Unit V

Quality

- Quality has been an age-old concern. The discerning customer in shops and market places has applied "quality techniques,"
- If the products were not adequate, the purchase would not take place.
- In the hustle and bustle of cattle markets farmers argued and bartered over the fitness of animals for breeding, dairy farming or consumption, providing evidence for their case by inspection against criteria learned from their forefathers. Those shoppers and farmers passed on their knowledge to their children and similarly it was passed on to their children's children

- The issue of quality of goods and services is not new. Throughout history, society has demanded that providers of goods and services should meet their obligations
- As long ago as 1700 BC King Hammurabi of Babylon introduced the concept of product quality and liability into the building industry of the time by declaring

- **Quality in the Middle Ages**
  - The maintenance of quality was one of the key functions of the craft guilds of the middle ages with only those workers who could achieve acceptable quality standards being admitted to membership

- Skilled craftsmen produced high quality products and had pride in their work. Tradesmen gained a reputation for quality products through skilled craftsmanship that was maintained over time by enforcing lengthy apprenticeship of newcomers to masters-of-the-trade

- Quality during the Industrial Revolution
  - The industrial revolution revolutionized the manufacturing of products. Mass production set in large factories employing armies of people gave rise to new management ways.
  - There were workers, supervisors and foremen, and managers. The establishment of factories and of this new organizational structure led to the withering of many small business trades and the removal of apprentices and masters from positions.

- Frederick Taylor's scientific management brought in efficient operations to increase output through mass production by breaking down jobs into parts with each part carried out by individual specialized workers.
- In 1931, W. A. Shewhart of the famous AT&T Bell Laboratories, published Economic Control of Quality of Manufactured Product.
- A precise and measurable definition of manufacturing control was worked out. Stringent techniques for monitoring and evaluating day-to-day production and improving quality were dictated

- In 1932, Shewhart visited the University of London to lecture and to discuss his and others' research ideas
- This visit attracted significant interest which led to the formation of the Industrial and Agricultural Section of the Royal Statistical Society and the publication by the British Standards Institute (BSI) of the first standard on quality control.
- Japanese businessman Konosuke Matsushita-- the founder of one of the world's largest electronics groups-- was greatly influenced by the work of Henry Ford.

- From Ford, Matsushita was inspired by the prospect of mass production and also the concept of using price reductions to generate more sales.
- The broader view of Matsushita was as follows:
- a. Employees are important – not mere functionaries ensuring a steady stream of products are produced.
- b. Customers are of course important.
- c. Suppliers are also important - Matsushita was visiting the factories of his suppliers in the 1930s and giving them advice on how to produce their products more effectively.
- d. If there is an effective partnership, all sides win and society benefits from the prosperity generated.

- Development of the Importance of Quality Management
  - The success of Japanese manufacturers during the 1960s and 1970s changed the emphasis from a quality control approach to a quality assurance approach requiring more of the business functions to be involved in the management of quality
  - By the 1970s the Japanese had become "masters" at achieving quality in their manufacturing sector.
  - They built on the technology transfer that had happened from the West to Japan.
  - Even today, the Japanese remain hungry for new innovative ideas sending their senior academicians to leading research groups in the West. They have not given up their quest for superior production by continuous improvement in knowledge, methods and techniques.

- The Japanese quality revolution enabled them to achieve immense economic power, dominating world trade.
- The Japanese success story urged some managers in Western and other countries to wake up to the quality issue. People recognized that Japanese success was not only due to national, cultural and social differences but also reflected strongly a new attitude and desire of Japanese management to ensure that consumers receive what is promised.
- By the 1980s Japan's huge success made evident the direct link between quality and viability of organizations and economies.

- The development of International Quality Assurance Management System Standards in the 1980s also acted as a catalyst in many countries, setting off joint management and quality thinking.
- The Japanese rapidly went beyond quality in production, recognizing the importance of quality in management. They devised several strategies that formed the basis of much of today's international efforts. These are summarized below:
- i) Senior managers should personally take charge of quality management implementation
- ii) Personnel from all levels and functions of an organization should undergo training in quality management
- iii) Quality improvement should be continuous
- iv) The workforce should participate in quality improvement

- Culture is the key to understanding and implementing the lessons preached by both Deming and Juran
- This combination of culture and measurement eventually evolved into what is now labeled Total Quality Management
- Total Quality Management everyone in the organization is involved in developing an improvement and prevention orientation which focuses upon the customer through teamwork. The 1990s has seen quality management become the international management philosophy continuing into the new millennium today.

- What is quality?
- The Oxford American Dictionary defines quality as "a degree or level of excellence." The definition of quality by the American National Standards Institute (ANSI) and the American Society for Quality Control (ASQC) is "the totality of features and characteristics of a product or service that bears on its ability to satisfy given needs." Quality can be defined in many ways, depending on who is defining it and to what product or service it is related.

- A wide variety of approaches to defining quality are evident. For example:
- i) Quality is defined as being about value (Feigenbaum, 1983)
- ii) Quality is conformance to standards, specifications or requirements (Crosby, 1979)
- iii) Quality is fitness for use (Juran, 1989)
- iv) Quality as excellence (Peters and Waterman, 1982)
- v) Quality is concerned with meeting or exceeding customer expectations (Parasuraman et al., 1985)
- vi) Quality means delighting the customer (Peters, 1989

- **TQM**
- Basic Concepts of TQM
- Total Quality Management (TQM) is an enhancement to the traditional way of doing business. It is a proven technique guaranteeing survival in world-class competition
- Total Quality Management (TQM) is a comprehensive and structured approach to organizational management that seeks to improve the quality of products and services through ongoing refinements in response to continuous feedback

- Analyzing the three words, we have:
- • Total-- Make up of the whole
- • Quality-- Degree of excellence a product or service provides
  • Management-- Act, art, or manner of handling, controlling, directing etc.
- TQM is an art of managing the whole to achieve excellence. TQM is also defined as both a philosophy and a set of benchmarks that represent the foundation of a continuously improving organization.
- TQM integrates fundamental management techniques, existing improvement efforts and technical tools under a disciplined approach.

Principles of Total Quality Management

- TQM is based on the following principles:
- Primary responsibility for product quality rests with top management-- Management should create an organizational structure, product design process, production process and incentive that encourages and rewards good quality
- Quality should be customer focused and evaluated using customer-based standards-- A product is not easy to use and a service is not courteous and prompt unless customers say they are.

- This fact requires organizations to work closely with their customers to determine what the customers want in the products and how they receive value from the products.
- The production process and work methods should be designed consciously to achieve quality conformance-
- Using the right tools and equipment, mistake-proofing processes, training workers in the best methods and providing good work environment help to prevent defects rather than catching them
- Every employee is responsible for achieving good product quality-- This translates into self-inspection by workers themselves rather than by separate quality control personnel

- Quality cannot be inspected in a product, so make it right the first time-- Making it right or doing it right the first time should be the goal of every worker
- Quality should be monitored to identify problems quickly and correct quality problems immediately-- Statistical methods can play a useful role in monitoring quality and identifying problems quickly
- The organization should strive for continuous improvement-- Excellent product quality is the result of workers striving to improve product quality and productivity on an ongoing basis using experience and experimentation.

- Companies should work with their suppliers and extend TQM programs to them to ensure quality inputs–
- The success of Japanese in producing quality products can be attributed to the following:
- 1. Their willingness to borrow and synthesize ideas from many sources
- 2. The effort of each organization to customize the quality system to its own character.

Basic Approach

- 1. A committed and involved management should provide long-term top-to-bottom organizational support-- All employees should participate in a quality program.
- A quality council should be established to develop a clear vision, set long-term goals and direct the program
- Quality goals are included in the business plan. An annual quality improvement program involves input from the entire workforce
- Managers participate in quality improvement teams and also act as coaches to other teams.
- TQM is a continual activity and should be entrenched in the culture. It means that it is not just a one-shot program. TQM should be communicated to all people.

- 2. The key to an effective TQM program is its focus on customers. An excellent place to start is by satisfying internal customers. One should always listen to the "voice of the customer" and emphasize on design quality and defect prevention.
- 3. Effective involvement and utilization of the entire work force-- TQM is an organization wide challenge that is everyone's responsibility
- All personnel should be trained in TQM, statistical process control (SPC) and other appropriate quality improvement skills to effectively participate in project teams.
- Including internal customers and, for that matter, internal suppliers on project teams is an excellent approach

- People should come to work not only to do their jobs but also to think about how to improve their jobs
- 4. Continuous improvement of business and production process
- There should be a continual striving to improve all business and production processes. Quality improvement projects such as on-time delivery, order entry efficiency, billing error rate, customer satisfaction, cycle time, scrap reduction and supplier management are good areas to begin.
- 5. Treating suppliers as partners-- On an average, 40% of the sales dollars is the purchase of product or service, therefore, the supplier quality should be outstanding.

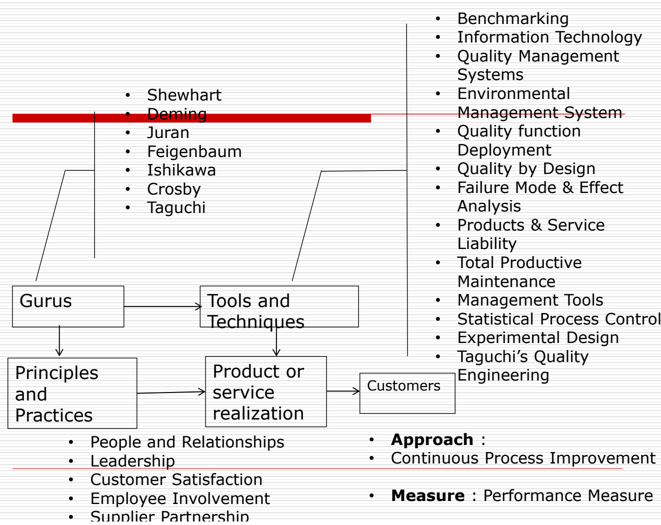
- A partnering relationship rather than an adversarial one should be developed. Both parties have as much to gain or lose based on the success or failure of a product or service.
- 6. Establish performance measures for the processes-- Performance measures such as uptime, percent nonconforming, absenteeism and customer satisfaction should be determined for each functional area. These measures should be posted for everyone to see. Quantitative data are necessary to measure the continuous quality improvement activity.

- The purpose of TQM is to provide a quality product and/or service to customers which will, in turn, increase productivity and decrease cost.
- With a higher quality product and lower price, competitive position in marketplace will be enhanced
- This series of events will allow an organization to achieve its objectives of profit and growth with greater ease.
- In addition, the workforce will have job security which will create a satisfying place to work.

- Table compares the previous state with the TQM state for typical quality elements.

Quality Element	Previous State	TQM
Definition	Product-orientated	Customer-oriented
Priorities	Second to service and cost	First among equals of service and cost
Decisions	Short-term	Long-term
Emphasis	Detection	Prevention
Errors	Operations	System
Responsibility	Quality control	Everyone
Problem Solving	Managers	Teams
Procurement	Price	Life-cycle costs, Partnership
Manager's Role	Plan, assign, control monitor	Delegate, coach facilitate and enforce

- Framework of TQM
- Figure shows the framework for a TQM system
- It begins with the knowledge provided by quality gurus-- Shewhart, Deming, Juran, Figenbaum, Ishikawa, Crosby and Taguchi
- As the figure shows, they contributed to the development of principles and practices and/or the tools and techniques. Some of these tools and techniques are used in the product and/or service realization activity. Feedback from internal/external customers or interested parties provides information to continually improve an organization's system, product and/or service.



- Awareness
- An organization will not begin the transformation to TQM until it is aware of the fact that the quality of product or service should be improved
- Awareness comes when an organization loses market share or realizes that quality and productivity go hand-in-hand
- It also occurs if TQM is mandated by a customer or if management realizes that TQM is a better way to run a business and compete in domestic and world markets

Obstacles

- Many organizations, especially small ones with a niche, feel comfortable with their current state. They are satisfied with the amount of work being performed, the profits realized and the perception that the customers are satisfied
- Organizations with this culture see little need for TQM until they begin to lose market share. Once an organization embarks on TQM, it faces some obstacles to its successful implementation. Some of the obstacles are as follows
- 1. Lack of Management Commitment
  - In order to make an organizational effort successful, there should be substantial management commitment of management time and organizational resources. The purpose should be clearly and continuously communicated to all personnel. Management should consistently apply the principles of TQM.

- 2. Inability to Change Organizational Culture
  - Changing an organization's culture is difficult and requires as much as five years. Individuals resist change as they become accustomed to doing a particular process and it becomes the preferred way.
  - Management should understand and utilize the basic concepts of change which are as follows:
  - i)People change when they want to and to meet their own needs.
  - ii) Never expect anyone to engage in behavior that serves an organization's values unless adequate reason (way) has been given.
  - iii) For change to be accepted, people should be moved from a state of fear to trust.
  - It is difficult for individuals to change their way of doing things. It is much more difficult for an organization to make cultural changes

- Organizations that spend more time in planning for the cultural aspects of implementing a TQM program will improve their chances of success.
- 3. Improper Planning
  - All constituents of an organization should be involved in the development of an implementation plan and any modifications that occur as the plan evolves. Of particular importance is the two-way communication of ideas among all personnel during the development of plan and its implementation.
  - The goal should be to achieve customer satisfaction not to achieve any financial or sales goals. Peterson Products, a metal stamping firm near Chicago, improved on-time delivery which resulted in a 25% increase in sales. Focus on quality and the other goals are considered thereafter.

- 4. Lack of Continuous Training and Education
  - Training and education is an ongoing process for everyone in an organization. Needs should be determined and a plan should be developed to achieve those needs
  - Training and education are the most effective when senior management conducts the training on the principles of TQM. Informal training occurs by communicating the TQM efforts to all personnel on a continual basis.

- 5. Incompatible Organizational Structure and Isolated Individuals and Departments
  - Differences between departments and individuals can create implementation problems. The use of multi-functional terms help to break down long-standing barriers
- 6. Ineffective Measurement Techniques and Lack of Access to Data and Results
  - The key characteristics of an organization should be measured in order to make effective decisions. In order to improve a process, one needs to measure an effect of improvement ideas. Access to data and quick retrieval is necessary to make a process effective
- 7. Paying Inadequate Attention to Internal and External Customers
  - Organizations need to understand the changing needs and expectations of their customers. Effective feedback mechanisms that provide data for decision making are necessary for this understanding.

- 8. Inadequate Use of Empowerment and Teamwork
  - Whenever possible, teams need to have the proper training and, atleast in the beginning, a facilitator and the team's recommendations should be followed. Individuals should be empowered to make decisions affecting the efficiency of their process or the satisfaction of their customers.
- 9. Failure to Improve Continually
  - It is tempting to sit back and rest on your laurels. However, a lack of continuous improvement of the process, product and/or service will even leave the leader of the pack in the dust.

- **Six Sigma**
- What is six sigma?
- Before moving forward in order to understand the concept of six sigma, let us first understand the term sigma and statistics
- Sigma
- The term sigma means standard deviation. Standard deviation measures how much variation exists in a distribution of data. It is a key factor in determining the acceptable number of defective units found in a population.

- Six sigma projects strive for no more than 3.4 defects per million opportunities, yet this number is confusing to many statisticians
- Standard Deviation
- Small standard deviation means that data cluster closely around the middle of a distribution and there is little variability among the data. Normal distribution is the bell-shaped curve that is symmetrical about the mean or average value of a population

- Definition
- Six sigma at many organizations simply means a measure of quality that strives for near perfection. Six sigma is a disciplined, data-driven approach and methodology for eliminating defects (driving toward six standard deviations between the mean and the nearest specification limit) in any process-- from manufacturing to transactional and from product to service

- Six sigma means a failure rate of 3.4 parts per million or 99.9997% perfect. However, the term in practice is used to denote more than simply counting defects
- Six sigma can now imply a whole culture of strategies, tools and statistical methodologies to improve the bottom line of companies. In all, six sigma is a rigorous analytical process for anticipating and solving problems
- The objective of six sigma is to improve profits through defect reduction, yield improvement, improved consumer satisfaction and best-in-class product/process performance.

- Unlike the statistical term, "sigma" is a measure of conformance to specification. Table below shows examples
- Six Sigma and Defective Units

Specification range	Percent of population within range	Defective units per billion
1	68.27	317,300,000
2	95.45	45,400,000
3	99.73	2,700,000
4	99.9937	63,000
5	99.999943	57
6	99.9999998	2

- Phases of Six Sigma
- There are six generic implementation phases for six sigma. These are as follows

- Establish management commitment
- Business diagnostics
- Develop the management infrastructure
- Business process identification and metrics
- Project selection
- Deployment
  - Training
  - Project execution
  - Review

- Why is it important?
- World-class companies typically operate at about four sigma or 99% perfection.
- To get to the six-sigma level means cutting down on huge costs and thereby wasted dollars.
- For example, if you were at four-sigma level, you would be producing products at the rate of 6,200 defectives for every million you produce vs. 3.4 defectives if you are at the six-sigma level
- Moreover, six sigma improvement projects typically return in excess of $150k to $250k per project with a black belt returning as much as $1 million to the bottom line each year.

- The popularity of six sigma is growing. Some of the companies that have successfully implemented six sigma are as follows
- Motorola (1987)
- Texas Instruments (1988)
- IBM (1990)
- Asea Brown Boveri (1993)
- Allied Signal/Kodak (1994)
- GE (1995)
- Whirlpool
- PACCAR
- Invensys and Polaroid (1996/98

- Recently, Ford, DuPont, Dow Chemical, Microsoft and American Express have started working on instituting six sigma processes

- **When to use it?**
- Bottom line drives management action
- What is your cost of (poor) quality?
- First you need to determine that.
- If properly implemented, six sigma implementation can become a profit center for the company.
- Jack Welch at GE claims that the returns on six sigma implementation amount to about $500 million as of 1998

- Remember that six sigma is complementary to other initiatives such as ISO or QS 9000 (which is mainly procedural), total quality management (which is mainly cultural), and statistical process control (which is primarily statistical process monitoring).
- **How to use it**
- Six sigma focuses on process quality. As such, it falls into the category of a process capability (Cp) technique
- Traditionally, a process is considered capable if the natural spread, plus and minus three sigma (a yield of 99.73%), was less than the engineering tolerance.

- A later refinement considered the process location as well as its spread (Cpk) and tightened the minimum acceptable so that the process was at least four sigma from the nearest engineering requirement.
- Six sigma requires that processes operate such that the nearest engineering requirement is at least plus or minus six sigma from the process mean
- Once you determine the process variables, using the other process analysis techniques, you need to consider the ones causing the major losses and work on making them more capable.

- Understand who your consumers are and what your product/service is
- Review consumer surveys, concession reports and other data
- Screen and prioritize issues by severity, frequency/ likelihood of occurrence etc
- Determine the internal processes causing most of the pain
- Find out why and where the defects are occurring
- Devise ways to address these defects effectively
- Setup a good metrics (six sigma places a lot of emphasis on measurement)

- There are a variety of nicknames for the principle players in the initiative
- Champions
  - o Executives with knowledge of six sigma methods
  - o Define projects
- Black belts
  - o Full-time position
  - o Lead improvement projects
  - o Serve as change agents
  - o Provide consulting to middle management
- Master black belts
  - o Full-time position
  - o Have additional training beyond black belt training
  - o Can train and coach black belts
  - o Provide consulting to management and champions

- • Green belts
- Have black belt training, but stay in present position
- **Champions and Sponsors**
- Six sigma champions are high-level individuals who understand six sigma and are committed to its success
- In larger organizations, six sigma will be led by a full time, high-level champion, such as an executive vice-president
- In all organizations, champions also include informal leaders who use six sigma in their day-to-day work and communicate the six sigma message at every opportunity.

- Who or what is a black belt?
  - A person who is part of the leadership structure for process improvement teams are called "black belts" (just as total quality utilized "quality improvement team leaders" to provide structure). Black belts are highly-regarded, technically-oriented product or line personnel who have the ability to lead teams as well as to advise management
- Black Belts
  - Candidates for black belt status are technically oriented individuals held in high regard by their peers.
  - They should be actively involved in the process of organizational change and development. Candidates may come from a wide range of disciplines and need not be formally trained statisticians or engineers

- However, because they are expected to master a wide variety of technical tools in a relatively short period of time, black belt candidates will probably possess a background including college-level mathematics and the basic tools of quantitative analysis.
- Successful candidates will be comfortable with computers. At a minimum, they should understand one or more operating systems, spreadsheets, database managers, presentation programs and word processors
- As part of their training, they will be required to become proficient in the use of one or more advanced statistical analysis software packages

- Six sigma black belts work to extract actionable knowledge from an organization's information warehouse.
- It makes no sense to hamstring these experts by saving a few dollars on computers or software.

- Master Black Belts-- Overview
- • Full-time position
- • Have additional training beyond black belt training
- • Can train and coach black belts
- • Provide consulting to management and champions

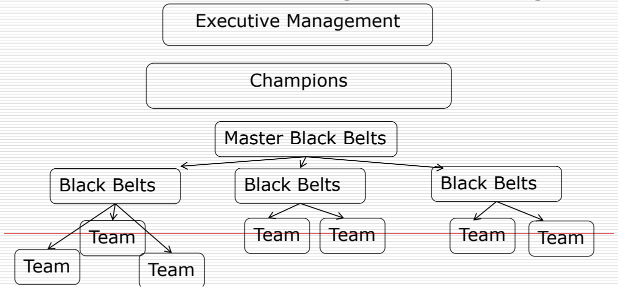
- Who or what is a master black belt?
  - A master black belt is a person trained in the six sigma methodology who acts as the organization-wide six sigma director or a program manager. He oversees black belts and process improvement projects and provides guidance to the black belts as required. A master black belt teaches other six sigma students and helps them achieve green belt and black belt status
- Master Black Belts
  - This is the highest level of technical and organizational proficiency. Master black belts provide technical leadership of the six sigma program

- Thus, they must know everything the black belts know, as well as understand the mathematical theory on which the statistical methods are based
- Master black belts must be able to assist black belts in applying the methods correctly in unusual situations
- Whenever possible, statistical training should be conducted only by master black belts. Otherwise, the familiar "propagation of error" phenomenon will occur, i.e. black belts pass on errors to green belts, who pass on greater errors to team members

- For example, black belts may be asked to provide assistance to the master during class discussions and exercises. Because of the nature of the master's duties, communications and teaching skills are as important as technical competence
- Green Belts-- Overview
- • Have black belt training, but stay in present position
- **Who or what is a green belt**?
- A green belt is a person trained in the six sigma methodology who is a team member of six sigma process improvement action teams.

- Green Belts
- Green belts are six sigma project leaders capable of forming and facilitating six sigma teams and managing six sigma projects from concept to completion
- Green belt training consists of five days of classroom training and is conducted in conjunction with six sigma projects.
- Training covers project management, quality management tools, quality control tools, problem solving and descriptive data analysis. Six sigma champions should attend green belt training.

- Usually, six sigma black belts help green belts define their projects prior to the training, attend training with their green belts and assist them with their projects after the training.
- The structure of a six sigma organization within a business would look something like the following:



- Who drives six sigma?
- Usually a top executive or senior manager who "talks the talk" and "walks the walk" of six sigma drives it. This person is the sponsor, a catalyst and the driving force behind the organization's six-sigma implementation
- Six sigma takes a handful of proven methods and trains a small cadre of in-house technical leaders known as six sigma black belts to a high level of proficiency in the application of these techniques.

- To be sure, some of the methods used by black belts are highly advanced, including the use of up-to-date computer technology
- But the tools are applied within a simple performance improvement model known as DMAIC, or Define-Measure-Analyze-Improve-Control. DMAIC can be described as follows:

D	**Define the goals of improvement activity. At the top level, the goals will be the strategic objectives of the organization, such as a higher ROI or market share. At the operations level, a goal might be to increase the throughput of a production department. At the project level goals might be to reduce the defect level and increase throughput. Apply data mining methods to identify potential improvement opportunities**
M	Measure the existing system. Establish valid and reliable metrics to help monitor progress toward the goal(s) defined in the previous step. Begin by determining the current baseline. Use exploratory and descriptive data analysis to help yourself understand the data
A	**Analyze the system to identify ways to eliminate the gap between the current performance of the system or process and the desired goal. Apply statistical tools to guide the analysis**
I	Improve the system. Be creative in finding new ways to do things better, cheaper or faster. Use project management and other planning and management tools to implement the new approach. Use statistical methods to validate the improvement
C	Control the new system. Institutionalize the improved system by modifying compensation and incentive systems, policies, procedures, MRP, budgets, operating instructions and other management systems. You may wish to utilize systems such as ISO 9000 to assure that documentation is correct

DEFECT REMOVAL EFFECTIVENESS

- Defect removal is one of the top expenses in any software project and it greatly affects schedules.
- Effective defect removal can lead to reductions in the development cycle time and good product quality.
- For improvements in quality, productivity, and cost, as well as schedule, it is important to use better defect prevention and removal technologies to maximize the effectiveness of the project.
- It is important for all projects and development organizations to measure the effectiveness of their defect removal processes.

- In the 1960s and earlier, only defect removal step was testing
- In the 1970s, formal reviews and inspections were recognized as important to productivity and product quality, and thus were adopted by development projects.
- Fagan (1976) touches on the concept of defect removal effectiveness. He defined error detection efficiency as:

$$\frac{\text{Errors found by an inspection}}{\text{Total errors in the product before inspection}} \times 100\%$$

- Jones, 1986 stated here, is very similar to Fagan's:

$$\text{Removal efficiency} = \frac{\text{Defects found by removal operation}}{\text{Defects present at removal operation}} \times 100\%$$

$$= \frac{\text{Defect found}}{\text{Defects found} + \underset{\text{(found later)}}{\text{Defects not found}}} \times 100\%$$

- From Ryan (1987) and Kolkhorst and Macina (1988):

$$\text{Early detection percentage} = \frac{\text{Number of major inspection errors}}{\text{Total number of errors}} \times 100\%$$

- The effectiveness measure by Dunn (1987) differs little from Fagan's and from Jones's second definition. Dunn's definition is:

$$E = \frac{N}{N+S} \times 100\%$$

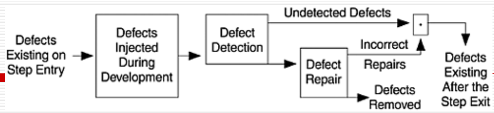
- E = Effectiveness of activity (development phase)
- N = Number of faults (defects) found by activity (phase)
- S = Number of faults (defects) found by subsequent activities (phases)
- According to Dunn (1987), this metric can be tuned by selecting only defects present at the time of the activity and susceptible to detection by the activity.

- To define defect removal effectiveness clearly, we must first understand the activities in the development process that are related to defect injections and to removals. Defects are injected into the product or intermediate deliverables of the product (e.g., design document) at various phases.
- Table shows an example of the activities in which defects can be injected or removed for a development process.

Development Phase	Defect Injection	Defect Removal
Requirements	Requirements-gathering process and the development of programming functional specifications	Requirement analysis and review
High-level design	Design work	High-level design inspections
Low-level design	Design work	Low-level design inspections
Code implementation	Coding	Code inspections
Integration/build	Integration and build process	Build verification testing
Unit test	Bad fixes	Testing itself
Component test	Bad fixes	Testing itself
System Test	Bad fixes	Testing itself

- For the testing phases, the testing itself is for defect removal.
- When the problems found by testing are fixed incorrectly, there is another chance to inject defects. In fact, even for the inspection steps, there are chances for bad fixes.
- Figure 6.3 describes the detailed mechanics of defect injection and removal at each step of the development process. From the figure, defect removal effectiveness for each development step, therefore, can be defined as:

$$\frac{\text{Defects removed (at the step)}}{\text{Defects existing on step entry} + \text{Defects injected during development (of the step)}} \times 100\%$$



- Note that defects removed is equal to defects detected minus incorrect repairs.
- In reality, however, it is extremely difficult to reliably track incorrect repairs. Assuming the percentages of incorrect repair or bad fixes are not high (based on my experience), defects removed can be approximated by defects detected.
- f the bad-fix percentage is high, one may want to adjust the effectiveness metric accordingly, if an estimate is available.

- To derive an operational definition, we propose a matrix approach by cross-classifying defect data in terms of the development phase in which the defects are found (and removed) and the phases in which the defects are injected.
- Let us look at the example

Defect Origin

Where Found	Requirements	High-Level Design	Low-Level Design	Code	Unit Test	Component Test	System Test	Field	Total
RQ	—			—					
I0	49	681							730
I1	6	42	681						729
I2	12	28	114	941					1095
UT	21	43	43	223	2				332
CT	20	41	61	261	—	4			387
ST	6	8	24	72	—	—	1		111
Field	8	16	16	40	—	—	—	1	81
Total	122	859	939	1537	2	4	1	1	3465

- Once the defect matrix is established, calculations of various effectiveness measures are straightforward.
- *High-Level Design Inspection Effectiveness; IE (I0)*

  Defects removed at I0 : 730

  Defects existing on step entry (escapes from requirements phase): 122

  Defects injected in current phase : 859

$$\text{IE (I0)} = \frac{730}{122 + 859} \times 100\% = 74\%$$

- *Low-Level Design Inspection Effectiveness; IE (I1)*
- Defects removed at I1: 729
- Defects existing on step entry (escapes from requirements phase and I0):

  122+859-730 = 251
- Defects injected in current phase: 939

$$\text{IE (I1)} = \frac{729}{251 + 939} \times 100\% = 61\%$$

- *Code Inspection Effectiveness; IE (I2)*
- Defects removed at I1: 1095
- Defects existing on step entry (escapes from requirements phase, I0 and I1):

  122 +859+939-730-729 = 461

- Defects injected in current phase: 1537

$$\text{IE (I2)} = \frac{1095}{461 + 1537} \times 100\% = 55\%$$

- *Unit Test Effectiveness; TE (UT)*
- Defects removed at I1: 332
- Defects existing on step entry (escapes from all previous phases):

  122+859+939+1537-730-729-1095 = 903
- Defects injected in current phase (bad fixes): 2

$$\text{TE (UT)} = \frac{332}{903 + 2} \times 100\% = \frac{332}{905} \times 100\% = 37\%$$

- For the testing phases, the defect injection (bad fixes) is usually a small number. In such cases, effectiveness can be calculated by an alternative method (Dunn's formula or Jones's second formula as discussed earlier). In cases with a high bad-fixes rate, the original method should be used.

$$\text{Effectiveness} = \frac{\text{Defects removed at current phase}}{\text{Defects removed at current phase} + \text{Defects removed at subsequent phases}} \times 100\%$$

$$\text{TE (UT)} = \frac{332}{332 + 387 + 111 + 81} \times 100\% = \frac{332}{911} \times 100\% = 36\%$$

- *Component Test Effectiveness; TE (CT)*

$$\text{TE (CT)} = \frac{387}{387+111+81} \times 100\% = 67\%$$

- *System Test Effectiveness; TE (ST)*

$$\text{TE (ST)} = \frac{111}{111+81} \times 100\% = 58\%$$

- *Overall Inspection Effectiveness; IE*

$$\text{IE} = \frac{730+729+1095}{122+859+939+1537} \times 100\% = \frac{2554}{3457} \times 100\% = 74\%$$

- *Overall Test Effectiveness; TE*

$$\text{TE} = \frac{332+387+111}{332+387+111+81} \times 100\% = 91\%$$

- *Overall Defect Removal Effectiveness of the Process; DRE*

$$\text{DRE} = \left(1 - \frac{81}{3465}\right) \times 100\% = 97.7\%$$

- To summarize, the values of defect removal effectiveness from this example are as follows:
- I0: 74%
- I1: 61%
- I2: 55%
- Overall Inspection Defect Removal Effectiveness: 74%
- UT: 36%
- CT: 67%
- ST: 58%
- Overall Test Defect Removal Effectiveness: 91%
- Overall Defect Removal Effectiveness of the Process: 97.7%

- From the matrix of Figure it is easy to understand that phase defect removal effectiveness refers to the overall ability of the phase inspection to remove defects that were present at that time.

Defect Removal Effectiveness and Quality Planning

- Phase defect removal effectiveness and related metrics associated with effectiveness analysis (such as defect removal and defect injection rates) are useful for quality planning and quality management.
- These measurements clearly indicate which phase of the development process we should focus on for improvement (e.g., unit testing in our example)

- Effectiveness analyses can be done for the entire project as well as for local areas, such as at the component level and specific departments in an organization, and the control chart technique can be used to enforce consistent improvement across the board
- Phase-Based Defect Removal Model
- The phase-based defect removal model (DRM) summarizes the relationships among three metrics—defect injection, defect removal, and effectiveness.

- The DRM takes a set of error-injection rates and a set of phase-effectiveness rates as input, then models the defect removal pattern step by step. It takes a simplified view of Figure and works like this:

Defects at exit of a development step = Defects escaped from previous step
+ Defects injected in current step
– Defects removed in current step

Phase	Defects/KLOC (removal)	Defect Injection per KLOC	Total Defect Injection (%)
Requirements	-	1.2 (122)	3.5 (122/3465)
High-level design	7.3 (730/1000)	8.6 (859)	24.9(860/3465)
Low-level design	7.3	9.4 (939)	27.2(939/3465)
Code	11.0	15.4	44.5
Unit test	3.3		
Component test	3.9		
System test	1.1		
Total	33.9	34.6	100.1

- DRM is a quality management tool, not a device for software reliability estimation.
- DRM cannot reliably estimate the product quality level. It cannot do so because the error injection rates may vary from case to case even for the same development team.

- **Example of Phase-Based Defect Removal Model**

Phase	Defect Escaped from Prev. phase (A)	Defect Injection (B)	Subtotal (A+B)	Removal Effectiveness	Defect Removal	Defects at Exit
Requirements	-	1.2	1.2	-	-	1.2
High-level design	1.2	8.6	9.82	× 74%	= 7.3	2.5 (1.2+8.6-7.3)
Low-level design	2.5	9.4	11.9	× 61%	= 7.3	4.6
Code	4.6	15.4	20.0	55%	= 11.0	9.0
Unit test	9.0		9.0	× 36%	= 3.2	5.8

Phase	Defect Escaped from Prev. phase	Defect Injection	Subtotal	Removal Effectiveness	Defect Removal	Defects at Exit
Component test	5.8	-	5.8	× 67%	= 3.9	1.9
System test	1.9	-	1.9	× 58%	= 1.1	0.8
Field Test	0.8					

- Some Characteristics of a Special Case Two-Phase Model
- Remus and Zilles (1979) elaborate the mathematical relationships of defect removal effectiveness, the number of defects found during the front end of the development process (before the code is integrated), the number found during testing, and the number remaining when the product is ready to ship to customers. They derived some interesting characteristics of the defect removal model in a special case:
- 1. There are only two phases of defect removal.
- 2. The defect removal effectiveness for the two phases is the same.

- The percentage of bad fixes is one of the parameters in the Remus and Zilles model; the derivation involves more than twenty formulas. Here we take a simplified approach without taking bad fixes into account. Interestingly, despite taking a different approach, we arrive at the same conclusion as Remus and Zilles did.
- Assume there are two broad phases of defect removal activities:
- 1. Those activities handled directly by the development team (design reviews, code inspections, unit test) for large software projects take place before the code is integrated into the system library.
- 2. The formal machine tests after code integration.

- Further assume that the defect removal effectiveness of the two broad phases is the same. Define:

MP	=Major problems found during reviews/inspections and unit testing (from phase 1); these are the problems that if not fixed, will result in testing defects or defects in the field.
PTR	=Problem tracking report after code integration: errors found during formal machine tests.
μ	=MP/PTR, μ>1 (Note: The higher the value of μ, the more effective the front end.)
Q	= Number of defects in the released software—defects found in the field (customer usage).
TD	=Total defects for the life of the software = MP + PTR + Q.

- Furthermore, from the definition of μ:

- We find that Equations can be useful for quality planning. Given the number of MP and μ, or PTR and μ, one can estimate the number of defects that remained in the product by Equations.

- $Q = TD / \mu^2$

Availability Metrics

- In this Internet age of network computing, one of the most critical quality attributes is system and network availability, along with reliability and security.
- Requirements for high availability by mission-critical operations have existed since society became reliant on computer technologies.
- In the Internet age, software code is distributed across networks and businesses increasingly share data, a lack of system availability is significantly increasing adverse impacts.

Definition and Measurements of System Availability

- Intuitively, system availability means the system is operational when you have work to do. The system is not down due to problems or other unplanned interruptions
- In measurement terms, system availability means that the system is available for use as a percentage of scheduled uptime. The key elements of this definition include:
- The frequency of system outages within the time frame for the calculation
- The duration of outages
- Scheduled uptime

- The frequency of outages is a direct reliability statement.
- The duration of outages reflects the severity of the outages It is also related to the recovery strategies, service responsiveness, and maintainability of the system
- Scheduled uptime is a statement of the customer's business requirements of system availability. It could range from 5 x 8 (5 days a weeks, 8 hours a day) to 7 x 24 (7 days a week, 24 hours a day) or 365 x 24 (365 days a year, 24 hours a day).
- The inverse measurement of system availability is the amount of down time per system per time period (for example, per year).

- If scheduled up-time is known or is a constant (for example, for the 7 x 24 businesses), given the value of one measurement, the other can be derived.
- Table 1 shows some examples of system availability and hours in down time per system per year.

System Availability (24 x365)	Down time per system per year
99.999	5.3 minutes
99.99	52.6 minutes
99.95	4.4 hours
99.90	8.8 hours
99.8	17.5
99.0	87.6 hours
98.0	175.2
97.5	219.0 hour

- In a study of cost of server ownership in enterprise relations management (ERM) customer sites, the consulting firm IDC (2001) compared the availability of three server platforms, which we relabeled as platforms A, B, and C for this discussion.
- The availability of these three categories of servers for ERM solutions are 99.98%, 99.67%, and 99.90%, respectively.
- Since system availability has a direct impact on user productivity, IDC called the availability-related metrics productivity metrics
- shows a summary of these metrics. For details, see the original IDC report.

User Productivity	Platform A Solution	Platform B Solution	Platform C Solution
Unplanned Downtime Hours per Month	0.24	2.7	1
Percent of Internal Users Affected	42	63	53
Unplanned User Downtime (Hours per Year/100 Users)	1,235	20,250	6,344
Availability (%)	99.98	99.67	99.9

- To achieve a certain level of system availability, the availability of the components has to be higher. For example, if the availability of a system's software is 99.95% and that of the hardware is 99.99%, then the system availability is 99.94% (99.99% x 99.95%).

- Quality Management Models
  - It is important to assess the quality of a software product, project the number of defects, or estimate the mean time to next failure when development work is complete
  - It is more important to monitor and manage the quality of the software when it is under development. Such a task is the purpose of the software quality management models and in-process metrics
  - The following sections describe models that we have developed or have used.
- The Rayleigh Model Framework
- Perhaps the most important principle in software engineering is "do it right the first time.

- This principle speaks to the importance of managing quality throughout the development process. Our interpretation of the principle, in the context of software quality management, is threefold:
- The best scenario is to prevent errors from being injected into the development process.
- When errors are introduced, improve the front end of the development process to remove as many of them as early as possible.
- If the project is beyond the design and code phases, unit tests and any additional tests by the developers serve as gatekeepers for defects to escape the front-end process before the code is integrated into the configuration management system (the system library).

- The Rayleigh model is a good overall model for quality management. It articulates the points on defect prevention and early defect removal related to the preceding items.
- Based on the model, if the error injection rate is reduced, the entire area under the Rayleigh curve becomes smaller, leading to a smaller projected field defect rate
- Also, more defect removal at the front end of the development process will lead to a lower defect rate at later testing phases and during maintenance. Both scenarios aim to lower the defects in the latter testing phases, which in turn lead to fewer defects in the field

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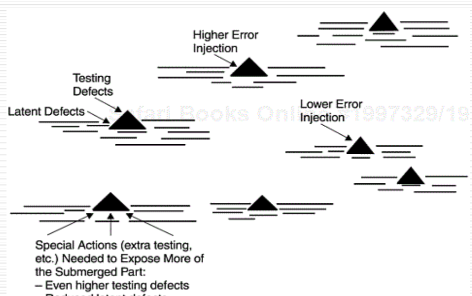
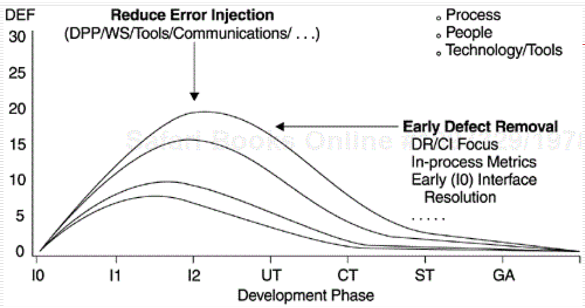
- The reason is that at the late stage of formal testing, error injection of the development process (mainly during design and code implementation) is basically determined (except for bad fixes during testing). High testing defect rates indicate that the error injection is high; if no extra effort is exerted, more defects will escape to the field.
- If we use the iceberg analogy to describe the relationship between testing and field defect rates, the tip of the iceberg is the testing defect rate and the submerged part is the field defect rate
- The size of the iceberg is equivalent to the amount of error injection.
- By the time formal testing starts, the iceberg is already formed and its size determined.

- The larger its tip, the larger the entire iceberg. To reduce the submerged part, extra effort must be applied to expose more of the iceberg above the water.

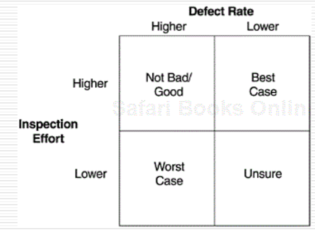


- The Rayleigh framework can serve as the basis for quality improvement strategy—especially the two principles associated with defect prevention and early defect removal.
- For each direction, actions are formulated and implemented. For instance, to facilitate early defect removal, actions implemented include focus on the design review/code inspection (DR/CI) process; deployment of moderator training (for review and inspection meeting); use of an inspection checklist;
- use of in-process escape measurements to track the effectiveness of reviews and inspections;
- Plans and actions to reduce error injection include the laboratory-wide implementation of the defect prevention process; the use of CASE tools for development;



- The ultimate target of IBM Rochester's strategy is to achieve the defect injection/removal pattern represented by the lowest curve, one with an error injection rate similar to that of IBM Houston's space shuttle software projects. In the figure, the Y-axis represents the defect rate. The development phases represented by the X-axis are high-level design review (I0), low-level design review (I1), code inspection (I2), unit test (UT), component test (CT), system test (ST), and product general availability (GA, or field quality, Fd).
- For instance, at IBM Rochester the metric of inspection effort is used as a proxy indicator for how rigorous the inspection process is executed.

- Specifically, a 2 × 2 matrix such as that shown in Figure can be used. The high—low comparisons are between actual data and the model, or between the current and previous releases of a product. Each of the four scenarios imparts valuable information.

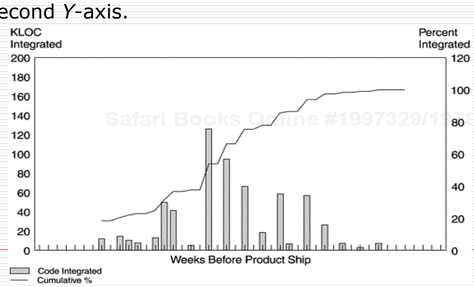


- ***Best case scenario—high effort/low defect rate:*** The design/code was cleaner before inspections, and yet the team spent enough effort in DR/CI (design review/code inspection) that good quality was ensured.
- ***Good/not bad scenario—high effort/high defect rate:*** Error injection may be high, but higher effort spent is a positive sign and that may be why more defects were removed. If effort is significantly higher than the model target, this may be a good scenario.
- ***Unsure scenario—low effort/low defect rate:*** Not sure whether the design and code were better, therefore less time was needed for inspection or inspections were hastily done, so fewer defects were found. In this scenario, we need to rely on the team's subjective assessment and other information for a better determination.

- ***Worst case scenario—low effort/high defect rate:*** High error injection but inspections were not rigorous enough. Chances are more defects remained in the design or code at the exit of the inspection process.

- Code Integration Pattern
- Among the major phases of any development process code development is perhaps the most fundamental activity.
- Completion of coding and unit testing, and therefore the integration of code into the system library is perhaps the most concrete intermediate deliverable of a project.
- code completion by no means implies that the project is near completion.
- The earlier the code is complete and integrated into the system library relative to the project completion date, the better chance it will be adequately tested.

- Figure shows the code integration pattern of a systems software relative to the product's ship date. The vertical bars are the amount of code completed and integrated into the system library over time. Their values are expressed via the first *Y*-axis. The S curve is the cumulative percentage of code integrated over time, and is represented by the second *Y*-axis.



- The PTR Submodel
- Many development organizations testing defects are tracked via some kind of problem tracking report (PTR), which is a part of the change control process during testing
- Valid PTRs are, therefore, valid code defects. It is a submodel because it is part of the overall defect removal model.
- PTR submodel spreads over time the number of defects that are expected to be removed during the machine-testing phases so that more precise tracking is possible. It is a function of three variables:
- Planned or actual lines of code integrated over time
- Expected overall PTR rate (per thousand lines of code or per function point)
- PTR-surfacing pattern after the code is integrated

- To derive the PTR model curve, the following steps can be used:
- Determine the code integration plan; plot the lines of code (or amount of function points) to be integrated over time (see Figure .
- For each code integration, multiply the expected PTR rate by the KLOC for each planned integration to get the expected number of PTRs for each integration.
- Spread over time the number of PTRs for each integration based on the PTR spread pattern and sum the number of PTRs for each time point to get the model curve.
- Update the model when the integration plan (e.g., KLOC to be integrated over time) changes or actual integration data become available.

- Plot the curve and track the current project in terms of months from the product’s general availability (GA) date.
- A calculator or a simple spreadsheet program is sufficient for the calculations involved in this model.
- Figure shows an example of the PTR submodel with actual data. The code integration changes over time during development, so the model is updated periodically.