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A Review in Software Quality Models for Software Quality Assurance

Kamal Borana[1], Dr. Meena Sharma [2], Dr. Deepak Abhyankar[3]

Research Scholar, Computer Engineering, IET Davv, Indore, India[1]

Professor, Computer Engineering, IET Davv, Indore, India[2]

Software Engineer, Computer Science & IT, SCSIT, Davv, Indore, India[3]

Abstract: To increase the worth of software products, every Software organization wants to develop high-quality software. Quality of software means satisfaction of stakeholders (end-user, developer, organization).The quality of software depends on the attributes such as functionality, usability, reliability, testability, etc. Software quality models later on abbreviated as SQM help software organizations, software developers, software quality researchers, and managers to decide which software quality attributes should be incorporated while developing the software. SQM are used for the prediction of software quality. Software quality is the central concept of software quality engineering. To achieve software quality assurance, we need to develop a high-quality software product. Software reliability plays a key role in software where time is a critical factor like in satellite launching, aerospace engineering, health care system, etc. If a software error occurs, the mission will fail. After the study of various SQM, we have studied, tabulated, and depicted software quality attributes in the form of bar graphs and tables. For the development of any new SQM, a literature review is essential.

Keywords: SQ (Software quality), SQM (software quality models), QF (quality factor), Software quality assurance, CBSD (component-based software development).

I. INTRODUCTION

The goal of this survey is to get an outline of different Software quality models. Once the concept of quality is understood, the structure of quality in the software can be understood in the Software. SQM play a vital role to improve the software. Such improvements can be measured in the form of quality attributes and increase customer satisfaction and decrease the cost of the software. Researchers have proposed numerous SQM to degree the best of software products. In this review, we provide an overview of various SQM which are divided into two categories: basic SQM and tailored SQM [1]. We have covered both types of SQM and compared and presented the results in the form of software quality attributes (factors) and comparison in the form of tables and bar graphs. Quality of software can be considered as a summation of different quality factors involved in the software development and it can be written in mathematical equation is as below.

SQ = $\sum_0^n$ QF = (QF0+QF1+QF2+QF3+……n)

To discuss the meaning and definition of (software) quality in the context of Conformance to specification and Meeting customer needs.

1) Conformance to specification: Quality is defined as counted of services and products whose measurable traits fulfil a set specification are conformance to specification.

2) Meeting customer needs: Quality this is recognized independently of any measurable characteristics. That is, high-quality is defined as the product's or service's capability to meet customer expectations- express or not. The term "Software Quality" described by way of the IEEE [2] as the scale to which a structure, module, or method meets particular demands and customer (end-user) desires (outlook).

II. REVIEW OF LITERATURE

BASIC SQM

There are many SQM in the software construction discipline. Each one of these SQM comprises of numerous quality factors. These QF can be used to reveal the quality of the software product from the regard of these QF. Select which one of the pleasant models is an actual provocation. SQM are used for the global assessment of software products. Basic SQM refer to those models which were developed until 2000. In view of this Literature, we will converse the contents of the following SQM such as McCall's SQM, Boehm's SQM, Dromey's SQM, Furps SQM, ISO 9126 SQM, and ISO 2510 SQM.

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2.1 McCall's SQM

McCall's SQM is offered by Jim McCall (also known as the General Electric's Model of 1977). It recognizes three areas of software work.

(I) Operation on Product, is the product's ability to be quickly understood, operates, and is capable of providing the results required by the user. It covers correctness, reliability, efficiency, integrity, and usability criteria.

(II) Revision of Product is the ability to change, including error rectification and system variation also covers Maintainability, flexibility, and testability criterion.

(III)Product transition is the adaptability to new environments, allotted processing collectively with swiftly converting hardware.

This model emphasizes the relationship between quality characteristics and metrics [3]. The main drawback of this model is, there is no accuracy in showing as it is based on Yes and No responses

.

Table 1. McCall's Table [3] [4]

McCall's SQM

Quality Type	Product Perspective	Factors	Criterion
Quality Software Product	Product Operation	Correctness	Traceability
			Completeness
			Consistency
		Reliability	Correctness
			Defect-Tolerance
			Consistency
		Efficiency	Executions
			luggage compartment
		Integrity	Control of Access
			Audit of Access
		Usability	Viability
			Exercise
			Accessibility
		Maintainability	Simplicity
			Conciseness
			Self Modularity
	Product Revision	Testability	Instrumentation
			Self Simplicity
			Modularity
		Flexibility	Simplicity
			Expandability
			Generality
	Product Transaction	Portability	Modularity
			Simplicity
			Software System
			Machine
		Reusability	Simplicity
			Generality
			Modularity
			Software System
			Machine

2.2 Boehm's SQM

Boehm's software quality model is developed by Boehm in 1978 which emphasis on maintainability for the software product. It adds maintainability to McCall's model. Boehm adds factors at different levels [2]. High-level factors are described as follows-

1. Utility means easy to use, reliable, and efficient use of a software product.
2. Maintainability that describes to able to modify, testable, and features of understanding.
3. Portability means easy to transfer between software products.

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Table 2. Boehm's Table [3]

Boehm Quality Model			
Quality Type	**Product Perspective**	**Factors**	**Criterion**
General Utility	As is utility	Correctness	Device Independent Completeness
		Reliability	Accuracy Completeness Consistency
		Efficiency	Device Efficiency Accessibility
		Human Engineering	Accessibility Communicativeness
	Maintainability	Testability	Communicativeness Accessibility
		Under stability	Structuredness Consistency
		Modifiability	Structuredness Conciseness Legibility Structuredness Augment-ability

2.3 Dromey's SQM

Dromey suggest a working skeleton for evaluate requirement fortitude, plan, and execution phases. The skeleton consists of three models, i.e. quality model of requirement, quality model of design, and quality model of Implementation.

The high-level product charters tics for the implementation quality model encompass:

(i) Correctness determines if some basic rules are desecrated, with functionality and reliability as software quality attributes.

(ii) Internal measures how properly a thing has been deployed in keeping with its meant use, with maintainability, efficiency, and reliability as a QF.

(iv) Descriptiveness of a component is calculated by the descriptive measures, with software quality attributes in maintainability, reusability, portability, and usability.

In the early stages (analysis and design) of the development process despite the design quality model takes into account explicitly even architectural integrity is not fully addressed. Testability is absolutely fixed in the inside product property. Domain-specific QF is not addressed. Furthermore, one inconvenience of the Dromey SQM is connected with maintainability and, reliability as it is not feasible to decide them before the software product is operational inside the production place. [5].

Quality Carrying Properties of Variable

Table 3. Quality Carrying Properties of variable [5]

Structural Form	**Quality Carrying Properties**
Variable →	Self Descriptive
	Assigned
	Consistent
	Utilized
	Encapsulated
	Documented
	Precise

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Quality Carrying Properties of Expression

Table 4. Quality Carrying Properties of expression [5]

Structural Form	Quality Carrying Properties
Expression	Computable
	Consistent
	Effective
	Encapsulated
	Adjustable

2.4 FURPS SQM

Robert Grady and Hewlett-Packard are the first ones to propose a model with the industrial approach. The characteristics that are taken into consideration in the FURPS model [2] [13] are:

(I) The QF Functionality, incorporate feature such as sets, capabilities, and security.

(II) The QF Usability, incorporate feature such as human factors, consistency in the user interface, online and context-sensitive help, wizards, user documentation, and training materials.

(III) The QF Reliability, incorporate feature such as frequency and severity of failure, recoverability, predictability, accuracy, and mean time between failures (MTBF).

(IV) The QF Performance, incorporate conditions on functional requirements such as speed, efficiency, availability, accuracy, throughput, response time and recovery time, and resource usage.

(V) The QF Supportability consists of testability, extensibility, adaptability, maintainability, and compatibility. One drawback of this model is that it fails to take account of the software portability. Domain-precise attributes are not protected inside the model.

Table 5. FURPS Quality Model [6] [7]

FURPS SQM	
FURPS	Functionality
	Usability
	Reliability
	Performance
	Supportability

2.5 ISO 9126 SQM

ISO 9126 [8]-[10] is an international standard for software evolution. This model was based on McCall and Boehm's models. The model was divided into four parts:

1. Quality Model.
2. Internal Quality Attribute.
3. External Quality Attribute.
4. Quality in use Metrics.

This version divides software program first-class attributes into 6 unbiased high-stage Quality traits which can be functionality, reliability, usability, performance, maintainability, and Portability. Further, those traits are divided into sub characteristics. Internal Quality Attribute relates to the structure traits that can be assessed exclusive of executing, while external Quality Attribute assessed by attentive throughout its execution [6]. The quality in use criterion is handling the usefulness of the product, the security of the product, and the satisfaction of the end-users [1].

Table 6. ISO-9126 Quality Model [3] [8]-[10]

ISO 9126 SQM			
Quality Type	**Product Perspective**	**Characteristics**	**Sub Characteristics**
Quality Software Product		Functionality	Suitability
			Accuracy
			Interoperability
			Security
		Reliability	Maturity
			Fault Tolerance
			Recoverability

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		Usability	Under-stability
			Learn-ability
			Operability
			Attractiveness
		Efficiency	Time behaviour
			Resource
		Maintainability	Analyzability
			Changeability
			Stability
			Testability
		Mobility	Adaptability
			Replace-ability
			Install-ability
			Co-Existence

2.6 2510 SQM

ISO 2510 is the updated version of ISO 9126. In this model, software product quality is subdivided into eight sub characteristics. The set of standards are based on the ISO-9126 Model. This model introduces new characteristics, such as security, and compatibility. It uses the term transferability as an extension of portability.

Table 7. ISO-9126 Quality Model [1] [8]-[11]

ISO 2510 SQM			
Quality Type	**Product Perspective**	**Characteristics**	**Sub Characteristics**
Quality Product Software		Functional suitability	Appropriateness
			Accuracy
			Compliance
		Reliability	Availability
			Fault Tolerance
			Recoverability
			Compliance
		Performance efficiency	Time behaviour
			Resource utilization
			Compliance
			Attractiveness
		Workability	Appropriateness
			Recognisability
			Learnability
			Ease of use
			Helpfulness
			Attractiveness
			Technical
			Accessibility
			Compliance
		Safety	Confidentiality
			Integrity
			No repudiation
			Accountability
			Authenticity
			Compliance
		Congruity	Replace ability
			Coexistence
			Interoperability
			Compliance
			Modularity

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		Maintainability	Reusability
			Analyzability
			Changeability
			Modification
			Stability
			Testability
			Compliance
		Movability	Portability
			Adaptability

III. COMPARATIVE ANALYSIS OF BASIC SQM

This comparison is resulted by applying effort from Al Baradeen [12][13], AlQutaish [14], Samarthyam [15], and Gayathri [16], who conducted comparative studies of Basics Quality Models. McCall having 11 QF, Boehm having 6 QF, FURPS having 5 QF, Dromy having 7 QF, ISO 9126 having 20 QF, and ISO 2510 having 24 QF. We observed none of the Quality Models have incorporated Communication as a Quality Factor in the provided research. Communication QF should be incorporated in future SQM because of the need for communication between all the stages in software development.

Table 8. Comparison of Basic SQM [1]

Characteristics	**McCall**	**Boehm**	**Furps**	**Dromey**	**ISO 9126**	**ISO 2510**
Accuracy					√	√
Adaptability			√			√
Analyzability					√	√
Attractiveness					√	√
Changeability					√	√
Correctness	√					√
Efficiency	√	√		√	√	√
Flexibility	√					
Functionality			√	√	√	√
Human Engg.		√				
Install ability					√	√
Integrity	√					√
Interoperability	√					√
Maintainability	√			√	√	√
Maturity					√	√
Modifiability						√
Operability						
Portability					√	√
Reliability	√	√	√	√	√	√
Resource Utilization					√	√
Reusability	√			√		√
Stability					√	√
Suitability					√	√
Supportability			√		√	√
Testability	√	√			√	√
Transferability						√
Understand ability		√			√	√
Usability	√		√	√	√	√
Total QF=28	**11**	**5**	**5**	**7**	**20**	**26**

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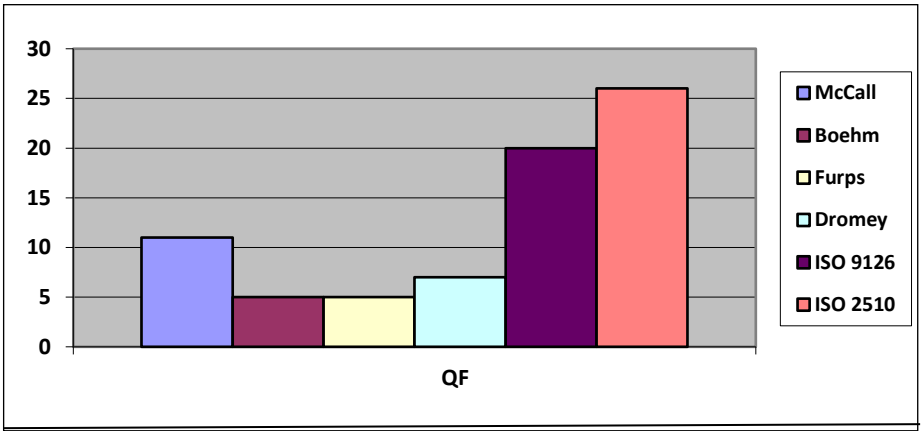

Fig. 1: Comparison of Basic SQM by Bar Graph

IV. TAILORED SQM

Tailored SQM began in the year 2001. They were building from the basic SQM. This model was developed on specific individual components. We have many tailored software quality models, however during our examination, we've uncovered that considering four tailored SQM which are below

1. Bertoa 2. Gequamo 3. Alvaro 4. Rewashdeh.

4.1 BERTOA SQM

The Quality Model Bertoa [17] is based on the ISO 9126 Model [8]. It defines a quality attribute for the evaluation of COTS (Commercial Off-The-Shelf Components). It is used to build complex software.

Table 9. Bertoa SQM [1] [17]

Bertoa SQM Characteristics	Sub Characteristics (Run Time)	Sub Characteristics (Life Cycle)
Functionality		Suitability
		Interoperability
		Compliance
Reliability	Accuracy	Maturity
		Learn-ability
Usability		Under-stability
Efficiency		Operability
	Security	Changeability
		Testability
Maintainability		
Portability		Replaceability
	Suitability	
	Time behaviour	
	Resource behaviour	

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4.2 GEQUAMO SQM

The GEQUAMO model (generic, multilayered, customizable) is created by E.Georgiadou [18] and consists of the breakdown of the sub-layers and features and encapsulates user requirements flexibly. With the help of this model, end-user can build their model.

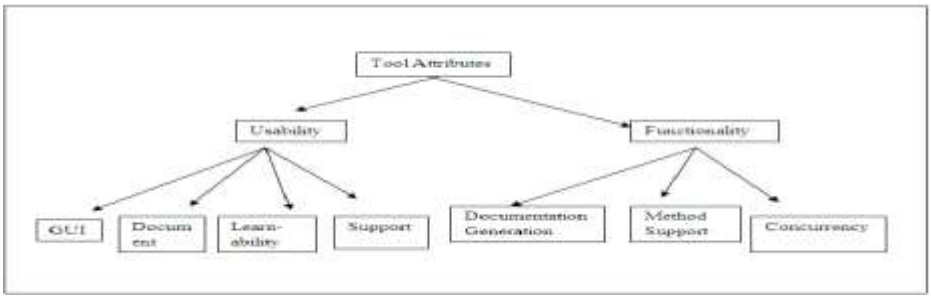

Fig. 2: Layer of Characteristics applied to a tool CASE [1] [18]

4.3 ALVERO SQM

Alvero model is used for the certification of software components to identify elements of quality components. Alvero model consists of a framework that can further divide into four parts.

1. Model quality components
2. Framework for the technical certification
3. Certification Process
4. A-frame containing Metrics.

Table 10 Alvaro SQM [1] [18] [19]

Alvaro SQM Characteristics	Sub Characteristics (Run Time)	Sub Characteristics (Life Cycle)
		Maturity
Rreliability		
Usability		Under-stability Learn-ability Operability
Efficiency		
Maintainability		Changeability Testability

4.4 RAWASHDEH SQM

Rawashdeh SQM [20] has been dominated by the ISO 9126 and Dromey SQM. It covers the actual need of different users. The model gives four steps to build a quality product.

1. Identification of a small group of high-level quality attributes. Then with the help of a top-down approach, each attribute is partitioned into a set of subordinate attributes.
2. Explore differences between internal and external metrics. Internal covers internal attributes like specifications or lines of code and external covers behavior during testing operations and components.
3. For each quality attribute, we have to identify users.
4. We can build the new SQM with the help of ISO 9126, and the Dromey SQM.

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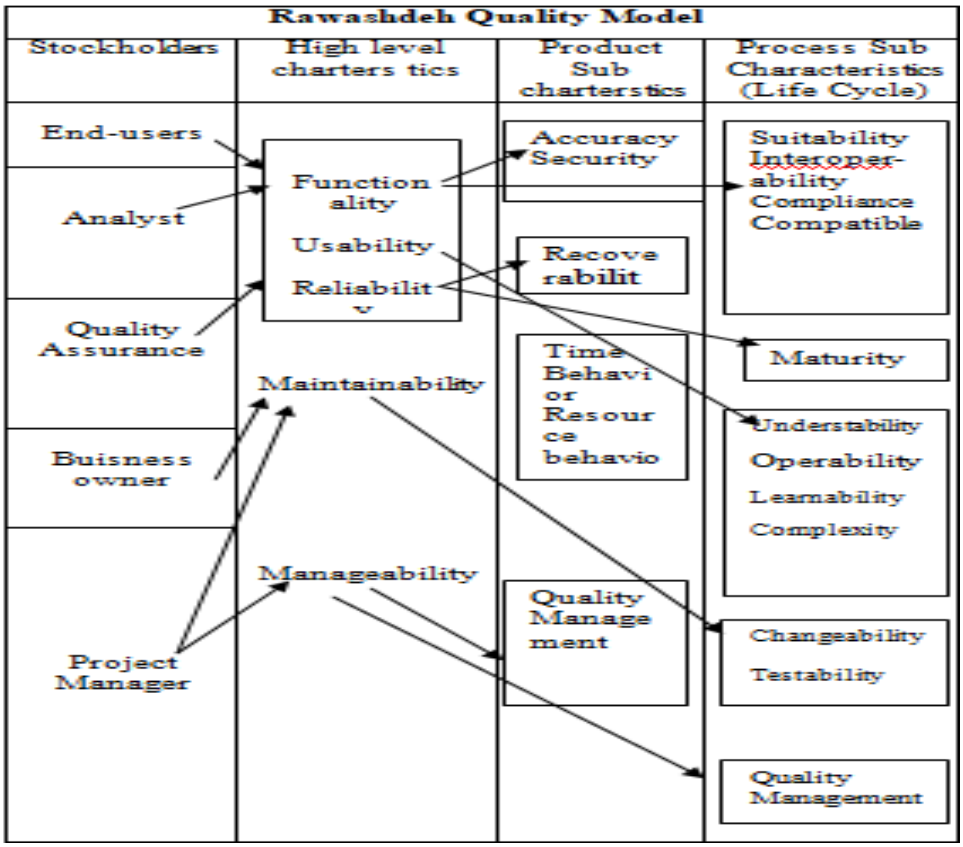

Fig. 3: Rawashdeh SQM [1] [20]

V. COMPARATIVE ANALYSIS OF TAILORED SQM

We have Compared tailored oriented SQM and observed that it is more difficult to compare because they use the model in a particular context. The models can be either product-oriented (GECUAMO [18]), or particular domain-oriented (Bertoa [17]), or from the point of view of an end-user (Rawashdeh [20]). Our comparison is based on the four tailored SQM which we have studied in our literature. We have observed that Alavero Tailored SQM has achieved the highest Quality Factor.

Table 11: Comparison of Tailored SQM [1] [17]-[21]

Characteristics	Bertoa	Gecuamo	Alvaro	Rawashdeh
Accuracy	√		√	√
Adaptability		√	√	
Analyzability				
Attractiveness				
Changeability	√		√	√
Correctness		√		
Efficiency			√	√
Flexibility				
Functionality	√	√	√	√
Human Engg.				
Installability				
Integrity				
Interoperability	√		√	√
Maintainability	√		√	√
Maturity	√	√	√	√
Modifiability				
Operability	√			√
Portability	√		√	

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Reliability	√		√	√
Resource Utilization	√	√	√	√
Reusability	√		√	
Stability			√	
Suitability	√		√	√
Supportability				
Testability	√	√	√	√
Compliance	√	√	√	√
Understandability	√	√	√	√
Usability	√	√	√	√
Time Behaviour	√		√	√
Self Contained			√	
Suitability	√		√	√
Configurability			√	
Compatibility				√
Fault Tolerance			√	
Flexibility				
Learnability	√	√	√	√
Manageability				√
Replace ability	√		√	
Time Behaviour	√		√	√
Recoverability	√			√
Total QF=40	**21**	**10**	**26**	**21**

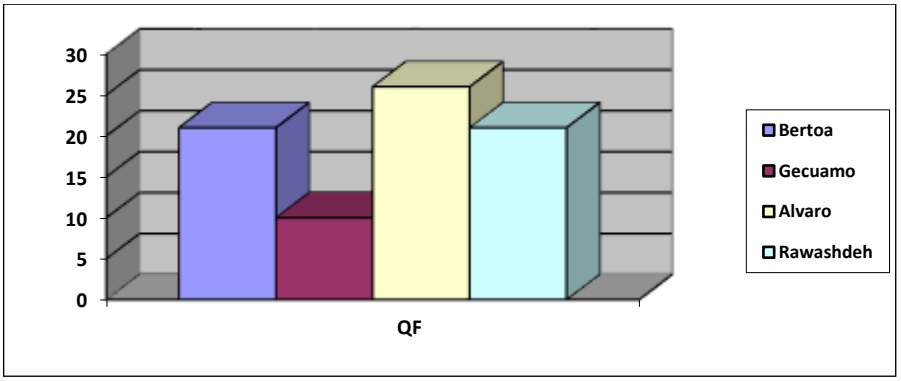

Fig. 3: Comparison of Tailored SQM by Bar Graph

VI. CONCLUSION & FUTURE WORK

Software Quality is a foremost issue for any software organization. A quality product must satisfy the customer's requirements furthermore, meet the detail. Software Quality is the emerging research area in the field of software engineering. Researchers have contributed towards the Software Quality field and proposed various SQM to enhance the quality of software products. We have collected data from various research papers, questionnaires, reviews, and conducted quizzes and conclude that for the development of any new software quality model, it is needed the complete study and analysis of various SQM.In this research, we have presented a comparative study of SQM based on software quality attributes (quality factors).

The journey of SQM begins from the basic SQM.The very first SQM which was anticipated by McCall et al [4] decide and pinpoint the quality of software products all the way through three programs: operation on product, revision on product, and transition on product. It works on eleven quality attributes. After the McCall SQM, Boehm et al (1988) [22] talk about mechanically and quantitative test the quality of software. This version starts off-evolved with the software's trendy application this is excessive-degree traits that represent basic excessive-stage necessities of actual use. The application is similarly subtle into reliability, efficiency, and human engineering, and maintainability is in addition refined into testability and modifiability. It helps 5 quality attributes. FURPS SQM [5][23] in (1992) discussed quality factor, functionality, usability, reliability, performance, and supportability. It supports five quality factors.

Dromy model [5] in (1995) gives contribution towards software product quality. Meanwhile, he proposed a running framework for comparing necessities purpose, plan, and execution phase and also focuses on quality carrying property

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in the software product. It supports seven quality factors. After that ISO model [8][9] came into existence. The ISO 9126 model received inputs from previous models and sets standards for assessing the quality of software.
Tailored SQM based on the product-oriented and end-user oriented. Among all the tailored SQM we have observed that the Alvaro SQM has achieved 26 quality factors.
In the future aspects towards SQM, firstly Software should be working on component-based software development because works on components are comparatively easy rather than whole software so that reusability can be achieved, secondly, the quality of component-based software development (CBSD) depends on what are the qualities of the individual component we are using. Communication as a quality factor should be incorporated during the development of any new SQM due to the demands of the communication whiles the development at all stages.

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