O C ANALYSIS

4.2.5 Critical To Quality (CTQ) Tree:

The next stage is to define the CTQ tree. It is used to brainstorm and validate the needs and requirements of the customer of the process targeted for improvement. It starts with the need of the customer and moves from left to right until we describe how to measure the detailed requirements. In this study, cycle time reduction of new product development is the need of the customer hence it is taken at the critical factor. Then the process is further detailed in order to identify the critical factors for reducing the cycle time. The critical to quality factors for new product development is given in Figure 4.4.

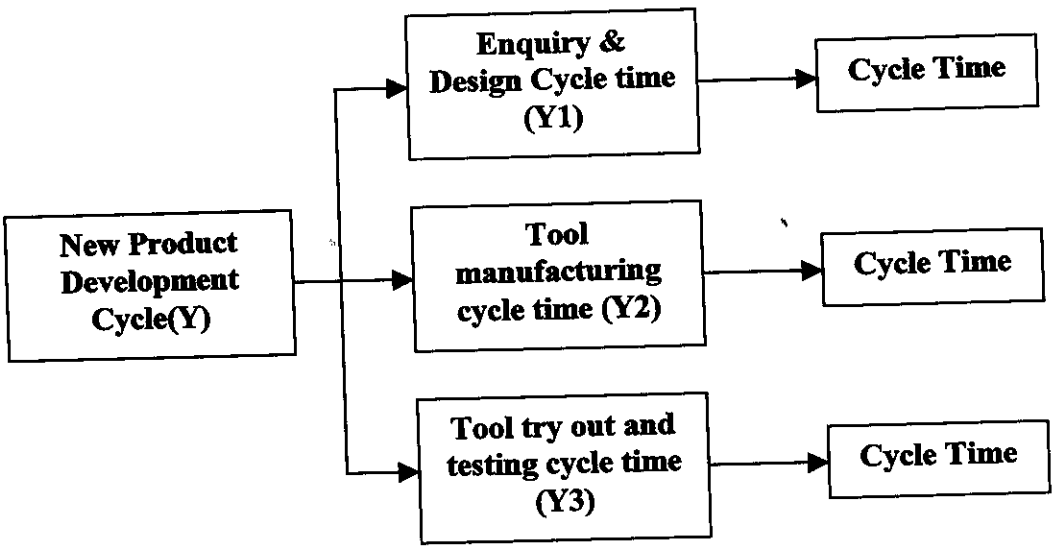


Figure 4.4 Critical To Quality Tree

The CTQ specification table for the new product development is given in table 4.1. The Specification table is formed based on the requirement of the customer and from the past experience of the company. The cycle time of the critical factors is to be measured and compared with the needs of customer. The results inferred are considered for improvement.

Table 4.1 CTQ SPECIFICATION TABLE

CTQ attributes	Measures	Defect Definition
New Product Development - Y	Actual time for sample submission	>75 days
Enquiry & Design – Y1	Cycle time	>10 days
Tool Developing – Y2	Cycle time	> 45 days
Tryout & testing – Y3	Cycle time	>20 days

4.3 MEASURE PHASE:

This phase focuses on measuring the internal processes that impact CTQs. It involves the collection of data from the existing production processes and practices. These data are collected from available records, feed back from supervisors, workers and from the field service employees. The collected data are compared with the requirements of the customer and the most critical factors are identified. These critical factors are considered for improvement and are further analyzed in the next phase.

4.3.1 New Product Development – Flow Chart

This involves the detailed study of the various process involved in the new process development. It gives the complete information about the processes and therefore helps in identifying the critical factors which resulted in the delay of the new product development. The New product development flow chart is given in Figure 4.5.

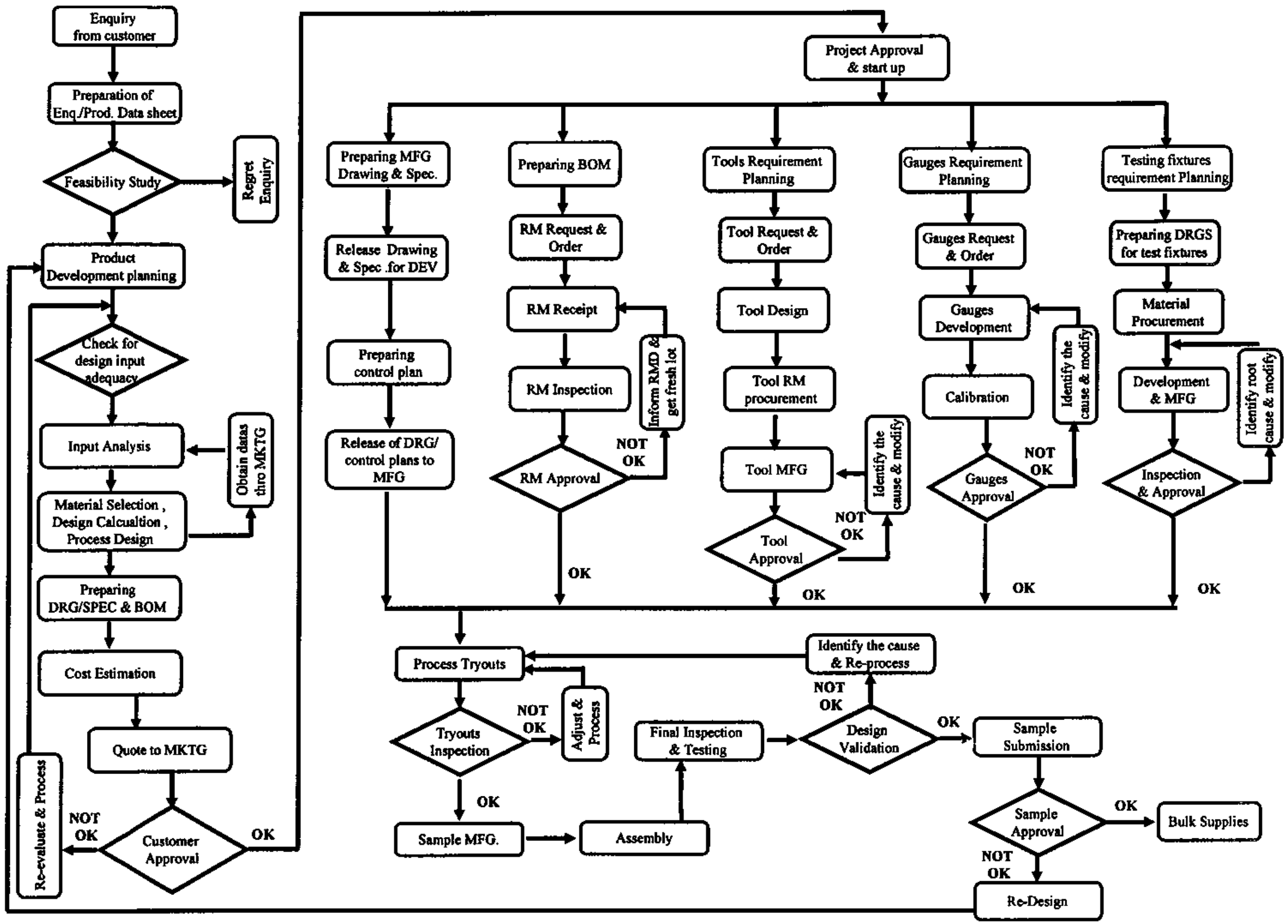


Figure 4.5 NEW PRODUCT DEVELOPMENT FLOW CHART

Table 4.2 Industrial chain development – Lead time

Customer	Chain Specific.	Drg. & Spec Issues(Y1) 10 Days	Tool Supply (Y2) 45 Days	Sample Supply (Y3) 20 Days
Ms. Hyderabad Industries	180mm pitch chain	13 ■	79 ■	21 ■
Ms. TRF	450 mm pitch chain	12 ■	87 ■	17 □
Ms. Elco Engg.	63.50mm pitch chain	14 ■	72 ■	30 ■
Ms. Elgi tread	101.60mm pitch chain	15 ■	79 ■	29 ■
Ms. Tissco	101.60mm pitch chain	15 ■	80 ■	28 ■
Ms. Bokaro Steel Plant	63.50mm pitch chain	12 ■	55 ■	18 □
Ms. Barmalt India Ltd.	101.60mm pitch chain	12 ■	45 □	18 □
Ms. Nalco Ltd.	R1595 with wiremesh	15 ■	66 ■	20 □
Ms. India Cements	450mm pitch plate & pin	12 ■	63 ■	21 ■
Ms. Fluidtherm Tech.	50.8mm pitch Chain with atta	12 ■	52 ■	18 □

■ DELAY □ ON TIME

Table 4.2 is the collection of data for the factors such as design & drawing cycle time, tool manufacturing, tool tryout and testing. These factors are the major contributors for the critical factor New product Development cycle. The data are collected for 10 types of industrial chains which are manufactured by the company. The data are collected based on the starting and ending time of the individual process.

4.3.2 Stratification

It's the method of grouping data by common points (or) characteristics to understand the similarities and characteristic of data. Here the data collected from the current process are compared with the requirement level for the customer. The factor which deviates more from the requirement level is taken for improvement. From table 4.3, the factor, tool manufacturing deviates more from the requirement level and hence it is considered as the major factor contributing to delay in New Product Development.

Table 4.3 COMPARISON BETWEEN ACTUAL TIME TAKEN AND TARGET TIME.

Description	Target (days)	Actual (days) Average
Design & Drawing (Y1)	10	13
Tool manufacturing(Y2)	45	❁ 68
Tool tryout & testing(Y3)	20	22

4.3.3 Sigma Rating Calculation-Before Improvement

Table 4.4 gives the sigma rating for the critical to quality factors(Y). It is calculated by finding out the defects per million opportunities and then selecting the corresponding sigma value from the table relating DPMO and sigma which is given in appendix .

DPMO Calculation

Total Number of projects analyzed = 10

The design and drawing cycle time should be completed with 10 days as per the requirement level. From the table 4.2 all the ten projects fail to meet the requirement level and hence the number of defects is 10.

Defect per opportunity = Number of defects / Number of projects analysed
= 10 / 10 = 1

Defects per million opportunity = 1 x 10,00,000 = 10,00,000

The sigma value corresponding to the DPMO value is found from the table relating the sigma and DPMO (table IV in appendices). It is found to be 0.00. Hence the sigma value for design and drawing cycle time is 0.00.

Similarly for the other factors the sigma value is found.

Table 4.4 SIGMA RATING FOR CTQ FACTORS

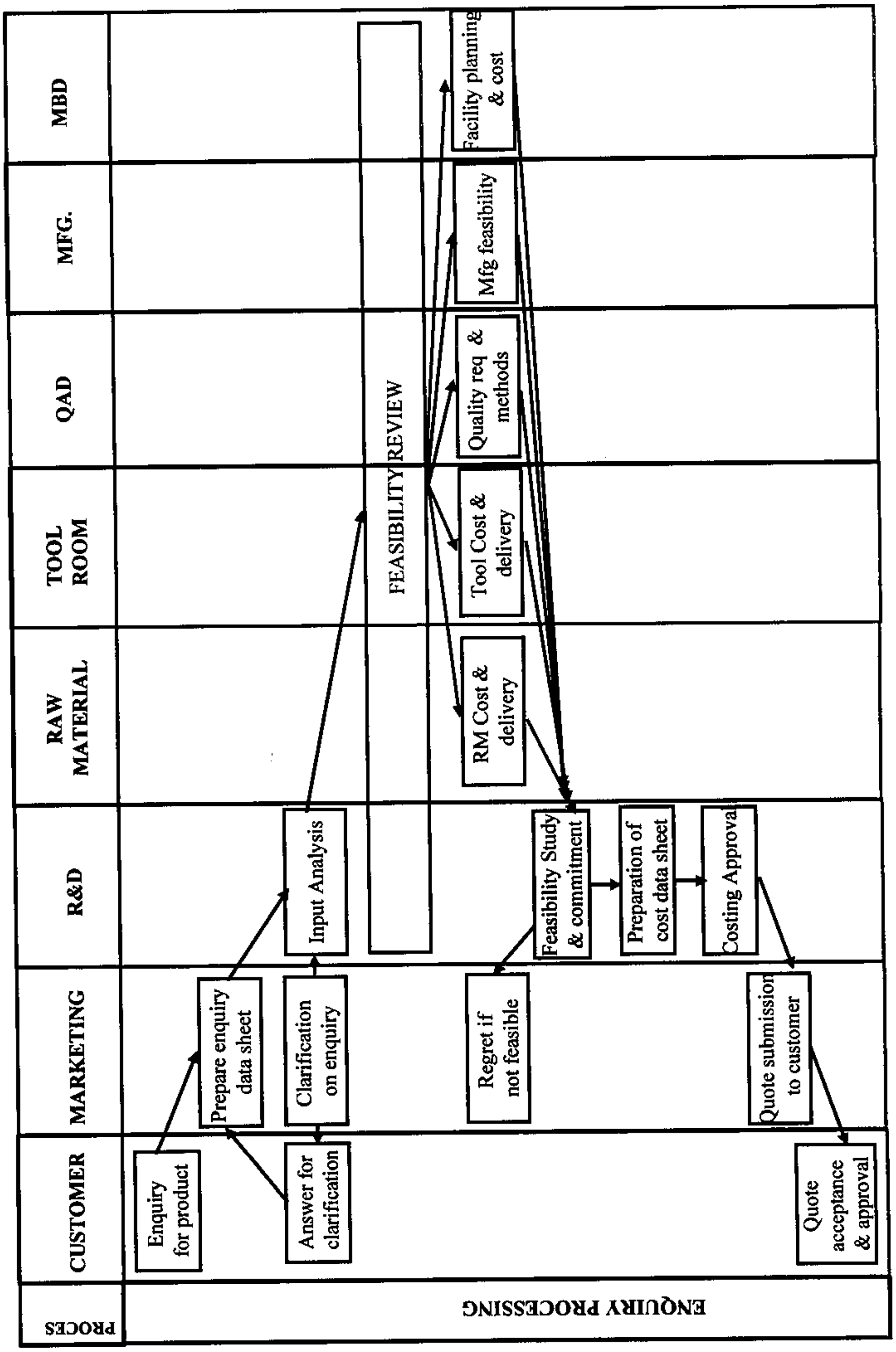
CTQ'	Avg. Cycle Time (Days)	Sigma Rating
New Product Dev Cycle Time - Y	103	0.22
Design & Drawing Cycle Time - Y1	13	0.00
Tool MFG Cycle Time - Y2	68	0.22
Tryout & Testing Cycle Time - Y3	22	1.50

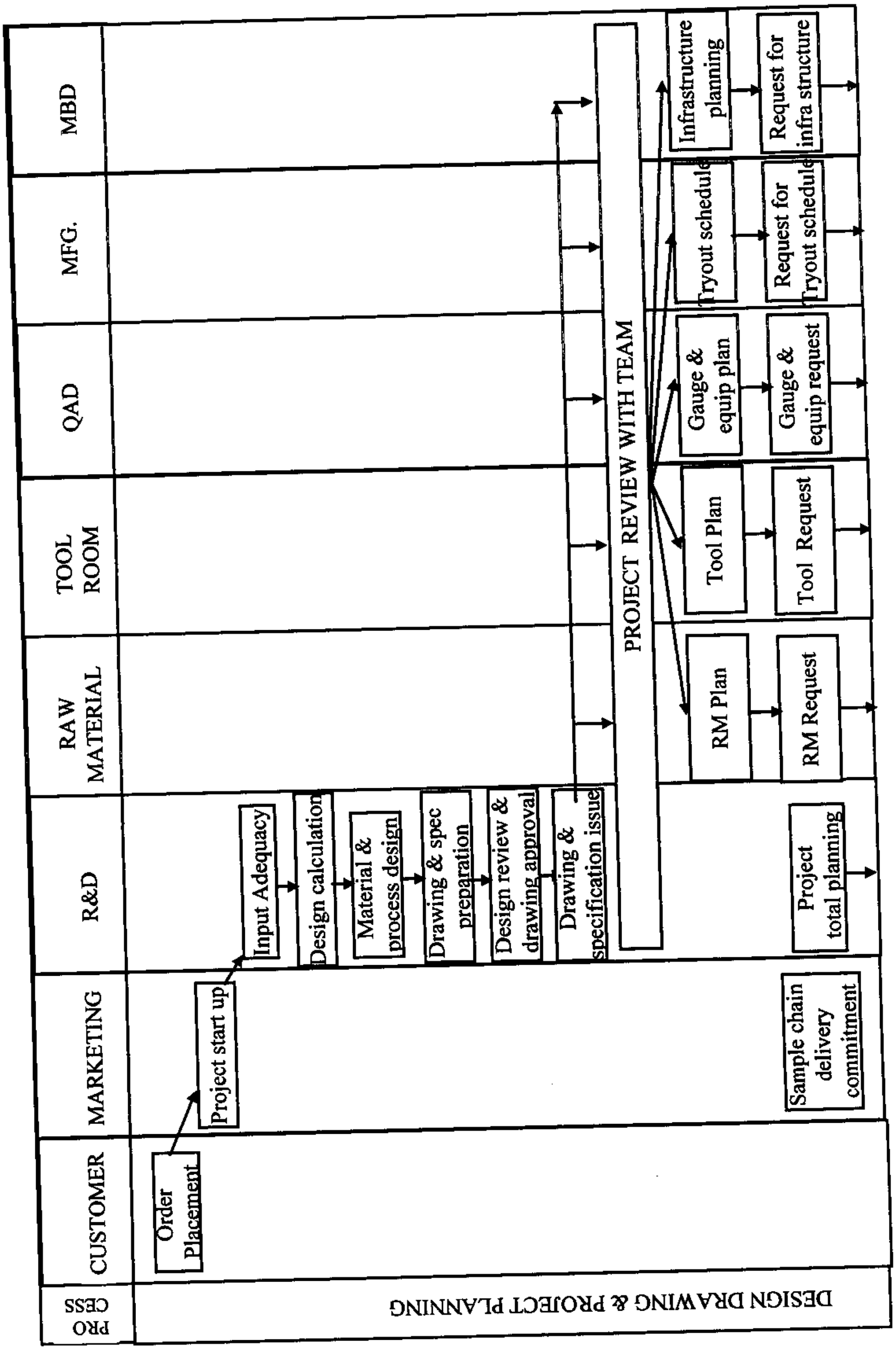
4.4 ANALYZE PHASE

The Analyze phase uses data to establish the key process inputs that affect the process outputs. It is used to identify the critical Xs which are to be improved in order to obtain the required Y (cycle time). This phase uses various statistical tools for identifying the critical Xs. Some of the tools used are cause and effect diagram, Pareto chart and failure mode effective analysis. It also makes use of flow charts in order to clarify the steps in the process and identify improvement opportunities in the process. These tools help in identifying the critical Xs on basis of their occurrence, severity, detection, frequency of occurrence, etc. These critical Xs are identified and are improved in the next phase.

4.4.1 Deployment Flow Chart

Deployment flowcharts show the detailed steps in a process and which people or groups are involved in each step. They are particularly useful in processes that involve the flow of information between people or functions, as they help highlight hands off areas. It clarifies roles and indicate responsibilities. In this study the flow chart clearly explains the roles and responsibilities of each individuals at each and every stage. Hence it is easy to identify the responsibility of the individuals incase of any failures. The flow chart is given explaining the roles and responsibilities of individual departments. The Figure 4.6 give the deployment chart for the new product development.


PROCES
ENQUIRY PROCESSING
CUSTOMER
MARKETING
R&D
RAW MATERIAL
TOOL ROOM
QAD
MFG.
MBD
Enquiry for product
Answer for clarification
Prepare enquiry data sheet
Clarification on enquiry
Input Analysis
FEASIBILITY REVIEW
RM Cost & delivery
Tool Cost & delivery
Quality req & methods
Mfg feasibility
Facility planning & cost
Feasibility Study & commitment
Regret if not feasible
Preparation of cost data sheet
Costing Approval
Quote submission to customer
Quote acceptance & approval


PROCESS
DESIGN DRAWING & PROJECT PLANNING
CUSTOMER
MARKETING
R&D
RAW MATERIAL
TOOL ROOM
QAD
MFG.
MBD
Order Placement
Project start up
Input Adequacy
Design calculation
Material & process design
Drawing & spec preparation
Design review & drawing approval
Drawing & specification issue
PROJECT REVIEW WITH TEAM
RM Plan
Tool Plan
Gauge & equip plan
Tryout schedule
Infrastructure planning
RM Request
Tool Request
Gauge & equip request
Request for Tryout schedule
Request for infra structure
Project total planning
Sample chain delivery commitment

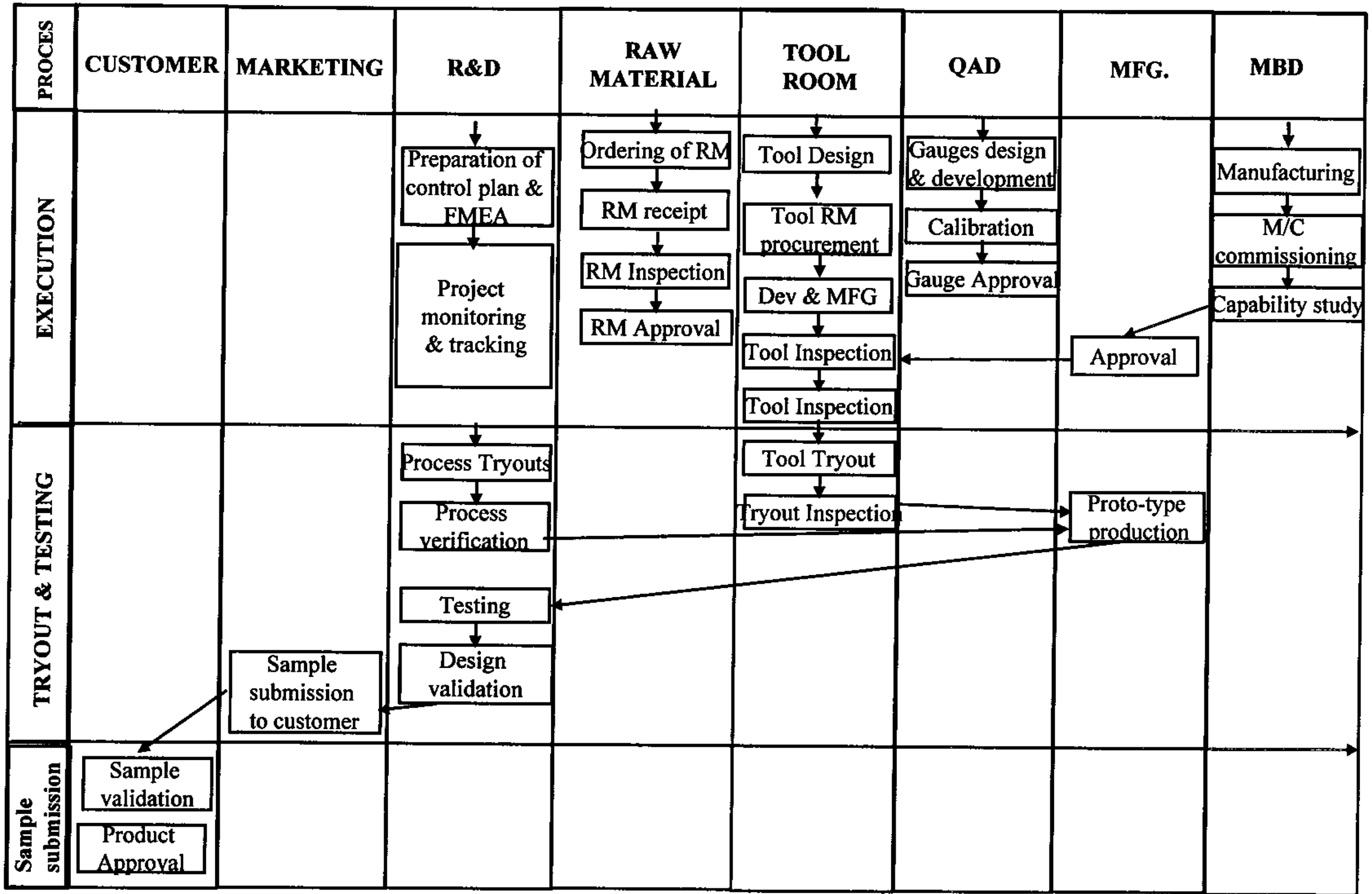
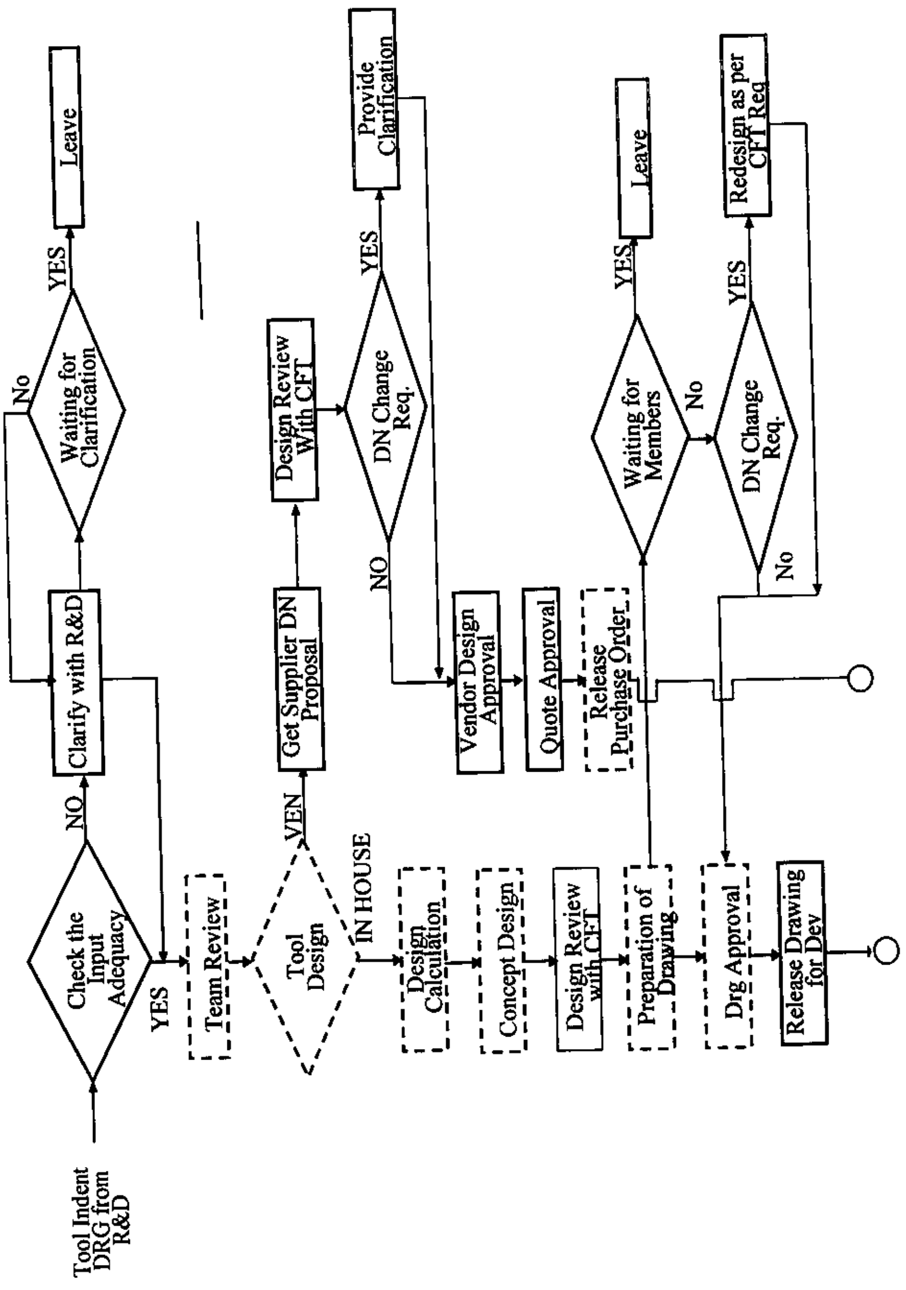


Figure 4.6 DEPLOYMENT FLOW CHART (ENQUIRY PROCESSING)


Tool Indent DRG from R&D
Check the Input Adequacy
YES
NO
Clarify with R&D
Waiting for Clarification
No
YES
Leave
Team Review
Tool Design
VEN
IN HOUSE
Get Supplier DN Proposal
Design Review With CFT
DN Change Req.
YES
NO
Provide Clarification
Vendor Design Approval
Quote Approval
Release Purchase Order
Design Calculation
Concept Design
Design Review with CFT
Preparation of Drawing
Waiting for Members
No
YES
Leave
DN Change Req.
YES
No
Redesign as per CFT Req
Drg Approval
Release Drawing for Dev

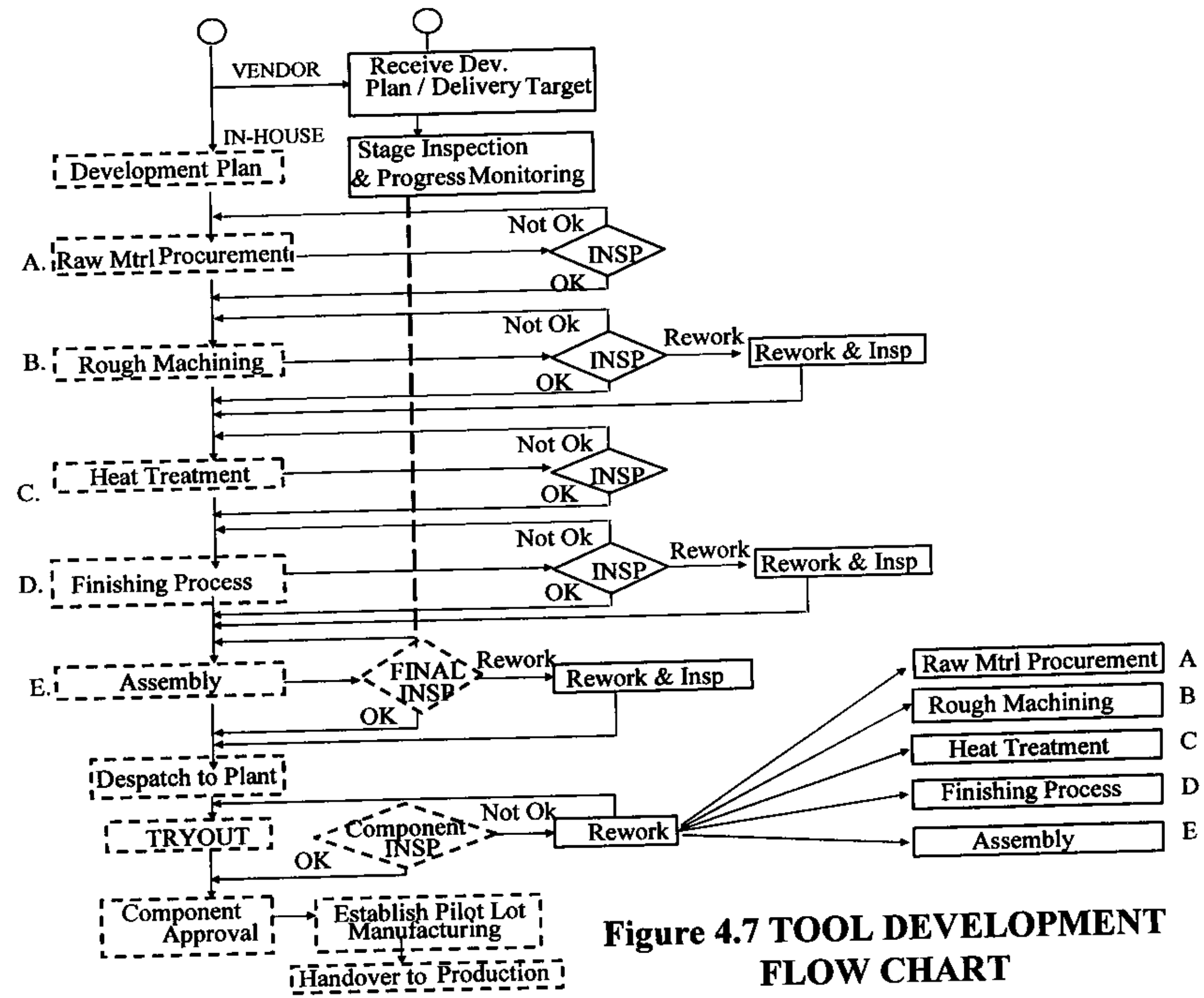


Figure 4.7 TOOL DEVELOPMENT FLOW CHART

4.4.2 Tool Development Process Analysis - Flow chart

From the Measure phase it was found that tool development cycle is the major reason for the delay in new product development. Hence tool development process is studied in order to identify the causes which would result in the delay of the process. Tool development process analysis flow chart (as shown in Figure 4.7) clearly explains the sequence of processes involved in the cycle. It also gives the value and non value added activities involved and the improvement process is carried out in such a way that the non value added activities are eliminated. This helps in reducing the cycle time.

4.4.3 Cause and Effect diagram – Tool Development Cycle

Cause and Effect diagram allows a team to identify and explore the important possible causes related to a problem or condition to discover its root causes. The cause and effect diagram for tool development cycle gives possible causes for the failure in meeting the required level. It is developed by first identifying the major causes and then the causes for these major causes. The back bone represents the effect (delay in tool development cycle) and the major causes are connected by means of bones to the back bone. The causes for these major causes are connected to the respective major cause bones. This helps in identifying the critical causes for the delay in tool development cycle. Figure 4.8 shows the cause and effect diagram of tool development cycle.

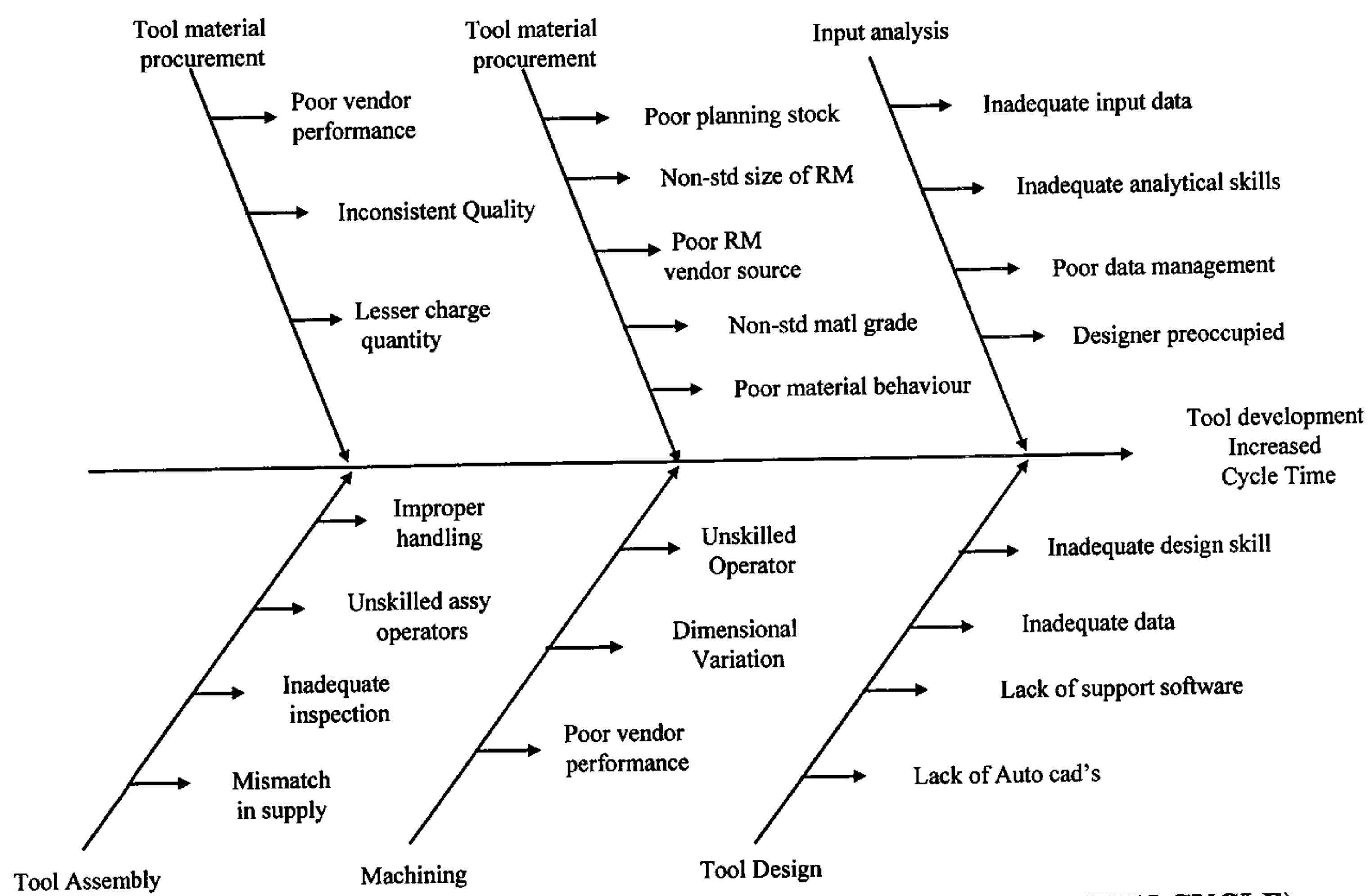


Figure 4.8 CAUSE AND EFFECT DIAGRAM (TOOL DEVELOPMENT CYCLE)

4.4.4 Data Collection Plan

With the help of the cause and effect diagram, the causes for the delay in tool development cycle are identified. The time taken for these causes is to be taken to identify the causes which contribute more to the delay. Data collection plan helps in arranging the causes in a sequence and makes the data collection easy. Table 4.5 gives the plan for the collection of data for the causes for the delay.

4.4.5 Data Collection

The data is collected for the time taken for individual process involved in the tool development cycle by referring to the starting and ending time of the individual process. The data collected for 10 projects which are taken for study are given in the table 4.6. From the data collected the average time taken for the individual process is found. This is compared with the estimated number of days for the process. The processes with higher deviation are taken for improvement. The table 4.7 gives the occurrence of the causes in each process for the individual projects. From the tables the frequencies of occurrence of the causes are found out.

Table 4.5 DATA COLLECTION PLAN OF CAUSES FOR DELAY IN TOOL DEVELOPMENT CYCLE

Y- Effect	Process Description	X – Causes for Delay	
Y2 TOOL MFG CYCLE TIME	**Input Analysis (Y2-1)**	X1	Inadequate Input Data
		X1	Inadequate nalytical Skill
		X3	Poor Data Management
	Tools Design Cycle time (Y2-2)	X4	Designer Pre-occupied
		X5	Less no. of auto cad systems
		X6	Lack of support software
		X7	New RM Grade Process Development
	Tool material procurement (Y2-3)	X8	Inadequate Design skill
		X9	Poor planning / stocking
		X10	Non Standard Raw Material Size.
		X11	Poor RM Vendor sourcing
		X12	Poor material behaviour
	Machining Vendor (Y2-4a)	X13	Non std RM Grade
		X14	Poor vendor performance
		X15	Specification variation
	Machining In-House (Y2-4b)	X16	Unskilled operator at vendor
		X17	Poor planning / priortisation
		X18	Low Skilled operator
	Heat Treatment (Y2-5)	X19	Waiting for Next Process
		X20	Poor vendor performance
		X21	Inconsistent output
	Tool Assembly shop (Y2-6)	X22	Lesser charge quantity
		X23	Mismatch in assembly
		X24	Mismatch in supply
		X25	Inadequate inspection
		X26	Unskilled assembly operators
		X27	Improper handling and storage

Table 4.6 ACTUAL TOOL DEVELOPMENT CYCLE TIME

Customer	Chain Specific.	TOOL DEVELOPMENT – target 45 days											
		Y2-1	Y2-2	Y2-3a	Y2-3b	Y2-3c	Y2-4a	Y2-4b	Y2-5a	Y2-5b	Y2-6a	Y2-6b	Total
		Estimated time taken (days)											
		1	5	1	12	2	15	2	3	1	2	1	45
Ms. Hyderabad Industries	180mm pitch chain	2	5	1	14	2	17	2	10	1	2	1	57
Ms. TRF	450 mm pitch chain	3	9	2	21	3	21	3	8	1	4	2	77
Ms. Elco Engg.	63.50mm pitch chain	6	5	2	18	1	30	3	8	1	6	1	81
Ms. Elgi tread	101.60mm pitch chain	7	9	1	25	2	20	1	3	1	2	1	72
Ms. Tissco	101.60mm pitch chain	2	6	2	20	2	32	2	6	2	6	1	81
Ms. Bokaro Steel Plant	63.50mm pitch chain	6	5	2	20	1	18	2	9	1	2	3	69
Ms. Barmalt India Ltd.	101.60mm pitch chain	2	7	3	29	2	22	2	7	1	5	1	81
Ms. Nalco Ltd.	R1595 with wiremesh	1	5	1	19	1	14	2	3	1	2	2	51
Ms. India Cements	450mm pitch plate & pin	4	7	2	27	1	24	2	4	2	5	1	79
Ms. Fluidtherm Tech.	50.8mm pitch Chain with atta	7	6	2	12	1	18	3	14	1	5	1	67
Actual Time Taken (Average)		4.00	6.40	1.80	20.5	1.60	21.6	2.2	7.2	1.2	3.6	1.4	71.5

○ ← **Tasks with Higher deviation**

Process Y2-1 : Input Analysis

Process Y2-2 : Tool Design cycle time

Process Y2-3 : a) Raw material indent
Y2-3 : b) Raw material procurement
Y2-3 : c) Raw material inspection

Process Y2-4 : a) Machining of components
Y2-4 : b) Inspection

Process Y2-5 : a) Heat Treatment of Parts
Y2-5 : b) Inspection

Process Y2-6 : a) Tool Assembly
Y2-5 : b) Inspection

Table 4.7 DATA COLLECTION SHEET – TOOL DEVELOPMENT

S NO	CHAIN DESCRIPTION	CHAIN NO.	TOOL DEVELOPMENT PROCESSING - 45 DAYS													
			x-1	x-2	x-3	x-4	x-5	x-6	x-7	x-8	x-9	x-10	x-11	x-12	x-13	x-14
1	M/s Barmalt India ltd	E 501			✠	✠					✠	✠				✠
2	M/s Bokaro steel plant	E 502	✠					✠			✠	✠				✠
3	M/s India cements	CM09	✠	✠	✠	✠		✠	✠			✠	✠	✠		✠
4	M/s Voltas ltd	SC300			✠		✠			✠	✠				✠	✠
5	M/s Max India	E 511			✠	✠		✠	✠			✠			✠	✠
6	M/s Fluid therm ltd	E 506		✠		✠				✠	✠					✠
7	M/s Bhillai steel plant	E 507	✠		✠						✠	✠				✠
8	M/s Welmech engg	E 514					✠					✠		✠		
9	M/s Leal makro	E 512	✠		✠							✠		✠		✠
10	M/s Nalco ltd	E 518	✠		✠			✠	✠			✠	✠	✠		✠
Occurrence			5 50%	2 20%	7 70%	4 40%	2 20%	4 40%	3 30%	2 20%	5 50%	8 80%	2 20%	4 40%	2 20%	9 90%

✠ - *Occurrence of causes*

S NO	CHAIN DESCRIPTION	CHAIN NO.	TOOL DEVELOPMENT PROCESSING - 45 DAYS												
			x-15	x-16	x-17	x-18	x-19	x-20	x-21	x-22	x-23	x-24	x-25	x-26	x-27
1	M/s Barmalt India ltd	E 501			✠		✠		✠	✠					
2	M/s Bokaro steel plant	E 502	✠		✠				✠		✠	✠	✠	✠	
3	M/s India cements	CM09		✠	✠	✠		✠	✠		✠	✠			
4	M/s Voltas ltd	SC300	✠												
5	M/s Max India	E 511		✠	✠				✠		✠	✠			✠
6	M/s Fluid therm ltd	E 506	✠		✠		✠		✠	✠			✠		
7	M/s Bhillai steel plant	E 507			✠	✠	✠	✠	✠			✠			✠
8	M/s Welmech engg	E 514	✠		✠								✠	✠	
9	M/s Leal makro	E 512		✠	✠	✠	✠	✠	✠		✠	✠			✠
10	M/s Nalco ltd	E 518				✠	✠		✠						
Occurrence			4 40%	3 30%	8 80%	4 40%	5 50%	3 30%	8 80%	2 20%	4 40%	5 50%	3 30%	2 20%	3 30%

4.4.6 Failure Mode and Effects Analysis

Failure mode and effects analysis (FMEA) allows an assessment of the risk of customers if a key process input (x) were to fail. The FMEA also helps to determine what actions to take to minimize the risk. The FMEA done for the tool development cycle is shown in table 4.8. From the FMEA table the most critical causes for delay are found out. This is done by calculating the RPN for each cause. RPN is calculated by

RPN = Severity * Occurrence * Detection

Severity, Occurrence and detection are given rankings from 1 to 10 based on the characteristics of causes. These values are referred from the tables I, II, III given in Appendices based on their characteristics.

For cause X 3: poor data Management, RPN number is calculated as follows

From table I in appendices, Severity = 9

From table II in appendices, Detection = 3

From table III in appendices, Occurrence = 7

RPN = Severity * Detection * Occurrence = 9 * 3 * 7 = 189.

Similarly the RPN number is calculated for the other causes. After calculating the RPN for each cause, tasks with higher RPN i.e. tasks with RPN greater than 100 are taken for improvement. The value 100 is selected based on the available resources. The FMEA table also gives the recommended action for minimizing the RPN for the causes with greater RPN number.

Table 4.8 FMEA TABLE – TOOL DEVELOPMENT

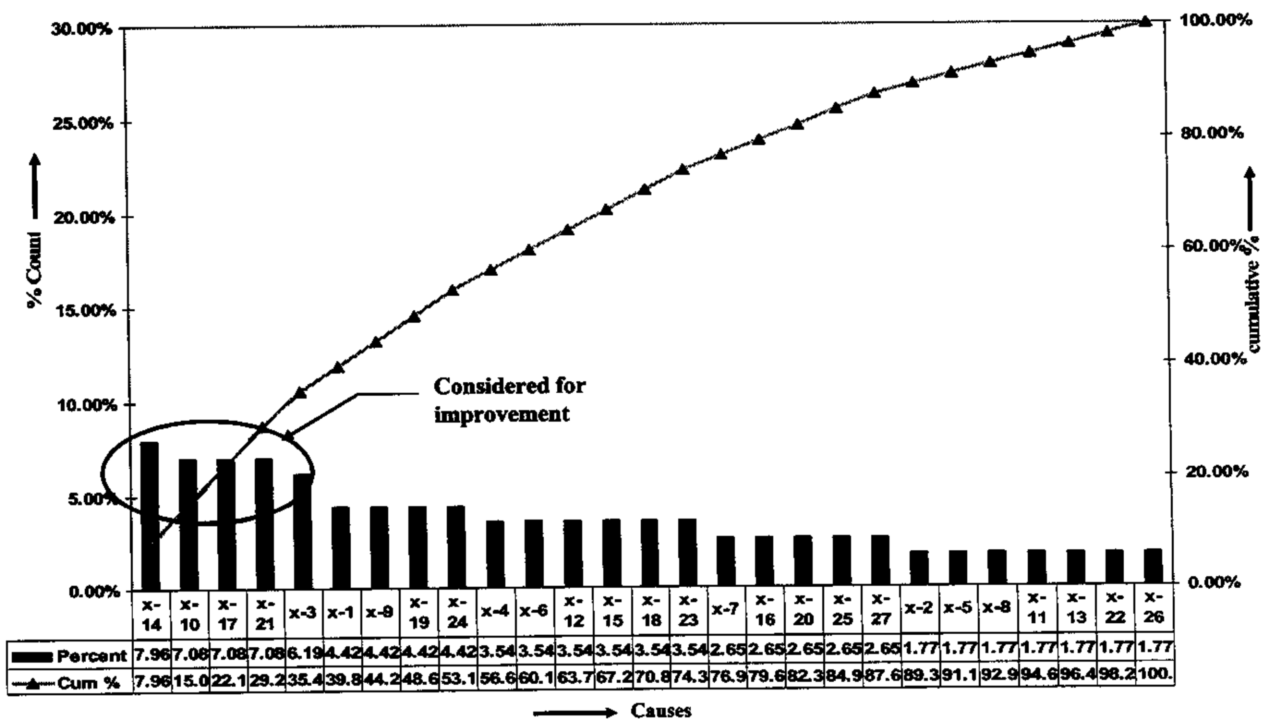
Item function	Potential Failure Mode	Potential Effect(s) Of Failure	Sev	Class	Potential Cause(s)/ Mechanisms Of Failure	OCC	Current Controls	DET	RPN	Recommended Action(s)
Tool Design &	Tool Development	1. Delay in New product			Y2-4b. Machining (In-house)					
Development < 45 Days	> 45 Days	development			X-17 - Longer Duration of M/c	8	Route Card / Job Card	2	144	d. Evaluate & Establish WI
Cont...	Cont...	2. Customer			X-18 - Low Skilled Operator	5	Training	2	90	----
		disatisfaction			X-19 - Waiting for Next Process	3	Route Card / Job Card	2	54	----
		3. Loss of turnover	5		Y2-5. Heat Treatment					
		Cont...			X-20 - Poor Vendor Performance	5	Vendor Approval	2	90	----
			9		X-21 - In-consistent Quality	7	Work Instruction	3	189	e. Evaluate vendor Rating
					X-22 - Lesser Charge Quantity	2	Batch Qty Scheduleing	3	54	----
			7		Y2-6. Tool Assembly					
					X-23 - Mismatch in assembly	4	Inward Inspection	2	72	----
					X-24 - Mismatch in Supply	5	Planning	3	135	----
					X-25 - Inadequate Inspection	3	Inward Inspection	3	81	----
					X-26 - Unskilled assy. Operators	2	Training	2	36	----
					X55 - Improper Handling & Storage	3	Work Inst & Maintainance Schedule	2	54	----

Item function	Potential Failure Mode	Potential Effect(s) Of Failure	Sev	Class	Potential Cause(s)/ Mechanisms Of Failure	OCC	Current Controls	DET	RPN	Recommended Action(s)
Tool Design & Development < 45 Days	Tool Development > 45 Days	1. Delay in New product development	5		**Y2-1. Input Analysis**					
Y2					X-1 - Inadequate input data.	5	Manual Checking	2	90	----
		2. Customer disatisfaction	9		X-2 - Inadequate analytical skills	2	Training	3	54	----
					X-3 - Poor data management	7	Manual verification	3	189	a. Establish Database
		3. Loss of turnover	7		X-4 - Designer preoccupied.	4	Multi skilling	2	72	----
					Y2-2. Tool Design Cycle Time					
					X-5 - Less no. of Autocad system	2	Resource Planning	2	36	----
					X-6 - Lack of support software	4	Resource Planning	2	72	----
					X-7 - New RM Gr Process Dev	3	Proto-type development	3	81	----
					X-8- Inadequate Design skill	2	Evaluation once in a year	5	90	----
					Y2-3. Tool Material Procurement					
					X-9 - Poor planning / Stocking	5	Make to Order	2	90	
					X-10 - Search Non Std Size of RM	7	Std RM Size Check List	4	252	b. Establish RM Stock Based on Future Project.
					X-11 - Poor RM Vendor Sourcing	2	Vendor Rating evaluation	3	54	----
					X-12 - Poor Material Behavior	2	Inward Inspection	5	90	----
					X-13 - Non Std RM Grade	2	RM Grade Check Sheet	2	36	----
					Y2-4a. Machining (Vendor)					
					X-14 - Longer Duration of M/c	8	Vendor Approval	3	216	c. Evaluate vendor Rating
					X-15 - Dimensional Variation	4	Supplier Inspection Report	2	72	----
					X-16 - Unskilled Operator at vendor	3	Training	3	81	----

4.7 Pareto Analysis

The Pareto principle is generally used to prioritize quality improvement projects to get most returns for the resources invested. It is one of the most powerful tools and is widely used as means of attacking bulk of the problems with the optimal utilization of resources. The basic principle of Pareto is "around 80% of overall effect is contributed by 20% of causes". It represents the ratio of each item to the whole.

For the causes of tool development cycle, the Pareto chart is drawn with % count on the Y axis and causes on the X axis. Each bar represents the percentage of each cause from the whole. From the chart in Figure 4.9 the causes which contribute more for the delay are taken for improvement. By Pareto principle "80% of the effect is caused by 20% of the causes". Improvement is concentrated on the 20% which plays a major role in delay.



	x-14	x-10	x-17	x-21	x-3	x-1	x-9	x-19	x-24	x-4	x-6	x-12	x-15	x-18	x-23	x-7	x-16	x-20	x-25	x-27	x-2	x-5	x-8	x-11	x-13	x-22	x-26
Percent	7.96	7.08	7.08	7.08	6.19	4.42	4.42	4.42	4.42	3.54	3.54	3.54	3.54	3.54	3.54	2.65	2.65	2.65	2.65	2.65	1.77	1.77	1.77	1.77	1.77	1.77	1.77
Cum %	7.96	15.0	22.1	29.2	35.4	39.8	44.2	48.6	53.1	56.6	60.1	63.7	67.2	70.8	74.3	76.9	79.6	82.3	84.9	87.6	89.3	91.1	92.9	94.6	96.4	98.2	100.

Figure 4.9 PARETO CHART (TOOL DEVELOPMENT CYCLE)

4.4.8 Root Causes

From the FMEA table and Pareto chart, the major causes for the delay are identified and they considered for improvement. They are

- X 3 - Poor data management
- X 10 – Non standard Raw material size
- X 14 – Longer duration of tool part M/C – Vendor
- X 17 – Longer duration of tool part M/C - In house
- X 21 – Inconsistent Heat treatment quality.

Thus with the help of analyze phase the critical causes for the delay of tool development cycle time is found and it is improved in the improve phase.

4.5 IMPROVE PHASE

The improve phase identifies the improvements to optimize the outputs and eliminate the variation in the process. The most critical causes for the delay in the tool development cycle found from the analyze phase are improved by discussing the solutions. The major causes which were identified using the Pareto chart were taken individually and through brainstorming sessions various solutions for the problems were obtained. The areas that are to be focused for the cycle time reduction are listed below.

X-3 : Poor Data Management

1. Data Collection
2. Software for Data Storage & Retrievel
3. Periodical Updation of Data

X-10 : Non Standard Raw Material Size

1. Plan for Min Inventory of Standard RM Stocking
2. Standard Tool Part pre-stocking
3. Non Standard Size Raw Material stocking
4. Peroidical review and Updation Future focused projects

X-14 : Longer Duration of Tool Part Machining - Vendor

1. Vendor re-assesment
2. Penalty & Incentive based on Delivery
3. Dedicated and Exclusive vendor selection

X-17 : Longer Duration of Tool Part Machining - Inhouse

1. Operator Training
2. Long-term Apprenticeship
3. Introduce Inspection Standard / Control Plan
4. Periodical review on Machine hour availablity.

X-21 : Inconsistent in Heat Treatment Quality

1. Check RM before HT - Review & Fix Norms
2. Standardise Heat Treatment Cycle Time
3. Furnace Evaluation / Process Control / Monitorning
4. Dedicated and Exclusive vendor

CHAPTER 5

RESULTS AND DISCUSSION

By applying the DMAIC method, the critical to quality factors for the delay in new product development were identified. The solutions for improving the critical to quality factors have been suggested to the company and partially have been implemented. The expected sigma rating after the implementation of the project is given in table 5.1.

Table 5.1 SIGMA RATING COMPARISON

C T Qs	Tar Get	Before		After (Expected)	
		Actual Days	SIGMA	Actual Days	SIGMA
Product Design - Y1	10	13	0.00	10	3.75
Tool MFG - Y2	45	68	0.22	49	3.25
Tryout - Y3	20	22	1.50	21	1.25
Total - Y	75	103	0.22	80	1.93

DPMO & Sigma rating Calculation

Total Number of projects analyzed = 10

The tool development cycle time is the most critical factor for the delay and there are about 11 processes involved in tool development cycle. So the total number of factors is 11 x 10 = 110.

Expected number of factors failing to meet the requirement = 5

Defect per opportunity = Number of defects / Number of projects analyzed

= 5 / 110 = 0.045

Defects per million opportunity = 0.045 x 10, 00,000 = 4, 50,000

The sigma value corresponding to the DPMO value is found from the table IV in appendices, relating the sigma and DPMO. It is found to be 3.75. Hence the sigma value for design and drawing cycle time is 3.75.

Similarly for the other factors the sigma value is calculated.

Thus significant results have been achieved and the cycle time of the new product development has been reduced. This would help the company to concentrate on developing new products. Thereby increasing the company's business and market share. It was also discussed to implement certain measures permanently so that the processes are done with high quality and in time. These measures once implemented would enable the manufacturing of the products within the required level in future process.

CHAPTER 6

CONCLUSION

The cycle time to manufacture the new chain was found to be 103 days on average, which was a major factor to meet the customer satisfaction. DMAIC methodology of Six Sigma has been employed to reduce the cycle time in manufacturing the new chain. The major critical factor for the delay in manufacturing process was tool development cycle. Twenty eight key elements of the tool development stage of new chain have been identified and focused to meet the delivery date. The most important CTQ have been identified using Six Sigma tools, namely pareto chart, Cause and effect diagram and Failure mode and effect analysis. The critical factors are

- Poor data management
- Non standard Raw material size
- Longer duration of tool part M/C – Vendor
- Longer duration of tool part M/C - In house
- Inconsistent Heat treatment quality.

In order to improve the service, the following suggestions have been made.

X-3 : Poor Data Management

1. Data Collection
2. Software for Data Storage & Retrievel
3. Periodical Updation of Data

X-10 : Non Standard Raw Material Size

1. Plan for Min Inventory of Standard RM Stocking
2. Standard Tool Part pre-stocking
3. Non Standard Size Raw Material stocking
4. Peroidical review and Updation Future focused projects

X-14 : Longer Duration of Tool Part Machining - Vendor

1. Vendor re-assesment
2. Penalty & Incentive based on Delivery
3. Dedicated and Exclusive vendor selection

X-17 : Longer Duration of Tool Part Machining - Inhouse

1. Operator Training
2. Long-term Apprenticeship
3. Introduce Inspection Standard / Control Plan
4. Periodical review on Machine hour availablity.

X-21 : Inconsistent in Heat Treatment Quality

1. Check RM before HT - Review & Fix Norms
2. Standardise Heat Treatment Cycle Time
3. Furnace Evaluation / Process Control / Monitorning
4. Dedicated and Exclusive vendor

Partially the suggestions have been implemented and the rest of the suggestion will be implemented in due courses. The sigma level (estimated) has been improved from 0.22 to 1.93.

Further, the company employees are exposed to a new approach and they have decided to implement it for the other areas in future

APPENDICES

Table I - SEVERITY RATING TABLE

Effect	(Customer effect)	(Manufacturing/ Assembly Effect)	Rank
Hazardous without warning	Very high Severity ranking when a potential Failure Mode affects safe vehicle operation and/or involves noncompliance with government regulation without warning.	Or may endanger operator (machine or assembly) without warning.	10
Hazardous with warning	Very high Severity ranking when a potential Failure Mode affects safe vehicle operation and/or involves noncompliance with government regulation with warning.	Or may endanger operator (machine or assembly) with warning.	9
Very High	Vehicle/item inoperable (loss of primary function).	Or 100% of product may have to be scrapped, or vehicle/item repaired in repair department with a repair time greater than one hour.	8
High	Vehicle/Item operable but at a reduced level of performance. Customer very dissatisfied.	Or product may have to be sorted and a portion (less than 100%) scrapped, or vehicle/item repaired in repair department with a repair time between half an hour andan hour.	7
Moderate	Vehicle/Item operable but Comfort/Convenience item(s) inoperable. Customer dissatisfied.	Or a portion (less than 100%) of the productmay have to be scrapped with no sorting, or vehicle/item repaired in repair departmentwith a repair time less than half an hour.	6

Effect	(Customer effect)	(Manufacturing/ Assembly Effect)	Rank
Low	Vehicle/Item operable but Comfort/Convenience item(s) operable at a reduced level of performance. Customer somewhat dissatisfied.	Or 100% of product may have to be reworked, or vehicle/item repaired off-line but does not go to repair department.	5
Very Low	Fit and finish/Squeak and rattle item does not conform. Defect noticed by most customers (greater than 75%).	Or the product may have to be sorted, with no scrap, and a portion (less than 100%) reworked.	4
Minor	Fit and finish/Squeak and rattle item does not conform. Defect noticed by 50 percent of customers.	Or a portion (less than 100%) of the product may have to be reworked, with no scrap, online but out-of-station.	3
Very Minor	Fit and finish/Squeak and rattle item does not conform. Defect noticed by discriminating customers (less than 25 percent).	Or a portion (less than 100%) of the product may have to be reworked, with no scrap, online but in-station.	3
None	No discernible effect.	Or slight inconvenience to operation or operator, or no effect.	1

Table II - OCCURRENCE RATING TABLE

Probability of Failure	**Likely Failure Rates**	**Ranking**
Very High: Persistent failures	>=100 per thousand pieces	10
	50 per thousand pieces	9
High: Frequent failures	20 per thousand pieces	8
	10 per thousand pieces	7
Moderate: Occasional failures	5 per thousand pieces	6
	2 per thousand pieces	5
	1 per thousand pieces	4
Low: Relatively failures	.5 per thousand pieces	3
	.1 per thousand pieces	2
Remote: Failure is unlikely	<=.1 per thousand pieces	1

Table III - DEDUCTION RATING TABLE

Detection	Criteria	Suggested Range of Detection Methods	Ranking
Almost Impossible	Absolute certainty of non-Detection.	Cannot detect or is not checked.	10
Very Remote	Controls will probably not detect	Control is achieved with indirect or random checks only.	9
Remote	Controls have poor chance of Detection.	Control is achieved with visual inspection only.	8
Very Low	Controls have poor chance of Detection.	Control is achieved with double visual inspection only.	7
Low	Controls may detect.	Control is achieved with charting methods, such as SPC {Statistical Process Control}.	6
Moderate	Controls may detect.	Control is based on variable gaging after parts have left the station, OR Go/No Go gaging performed on 100% of the parts after parts have left the station.	5
Moderately High	Controls have a good chance to detect.	Error Detection in subsequent operations, OR gaging performed on setup and firstpiece check (for set-up Causes only).	4
High	Controls have a good chance to detect.	Error Detection in-station, OR error Detection in subsequent operations by multiple layers of acceptance: supply, select, install, verify.	3

Detection	Criteria	Suggested Range of Detection Methods	Ranking
Very High	Controls almost certain to detect.	Error Detection in-station (automatic gaging with automatic stop feature). Cannot pass discrepant part.	2
Very High	Controls certain to detect.	Discrepant parts cannot be made because item has been error proofed by process/product design.	1

Table IV - SIGMA AND DPMO CONVERSION TABLE (Source: ISI SQC unit, Bangalore)

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
0.01	931888	0.26	892512	0.51	838913	0.76	770350	1.01	687933	1.26	594835	1.51	496011	1.76	397432
0.02	930563	0.27	890651	0.52	836457	0.77	767305	1.02	684386	1.27	590954	1.52	492022	1.77	393580
0.03	929219	0.28	888767	0.53	833977	0.78	764238	1.03	680822	1.28	587064	1.53	488033	1.78	389739
0.04	927855	0.29	886860	0.54	831472	0.79	761148	1.04	677242	1.29	583166	1.54	484047	1.79	385908
0.05	926471	0.30	884930	0.55	828944	0.80	758036	1.05	673645	1.30	579260	1.55	480061	1.80	382089
0.06	925066	0.31	882977	0.56	826391	0.81	754903	1.06	670031	1.31	575345	1.56	476078	1.81	378281
0.07	923641	0.32	881000	0.57	823814	0.82	751748	1.07	666402	1.32	571424	1.57	472097	1.82	374484
0.08	922196	0.33	878999	0.58	821214	0.83	748571	1.08	662757	1.33	567495	1.58	468119	1.83	370700
0.09	920730	0.34	876976	0.59	818589	0.84	745373	1.09	659097	1.34	563559	1.59	464144	1.84	366928
0.10	919243	0.35	874928	0.60	815940	0.85	742154	1.10	655422	1.35	559618	1.60	460172	1.85	363169
0.11	917736	0.36	872857	0.61	813267	0.86	738914	1.11	651732	1.36	555670	1.61	456205	1.86	359424
0.12	916207	0.37	870762	0.62	810570	0.87	735653	1.12	648027	1.37	551717	1.62	452242	1.87	355691
0.13	914656	0.38	868643	0.63	807850	0.88	732371	1.13	644309	1.38	547758	1.63	448283	1.88	351973
0.14	913085	0.39	866500	0.64	805106	0.89	729069	1.14	640576	1.39	543795	1.64	444330	1.89	348268
0.15	911492	0.40	864334	0.65	802338	0.90	725747	1.15	636831	1.40	539828	1.65	440382	1.90	344578
0.16	909877	0.41	862143	0.66	799546	0.91	722405	1.16	633072	1.41	535856	1.66	436441	1.91	340903
0.17	908241	0.42	859929	0.67	796731	0.92	719043	1.17	629300	1.42	531881	1.67	432505	1.92	337243
0.18	906582	0.43	857690	0.68	793892	0.93	715661	1.18	625516	1.43	527903	1.68	428576	1.93	333598
0.19	904902	0.44	855428	0.69	791030	0.94	712260	1.19	621719	1.44	523922	1.69	424655	1.94	329969
0.20	903199	0.45	853141	0.70	788145	0.95	708840	1.20	617911	1.45	519939	1.70	420740	1.95	326355
0.21	901475	0.46	850830	0.71	785236	0.96	705402	1.21	614092	1.46	515953	1.71	416834	1.96	322758
0.22	899727	0.47	848495	0.72	782305	0.97	701944	1.22	610261	1.47	511967	1.72	412936	1.97	319178
0.23	897958	0.48	846136	0.73	779350	0.98	698468	1.23	606420	1.48	507978	1.73	409046	1.98	315614
0.24	896165	0.49	843752	0.74	776373	0.99	694974	1.24	602568	1.49	503989	1.74	405165	1.99	312067
0.25	894350	0.50	841345	0.75	773373	1.00	691462	1.25	598706	1.50	500000	1.75	401294	2.00	308538

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
2.01	305026	2.26	223627	2.51	156248	2.76	103835	3.01	65522	3.26	39204	3.51	22216	3.76	11911
2.02	301532	2.27	220650	2.52	153864	2.77	102042	3.02	64256	3.27	38364	3.52	21692	3.77	11604
2.03	298056	2.28	217695	2.53	151505	2.78	100273	3.03	63008	3.28	37538	3.53	21178	3.78	11304
2.04	294598	2.29	214764	2.54	149170	2.79	98525	3.04	61780	3.29	36727	3.54	20675	3.79	11011
2.05	291160	2.30	211855	2.55	146859	2.80	96801	3.05	60571	3.30	35930	3.55	20182	3.80	10724
2.06	287740	2.31	208970	2.56	144572	2.81	95098	3.06	59380	3.31	35148	3.56	19699	3.81	10444
2.07	284339	2.32	206108	2.57	142310	2.82	93418	3.07	58208	3.32	34379	3.57	19226	3.82	10170
2.08	280957	2.33	203269	2.58	140071	2.83	91759	3.08	57053	3.33	33625	3.58	18763	3.83	9903
2.09	277595	2.34	200454	2.59	137857	2.84	90123	3.09	55917	3.34	32884	3.59	18309	3.84	9642
2.10	274253	2.35	197662	2.60	135666	2.85	88508	3.10	54799	3.35	32157	3.60	17864	3.85	9387
2.11	270931	2.36	194894	2.61	133500	2.86	86915	3.11	53699	3.36	31443	3.61	17429	3.86	9137
2.12	267629	2.37	192150	2.62	131357	2.87	85344	3.12	52616	3.37	30742	3.62	17003	3.87	8894
2.13	264347	2.38	189430	2.63	129238	2.88	83793	3.13	51551	3.38	30054	3.63	16586	3.88	8656
2.14	261086	2.39	186733	2.64	127143	2.89	82264	3.14	50503	3.39	29379	3.64	16177	3.89	8424
2.15	257846	2.40	184060	2.65	125072	2.90	80757	3.15	49471	3.40	28716	3.65	15778	3.90	8198
2.16	254627	2.41	181411	2.66	123024	2.91	79270	3.16	48457	3.41	28067	3.66	15386	3.91	7976
2.17	251429	2.42	178786	2.67	121001	2.92	77804	3.17	47460	3.42	27429	3.67	15003	3.92	7760
2.18	248252	2.43	176186	2.68	119000	2.93	76359	3.18	46479	3.43	26803	3.68	14629	3.93	7549
2.19	245097	2.44	173609	2.69	117023	2.94	74934	3.19	45514	3.44	26190	3.69	14262	3.94	7344
2.20	241964	2.45	171056	2.70	115070	2.95	73529	3.20	44565	3.45	25588	3.70	13903	3.95	7143
2.21	238852	2.46	168528	2.71	113140	2.96	72145	3.21	43633	3.46	24998	3.71	13553	3.96	6947
2.22	235762	2.47	166023	2.72	111233	2.97	70781	3.22	42716	3.47	24419	3.72	13209	3.97	6756
2.23	232695	2.48	163543	2.73	109349	2.98	69437	3.23	41815	3.48	23852	3.73	12874	3.98	6569
2.24	229650	2.49	161087	2.74	107488	2.99	68112	3.24	40929	3.49	23295	3.74	12545	3.99	6387
2.25	226627	2.50	158655	2.75	105650	3.00	66807	3.25	40059	3.50	22750	3.75	12224	4.00	6210

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
4.01	6037	4.26	2890	4.51	1306	4.76	557	5.01	224	5.26	85	5.51	30.4	5.76	10.2
4.02	5868	4.27	2803	4.52	1264	4.77	538	5.02	216	5.27	82	5.52	29.1	5.77	9.8
4.03	5703	4.28	2718	4.53	1223	4.78	519	5.03	208	5.28	78	5.53	27.9	5.78	9.4
4.04	5543	4.29	2635	4.54	1183	4.79	501	5.04	200	5.29	75	5.54	26.7	5.79	8.9
4.05	5386	4.30	2555	4.55	1144	4.80	483	5.05	193	5.30	72	5.55	25.6	5.80	8.5
4.06	5234	4.31	2477	4.56	1107	4.81	467	5.06	185	5.31	70	5.56	24.5	5.81	8.2
4.07	5085	4.32	2401	4.57	1070	4.82	450	5.07	179	5.32	67	5.57	23.5	5.82	7.8
4.08	4940	4.33	2327	4.58	1035	4.83	434	5.08	172	5.33	64	5.58	22.5	5.83	7.5
4.09	4799	4.34	2256	4.59	1001	4.84	419	5.09	165	5.34	62	5.59	21.6	5.84	7.1
4.10	4661	4.35	2186	4.60	968	4.85	404	5.10	159	5.35	59	5.60	20.7	5.85	6.8
4.11	4527	4.36	2118	4.61	936	4.86	390	5.11	153	5.36	57	5.61	19.8	5.86	6.5
4.12	4397	4.37	2052	4.62	904	4.87	376	5.12	147	5.37	54	5.62	19.0	5.87	6.2
4.13	4269	4.38	1988	4.63	874	4.88	362	5.13	142	5.38	52	5.63	18.1	5.88	5.9
4.14	4145	4.39	1926	4.64	845	4.89	350	5.14	136	5.39	50	5.64	17.4	5.89	5.7
4.15	4025	4.40	1866	4.65	816	4.90	337	5.15	131	5.40	48	5.65	16.6	5.90	5.4
4.16	3907	4.41	1807	4.66	789	4.91	325	5.16	126	5.41	46	5.66	15.9	5.91	5.2
4.17	3793	4.42	1750	4.67	762	4.92	313	5.17	121	5.42	44	5.67	15.2	5.92	4.9
4.18	3681	4.43	1695	4.68	736	4.93	302	5.18	117	5.43	42	5.68	14.6	5.93	4.7
4.19	3573	4.44	1641	4.69	711	4.94	291	5.19	112	5.44	41	5.69	14.0	5.94	4.5
4.20	3467	4.45	1589	4.70	687	4.95	280	5.20	108	5.45	39	5.70	13.4	5.95	4.3
4.21	3364	4.46	1538	4.71	664	4.96	270	5.21	104	5.46	37	5.71	12.8	5.96	4.1
4.22	3264	4.47	1489	4.72	641	4.97	260	5.22	100	5.47	36	5.72	12.2	5.97	3.9
4.23	3167	4.48	1441	4.73	619	4.98	251	5.23	96	5.48	34	5.73	11.7	5.98	3.7
4.24	3072	4.49	1395	4.74	598	4.99	242	5.24	92	5.49	33	5.74	11.2	5.99	3.6
4.25	2980	4.50	1350	4.75	577	5.00	233	5.25	88	5.50	32	5.75	10.7	6.00	3.4

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