MODULE--5

SOFTWARE RELIABILITY --

Reliability of a software product essentially denotes its trustworthiness or dependability. Alternatively, reliability of a software product can also be defined as the probability of the product working "correctly" over a given period of time.

It is obvious that a software product having a large number of defects is unreliable. It is also clear that the reliability of a system improves, if the number of defects in it is reduced. However, there is no simple relationship between the observed system reliability and the number of latent defects in the system. For example, removing errors from parts of software which are rarely executed makes little difference to the perceived reliability of the product. It has been experimentally observed by analyzing the behavior of a large number of programs that 90% of the execution time of a typical program is spent in executing only 10% of the instructions in the program. These most used 10% instructions are often called the core of the program. The rest 90% of the program statements are called non-core and are executed only for 10% of the total execution time. It therefore may not be very surprising to note that removing 60% product defects from the least used parts of a system would typically lead to only 3% improvement to the product reliability. It is clear that the quantity by which the overall reliability of a program improves due to the correction of a single error depends on how frequently the corresponding instruction is executed.

Thus, reliability of a product depends not only on the number of latent errors but also on the exact location of the errors. Apart from this, reliability also depends upon how the product is used, i.e. on its execution profile. If it is selected input data to the system such that only the "correctly" implemented functions are executed, none of the errors will be exposed and the perceived reliability of the product will be high. On the other hand, if the input data is selected such that only those functions which contain errors are invoked, the perceived reliability of the system will be very low.

Reasons for software reliability being difficult to measure--

The reasons why software reliability is difficult to measure can be summarized as follows:

The reliability improvement due to fixing a single bug depends on where the bug is located in the code.

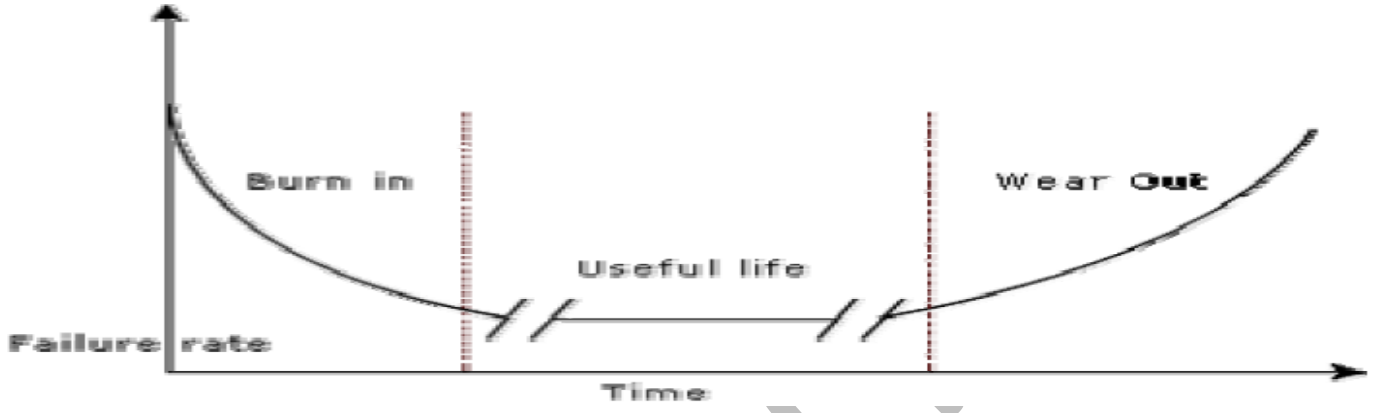
The perceived reliability of a software product is highly observer-dependent.

The reliability of a product keeps changing as errors are detected and fixed.

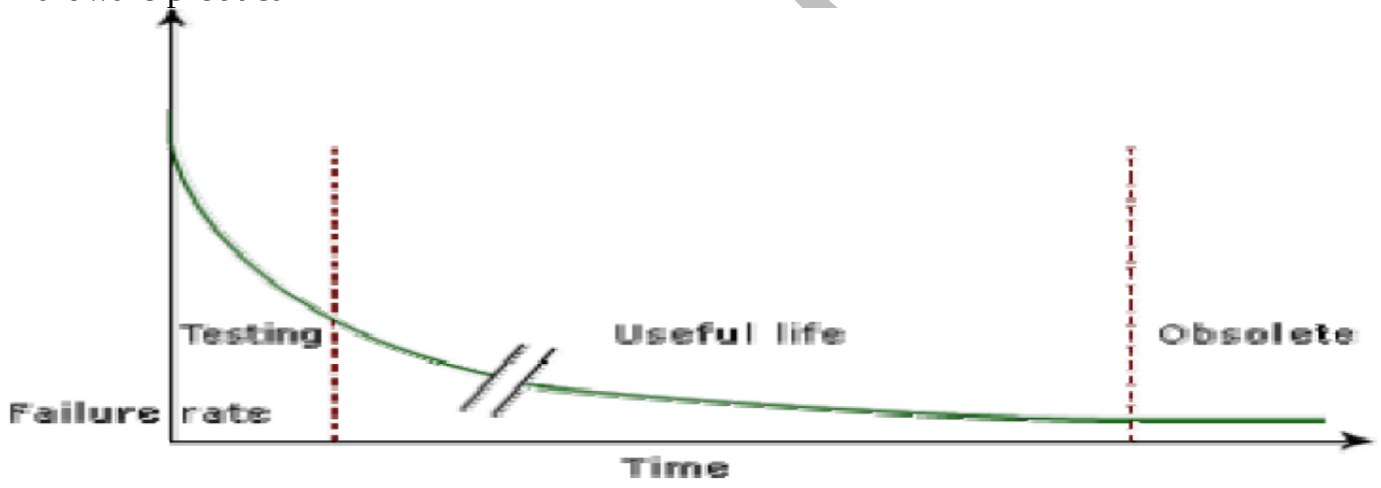
Hardware reliability vs. software reliability differs.

Reliability behavior for hardware and software are very different. For example, hardware failures are inherently different from software failures. Most hardware failures are due to component wear and tear. A logic gate may be stuck at 1 or 0, or a resistor might short circuit. To fix hardware faults, one has to either replace or repair the failed part. On the other hand, a software product would continue to fail until the error is tracked down and either the design or the code is changed. For this reason, when hardware is repaired its reliability is maintained at the level that existed before the failure occurred; whereas when a software failure is repaired, the reliability may either increase or decrease (reliability may decrease if a bug introduces new errors). To put this fact in a different perspective, hardware reliability study is concerned with stability (for example, inter-failure times remain constant). On the other hand, software reliability study aims at reliability growth (i.e. inter-failure times increase). The change of failure rate over the product lifetime for a typical hardware and a

software product are sketched in fig. 26.1. For hardware products, it can be observed that failure rate is high initially but decreases as the faulty components are identified and removed. The system then enters its useful life. After some time (called product life time) the components wear out, and the failure rate increases. This gives the plot of hardware reliability over time its characteristics "bath tub" shape. On the other hand, for software the failure rate is at it's highest during integration and test. As the system is tested, more and more errors are identified and removed resulting in reduced failure rate. This error removal continues at a slower pace during the useful life of the product. As the software becomes obsolete no error corrections occurs and the failure rate remains unchanged.



(a) Hardware product



(b) Software product

Figure: Change in failure rate of a product

Reliability Metrics --

The reliability requirements for different categories of software products may be different. For this reason, it is necessary that the level of reliability required for a software product should be specified in the SRS (software requirements specification) document. In order to be able to do this, some metrics are needed to quantitatively express the reliability of a software product. A good reliability measure should be observer-dependent, so that different people can agree on the degree of reliability a system has. For example, there are precise techniques for measuring performance, which would result in obtaining the same performance value irrespective of who is carrying out the performance measurement. However, in practice, it is very difficult to formulate a precise reliability measurement technique. The next base case is to have measures that correlate with reliability. There are six reliability metrics which can be used to quantify the reliability of software products.

Rate of occurrence of failure (ROCOF)- ROCOF measures the frequency of occurrence of unexpected behavior (i.e. failures). ROCOF measure of a software product can be obtained by observing the behavior of a software product in operation over a specified time interval and then recording the total number of failures occurring during the interval.

Mean Time To Failure (MTTF) - MTTF is the average time between two successive failures, observed over a large number of failures. To measure MTTF, we can record the failure data for n failures. Let the failures occur at the time instants *t1*, *t2*, …, *tn*. Then,

MTTF can be calculated as $\sum_{i=1}^{n} \frac{t_{i+1} - t_i}{(n-1)}$

It is important to note that only run time is considered in the time measurements, i.e. the time for which the system is down to fix the error, the boot time, etc are not taken into account in the time measurements and the clock is stopped at these times.

Mean Time To Repair (MTTR) - Once failure occurs, sometime is required to fix the error. MTTR measures the average time it takes to track the errors causing the failure and to fix them.

Mean Time Between Failure (MTBR) - MTTF and MTTR can be combined to get the MTBR metric: MTBF = MTTF + MTTR. Thus, MTBF of 300 hours indicates that once a failure occurs, the next failure is expected after 300 hours. In this case, time measurements are real time and not the execution time as in MTTF.

Probability of Failure on Demand (POFOD) - Unlike the other metrics discussed, this metric does not explicitly involve time measurements. POFOD measures the likelihood of the system failing when a service request is made. For example, a POFOD of 0.001 would mean that 1 out of every 1000 service requests would result in a failure.

Availability- Availability of a system is a measure of how likely shall the system be available for use over a given period of time. This metric not only considers the number of failures occurring during a time interval, but also takes into account the repair time (down time) of a system when a failure occurs. This metric is important for systems such as telecommunication systems, and operating systems, which are supposed to be never down and where repair and restart time, are significant and loss of service during that time is important.

Classification of software failures

A possible classification of failures of software products into five different types is as follows:

Transient- Transient failures occur only for certain input values while invoking a function of the system.

Permanent- Permanent failures occur for all input values while invoking a function of the system.

Recoverable- When recoverable failures occur, the system recovers with or without operator intervention.

Unrecoverable- In unrecoverable failures, the system may need to be restarted.

Cosmetic- These classes of failures cause only minor irritations, and do not lead to incorrect results. An example of a cosmetic failure is the case where the mouse button has to be clicked twice instead of once to invoke a given function through the graphical user interface.

RELIABILITY GROWTH MODELS --

A reliability growth model is a mathematical model of how software reliability improves as errors are detected and repaired. A reliability growth model can be used to predict when (or if at all) a particular level of reliability is likely to be attained. Thus, reliability growth modeling can be used to determine when to stop testing to attain a given reliability level. Although several different reliability growth models have been proposed, in this text we will discuss only two very simple reliability growth models.

Jelinski and Moranda Model -The simplest reliability growth model is a step function model where it is assumed that the reliability increases by a constant increment each time an error is detected and repaired. Such a model is shown in figure below. However, this simple model of reliability which implicitly assumes that all errors contribute equally to reliability growth, is highly unrealistic since it is already known that correction of different types of errors contribute differently to reliability growth.

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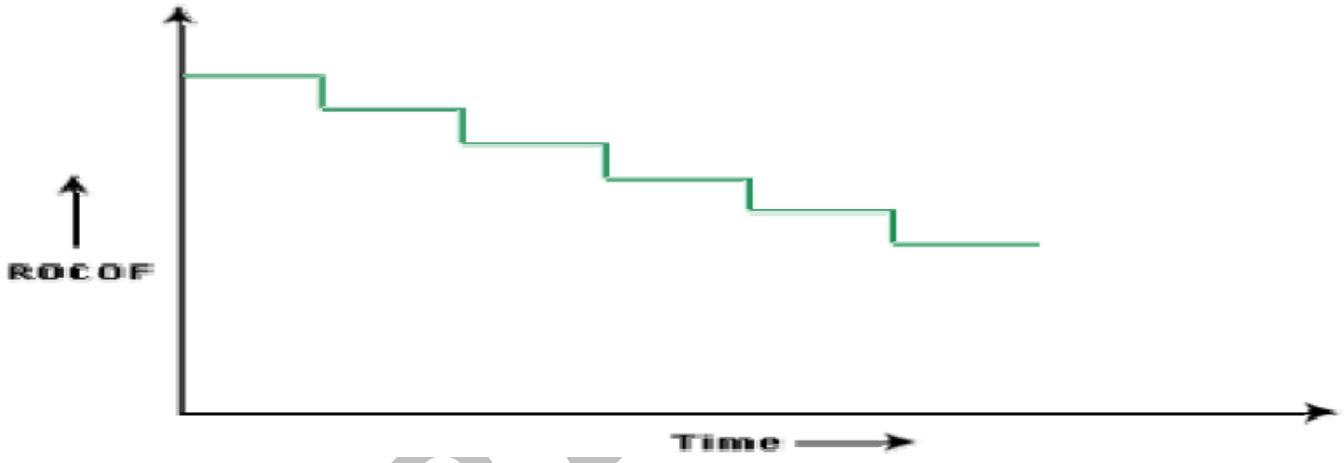


Figure: Step function model of reliability growth

Littlewood and Verall's Model -This model allows for negative reliability growth to reflect the fact that when a repair is carried out, it may introduce additional errors. It also models the fact that as errors are repaired, the average improvement in reliability per repair decreases (Figure below). It treat's an error's contribution to reliability improvement to be an independent random variable having Gamma distribution. This distribution models the fact that error corrections with large contributions to reliability growth are removed first. This represents diminishing return as test continues.

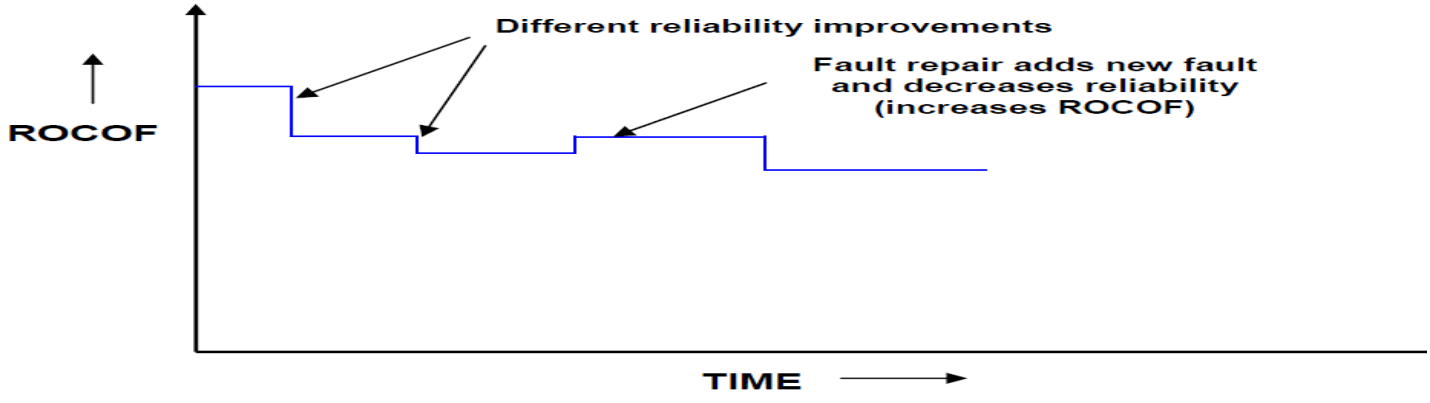


Fig : Random-step function model of reliability growth

STATISTICAL TESTING --

Statistical testing is a testing process whose objective is to determine the reliability of the product rather than discovering errors. The test cases designed for statistical testing with an entirely different objective from those of conventional testing. To carry out statistical testing, we need to first define the operation profile of the product.

Operation profile:

Different categories of users may use a software product for very different purposes. For example, a librarian might use the Library Automation Software to create member records, delete member records, add books to the library, etc.,

- Where as a library member might use software to query about the availability of a book, and to issue and return books. Formally, we can define the operation profile of software as the probability of a user selecting the different functionalities of the software.
- If we denote the set of various functionalities offered by the software by {fi}, the operational profile would associate with each function {fi} with the probability with which an average user would select {fi} as his next function to use.
- Thus, we can think of the operation profile as assigning a probability value pi to each functionality fi of the software.

How to define the operation profile for a product?

We need to divide the input data into a number of input classes. For example, for a graphical editor software, we might divide the input into data associated with the edit, print, and file operations. We then need to assign a probability value to each input class; to signify the probability for an input value from that class to be selected. The operation profile of a software product can be determined by observing and analyzing the usage pattern of the software by a number of users.

Steps in Statistical Testing--

The first step is to determine the operation profile of the software. The next step is to generate a set of test data corresponding to the determined operation profile. The third step is to apply the test cases to the software and record the time between each failure. After a statistically significant number of failures have been observed, the reliability can be computed.

- For accurate results, statistical testing requires some fundamental assumptions to be satisfied. It requires a statistically significant number of test cases to be used. It further requires that a small percentage of test inputs that are likely to cause system failure to be included.
- Now let us discuss the implications of these assumptions. It is straight forward to generate test cases for the common types of inputs, since one can easily write a test case generator program which can automatically generate these test cases.
- However, it is also required that a statistically significant percentage of the unlikely inputs should also be included in the test suite. Creating these unlikely inputs using a test case generator is very difficult.

Pros and cons of statistical testing --

- Statistical testing allows one to concentrate on testing parts of the system that are most likely to be used.

- Therefore, it results in a system that the users can find to be more reliable (than actually it is!). Also, the reliability estimation arrived by using statistical testing is more accurate compared to those of other methods discussed.
- However, it is not easy to perform the statistical testing satisfactorily due to the following two reasons.
- There is no simple and repeatable way of defining operation profiles. Also, the number of test cases with which the system is to be tested should be statistically significant.

SOFTWARE QUALITY --

Traditionally, a quality product is defined in terms of its fitness of purpose. That is, a quality product does exactly what the users want it to do. For software products, fitness of purpose is usually interpreted in terms of satisfaction of the requirements laid down in the SRS document. Although "fitness of purpose" is a satisfactory definition of quality for many products such as a car, a table fan, a grinding machine, etc. ,for software products, "fitness of purpose" is not a wholly satisfactory definition of quality. To give an example, consider a software product that is functionally correct. That is, it performs all functions as specified in the SRS document. But, has an almost unusable user interface. Even though it may be functionally correct, we cannot consider it to be a quality product. Another example may be that of a product which does everything that the users want but has an almost incomprehensible and unmaintainable code. Therefore, the traditional concept of quality as "fitness of purpose" for software products is not wholly satisfactory.

The modern view of a quality associates with a software product several quality factors such as the following:

Portability: A software product is said to be portable, if it can be easily made to work in different operating system environments, in different machines, with other software products, etc.

Usability: A software product has good usability, if different categories of users (i.e. both expert and novice users) can easily invoke the functions of the product.

Reusability: A software product has good reusability, if different modules of the product can easily be reused to develop new products.

Correctness: A software product is correct, if different requirements as specified in the SRS document have been correctly implemented.

Maintainability: A software product is maintainable, if errors can be easily corrected as and when they show up, new functions can be easily added to the product, and the functionalities of the product can be easily modified, etc.

Software Quality Management System

A quality management system (often referred to as quality system) is the principal methodology used by organizations to ensure that the products they develop have the desired quality.

A quality system consists of the following:

Managerial Structure and Individual Responsibilities- A quality system is actually the responsibility of the organization as a whole. However, every organization has a separate quality department to perform several quality system activities. The quality system of an organization should have support of the top management. Without support for the quality system at a high level in a company, few members of staff will take the quality system seriously.

Quality System Activities- The quality system activities encompass the following:
- auditing of projects
- review of the quality system
- development of standards, procedures, and guidelines, etc.
- production of reports for the top management summarizing the effectiveness of the quality system in the organization.

Evolution of Quality Management System

Quality systems have rapidly evolved over the last five decades. Prior to World War II, the usual method to produce quality products was to inspect the finished products to eliminate defective products. Since that time, quality systems of organizations have undergone through four stages of evolution as shown in the fig. 28.1. The initial product inspection method gave way to quality control (QC). Quality control focuses not only on detecting the defective products and eliminating them but also on determining the causes behind the defects. Thus, quality control aims at correcting the causes of errors and not just rejecting the products. The next breakthrough in quality systems was the development of quality assurance principles.

The basic premise of modern quality assurance is that if an organization's processes are good and are followed rigorously, then the products are bound to be of good quality. The modern quality paradigm includes guidance for recognizing, defining, analyzing, and improving the production process. Total quality management (TQM) advocates that the process followed by an organization must be continuously improved through process measurements. TQM goes a step further than quality assurance and aims at continuous process improvement. TQM goes beyond documenting processes to optimizing them through redesign. A term related to TQM is Business Process Reengineering (BPR). BPR aims at reengineering the way business is carried out in an organization. From the above discussion it can be stated that over the years the quality paradigm has shifted from product assurance to process assurance (as shown in figure).

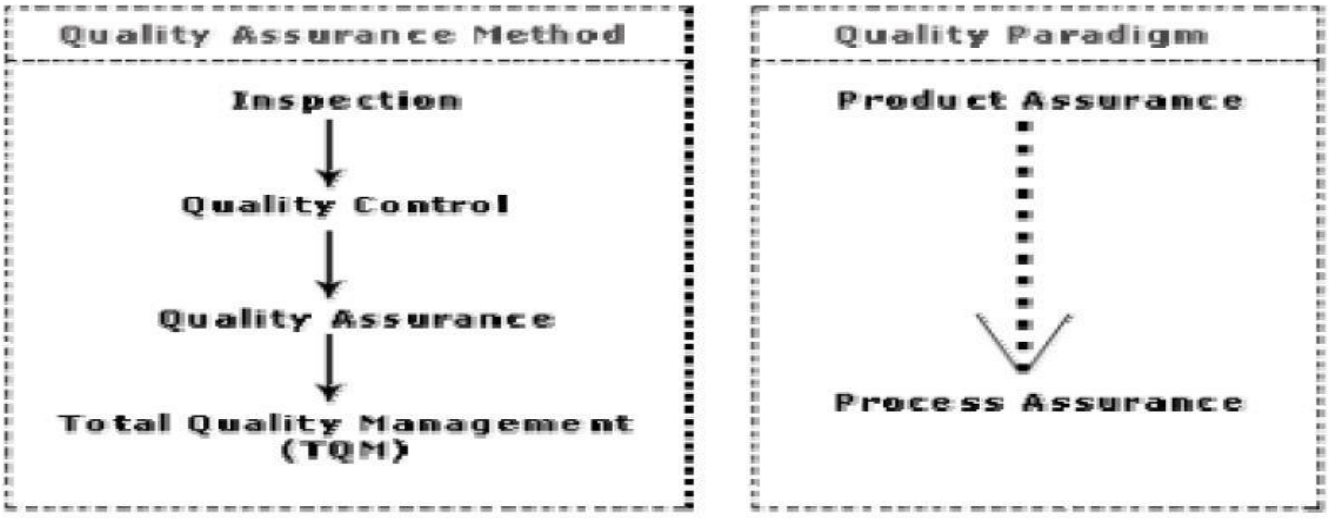


Figure: Evolution of quality system and corresponding shift in the quality paradigm

ISO 9000 certification

ISO (International Standards Organization) is a consortium of 63 countries established to formulate and foster standardization. ISO published its 9000 series of standards in 1987. ISO certification serves as a reference for contract between independent parties. The ISO 9000 standard specifies the guidelines for maintaining a quality system. We have already seen that

the quality system of an organization applies to all activities related to its product or service. The ISO standard mainly addresses operational aspects and organizational aspects such as responsibilities, reporting, etc. In a nutshell, ISO 9000 specifies a set of guidelines for repeatable and high quality product development. It is important to realize that ISO 9000 standard is a set of guidelines for the production process and is not directly concerned about the product itself.

Types of ISO 9000 quality standards

ISO 9000 is a series of three standards: ISO 9001, ISO 9002, and ISO 9003. The ISO 9000 series of standards is based on the premise that if a proper process is followed for production, then good quality products are bound to follow automatically. The types of industries to which the different ISO standards apply are as follows.

ISO 9001 applies to the organizations engaged in design, development, production, and servicing of goods. This is the standard that is applicable to most software development organizations.

ISO 9002 applies to those organizations which do not design products but are only involved in production. Examples of these category industries include steel and car manufacturing industries that buy the product and plant designs from external sources and are involved in only manufacturing those products. Therefore, ISO 9002 is not applicable to software development organizations.

ISO 9003 applies to organizations that are involved only in installation and testing of the products.

Software products vs. other products

There are mainly two differences between software products and any other type of products.

 Software is intangible in nature and therefore difficult to control. It is very difficult to control and manage anything that is not seen. In contrast, any other industries such as car manufacturing industries where one can see a product being developed through various stages such as fitting engine, fitting doors, etc. Therefore, it is easy to accurately determine how much work has been completed and to estimate how much more time will it take.

 During software development, the only raw material consumed is data. In contrast, large quantities of raw materials are consumed during the development of any other product.

Need for obtaining ISO 9000 certification

There is a mad scramble among software development organizations for obtaining ISO certification due to the benefits it offers. Some benefits that can be acquired to organizations by obtaining ISO certification are as follows:

 Confidence of customers in an organization increases when organization qualifies for ISO certification. This is especially true in the international market. In fact, many organizations awarding international software development contracts insist that the development organization have ISO 9000 certification. For this reason, it is vital for software organizations involved in software export to obtain ISO 9000 certification.

 ISO 9000 requires a well-documented software production process to be in place. A well-documented software production process contributes to repeatable and higher quality of the developed software.

 ISO9000 makes the development process focused, efficient, and cost-effective.

 ISO 9000 certification points out the weak points of an organization and recommends remedial action.

 ISO 9000 sets the basic framework for the development of an optimal process and Total Quality Management (TQM).

Summary of ISO 9001 certification

A summary of the main requirements of ISO 9001 as they relate of software development is as follows. Section numbers in brackets correspond to those in the standard itself:

Management Responsibility (4.1)

 The management must have an effective quality policy.

 The responsibility and authority of all those whose work affects quality must be defined and documented.

 A management representative, independent of the development process, must be responsible for the quality system. This requirement probably has been put down so that the person responsible for the quality system can work in an unbiased manner.

 The effectiveness of the quality system must be periodically reviewed by audits.

Quality System (4.2)

A quality system must be maintained and documented.

Contract Reviews (4.3)

Before entering into a contract, an organization must review the contract to ensure that it is understood, and that the organization has the necessary capability for carrying out its obligations.

Design Control (4.4)

 The design process must be properly controlled, this includes controlling coding also. This requirement means that a good configuration control system must be in place.

 Design inputs must be verified as adequate.

 Design must be verified.

 Design output must be of required quality.

 Design changes must be controlled.

Document Control (4.5)

 There must be proper procedures for document approval, issue and removal.

 Document changes must be controlled. Thus, use of some configuration management tools is necessary.

Purchasing (4.6)

Purchasing material, including bought-in software must be checked for conforming to requirements.

Purchaser Supplied Product (4.7)

Material supplied by a purchaser, for example, client-provided software must be properly managed and checked.

Product Identification (4.8)

The product must be identifiable at all stages of the process. In software terms this means configuration management.

Process Control (4.9)

 The development must be properly managed.

 Quality requirement must be identified in a quality plan.

Inspection and Testing (4.10)

In software terms this requires effective testing i.e., unit testing, integration testing and system testing. Test records must be maintained.

Inspection, Measuring and Test Equipment (4.11)

If integration, measuring, and test equipments are used, they must be properly maintained and calibrated.

Inspection and Test Status (4.12)

The status of an item must be identified. In software terms this implies configuration management and release control.

Control of Nonconforming Product (4.13)

In software terms, this means keeping untested or faulty software out of the released product, or other places whether it might cause damage.

Corrective Action (4.14)

This requirement is both about correcting errors when found, and also investigating why the errors occurred and improving the process to prevent occurrences. If an error occurs despite the quality system, the system needs improvement.

Handling, (4.15)

This clause deals with the storage, packing, and delivery of the software product.

Quality records (4.16)

Recording the steps taken to control the quality of the process is essential in order to be able to confirm that they have actually taken place.

Quality Audits (4.17)

Audits of the quality system must be carried out to ensure that it is effective.

Training (4.18)

Training needs must be identified and met.

Salient features of ISO 9001 certification

The salient features of ISO 9001 are as follows:

 All documents concerned with the development of a software product should be properly managed, authorized, and controlled. This requires a configuration management system to be in place.

 Proper plans should be prepared and then progress against these plans should be monitored.

 Important documents should be independently checked and reviewed for effectiveness and correctness.

 The product should be testedagainst specification.

 Several organizational aspects should be addressed e.g., management reporting of the quality team.

Shortcomings of ISO 9000 certification

Even though ISO 9000 aims at setting up an effective quality system in an organization, it suffers from several shortcomings. Some of these shortcomings of the ISO 9000 certification process are the following:

 ISO 9000 requires a software production process to be adhered to but does not guarantee the process to be of high quality. It also does not give any guideline for defining an appropriate process.

 ISO 9000 certification process is not fool-proof and no international accreditation agency exists. Therefore it is likely that variations in the norms of awarding certificates can exist among the different accreditation agencies and also among the registrars.
 Organizations getting ISO 9000 certification often tend to downplay domain expertise. These organizations start to believe that since a good process is in place, any engineer is as effective as any other engineer in doing any particular activity relating to software development. However, many areas of software development are so specialized that special expertise and experience in these areas (domain expertise) is required. In manufacturing industry there is a clear link between process quality and product quality. Once a process is calibrated, it can be run again and again producing quality goods. In contrast, software development is a creative process and individual skills and experience are important.
 ISO 9000 does not automatically lead to continuous process improvement, i.e. does not automatically lead to TQM.

SEI CAPABILITY MATURITY MODEL --

SEI Capability Maturity Model (SEI CMM) helped organizations to improve the quality of the software they develop and therefore adoption of SEI CMM model has significant business benefits.

SEI CMM can be used two ways: capability evaluation and software process assessment. Capability evaluation and software process assessment differ in motivation, objective, and the final use of the result. Capability evaluation provides a way to assess the software process capability of an organization. The results of capability evaluation indicates the likely contractor performance if the contractor is awarded a work. Therefore, the results of software process capability assessment can be used to select a contractor. On the other hand, software process assessment is used by an organization with the objective to improve its process capability. Thus, this type of assessment is for purely internal use.

SEI CMM classifies software development industries into the following five maturity levels. The different levels of SEI CMM have been designed so that it is easy for an organization to slowly build its quality system starting from scratch.

Level 1: Initial - A software development organization at this level is characterized by ad hoc activities. Very few or no processes are defined and followed. Since software production processes are not defined, different engineers follow their own process and as a result development efforts become chaotic. Therefore, it is also called chaotic level. The success of projects depends on individual efforts and heroics. When engineers leave, the successors have great difficulty in understanding the process followed and the work completed. Since formal project management practices are not followed, under time pressure short cuts are tried out leading to low quality.

Level 2: Repeatable - At this level, the basic project management practices such as tracking cost and schedule are established. Size and cost estimation techniques like function point analysis, COCOMO, etc. are used. The necessary process discipline is in place to repeat earlier success on projects with similar applications. Please remember that opportunity to repeat a process exists only when a company produces a family of products.

Level 3: Defined - At this level the processes for both management and development activities are defined and documented. There is a common organization-wide understanding of activities, roles, and responsibilities. The processes though defined, the process and product qualities are not measured. ISO 9000 aims at achieving this level.

Level 4: Managed - At this level, the focus is on software metrics. Two types of metrics are collected. Product metrics measure the characteristics of the product being developed, such as its size, reliability, time complexity, understandability, etc. Process metrics reflect the effectiveness of the process being used, such as average defect correction time, productivity, average number of defects found per hour inspection, average number of failures detected during testing per LOC, etc. Quantitative quality goals are set for the products. The software process and product quality are measured and quantitative quality requirements for the product are met. Various tools like Pareto charts, fishbone diagrams, etc. are used to measure the product and process quality. The process metrics are used to check if a project performed satisfactorily. Thus, the results of process measurements are used to evaluate project performance rather than improve the process.

Level 5: Optimizing - At this stage, process and product metrics are collected. Process and product measurement data are analyzed for continuous process improvement. For example, if from an analysis of the process measurement results, it was found that the code reviews were not very effective and a large number of errors were detected only during the unit testing, then the process may be fine-tuned to make the review more effective. Also, the lessons learned from specific projects are incorporated in to the process. Continuous process improvement is achieved both by carefully analyzing the quantitative feedback from the process measurements and also from application of innovative ideas and technologies. Such an organization identifies the best software engineering practices and innovations which may be tools, methods, or processes. These best practices are transferred throughout the organization.

Key process areas (KPA) of a software organization

Except for SEI CMM level 1, each maturity level is characterized by several Key Process Areas (KPAs) that includes the areas an organization should focus to improve its software process to the next level. The focus of each level and the corresponding key process areas are shown in the figure below.

CMM Level	Focus	Key Process Ares
1. Initial	Competent people	
2. Repeatable	Project management	Software project planning
		Software configuration management
3. Defined	Definition of processes	Process definition
		Training program
		Peer reviews
4. Managed	Product and process quality	Quantitative process metrics
		Software quality management
5. Optimizing	Continuous process improvement	Defect prevention
		Process change management
		Technology change management

Personal Software Process (PSP) --

 PSP is based on the work of David Humphrey. PSP is a scaled down version of industrial software process discussed in the last section.

 PSP is suitable for individual use. It is important to note that SEI CMM does not tell software developers how to analyze, design, code, test, or document software products, but assumes that engineers use effective personal practices.

 PSP recognizes that the process for individual use is different from that necessary for a team.

 The quality and productivity of an engineer is to a great extent dependent on his process. PSP is a framework that helps engineers to measure and improve the way they work.

 It helps in developing personal skills and methods by estimating, planning, and tracking performance against plans, and provides a defined process which can be tuned by individuals.

Time measurement: the actual time spent on a task should be measured with the help of a stop-watch to get an objective picture of the time spent. For example, he may stop the clock when attending a telephone call, taking a coffee break, etc. An engineer should measure the time he spends for various development activities such as designing, writing code, testing, etc.

PSP Planning: Individuals must plan their project. Unless an individual properly plans his activities, disproportionately high effort may be spent on trivial activities and important activities may be compromised, leading to poor quality results. The developers must estimate the maximum, minimum, and the average LOC required for the product. They should use their productivity in minutes/LOC to calculate the maximum, minimum, and the average development time. They must record the plan data in a project plan summary.

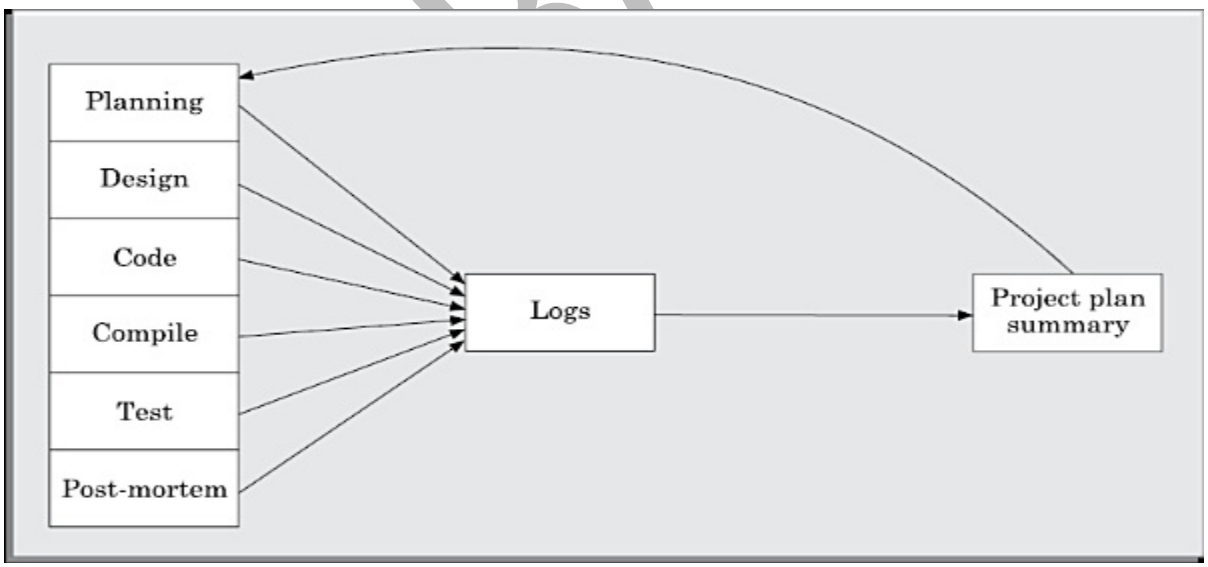


Figure: A schematic representation of PSP.

The PSP levels are summarized in Figure 11.5. PSP2 introduces defect management via the use of checklists for code and design reviews. The checklists are developed by analyzing the defect data gathered from earlier projects.

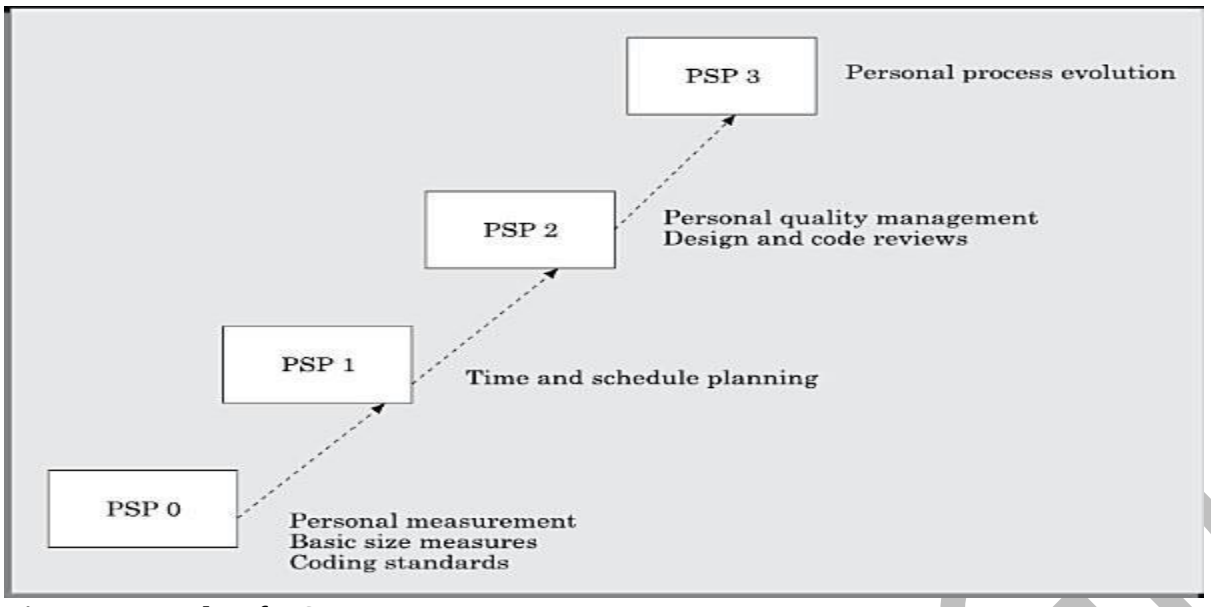


Figure: Levels of PSP.

SIX SIGMA --

The purpose of Six Sigma is to improve processes to do things better, faster, and at lower cost. It can be used to improve every facet of business, from production, to human resources, to order entry, to technical support.

 Six Sigma can beused for any activity that is concerned with cost, timeliness, and quality of results. Therefore, it is applicable to virtually every industry. Six Sigma at many organizations simply means striving for near perfection.

 Six Sigma is a disciplined, data-driven approach to eliminate defects in any process – from manufacturing to transactional and from product to service.

 The statistical representation of Six Sigma describes quantitatively how a process is performing. To achieve Six Sigma, a process must not produce more than 3.4 defects per million opportunities.

 A Six Sigma defect is defined as any system behavior that is not as per customer specifications. Total number of Six Sigma opportunities is then the total number of chances for a defect. Process sigma can easily be calculated using a Six Sigma calculator.

 The fundamental objective of the Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process improvement and variation reduction through the application of Six Sigma improvement projects.

 This is accomplished through the use of two Six Sigma sub-methodologies—DMAIC and DMADV. The Six Sigma DMAIC process (define, measure, analyze, improve, control) is an improvement system for existing processes falling below specification and looking for incremental improvement.

 The Six Sigma DMADV process (define, measure, analyze, design, verify) is an improvement system used to develop new processes or products at Six Sigma quality levels.

 It can also be employed if a current process requires more than just incremental improvement. Both Six Sigma processes are executed by Six Sigma Green Belts and Six Sigma Black Belts, and are overseen by Six Sigma Master Black Belts.

CASE Tools--

CASE stands for **C**omputer **A**ided **S**oftware **E**ngineering. It means, development and maintenance of software projects with help of various automated software tools.

CASE Tools

CASE tools are set of software application programs, which are used to automate SDLC activities. CASE tools are used by software project managers, analysts and engineers to develop software system.

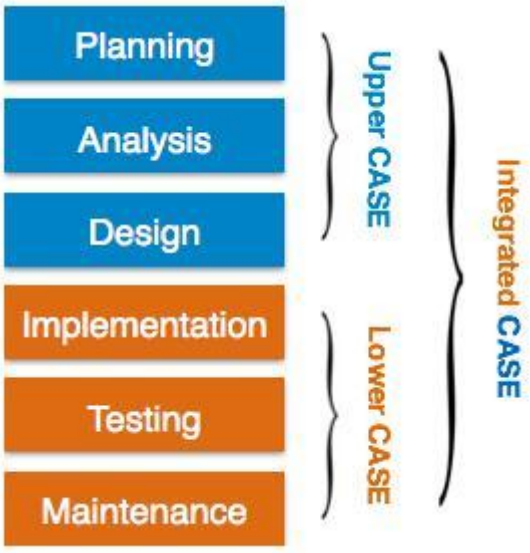
There are number of CASE tools available to simplify various stages of Software Development Life Cycle such as Analysis tools, Design tools, Project management tools, Database Management tools, Documentation tools are to name a few.

Use of CASE tools accelerates the development of project to produce desired result and helps to uncover flaws before moving ahead with next stage in software development.

Components of CASE Tools

CASE tools can be broadly divided into the following parts based on their use at a particular SDLC stage:

- **Central Repository** - CASE tools require a central repository, which can serve as a source of common, integrated and consistent information. Central repository is a central place of storage where product specifications, requirement documents, related reports and diagrams, other useful information regarding management is stored. Central repository also serves as data dictionary.



- **Upper Case Tools** - Upper CASE tools are used in planning, analysis and design stages of SDLC.
- **Lower Case Tools** - Lower CASE tools are used in implementation, testing and maintenance.
- **Integrated Case Tools** - Integrated CASE tools are helpful in all the stages of SDLC, from Requirement gathering to Testing and documentation.

CASE tools can be grouped together if they have similar functionality, process activities and capability of getting integrated with other tools.

Scope of Case Tools

The scope of CASE tools goes throughout the SDLC.

Case Tools Types

Now we briefly go through various CASE tools

Diagram tools

These tools are used to represent system components, data and control flow among various software components and system structure in a graphical form. For example, Flow Chart Maker tool for creating state-of-the-art flowcharts.

Process Modeling Tools

Process modeling is method to create software process model, which is used to develop the software. Process modeling tools help the managers to choose a process model or modify it as per the requirement of software product. For example, EPF Composer

Project Management Tools

These tools are used for project planning, cost and effort estimation, project scheduling and resource planning. Managers have to strictly comply project execution with every mentioned step in software project management. Project management tools help in storing and sharing project information in real-time throughout the organization. For example, Creative Pro Office, Trac Project, Basecamp.

Documentation Tools

Documentation in a software project starts prior to the software process, goes throughout all phases of SDLC and after the completion of the project.

Documentation tools generate documents for technical users and end users. Technical users are mostly in-house professionals of the development team who refer to system manual, reference manual, training manual, installation manuals etc. The end user documents describe the functioning and how-to of the system such as user manual. For example, Doxygen, DrExplain, Adobe RoboHelp for documentation.

Analysis Tools

These tools help to gather requirements, automatically check for any inconsistency, inaccuracy in the diagrams, data redundancies or erroneous omissions. For example, Accept 360, Accompa, CaseComplete for requirement analysis, Visible Analyst for total analysis.

Design Tools

These tools help software designers to design the block structure of the software, which may further be broken down in smaller modules using refinement techniques. These tools provides detailing of each module and interconnections among modules. For example, Animated Software Design

Configuration Management Tools

An instance of software is released under one version. Configuration Management tools deal with –

- Version and revision management
- Baseline configuration management
- Change control management

CASE tools help in this by automatic tracking, version management and release management. For example, Fossil, Git, Accu REV.

Change Control Tools

These tools are considered as a part of configuration management tools. They deal with changes made to the software after its baseline is fixed or when the software is first released. CASE tools automate change tracking, file management, code management and more. It also helps in enforcing change policy of the organization.

Programming Tools

These tools consist of programming environments like IDE (Integrated Development Environment), in-built modules library and simulation tools. These tools provide comprehensive aid in building software product and include features for simulation and testing. For example, Cscope to search code in C, Eclipse.

Prototyping Tools

Software prototype is simulated version of the intended software product. Prototype provides initial look and feel of the product and simulates few aspect of actual product.

Prototyping CASE tools essentially come with graphical libraries. They can create hardware independent user interfaces and design. These tools help us to build rapid prototypes based on existing information. In addition, they provide simulation of software prototype. For example, Serena prototype composer, Mockup Builder.

Web Development Tools

These tools assist in designing web pages with all allied elements like forms, text, script, graphic and so on. Web tools also provide live preview of what is being developed and how will it look after completion. For example, Fontello, Adobe Edge Inspect, Foundation 3, Brackets.

Quality Assurance Tools

Quality assurance in a software organization is monitoring the engineering process and methods adopted to develop the software product in order to ensure conformance of quality as per organization standards. QA tools consist of configuration and change control tools and software testing tools. For example, SoapTest, AppsWatch, JMeter.

Maintenance Tools

Software maintenance includes modifications in the software product after it is delivered. Automatic logging and error reporting techniques, automatic error ticket generation and root cause Analysis are few CASE tools, which help software organization in maintenance phase of SDLC. For example, Bugzilla for defect tracking, HP Quality Center.

SOFTWARE MAINTENANCE

Necessity of Software Maintenance--

Software maintenance is becoming an important activity of a large number of software organizations. This is no surprise, given the rate of hardware obsolescence, the immortality of a software product , and the demand of the user community to see the existing software products run on newer platforms, run in newer environments, and/or with enhanced features. When the hardware platform is changed, and a software product performs some low-level functions, maintenance is necessary. Also, whenever the support environment of a software product changes, the software product requires rework to cope up with the newer interface. For instance, a software product may need to be maintained when the operating system changes. Thus, every software product continues to evolve after its development through maintenance efforts. Therefore it can be stated that software maintenance is needed to correct errors, enhance features, port the software to new platforms, etc.

Types of software maintenance

There are basically three types of software maintenance. These are:

Corrective: Corrective maintenance of a software product is necessary to rectify the bugs observed while the system is in use.

Adaptive: A software product might need maintenance when the customers need the product to run on new platforms, on new operating systems, or when they need the product to interface with new hardware or software.

Perfective: A software product needs maintenance to support the new features that users want it to support, to change different functionalities of the system according to customer demands, or to enhance the performance of the system.

Problems associated with software maintenance

Software maintenance work typically is much more expensive than what it should be and takes more time than required. In software organizations, maintenance work is mostly carried out using ad hoc techniques. The primary reason being that software maintenance is one of the most neglected areas of software engineering. Even though software maintenance is fast becoming an important area of work for many companies as the software products of yester years age, still software maintenance is mostly being carried out as fire-fighting operations, rather than through systematic and planned activities. Software maintenance has a very poor image in industry. Therefore, an organization often cannot employ bright engineers to carry out maintenance work. Even though maintenance suffers from a poor image, the work involved is often more challenging than development work. During maintenance it is necessary to thoroughly understand someone else's work and then carry out the required modifications and extensions.

Another problem associated with maintenance work is that the majority of software products needing maintenance are legacy products.

Software Reverse Engineering--

Software reverse engineering is the process of recovering the design and the requirements specification of a product from an analysis of its code. The purpose of reverse engineering is to facilitate maintenance work by improving the understandability of a system and to produce the necessary documents for a legacy system. Reverse engineering is becoming important, since legacy software products lack proper documentation, and are highly unstructured. Even well-designed products become legacy software as their structure degrades through a series of maintenance efforts.

The first stage of reverse engineering usually focuses on carrying out cosmetic changes to the code to improve its readability, structure, and understandability, without changing of its functionalities. A process model for reverse engineering has been shown in fig. 24.1. A program can be reformatted using any of the several available prettyprinter programs which layout the program neatly. Many legacy software products with complex control structure and unthoughtful variable names are difficult to comprehend. Assigning meaningful variable names is important because meaningful variable names are the most helpful thing in code documentation. All variables, data structures, and functions should be assigned meaningful names wherever possible. Complex nested conditionals in the program can be replaced by simpler conditional statements or whenever appropriate by case statements.

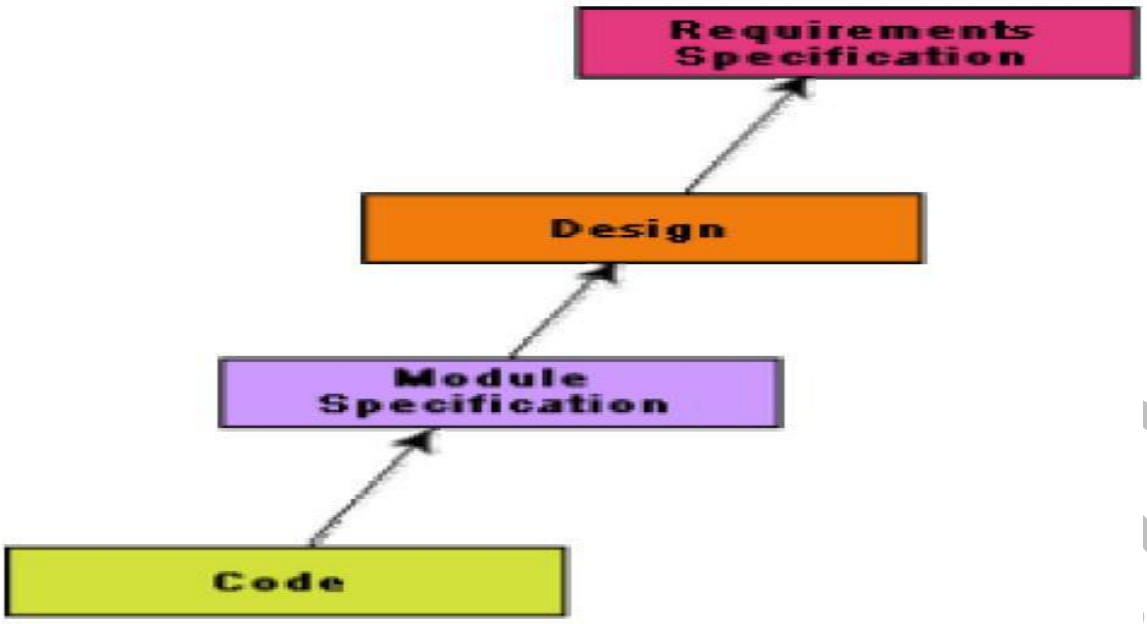


Fig. A process model for reverse engineering

After the cosmetic changes have been carried out on legacy software the process of extracting the code, design, and the requirements specification can begin. These activities are schematically shown in figure. In order to extract the design, a full understanding of the code is needed. Some automatic tools can be used to derive the data flow and control flow diagram from the code. The structure chart (module invocation sequence and data interchange among modules) should also be extracted. The SRS document can be written once the full code has been thoroughly understood and the design extracted.

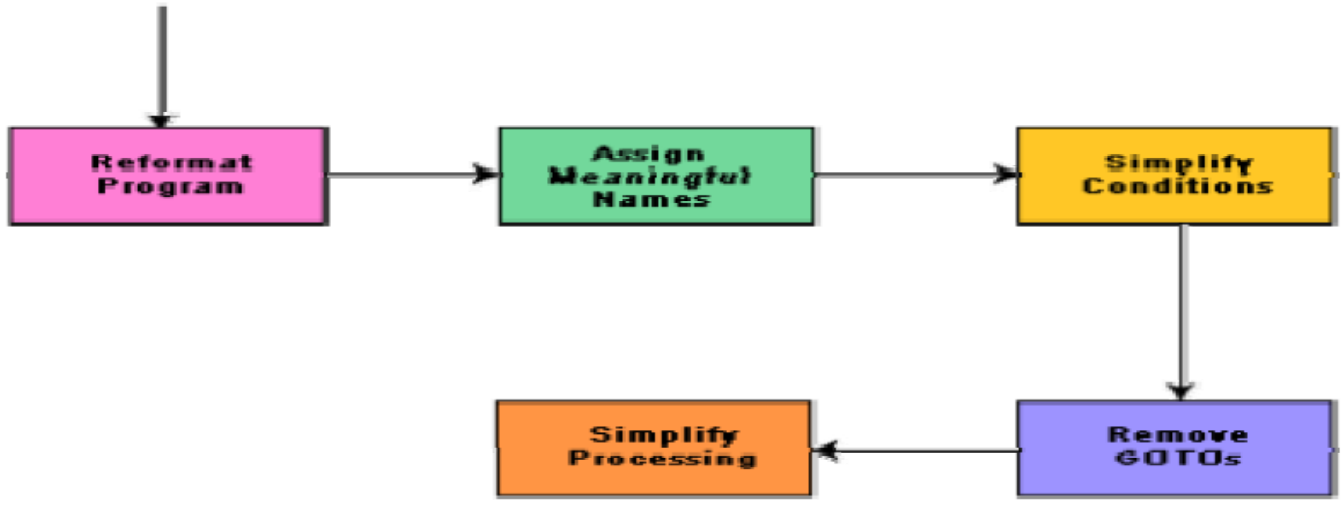


Figure: Cosmetic changes carried out before reverse engineering

Legacy software products --

It is prudent to define a legacy system as any software system that is hard to maintain. The typical problems associated with legacy systems are poor documentation, unstructured (spaghetti code with ugly control structure), and lack of personnel knowledgeable in the product. Many of the legacy systems were developed long time back. But, it is possible that a recently developed system having poor design and documentation can be considered to be a legacy system.

The activities involved in a software maintenance project are not unique and depend on several factors such as:

• The extent of modification to the product required
• The resources available to the maintenance team
• The conditions of the existing product (e.g., how structured it is, how well documented it is, etc.)
• The expected project risks, etc.

When the changes needed to a software product are minor and straightforward, the code can be directly modified and the changes appropriately reflected in all the documents. But more elaborate activities are required when the required changes are not so trivial. Usually, for complex maintenance projects for legacy systems, the software process can be represented by a reverse engineering cycle followed by a forward engineering cycle with an emphasis on as much reuse as possible from the existing code and other documents.

SOFTWARE MAINTENANCE PROCESS MODELS --

Two broad categories of process models for software maintenance can be proposed. The first model is preferred for projects involving small reworks where the code is changed directly and the changes are reflected in the relevant documents later. This maintenance process is graphically presented in figure below. In this approach, the project starts by gathering the requirements for changes. The requirements are next analyzed to formulate the strategies to be adopted for code change. At this stage, the association of at least a few members of the original development team goes a long way in reducing the cycle team, especially for projects involving unstructured and inadequately documented code. The availability of a working old system to the maintenance engineers at the maintenance site greatly facilitates the task of the maintenance team as they get a good insight into the working of the old system and also can compare the working of their modified system with the old system. Also, debugging of the reengineered system becomes easier as the program traces of both the systems can be compared to localize the bugs.

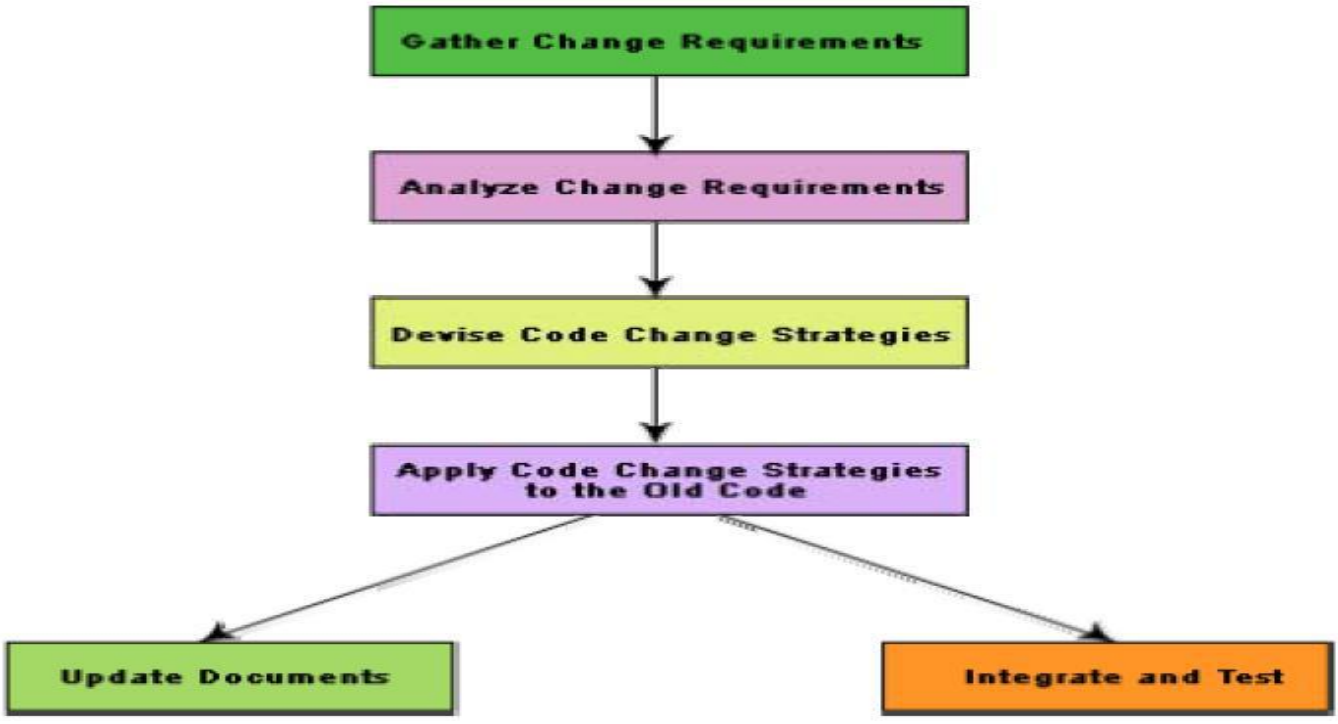


Figure: Maintenance process model 1

The second process model for software maintenance is preferred for projects where the amount of rework required is significant. This approach can be represented by a reverse engineering cycle followed by a forward engineering cycle. Such an approach is also known as software reengineering. This process model is depicted in figure below. The reverse engineering cycle is required for legacy products. During the reverse engineering, the old code is analyzed (abstracted) to extract the module specifications. The module specifications are then analyzed to produce the design. The design is analyzed (abstracted) to produce the original requirements specification. The change requests are then applied to this requirements specification to arrive at the new requirements specification. At the design, module specification, and coding a substantial reuse is made from the reverse engineered products. An important advantage of this approach is that it produces a more structured design compared to what the original product had, produces good documentation, and very often results in increased efficiency. The efficiency improvements are brought about by a more efficient design. However, this approach is more costly than the first approach. An empirical study indicates that process 1 is preferable when the amount of rework is no more than 15%. Besides the amount of rework, several other factors might affect the decision regarding using process model 1 over process model 2:

- Reengineering might be preferable for products which exhibit a high failure rate.
- Reengineering might also be preferable for legacy products having poor design and code structure.

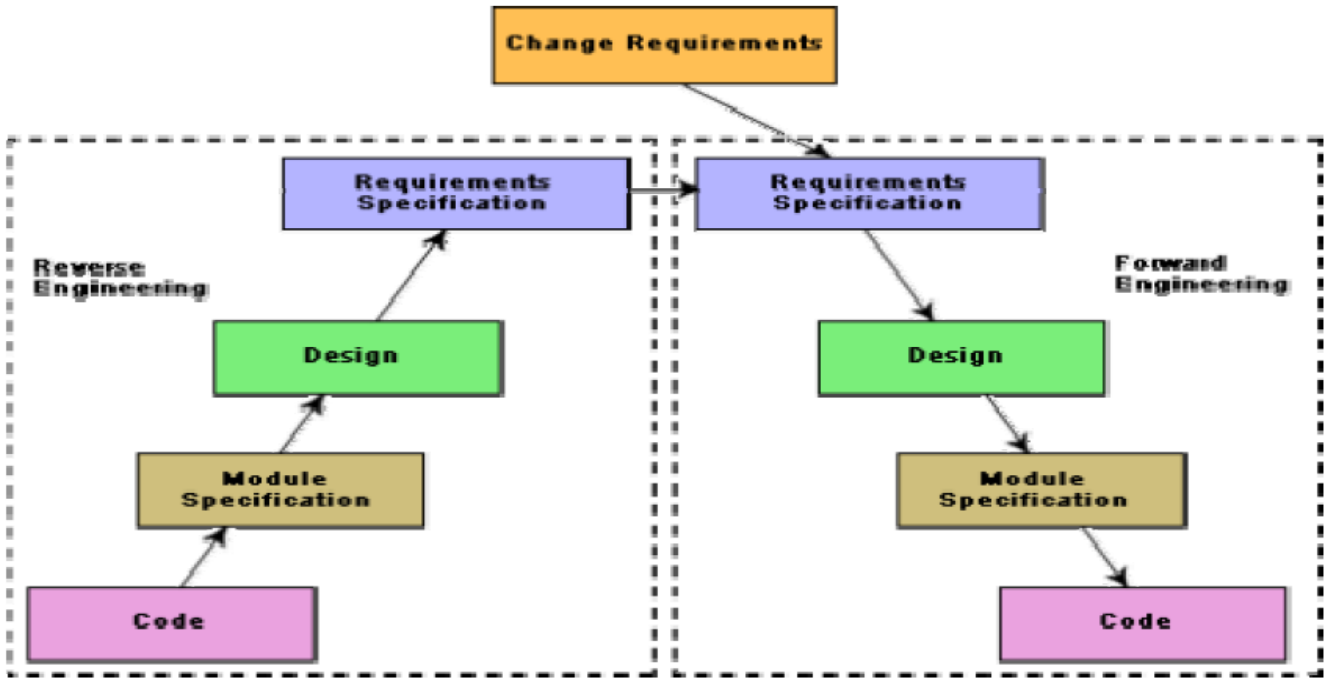


Figure: Maintenance process model 2

Software Reengineering --

Software reengineering is a combination of two consecutive processes i.e. software reverse engineering and software forward engineering as shown in the figure above.

Estimation of approximate maintenance cost

It is well known that maintenance efforts require about 60% of the total life cycle cost for a typical software product. However, maintenance costs vary widely from one application domain to another. For embedded systems, the maintenance cost can be as much as 2 to 4 times the development cost.

Boehm proposed a formula for estimating maintenance costs as part of his COCOMO cost estimation model. Boehm's maintenance cost estimation is made in terms of a quantity called the Annual Change Traffic (ACT). Boehm defined ACT as the fraction of a software product's source instructions which undergo change during a typical year either through addition or deletion.

ACT = (KLOC added + KLOC deleted)/ KLOCtotal

where, *KLOCadded* is the total kilo lines of source code added during maintenance.

KLOCdeleted is the total kilo lines of source code deleted during maintenance.

Thus, the code that is changed, should be counted in both the code added and the code deleted. The annual change traffic (ACT) is multiplied with the total development cost to arrive at the maintenance cost:

maintenance cost = *ACT* × development cost.

Most maintenance cost estimation models, however, yield only approximate results because they do not take into account several factors such as experience level of the engineers, and familiarity of the engineers with the product, hardware requirements, software complexity, etc.

Software Reuse--

Software reuse is a term used for developing the software by using the existing software components. Some of the components that can be reuse are as follows;

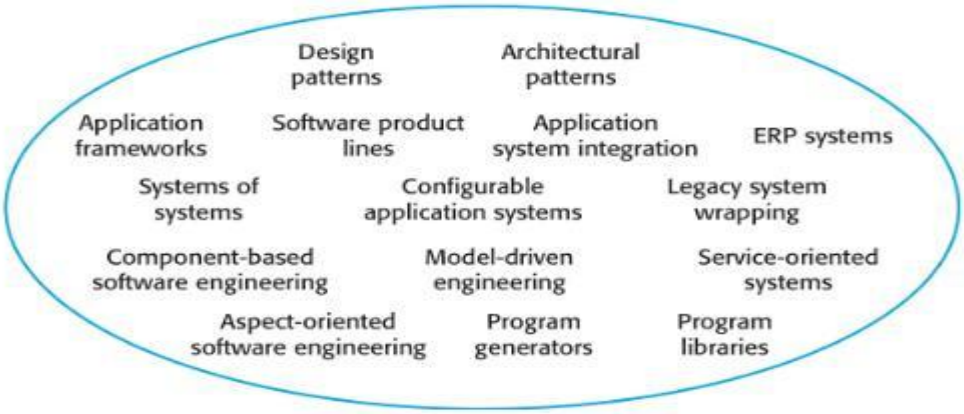
- Source code
- Design and interfaces
- User manuals
- Software Documentation
- Software requirement specifications and many more.

Scale of software reuse:

- **System reuse:** Complete systems, which may include several application programs.
- **Application reuse:** An application may be reused either by incorporating it without change into other or by developing application families.
- **Component reuse:** Components of an application from sub-systems to single objects may be reused.
- **Object and function reuse:** Small-scale software components that implement a single well-defined object or function may be reused.

The reuse landscape--

Although reuse is often simply thought of as the reuse of system components, there are many different approaches to reuse that may be used. Reuse is possible at a range of levels from simple functions to complete application systems. The reuse landscape covers the range of possible reuse techniques.



Key factors for reuse planning:

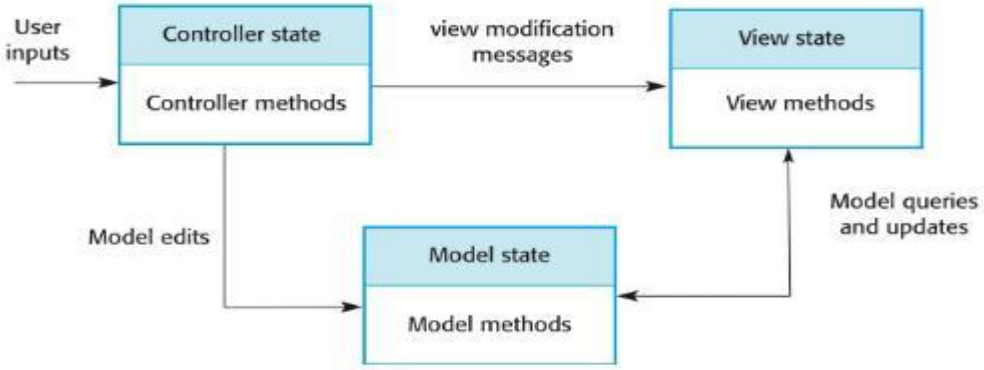
- The development schedule for the software.
- The expected software lifetime.
- The background, skills and experience of the development team.
- The criticality of the software and its non-functional requirements.
- The application domain.
- The execution platform for the software.

Application frame work--

Frameworks are moderately large entities that can be reused. They are somewhere between system and component reuse. Frameworks are a sub-system design made up of a collection of abstract and concrete classes and the interfaces between them. The sub-system is implemented by adding components to fill in parts of the design and by instantiating the abstract classes in the framework.

Application frameworks are moderately large entities that can be reused. They are somewhere between system and component reuse. Frameworks are a sub-system design made up of a collection of abstract and concrete classes and the interfaces between them. The sub-system is implemented by adding components to fill in parts of the design and by instantiating the abstract classes in the framework.

Web application frameworks (WAF) support the construction of dynamic websites as a front-end for web applications. WAFs are now available for all of the commonly used web programming languages e.g. Java, Python, Ruby, etc. Interaction model is based on the Model-View-Controller composite design pattern. An MVC framework supports the presentation of data in different ways and allows interaction with each of these presentations. When the data is modified through one of the presentations, the system model is changed and the controllers associated with each view update their presentation.



Software product lines--

Software product lines or application families are applications with generic functionality that can be adapted and configured for use in a specific context. A software product line is a set of applications with a common architecture and shared components, with each application specialized to reflect different requirements. Examples: a mobile operating system that works on different hardware models, a software line for a family of printers with varying features. Adaptation of a software line may involve:

- Component and system configuration;
- Adding new components to the system;
- Selecting from a library of existing components;
- Modifying components to meet new requirements.

The **base application** of a software product line includes:

- **Core components** that provide infrastructure support. These are not usually modified when developing a new instance of the product line.
- **Configurable components** that may be modified and configured to specialize them to a new application. Sometimes, it is possible to reconfigure these components without changing their code by using a built-in component configuration language.
- **Specialized, domain-specific components** some or all of which may be replaced when a new instance of a product line is created.

Product line architectures must be structured in such a way to separate different sub-systems and to allow them to be modified. The architecture should also separate entities and their descriptions and the higher levels in the system access entities through descriptions rather than directly.

Various types of specialization of a software product line may be developed:

- Different versions of the application are developed for different **platforms**.
- Different versions of the application are created to handle different operating **environments** e.g. different types of communication equipment.
- Different versions of the application are created for customers with different **functional** requirements.
- Different versions of the application are created to support different business **processes**.

Software product lines are designed to be reconfigurable. This configuration may occur at different stages in the development process:

- **Design time configuration:** The organization that is developing the software modifies a common product line core by developing, selecting or adapting components to create a new system for a customer.
- **Deployment time configuration:** A generic system is designed for configuration by a customer or consultants working with the customer. Knowledge of the customer's specific requirements and the system's operating environment is embedded in configuration data that are used by the generic system.

Application system reuse—

An application system product is a software system that can be adapted for different customers without changing the source code of the system. Application systems have generic

features and so can be used/reused in different environments. Application system products are adapted by using built-in configuration mechanisms that allow the functionality of the system to be tailored to specific customer needs.

Configurable application systems are generic application systems that may be designed to support a particular business type, business activity or, sometimes, a complete business enterprise. For example, an application system may be produced for dentists that handles appointments, dental records, patient recall, etc. Domain-specific systems, such as systems to support a business function (e.g. document management) provide functionality that is likely to be required by a range of potential users.

An **Enterprise Resource Planning** (ERP) system is a generic system that supports common business processes such as ordering and invoicing, manufacturing, etc. These are very widely used in large companies - they represent probably the most common form of software reuse. The generic core is adapted by including modules and by incorporating knowledge of business processes and rules. A number of modules to support different business functions. A defined set of business processes, associated with each module, which relate to activities in that module. A common database that maintains information about all related business functions. A set of business rules that apply to all data in the database.

Integrated application systems—

Integrated application systems are applications that include two or more application system products and/or legacy application systems. You may use this approach when there is no single application system that meets all of your needs or when you wish to integrate a new application system with systems that you already use. To develop integrated application systems, you have to make a number of design choices:

- Which individual application systems offer the most appropriate functionality? Typically, there will be several application system products available, which can be combined in different ways.
- How will data be exchanged? Different products normally use unique data structures and formats. You have to write adaptors that convert from one representation to another.
- What features of a product will actually be used? Individual application systems may include more functionality than you need and functionality may be duplicated across different products.

Application system integration can be simplified if a **service-oriented approach** is used. A service-oriented approach means allowing access to the application system's functionality through a standard service interface, with a service for each discrete unit of functionality. Some applications may offer a service interface but, sometimes, this service interface has to be implemented by the system integrator. You have to program a wrapper that hides the application and provides externally visible services.