

1. Software Quality Models and Philosophies

1.1. Introduction

The purpose of this chapter is to provide an overview to different quality models. It will also discuss what quality is by presenting a number of high-profile quality gurus together with their thoughts on quality (which in some cases actually results in a more or less formal quality model). The chapter is structured as follows: To be able to discuss the topic of quality and quality models, we as many others, must first embark on trying to define the concept of quality. Section 1.2 provides some initial definitions and scope on how to approach this elusive and subjective word. Section 1.3 provides a wider perspective on quality by presenting a more philosophical management view on what quality can mean. Section 1.4 continues to discuss quality through a model specific overview of several of the most popular quality models and quality structures of today. The chapter is concluded in Section 1.5 with a discussion about presented structures of quality, as well as some concluding personal reflections.

1.2. What is Quality

To understand the landscape of software quality it is central to answer the so often asked question: *what is quality?* Once the concept of quality is understood it is easier to understand the different structures of quality available on the market. As follows, and before we embark into the quality quagmire, we will spend some time to sort out **the** question: *what is quality*. As many prominent authors and researchers have provided an answer to that question, we do not have the ambition of introducing yet another answer but we will rather answer the question by studying the answers that some of the more prominent gurus of the quality management community have provided. By learning from those gone down this path before us we can identify that there are two major camps when discussing the meaning and definition of (software) quality [1]:

- 1) **Conformance to specification:** Quality that is defined as a matter of products and services whose measurable characteristics satisfy a fixed specification – that is, conformance to an in beforehand defined specification.
- 2) **Meeting customer needs:** Quality that is identified independent of any measurable characteristics. That is, quality is defined as the products or services capability to meet customer expectations – explicit or not.

1.3. Quality Management Philosophies

One of the two perspectives chosen to survey the area of quality structures within this technical paper is by means of quality management gurus. This perspective provides a qualitative and flexible [2] alternative on how to view quality structures. As will be discussed in Section 1.5, quality management philosophies can sometimes be a good alternative to the more formalized quality models discussed in Section 1.4.

1.3.1. Quality according to Crosby

In the book “Quality is free: the art of making quality certain” [3], Philip B. Crosby writes:

The first erroneous assumption is that quality means goodness, or luxury or shininess. The word “quality” is often used to signify the relative worth of something in such phrases as “good quality”, “bad quality” and “quality of life” - which means different things to each and every person. As follows quality must be defined as “conformance to requirements” if we are to manage it. Consequently, the nonconformance detected is the absence of quality, quality problems become nonconformance problems, and quality becomes definable.

Crosby is a clear “conformance to specification” quality definition adherer. However, he also focuses on trying to understand the full array of expectations that a customer has on quality by expanding the, of today’s measure, somewhat narrow production perspective on quality with a supplementary external perspective. Crosby also emphasizes that it is important to clearly define quality to be able to measure and manage the concept. Crosby summarizes his perspective on quality in fourteen steps but is built around four fundamental “absolutes” of quality management:

- 1) Quality is defined as conformance to requirements, not as “goodness” or “elegance”
- 2) The system for causing quality is prevention, not appraisal. That is, the quality system for suppliers attempting to meet customers' requirements is to do it right the first time. As follows, Crosby is a strong advocate of prevention, not inspection. In a Crosby oriented quality organization everyone has the responsibility for his or her own work. There is no one else to catch errors.
- 3) The performance standard must be Zero Defects, not "that's close enough". Crosby has advocated the notion that zero errors can and should be a target.
- 4) The measurement of quality is the cost of quality. Costs of imperfection, if corrected, have an immediate beneficial effect on bottom-line performance as well as on customer relations. To that extent, investments should be made in training and other supporting activities to eliminate errors and recover the costs of waste.

1.3.2. Quality according to Deming

Walter Edwards Deming's “Out of the crisis: quality, productivity and competitive position” [4], states:

The problem inherent in attempts to define the quality of a product, almost any product, where stated by the master Walter A. Shewhart. The difficulty in defining quality is to translate future needs of the user into measurable characteristics, so that a product can be designed and turned out to give satisfaction at a price that the user will pay. This is not easy, and as soon as one feels fairly successful in the endeavor, he finds that the needs of the consumer have changed, competitors have moved in etc.

One of Deming's strongest points is that quality must be defined in terms of customer satisfaction – which is a much wider concept than the “conformance to specification” definition of quality (i.e. “meeting customer needs” perspective). Deming means that quality should be defined only in terms of the agent – the judge of quality.

Deming's philosophy of quality stresses that meeting and exceeding the customers' requirements is the task that everyone within an organization needs to accomplish. Furthermore, the management system has to enable everyone to be responsible for the quality of his output to his internal customers. To implement his perspective on quality Deming introduced his 14 Points for Management in order to help people understand and implement the necessary transformation:

- 1) **Create constancy of purpose for improvement of product and service:** A better way to make money is to stay in business and provide jobs through innovation, research, constant improvement and maintenance.
- 2) **Adopt the new philosophy:** For the new economic age, management needs to take leadership for change into a *learning organization*. Furthermore, we need a new belief in which mistakes and negativism are unacceptable.
- 3) **Cease dependence on mass inspection:** Eliminate the need for mass inspection by building quality into the product.
- 4) **End awarding business on price:** Instead, aim at minimum total cost and move towards single suppliers.
- 5) **Improve constantly and forever the system of production and service:** Improvement is not a one-time effort. Management is obligated to continually look for ways to reduce waste and improve quality.
- 6) **Institute training:** Too often, workers have learned their job from other workers who have never been trained properly. They are forced to follow unintelligible instructions. They can't do their jobs well because no one tells them how to do so.
- 7) **Institute leadership:** The job of a supervisor is not to tell people what to do nor to punish them, but to lead. Leading consists of helping people to do a better job and to learn by objective methods.
- 8) **Drive out fear:** Many employees are afraid to ask questions or to take a position, even when they do not understand what their job is or what is right or wrong. To assure better quality and productivity, it is necessary that people feel secure. "The only stupid question is the one that is not asked."
- 9) **Break down barriers between departments:** Often a company's departments or units are competing with each other or have goals that conflict. They do not work as a team; therefore they cannot solve or foresee problems. Even worse, one department's goal may cause trouble for another.
- 10) **Eliminate slogans, exhortations and numerical targets:** These never help anybody do a good job. Let workers formulate their own slogans. Then they will be committed to the contents.
- 11) **Eliminate numerical quotas or work standards:** Quotas take into account only numbers, not quality or methods. They are usually a guarantee of inefficiency and high cost. A person, in order to hold a job, will try to meet a quota at any cost, including doing damage to his company.
- 12) **Remove barriers to taking pride in workmanship:** People are eager to do a good job and distressed when they cannot.
- 13) **Institute a vigorous programme of education:** Both management and the work force will have to be educated in the new knowledge and understanding, including teamwork and statistical techniques.
- 14) **Take action to accomplish the transformation:** It will require a special top management team with a plan of action to carry out the quality mission. A critical mass of people in the company must understand the 14 points.

1.3.3. Quality according to Feigenbaum

The name Feigenbaum and the term total quality control are virtually synonymous due to his profound influence on the concept of total quality control (but also due to being the originator of the concept). In “Total quality control” [5] Armand Vallin Feigenbaum explains his perspective on quality through the following text:

Quality is a customer determination, not an engineer's determination, not a marketing determination, nor a general management determination. It is based on upon the customer's actual experience with the product or service, measured against his or her requirements – stated or unstated, conscious or merely sensed, technically operational or entirely subjective – and always representing a moving target in a competitive market.

Product and service quality can be defined as: The total composite product and service characteristics of marketing, engineering, manufacture and maintenance though which the product and service in use will meet the expectations of the customer.

Feigenbaum's definition of quality is unmistakable a “meeting customer needs” definition of quality. In fact, he goes very wide in his quality definition by emphasizing the importance of satisfying the customer in both actual and expected needs. Feigenbaum essentially points out that quality must be defined in terms of customer satisfaction, that quality is multidimensional (it must be comprehensively defined), and as the needs are changing quality is a dynamic concept in constant change as well. It is clear that Feigenbaum's definition of quality not only encompasses the management of product and services but also of the customer and the customer's expectations.

1.3.4. Quality according to Ishikawa

Kaoru Ishikawa writes the following in his book “What is quality control? The Japanese Way” [6]:

We engage in quality control in order to manufacture products with the quality which can satisfy the requirements of consumers. The mere fact of meeting national standards or specifications is not the answer, it is simply insufficient. International standards established by the International Organization for Standardization (ISO) or the International Electrotechnical Commission (IEC) are not perfect. They contain many shortcomings. Consumers may not be satisfied with a product which meets these standards. We must also keep in mind that consumer requirements change from year to year and even frequently updated standards cannot keep the pace with consumer requirements. How one interprets the term “quality” is important. Narrowly interpreted, quality means quality of products. Broadly interpreted, quality means quality of product, service, information, processes, people, systems etc. etc.

Ishikawa's perspective on quality is a “meeting customer needs” definition as he strongly couples the level of quality to every changing customer expectations. He further means that quality is a dynamic concept as the needs, the requirements and the expectations of a customer continuously change. As follows, quality must be defined comprehensively and dynamically. Ishikawa also includes that price as an attribute on quality – that is, an overpriced product can neither gain customer satisfaction and as follows not high quality.

1.3.5. Quality according to Juran

In “Jurans's Quality Control Handbook” [7] Joseph M. Juran provides two meanings to quality:

The word quality has multiple meanings. Two of those meanings dominate the use of the word: 1) Quality consists of those product features which meet the need of customers and thereby provide product satisfaction. 2) Quality consists of freedom from deficiencies. Nevertheless, in a handbook such as this it is most convenient to standardize on a short definition of the word quality as “fitness for use”

Juran takes a somewhat different road to defining quality than the other gurus previously mentioned. His point is that we cannot use the word quality in terms of satisfying customer expectations or specifications as it is very hard to achieve this. Instead he defines quality as “fitness for use” – which indicates references to requirements and products characteristics. As follows Juran's definition could be interpreted as a “conformance to specification” definition more than a “meeting customer needs” definition. Juran proposes three fundamental managerial processes for the task of managing quality. The three elements of the Juran Trilogy are:

- Quality planning: A process that identifies the customers, their requirements, the product and service features that customers expect, and the processes that will deliver those products and services with the correct attributes and then facilitates the transfer of this knowledge to the producing arm of the organization.
- Quality control: A process in which the product is examined and evaluated against the original requirements expressed by the customer. Problems detected are then corrected.
- Quality improvement: A process in which the sustaining mechanisms are put in place so that quality can be achieved on a continuous basis. This includes allocating resources, assigning people to pursue quality projects, training those involved in pursuing projects, and in general establishing a permanent structure to pursue quality and maintain the gains secured.

1.3.6. Quality according to Shewhart

As referred to by W.E. Deming, “the master”, Walter A. Shewhart defines quality in “Economic control of quality of manufactured product” [8] as follows:

There are two common aspects of quality: One of them has to do with the consideration of the quality of a thing as an objective reality independent of the existence of man. The other has to do with what we think, feel or sense as a result of the objective reality. In other word, there is a subjective side of quality.

Although Shewhart’s definition of quality is from 1920s, it is still considered by many to be the best and most superior. Shewhart talks about both an objective and subjective side of quality which nicely fits into both “conformance to specification” and “meeting customer needs” definitions.

1.4. Quality Models

In the previous section we presented some quality management gurus as well as their ideas and views on quality – primarily because this is a used and appreciated approach for dealing with quality issues in software developing organizations. Whereas the quality management philosophies presented represent a more flexible and qualitative view on quality, this section will present a more fixed and quantitative [2] quality structure view.

1.4.1. McCall’s Quality Model (1977)

One of the more renown predecessors of today’s quality models is the quality model presented by Jim McCall et al. [9-11] (also known as the General Electrics Model of 1977). This model, as well as other contemporary models, originates from the US military (it was developed for the US Air Force, promoted within DoD) and is primarily aimed towards the system developers and the system development process. In his quality model McCall attempts to bridge the gap between users and developers by focusing on a number of software quality factor that reflect both the users’ views and the developers’ priorities.

The McCall quality model has, as shown in Figure 1, three major perspectives for defining and identifying the quality of a software product: product revision (ability to undergo changes), product transition (adaptability to new environments) and product operations (its operation characteristics).

Product revision includes maintainability (the effort required to locate and fix a fault in the program within its operating environment), flexibility (the ease of making changes required by changes in the operating environment) and testability (the ease of testing the program, to ensure that it is error-free and meets its specification).

Product transition is all about portability (the effort required to transfer a program from one environment to another), reusability (the ease of reusing software in a different context) and interoperability (the effort required to couple the system to another system).

Quality of product operations depends on correctness (the extent to which a program fulfils its specification), reliability (the systems ability not to fail), efficiency (further categorized into execution efficiency and storage efficiency and generally meaning the use of resources, e.g. processor time, storage), integrity (the protection of the program from unauthorized access) and usability (the ease of the software).

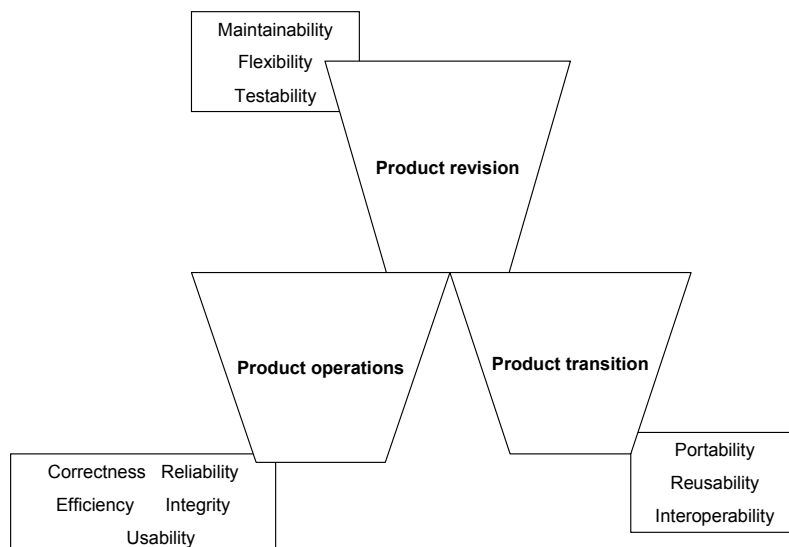


Figure 1: The McCall quality model (a.k.a. McCall’s Triangle of Quality) organized around three types of quality characteristics.

The model furthermore details the three types of quality characteristics (major perspectives) in a hierarchy of factors, criteria and metrics:

- 11 Factors (To specify): They describe the external view of the software, as viewed by the users.
- 23 quality criteria (To build): They describe the internal view of the software, as seen by the developer.
- Metrics (To control): They are defined and used to provide a scale and method for measurement.

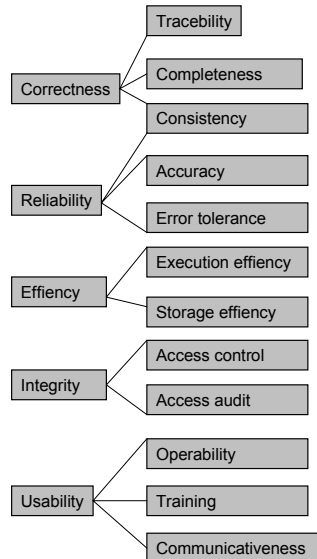


Figure 2: McCall's Quality Model illustrated through a hierarchy of 11 quality factors (on the left hand side of the figure) related to 23 quality criteria (on the right hand side of the figure).

The quality factors describe different types of system behavioral characteristics, and the quality criterions are attributes to one or more of the quality factors. The quality metric, in turn, aims to capture some of the aspects of a quality criterion.

The idea behind McCall's Quality Model is that the quality factors synthesized should provide a complete software quality picture [11]. The actual quality metric is achieved by answering yes and no questions that then are put in relation to each other. That is, if answering equally amount of "yes" and "no" on the questions measuring a quality criteria you will achieve 50% on that quality criteria¹. The metrics can then be synthesized per quality criteria, per quality factor, or if relevant per product or service.

¹ The critique of this approach is that the quality judgment is subjectively measured based on the judgment on the person(s) answering the questions.

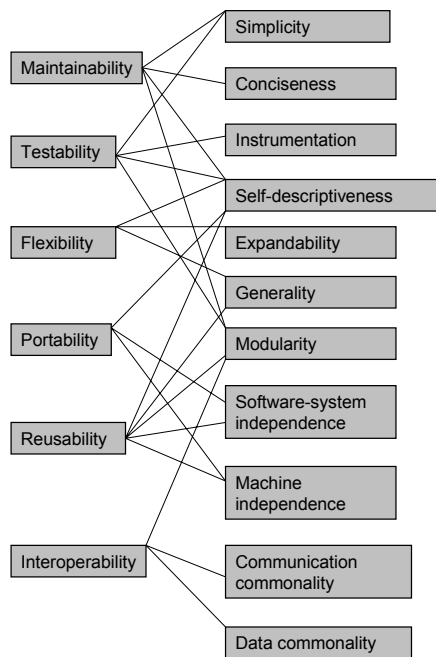


Figure 3: McCall's Quality Model (cont.) illustrated through a hierarchy of 11 quality factors (on the left hand side of the figure) related to 23 quality criteria (on the right hand side of the figure).

1.4.2. Boehm's Quality Model (1978)

The second of the basic and founding predecessors of today's quality models is the quality model presented by Barry W. Boehm [12;13]. Boehm addresses the contemporary shortcomings of models that automatically and quantitatively evaluate the quality of software. In essence his models attempts to qualitatively define software quality by a given set of attributes and metrics. Boehm's model is similar to the McCall Quality Model in that it also presents a hierarchical quality model structured around high-level characteristics, intermediate level characteristics, primitive characteristics - each of which contributes to the overall quality level.

The high-level characteristics represent basic high-level requirements of actual use to which evaluation of software quality could be put – the general utility of software. The high-level characteristics address three main questions that a buyer of software has:

- As-is utility: How well (easily, reliably, efficiently) can I use it as-is?
- Maintainability: How easy is it to understand, modify and retest?
- Portability: Can I still use it if I change my environment?

The intermediate level characteristic represents Boehm's 7 quality factors that together represent the qualities expected from a software system:

- Portability (General utility characteristics): Code possesses the characteristic portability to the extent that it can be operated easily and well on computer configurations other than its current one.
- Reliability (As-is utility characteristics): Code possesses the characteristic reliability to the extent that it can be expected to perform its intended functions satisfactorily.
- Efficiency (As-is utility characteristics): Code possesses the characteristic efficiency to the extent that it fulfills its purpose without waste of resources.
- Usability (As-is utility characteristics, Human Engineering): Code possesses the characteristic usability to the extent that it is reliable, efficient and human-engineered.
- Testability (Maintainability characteristics): Code possesses the characteristic testability to the extent that it facilitates the establishment of verification criteria and supports evaluation of its performance.
- Understandability (Maintainability characteristics): Code possesses the characteristic understandability to the extent that its purpose is clear to the inspector.
- Flexibility (Maintainability characteristics, Modifiability): Code possesses the characteristic modifiability to the extent that it facilitates the incorporation of changes, once the nature of the desired change has been determined. (Note the higher level of abstractness of this characteristic as compared with augmentability).

The lowest level structure of the characteristics hierarchy in Boehm's model is the primitive characteristics metrics hierarchy. The primitive characteristics provide the foundation for defining qualities metrics – which was one of the

goals when Boehm constructed his quality model. Consequently, the model presents one ore more metrics² supposedly measuring a given primitive characteristic.

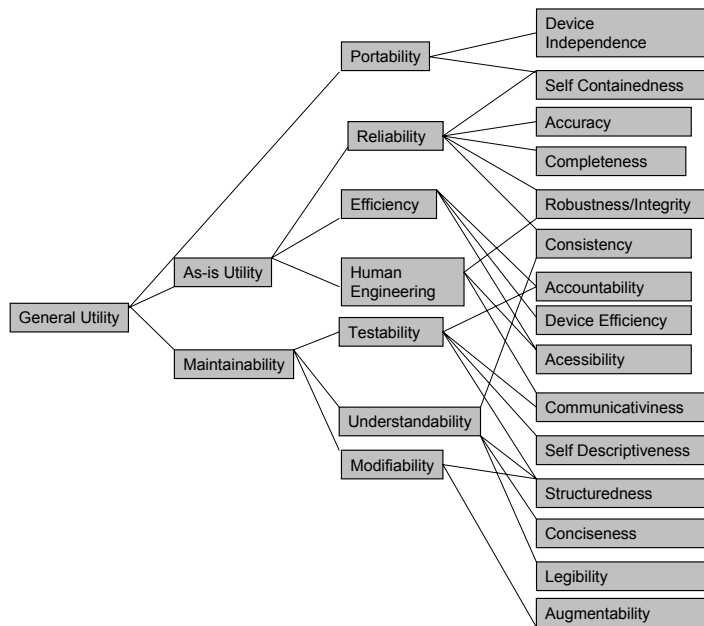


Figure 4: Boehm's Software Quality Characteristics Tree [13]. As-is Utility, Maintainability, and Portability are necessary (but not sufficient) conditions for General Utility. As-is Utility requires a program to be Reliable and adequately Efficient and Human-Engineered. Maintainability requires that the user be able to understand, modify, and test the program, and is aided by good Human-engineering

Though Boehm's and McCall's models might appear very similar, the difference is that McCall's model primarily focuses on the precise measurement of the high-level characteristics "As-is utility" (see Figure 4 above), whereas Boehm's quality mode model is based on a wider range of characteristics with an extended and detailed focus on primarily maintainability. Figure 5 compares the two quality models, quality factor by quality factor.

<i>Criteria/goals</i>	<i>McCall, 1977</i>	<i>Boehm, 1978</i>
Correctness	*	*
Reliability	*	*
Integrity	*	*
Usability	*	*
Efficiency	*	*
Maintainability	*	*
Testability	*	
Interoperability	*	
Flexibility	*	*
Reusability	*	*
Portability	*	*
Clarity		*
Modifiability		*
Documentation		*
Resilience		*
Understandability		*
Validity		*
Functionality		
Generality		*
Economy		*

² Defined by Boehm as: "a measure of extent or degree to which a product possesses and exhibits a certain (quality) characteristic".

Figure 5: Comparison between criteria/goals of the McCall and Boehm quality models [14].

As indicated in Figure 5 above Boehm focuses a lot on the models effort on software maintenance cost-effectiveness – which, he states, is the primary payoff of an increased capability with software quality considerations.

1.4.3. FURPS/FURPS+

A later, and perhaps somewhat less renown, model that is structured in basically the same manner as the previous two quality models (but still worth at least to be mentioned in this context) is the FURPS model originally presented by Robert Grady [15] (and extended by Rational Software [16-18] - now IBM Rational Software - into FURPS+³). FURPS stands for:

- Functionality – which may include feature sets, capabilities and security
- Usability - which may include human factors, aesthetics, consistency in the user interface, online and context-sensitive help, wizards and agents, user documentation, and training materials
- Reliability - which may include frequency and severity of failure, recoverability, predictability, accuracy, and mean time between failure (MTBF)
- Performance - imposes conditions on functional requirements such as speed, efficiency, availability, accuracy, throughput, response time, recovery time, and resource usage
- Supportability - which may include testability, extensibility, adaptability, maintainability, compatibility, configurability, serviceability, installability, localizability (internationalization)

The FURPS-categories are of two different types: Functional (F) and Non-functional (URPS). These categories can be used as both product requirements as well as in the assessment of product quality.

1.4.4. Dromey's Quality Model

An even more recent model similar to the McCall's, Boehm's and the FURPS(+) quality model, is the quality model presented by R. Geoff Dromey [19;20]. Dromey proposes a product based quality model that recognizes that quality evaluation differs for each product and that a more dynamic idea for modeling the process is needed to be wide enough to apply for different systems. Dromey is focusing on the relationship between the quality attributes and the sub-attributes, as well as attempting to connect software product properties with software quality attributes.

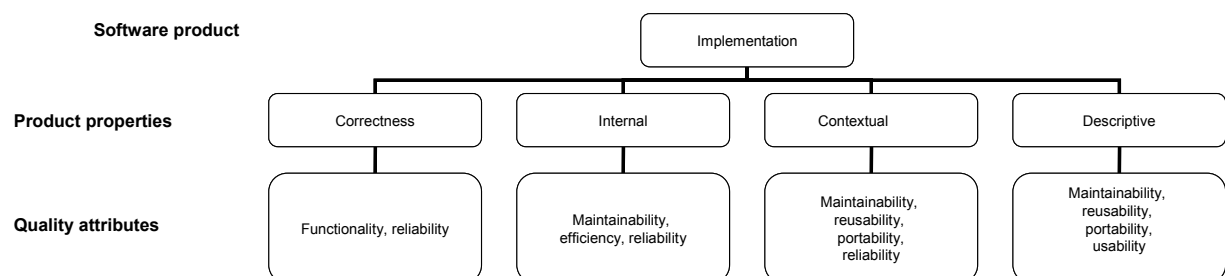


Figure 6: Principles of Dromey's Quality Model

As Figure 6 illustrates, there are three principal elements to Dromey's generic quality model

³ The "+" in FURPS+ includes such requirements as design constraints, implementation requirements, interface requirements and physical requirements.

- 1) Product properties that influence quality
- 2) High level quality attributes
- 3) Means of linking the product properties with the quality attributes.

Dromey's Quality Model is further structured around a 5 step process:

- 1) Chose a set of high-level quality attributes necessary for the evaluation.
- 2) List components/modules in your system.
- 3) Identify quality-carrying properties for the components/modules (qualities of the component that have the most impact on the product properties from the list above).
- 4) Determine how each property effects the quality attributes.
- 5) Evaluate the model and identify weaknesses.

1.4.5. ISO

1.4.5.1 ISO 9000

The renowned ISO acronym stands for International Organization for Standardization⁴. The ISO organization is responsible for a whole battery of standards of which the ISO 9000 [21-25] (depicted in Figure 7 below) family probably is the most well known, spread and used.

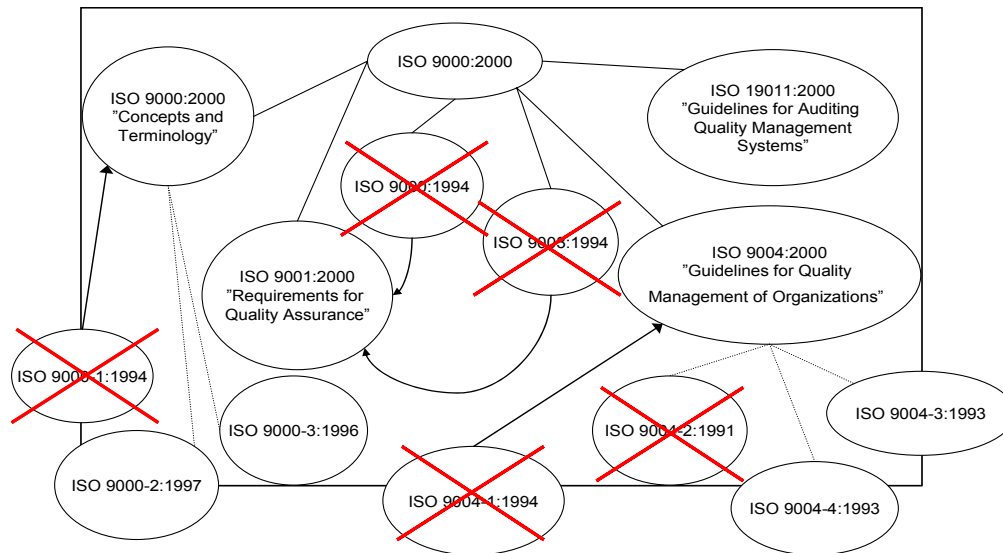


Figure 7: The ISO 9000:2000 standards. The crosses and arrows indicate changes made from the older ISO 9000 standard to the new ISO 9000:2000 standard.

ISO 9001 is an international quality management system standard applicable to organizations within all type of businesses. ISO 9001 internally addresses an organization's processes and methods and externally at managing (controlling, assuring etc.) the quality of delivered products and services. ISO 9001 is a process oriented approach towards quality management. That is, it proposes designing, documenting, implementing, supporting, monitoring, controlling and improving (more or less) each of the following processes:

- Quality Management Process
- Resource Management Process
- Regulatory Research Process
- Market Research Process
- Product Design Process
- Purchasing Process
- Production Process
- Service Provision Process
- Product Protection Process
- Customer Needs Assessment Process

⁴ ISO was chosen instead of IOS, because iso in Greek means equal, and ISO wanted to convey the idea of equality - the idea that they develop standards to place organizations on an equal footing.

- Customer Communications Process
- Internal Communications Process
- Document Control Process
- Record Keeping Process
- Planning Process
- Training Process
- Internal Audit Process
- Management Review Process
- Monitoring and Measuring Process
- Nonconformance Management Process
- Continual Improvement Process

1.4.5.2 ISO 9126

Besides the famous ISO 9000, ISO has also release the ISO 9126: Software Product Evaluation: Quality Characteristics and Guidelines for their Use-standard⁵ [26] (among other standards).

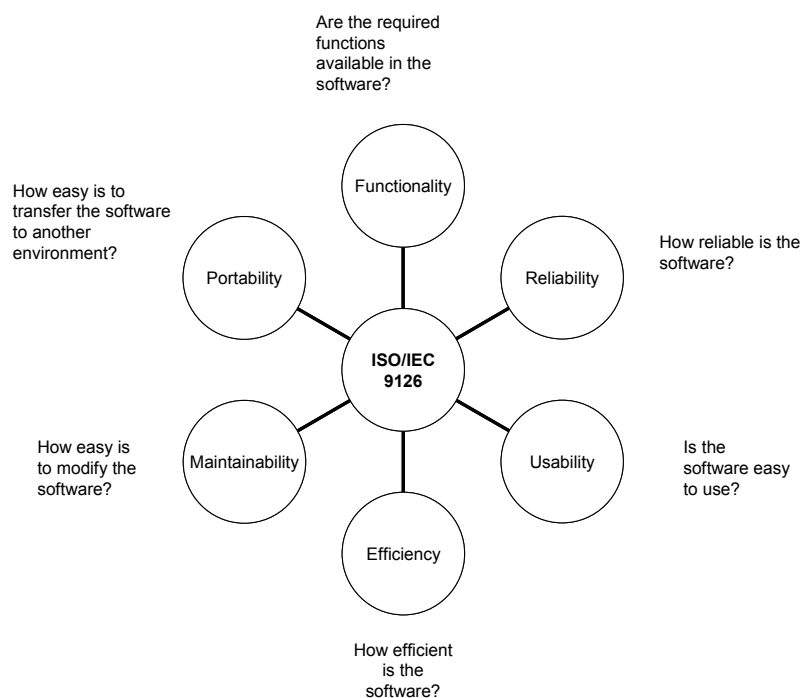


Figure 8: The ISO 9126 quality model

This standard was based on the McCall and Boehm models. Besides being structured in basically the same manner as these models (see Figure 10), ISO 9126 also includes functionality as a parameter, as well as identifying both internal and external quality characteristics of software products.

⁵ ISO/IEC 9126:2001 contains 4 parts

- Part 1: Quality Model
- Part 2: External Metrics
- Part 3: Internal Metrics
- Part 4: Quality in use metrics

<i>Criteria/goals</i>	<i>McCall, 1977</i>	<i>Boehm, 1978</i>	<i>ISO 9126, 1993</i>
Correctness	*	*	maintainability
Reliability	*	*	
Integrity	*	*	
Usability	*	*	*
Efficiency	*	*	*
Maintainability	*	*	*
Testability	*		maintainability
Interoperability	*		
Flexibility	*	*	
Reusability	*	*	
Portability	*	*	*
Clarity		*	
Modifiability		*	maintainability
Documentation		*	
Resilience		*	
Understandability		*	
Validity		*	maintainability
Functionality			
Generality		*	
Economy		*	

Figure 9: Comparison between criteria/goals of the McCall, Boehm and ISO 9126 quality models [14].

ISO 9126 proposes a standard which species six areas of importance, i.e. quality factors, for software evaluation.

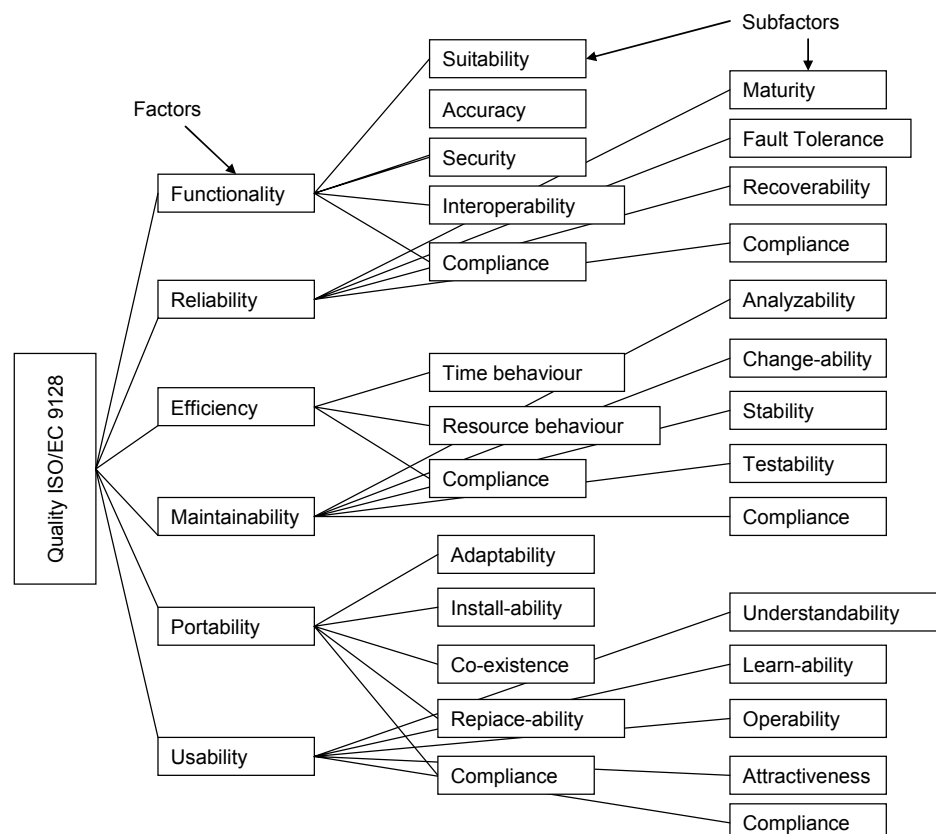


Figure 10: ISO 9126: Software Product Evaluation: Quality Characteristics and Guidelines for their Use

Each quality factors and its corresponding sub-factors are defined as follows:

- **Functionality:** A set of attributes that relate to the existence of a set of functions and their specified properties. The functions are those that satisfy stated or implied needs.
 - **Suitability:** Attribute of software that relates to the presence and appropriateness of a set of functions for specified tasks.
 - **Accuracy:** Attributes of software that bare on the provision of right or agreed results or effects.
 - **Security:** Attributes of software that relate to its ability to prevent unauthorized access, whether accidental or deliberate, to programs and data.
 - **Interoperability:** Attributes of software that relate to its ability to interact with specified systems.
 - **Compliance:** Attributes of software that make the software adhere to application related standards or conventions or regulations in laws and similar prescriptions.
- **Reliability:** A set of attributes that relate to the capability of software to maintain its level of performance under stated conditions for a stated period of time.
 - **Maturity:** Attributes of software that relate to the frequency of failure by faults in the software.
 - **Fault tolerance:** Attributes of software that relate to its ability to maintain a specified level of performance in cases of software faults or of infringement of its specified interface.
 - **Recoverability:** Attributes of software that relate to the capability to re-establish its level of performance and recover the data directly affected in case of a failure and on the time and effort needed for it.
 - **Compliance:** See above.
- **Usability:** A set of attributes that relate to the effort needed for use, and on the individual assessment of such use, by a stated or implied set of users.
 - **Understandability:** Attributes of software that relate to the users' effort for recognizing the logical concept and its applicability.
 - **Learnability:** Attributes of software that relate to the users' effort for learning its application (for example, operation control, input, output).
 - **Operability:** Attributes of software that relate to the users' effort for operation and operation control.
 - **Attractiveness:** -
 - **Compliance:** Attributes of software that make the software adhere to application related standards or conventions or regulations in laws and similar prescriptions.
- **Efficiency:** A set of attributes that relate to the relationship between the level of performance of the software and the amount of resources used, under stated conditions.
 - **Time behavior:** Attributes of software that relate to response and processing times and on throughput rates in performing its function.
 - **Resource behavior:** Attributes of software that relate to the amount of resources used and the duration of such use in performing its function.
 - **Compliance:** See above.
- **Maintainability:** A set of attributes that relate to the effort needed to make specified modifications.
 - **Analyzability:** Attributes of software that relate to the effort needed for diagnosis of deficiencies or causes of failures, or for identification of parts to be modified.
 - **Changeability:** Attributes of software that relate to the effort needed for modification, fault removal or for environmental change.
 - **Stability:** Attributes of software that relate to the risk of unexpected effect of modifications.
 - **Testability:** Attributes of software that relate to the effort needed for validating the modified software.
 - **Compliance:** See above.
- **Portability:** A set of attributes that relate to the ability of software to be transferred from one environment to another.
 - **Adaptability:** Attributes of software that relate to on the opportunity for its adaptation to different specified environments without applying other actions or means than those provided for this purpose for the software considered.
 - **Installability:** Attributes of software that relate to the effort needed to install the software in a specified environment.
 - **Conformance:** Attributes of software that make the software adhere to standards or conventions relating to portability.
 - **Replaceability:** Attributes of software that relate to the opportunity and effort of using it in the place of specified other software in the environment of that software.

1.4.5.3 ISO/IEC 15504 (SPICE⁶)

The ISO/IEC 15504: Information Technology - Software Process Assessment is a large international standard framework for process assessment that intends to address all processes involved in:

- Software acquisition
- Development
- Operation
- Supply
- Maintenance
- Support

ISO/IEC 15504 consists of 9 component parts covering concepts, process reference model and improvement guide, assessment model and guides, qualifications of assessors, and guide for determining supplier process capability:

- 1) ISO/IEC 15504-1 Part 1: Concepts and Introductory Guide.
- 2) ISO/IEC 15504-2 Part 2: A Reference Model for Processes and Process Capability.
- 3) ISO/IEC 15504-3 Part 3: Performing an Assessment.
- 4) ISO/IEC 15504-4 Part 4: Guide to Performing Assessments.
- 5) ISO/IEC 15504-5 Part 5: An Assessment Model and Indicator Guidance.
- 6) ISO/IEC 15504-6 Part 6: Guide to Competency of Assessors.
- 7) ISO/IEC 15504-7 Part 7: Guide for Use in Process Improvement.
- 8) ISO/IEC 15504-8 Part 8: Guide for Use in Determining Supplier Process Capability.
- 9) ISO/IEC 15504-9 Part 9: Vocabulary.

Given the structure and contents of the ISO/IEC 15504 documentation it is more closely related to ISO 9000, ISO/IEC 12207 and CMM, rather than the initially discussed quality models (McCall, Boehm and ISO 9126).

1.4.6. IEEE

IEEE has also release several standards, more or less related to the topic covered within this technical paper. To name a few:

- IEEE Std. 1220-1998: IEEE Standard for Application and Management of the Systems Engineering Process
- IEEE Std 730-1998: IEEE Standard for Software Quality Assurance Plans
- IEEE Std 828-1998: IEEE Standard for Software Configuration Management Plans – Description
- IEEE Std 829-1998: IEEE Standard For Software Test Documentation
- IEEE Std 830-1998: IEEE recommended practice for software requirements specifications
- IEEE Std 1012-1998: IEEE standard for software verification and validation plans
- IEEE Std 1016-1998: IEEE recommended practice for software design descriptions
- IEEE Std 1028-1997: IEEE Standard for Software Reviews
- IEEE Std 1058-1998: IEEE standard for software project management plans
- IEEE Std 1061-1998: IEEE standard for a software quality metrics methodology
- IEEE Std 1063-2001: IEEE standard for software user documentation
- IEEE Std 1074-1997: IEEE standard for developing software life cycle processes
- IEEE/EIA 12207.0-1996: Standard Industry Implementation of International Standard ISO/IEC 12207: 1995 (ISO/IEC 12207) Standard for Information Technology Software Life Cycle Processes

Of the above mentioned standards it is probably the implementation of ISO/IEC 12207: 1995 that most resembles previously discussed models in that it describes the processes for the following life-cycle:

- Primary Processes: Acquisition, Supply, Development, Operation, and Maintenance.
- Supporting Processes: Documentation, Configuration Management, Quality Assurance, Verification, Validation, Joint Review, Audit, and Problem Resolution.
- Organization Processes: Management, Infrastructure, Improvement, and Training

In fact, IEEE/EIA 12207.0-1996 is so similar to the ISO 9000 standard that it could actually be seen as a potential replacement for ISO within software engineering organizations.

The IEEE Std 1061-1998 is another standard that is relevant from the perspective of this technical paper as the standard provides a methodology for establishing quality requirements and identifying, implementing, analyzing and validating the process and product of software quality metrics.

⁶ SPICE is an acronym for “Software Process Improvement and Capability dEtermination”

1.4.7. Capability Maturity Model(s)

The Carnegie Mellon Software Engineering Institute (SEI), non-profit group sponsored by the DoD work at getting US software more reliable. Examples of relevant material produced from SEI is the PSP [27;28] and TSPi [29]. While PSP and TSPi briefly brushes the topic of this technical paper, SEI has also produced a number of more extensive Capability Maturity Models that in a very IEEE and ISO 9000 similar manner addresses the topic of software quality:

- CMM / SW-CMM [28;30;31]
- P-CMM [32]
- CMMI [33]
 - PDD-CMM
 - SE-CMM
 - SA-CMM

The CMM/SW-CMM depicted in Figure 11 below addresses the issue of software quality from a process perspective.

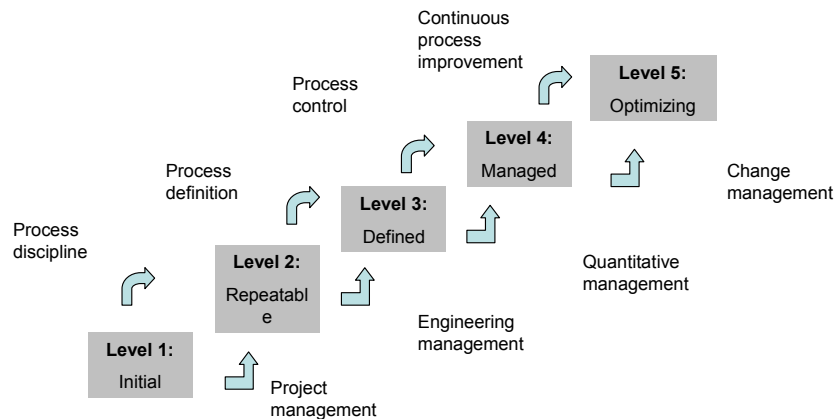


Figure 11: Maturity Levels of (SW-)CMM

Table 1: Maturity levels with corresponding focus and key process areas for CMM.

Level	Focus	Key Process Area
Level 5 – Optimizing level	Continuous improvement	Process Change Management Technology Change Management Defect Prevention
Level 4 – Managed level	Product and process quality	Software Quality Management Quantitative Process Management
Level 3 – Defined level	Engineering process	Organization Process Focus Organization Process Definition Peer Reviews Training Program Intergroup Coordination Software Product Engineering Integrated Software Management
Level 2 – Repeatable level	Project Management	Requirements Management Software Project Planning Software Project Tracking and Oversight Software Subcontract Management Software Quality Assurance Software Configuration Management
Level 1 – Initial level	Heroes	No KPAs at this time

The SW-CMM is superseded by the CMMI model which also incorporates some other CMM models into a wider scope. CMMI Integrates systems and software disciplines into one process improvement framework and is structured around the following process areas:

- Process management
- Project management
- Engineering
- Support

...and similarly to the SW-CMM the following maturity levels:

- Maturity level 5: Optimizing - Focus on process improvement
- Maturity level 4: Quantitatively managed - Process measured and controlled.
- Maturity level 3: Defined - Process characterized for the organization and is proactive.
- Maturity level 2: Managed - Process characterized for projects and is often reactive.
- Maturity level 1: Initial - Process unpredictable, poorly controlled and reactive.
- Maturity level 0: Incomplete

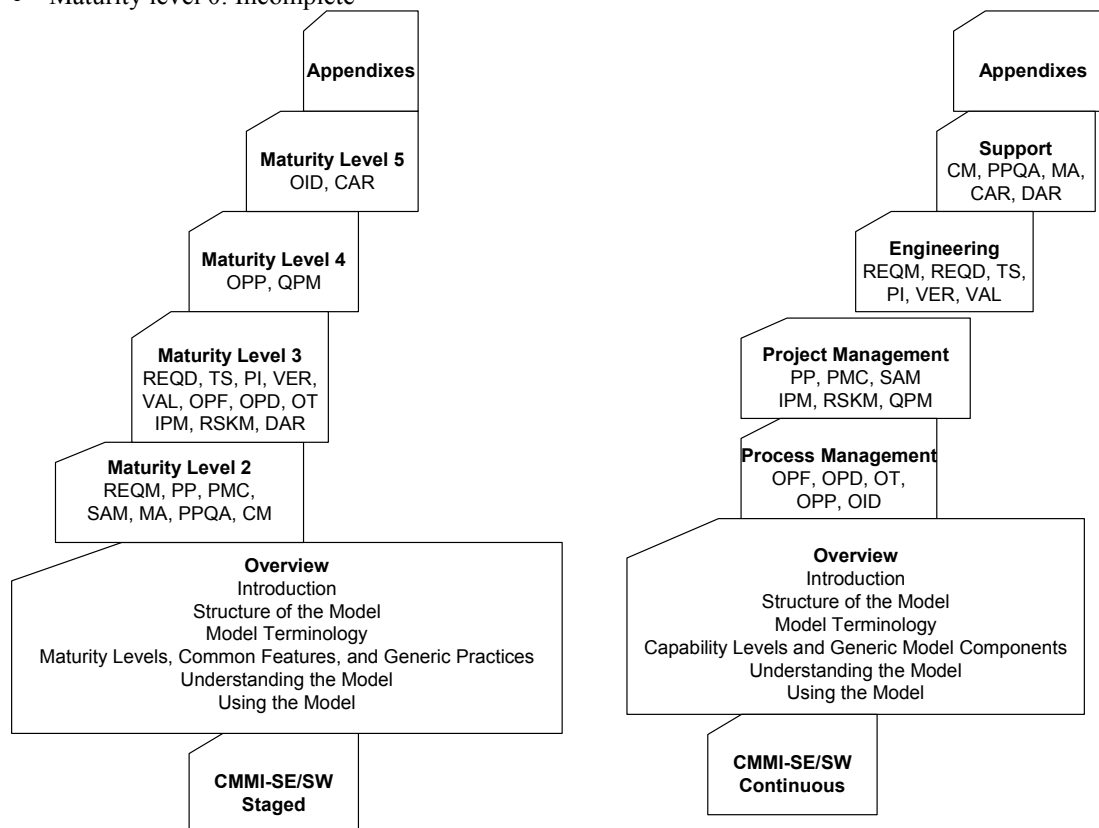


Figure 12: The two representations of the CMMI model.

1.4.8. Six Sigma

Given that we are trying to provide a somewhat all covering picture of the more known quality models and philosophies we also need to at least mention Six Sigma. Six Sigma can be viewed as a management philosophy that uses customer-focused measurement and goal-setting to create bottom-line results. It strongly advocates listening to the voice of the customer and converting customer needs into measurable requirements.

1.5. Conclusion and discussions

Throughout this chapter the ambition has been to briefly survey some different structures of quality – without any deepening drilldowns in a particular model or philosophy. The idea was to nuance and provide an overview of the landscape of what sometimes briefly (and mostly thoughtlessly) simply is labeled quality. The paper has shown that quality can be a very elusive concept that can be approached from a number of perspective dependent on once take and interest. Garvin [11;34] has made a cited attempt to sort out the different views on quality. He the following organization of the views:

- Transcendental view, where quality is recognized but not defined. The transcendental view is a subjective and non quantifiable of defining software quality. It often results in software that transcends customer expectations.
- User view on quality or “fitness for purpose” takes the starting point in software that meets the users’ needs. Reliability (failure rate, MTBF), Performance/Efficiency (time to perform a task), Maintainability and Usability are issues within this view.
- Manufacturing view on quality focuses on conformance to specification and the organizations capacity to produce software according to the software process. Here product quality is achieved through process quality. Waste reduction, Zero defect, Right the first time (defect count and fault rates, staff effort rework costs) are concepts usually found within this view.
- Product view on quality usually specifies that the characteristics of product are defined by the characteristics of its subparts, e.g. size, complexity, and test coverage. Module complexity measures, Design & code measures etc.
- Value based view on quality measures and produces value for money by balancing requirements, budget and time, cost & price, deliver dates (lead time, calendar time), productivity etc.

Most of the quality models presented within this technical paper probably could be fitted within the user view, manufacturing view or product view – though this is a futile exercise with little meaning. The models presented herein are focused around either processes or capability level (ISO, CMM etc.) where quality is measured in terms of adherence to the process or capability level, or a set of attributed/metrics used to distinctively assess quality (McCall, Boehm etc.) by making quality a quantifiable concept. Though having some advantages (in terms of objective measurability), quality models actually reduce the notion of quality to a few relatively simple and static attributes. This structure of quality is in great contrast to the dynamic, moving target, fulfilling the customers’ ever changing expectations perspective presented by some of the quality management gurus. It is easy to see that the quality models represent leaner and narrower perspectives on quality than the management philosophies presented by the quality gurus. The benefit of quality models is that they are simpler to use. The benefit of the quality management philosophies is that they probably more to the point capture the idea of quality.

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