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Software Product Quality Evaluation Model with Multiple Criteria Decision Making Analysis

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***Abstract*—**This paper presents a software product quality evaluation model based on the ISO/IEC 25010 quality model. The evaluation characteristics and sub characteristics were identified from the ISO/IEC 25010 quality model. The multidimensional structure of the quality model is based on characteristics such as functional suitability, performance efficiency, compatibility, usability, reliability, security, maintainability, and portability, and associated sub characteristics.

Random numbers are generated to establish the decision maker's importance weights for each sub characteristics. Also, random numbers are generated to establish the decision matrix of the decision maker's final scores for each software product against each sub characteristics. Thus, objective criteria importance weights and index scores for datasets were obtained from the random numbers.

In the proposed model, five different software product quality evaluation datasets under three different weight vectors were applied to multiple criteria decision analysis method, preference analysis for reference ideal solution (PARIS) for comparison, and sensitivity analysis procedure. This study contributes to provide a better understanding of the application of MCDMA methods and ISO/IEC 25010 quality model guidelines in software product quality evaluation process.

***Keywords*—**ISO/IEC 25010 quality model, multiple criteria decisions making, multiple criteria decision making analysis, MCDMA, PARIS.

I. Introduction

SOFTWARE is a basic component of modern digital products, and services, and most contemporary organizations rely on the quality of the software for their success in real-life activities and gain competitive advantages. Software is considered a selectable item, and the selection depends on a variety of quality factors, characteristics, and the competitive environment in software industry.

In the relevant literature review mapping study [1-2], software quality assessment models depend on the application context, the structure of quality factors, and the metrics adopted in different models are diverse in the context of different models. However, very few studies suggest a guide on how to create a quality assessment framework, from metrics to factors in the context of different applications. Seven aggregation methods (weighted linear equations, probabilistic, fuzzy logic, machine learning, expert based, outrank relation, geometric mean) are systematically mapped in the selected quality assessment studies. Each method has its advantages and difficulties when it comes to choose the appropriate aggregate method in different contexts. Few quality assessment studies have been proposed to conclude the effectiveness, strength, and weakness of different aggregation methods to guide the method selection in different contexts. Further research is needed to explore which aggregation method is the most appropriate choice in different environments.

Software product quality model evaluation is a difficult task due to the lack of standard data in the field. It should be noted that only a few systematic industrial case studies have been published to evaluate the quality assessment models. Therefore, further research is needed to explore the benefits and problems of implementing quality assessment models in the context of industrial cases.

Also, only a small part of the selected studies provides a tool for implementing automatic evaluation. Many of these tools that do not meet the requirements of the industrial environment are not widely used in quality assessment models. Further research should be conducted to address this question in software quality assessment.

Software product quality evaluation process becomes imperative to properly evaluate the existing software products and to select the most suitable software product with the optimal quality characteristics [2]. Various decision quality characteristics and sub-characteristics should be considered to select the best alternative from available set of candidates. This multiple characteristic assessment process can be formulated as a multiple criteria decision making analysis (MCDMA) problem. Multiple criteria decision making assessment process involves a finite set of alternatives that decision makers must select, evaluate, or rank according to their importance weights on a finite set of criteria (characteristics). In this study, ISO/IEC 25010 software product quality standard is used for multiple criteria software product evaluation process.

The aim of the study is to compare the ranking schemes of MCDMA method to know if all processes will propose the same software product for adoption, given the same set of objective data and produce the same ranking schemes. The objectives are to establish the hierarchy of the software product model using ISO/IEC 25010 [3] as basis and to perform the evaluation following the MCDMA processes outlined in the proposed methodology.

MCDMA is a technique that combines the performance of alternatives among multiple, contradictory, qualitative and/or quantitative criteria, resulting in a quantitative solution that

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requires consensus. In decision analysis, information obtained from multiple fields such as decision theory, computics, economics, informatics, and mathematics is used.

In the relevant literature, many MCDMA approaches have been developed, proposed, and successfully applied in many application areas of engineering and technology [6-43]. The purpose of MCDMA is not to recommend the best decision, but to assist decision makers in choosing the shortlisted alternatives or a single alternative that satisfies their needs and is with their preferences in the solution domain. The use of MCDMA methods and the decision maker's own perspectives in the decision process is essential for efficient and effective decision making.

Various MCDMA methods are available, such as preference analysis for reference ideal solution (PARIS) [7-9], analytical hierarchical process (AHP) [10-12], VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [13-15], preference ranking organization method for enrichment evaluation (PROMETHEE) [16-19], technique for order of preference by similarity to ideal solution (TOPSIS) [20-23], ÉLimination et Choix Traduisant la REalité (ELECTRE) [24-25], and fuzzy decision making. MCDMA has been one of the fastest growing problem areas in many disciplines. In recent decades, many researchers have applied these methods to decision making problems. All MCDMA methods are equally capable of making decisions under uncertainty, and each has its own advantages and disadvantages [26-43].

Software product quality assessment is a MCDMA problem because the entire software evaluation and selection cycle considers different criteria related to each sub-criteria of the software selection cycle. To manage the overall software selection, the relationship of each criterion in turn affecting the performance of the software selection is determined. Software quality evaluation decisions are made according to the determined evaluation indicators and characteristics. This demonstrates that decision making is critical in the process of the software selection cycle and software selection is a MCDMA issue. Software selection decisions are made under conflicting criteria such as maximizing profits and customer responsiveness while minimizing software selection risk. MCDMA in software selection process provides a comprehensive analysis of decision making assessment model.

The appropriate software product selection plays a vital role in organizational success. The software quality model is based on eight characteristics and their associated sub-characteristics for evaluating, managing, and improving software product quality. The categories of quality models for software products are the definition model, the evaluation model, and the prediction model. The software quality assessment model is a quantitative approach to assessing software product quality. There is limited research on software quality assessment, to address this gap, a multiple criteria decision making analysis model has been proposed to assess software product quality. The proposed method focuses on software criteria, quality factors, collection methods, evaluation methods and tool support. This model considers a quality framework, i.e., a structure of software characteristics and quality factors according to different characteristics. The proposed model can be used to evaluate other methods in the context of industrial cases or real-life case studies. The proposed model can be used to create a general and diverse software benchmark that can be adopted in different application context.

The remainder of this paper is structured as follows. Chapter 2 presents the multiple criteria decision making analysis methodology, i.e., PARIS method, and ISO/IEC 25010 quality model. Chapter 3 presents a numerical application of the proposed methodology including the research results of PARIS calculations as well as a discussion. Finally, Chapter 4 presents the conclusion.

II. Methodology

A. ISO/IEC 25010:2011 Quality Model

ISO/IEC 25010:2011 defines: 1.A quality in use model composed of five characteristics (some of which are further subdivided into sub characteristics) that relate to the outcome of interaction when a product is used in a particular context of use. This system model is applicable to the complete human-computer system, including both computer systems in use and software products in use. 2.A product quality model composed of eight characteristics (which are further subdivided into sub characteristics) that relate to static properties of software and dynamic properties of the computer system. The model is applicable to both computer systems and software products [3].

The characteristics defined by both models are relevant to all software products and computer systems. The characteristics and sub characteristics provide consistent terminology for specifying, measuring, and evaluating system and software product quality. They also provide a set of quality characteristics against which stated quality requirements can be compared for completeness. Although the scope of the product quality model is intended to be software and computer systems, many of the characteristics are also relevant to wider systems and services [3].

The quality model is the cornerstone of a product quality evaluation system. The quality model determines which quality characteristics will be taken into account when evaluating the properties of a software product.

The quality of a system is the degree to which the system satisfies the stated and implied needs of its various stakeholders, and thus provides value. Those stakeholders' needs (functionality, performance, security, maintainability, etc.) are precisely what is represented in the quality model, which categorizes the product quality into characteristics and sub-characteristics.

The product quality model defined in ISO/IEC 25010 comprises the eight quality characteristics and their sub characteristics shown in the Table 1 to Table 13 [3].

Functional Suitability: This characteristic represents the degree to which a product or system provides functions that meet stated and implied needs when used under specified conditions. This characteristic is composed of the following sub-characteristics:

Functional completeness - Degree to which the set of functions covers all the specified tasks and user objectives.

Functional correctness - Degree to which a product or system provides the correct results with the needed degree of precision.

Functional appropriateness - Degree to which the functions facilitate the accomplishment of specified tasks and objectives.

Performance efficiency: This characteristic represents the performance relative to the amount of resources used under stated conditions. This characteristic is composed of the following sub-characteristics:

Time behaviour - Degree to which the response and processing times and throughput rates of a product or system, when performing its functions, meet requirements.

Resource utilization - Degree to which the amounts and types of resources used by a product or system, when performing its functions, meet requirements.

Capacity - Degree to which the maximum limits of a product or system parameter meet requirements.

Compatibility: Degree to which a product, system or component can exchange information with other products, systems, or components, and/or perform its required functions while sharing the same hardware or software environment. This characteristic is composed of the following sub-characteristics:

Co-existence - Degree to which a product can perform its required functions efficiently while sharing a common environment and resources with other products, without detrimental impact on any other product.

Interoperability - Degree to which two or more systems, products or components can exchange information and use the information that has been exchanged.

Usability: Degree to which a product or system can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. This characteristic is composed of the following sub-characteristics:

Appropriateness recognizability - Degree to which users can recognize whether a product or system is appropriate for their needs.

Learnability - Degree to which a product or system can be used by specified users to achieve specified goals of learning to use the product or system with effectiveness, efficiency, freedom from risk and satisfaction in a specified context of use.

Operability - Degree to which a product or system has attributes that make it easy to operate and control.

User error protection. Degree to which a system protects users against making errors.

User interface aesthetics - Degree to which a user interface enables pleasing and satisfying interaction for the user.

Accessibility - Degree to which a product or system can be used by people with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use.

Reliability: Degree to which a system, product or component performs specified functions under specified conditions for a specified period of time. This characteristic is composed of the following sub-characteristics:

Maturity - Degree to which a system, product or component meets needs for reliability under normal operation.

Availability - Degree to which a system, product or component is operational and accessible when required for use.

Fault tolerance - Degree to which a system, product or component operates as intended despite the presence of hardware or software faults.

Recoverability - Degree to which, in the event of an interruption or a failure, a product or system can recover the data directly affected and re-establish the desired state of the system.

Security: Degree to which a product or system protects information and data so that persons or other products or systems have the degree of data access appropriate to their types and levels of authorization. This characteristic is composed of the following sub-characteristics:

Confidentiality - Degree to which a product or system ensures that data are accessible only to those authorized to have access.

Integrity - Degree to which a system, product or component prevents unauthorized access to, or modification of, computer programs or data.

Non-repudiation - Degree to which actions or events can be proven to have taken place so that the events or actions cannot be repudiated later.

Accountability - Degree to which the actions of an entity can be traced uniquely to the entity.

Authenticity - Degree to which the identity of a subject or resource can be proved to be the one claimed.

Maintainability: This characteristic represents the degree of effectiveness and efficiency with which a product or system can be modified to improve it, correct it or adapt it to changes in environment, and in requirements. This characteristic is composed of the following sub-characteristics:

Modularity - Degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components.

Reusability - Degree to which an asset can be used in more than one system, or in building other assets.

Analysability - Degree of effectiveness and efficiency with which it is possible to assess the impact on a product or system of an intended change to one or more of its parts, or to diagnose a product for deficiencies or causes of failures, or to identify parts to be modified.

Modifiability - Degree to which a product or system can be effectively and efficiently modified without introducing defects or degrading existing product quality.

Testability - Degree of effectiveness and efficiency with which test criteria can be established for a system, product or component and tests can be performed to determine whether those criteria have been met.

Portability: Degree of effectiveness and efficiency with which a system, product or component can be transferred from one hardware, software or other operational or usage environment to another. This characteristic is composed of the following sub-characteristics:

Adaptability - Degree to which a product or system can effectively and efficiently be adapted for different or evolving hardware, software or other operational or usage environments.

Installability - Degree of effectiveness and efficiency with which a product or system can be successfully installed and/or uninstalled in a specified environment.

Replaceability - Degree to which a product can replace another specified software product for the same purpose in the same environment.

B. ISO/IEC 25012 Data Quality Model

The Data Quality model represents the grounds where the system for assessing the quality of data products is built on. In a Data Quality model, the main Data Quality characteristics that must be taken into account when assessing the properties of the intended data product are established.

The Quality of a Data Product may be understood as the degree to which data satisfy the requirements defined by the product-owner organization. Specifically, those requirements are the ones that are reflected in the Data Quality model through its characteristics (Accuracy, Completeness, Consistency, Credibility, Currentness, Accessibility...).

The Data Quality model defined in the standard ISO/IEC 25012 is composed of 15 characteristics [4]:

The Data Quality characteristics are classified in to main categories:

Inherent Data Quality: Inherent data quality refers to the degree to which quality characteristics of data have the intrinsic potential to satisfy stated and implied needs when data is used under specified conditions. From the inherent point of view, data quality refers to data itself, in particular to:

- data domain values and possible restrictions (e.g. business rules governing the quality required for the characteristic in a given application);
- relationships of data values (e.g. consistency);
- metadata.

System-Dependent Data Quality: System dependent data quality refers to the degree to which data quality is reached and preserved within a computer system when data is used under specified conditions.

From this point of view data quality depends on the technological domain in which data are used; it is achieved by the capabilities of computer systems' components such as: hardware devices (e.g. to make data available or to obtain the required precision), computer system software (e.g. backup software to achieve recoverability), and other software (e.g. migration tools to achieve portability).

Inherent Data Quality

Accuracy: The degree to which data has attributes that correctly represent the true value of the intended attribute of a concept or event in a specific context of use.

It has two main aspects:

Syntactic Accuracy: Syntactic accuracy is defined as the closeness of the data values to a set of values defined in a domain considered syntactically correct.

Semantic Accuracy: Semantic accuracy is defined as the closeness of the data values to a set of values defined in a domain considered semantically correct.

Completeness: The degree to which subject data associated with an entity has values for all expected attributes and related entity instances in a specific context of use.

Consistency: The degree to which data has attributes that are free from contradiction and are coherent with other data in a specific context of use. It can be either or both among data regarding one entity and across similar data for comparable entities.

Credibility: The degree to which data has attributes that are regarded as true and believable by users in a specific context of use. Credibility includes the concept of authenticity (the truthfulness of origins, attributions, commitments).

Currentness: The degree to which data has attributes that are of the right age in a specific context of use.

Inherent and System-Dependent Data Quality

Accessibility: The degree to which data can be accessed in a specific context of use, particularly by people who need supporting technology or special configuration because of some disability.

Compliance: The degree to which data has attributes that adhere to standards, conventions or regulations in force and similar rules relating to data quality in a specific context of use.

Confidentiality: The degree to which data has attributes that ensure that it is only accessible and interpretable by authorized users in a specific context of use. Confidentiality is an aspect of information security (together with availability, integrity) as defined in ISO/IEC 13335-1:2004.

Efficiency: The degree to which data has attributes that can be processed and provide the expected levels of performance by using the appropriate amounts and types of resources in a specific context of use.

Precision: The degree to which data has attributes that are exact or that provide discrimination in a specific context of use.

Traceability: The degree to which data has attributes that provide an audit trail of access to the data and of any changes made to the data in a specific context of use.

Understandability: The degree to which data has attributes that enable it to be read and interpreted by users, and are expressed in appropriate languages, symbols, and units in a specific context of use.

Some information about data understandability is provided by metadata.

System-Dependent Data Quality

Availability: The degree to which data has attributes that enable it to be retrieved by authorized users and/or applications in a specific context of use.

Portability: The degree to which data has attributes that enable it to be installed, replaced or moved from one system to another preserving the existing quality in a specific context of use.

Recoverability: The degree to which data has attributes that enable it to maintain and preserve a specified level of operations and quality, even in the event of failure, in a specific context of use.

C. ISO/IEC 25040 Evaluation Process

ISO/IEC 25040 provides a process description for evaluating quality of software product and states the requirements for the application of this process. The evaluation process is composed of five activities [5].

Activity 1: Establish the evaluation requirements

The first step in the evaluation process is to establish the requirements of the evaluation.

Task 1.1: Establish the purpose of the evaluation

The goal of this task is to document the purpose for which the organization wants to evaluate the quality of the software product (decide on the acceptance of the product, decide when to release the product, compare the product with competitive products, select a product from among alternative products, etc.).

Task 1.2: Obtain the software product quality requirements

The goal of this task is to identify the stakeholders of the software product (developer, acquirer, independent evaluator, user, maintainer, supplier, etc.) and to specify the software product quality requirements using a quality model.

Task 1.3: Identify product parts to be included in the evaluation

All product parts to be included in the evaluation shall be identified and documented. The type of software product to be evaluated (e.g. requirements specification, design diagrams and test documentation) depends on the stage in the life cycle and the purpose of the evaluation.

Task 1.4: Define the stringency of the evaluation

The evaluation stringency shall be defined in order to provide confidence in the software product quality according to its intended use and purpose of the evaluation. The evaluation stringency should establish expected evaluation levels which define the evaluation techniques to be applied and evaluation results to be achieved.

Activity 2: Specify the evaluation

In this activity the evaluation modules and the decision criteria for quality measures are specified.

Task 2.1: Select quality measures (evaluation modules)

In this task the evaluator shall select quality measures (evaluation modules) to cover all software quality evaluation requirements. Measurement procedures should measure the software quality characteristic (or sub characteristic) they claim to be measuring with sufficient accuracy to allow criteria to be set and comparisons to be made. Standards in the ISO/IEC 2502n division can be helpful in this task.

Task 2.2: Define decision criteria for quality measures

Decision criteria shall be defined for the selected individual measures. Decision criteria are numerical thresholds or targets used to determine the need for action or further investigation, or to describe the level of confidence in a given result. Users may use benchmarks, statistical control limits, historical data, customer requirements or other techniques to set decision criteria.

Task 2.3: Define decision criteria for evaluation

The evaluator should prepare a procedure for further summarization, with separate criteria for different quality characteristics, each of which may be in terms of sub characteristics and quality measures. The summarization results should be used as a basis for the software product quality assessment.

Activity 3: Design the evaluation

In this activity the evaluation plan is defined.

Task 3.1: Plan evaluation activities

The identified software product quality evaluation activities shall be scheduled, taking into account the availability of resources such as personnel, software tools and computers. The evaluation plan should also include the purpose of the evaluation, the budget, evaluation methods and tools, adopted standards, etc.

The evaluation plan shall be revised as the evaluation activities evolve, providing additional information that allows the plan to be adjusted or detailed.

Activity 4: Execute the evaluation

In this activity the evaluation is executed, getting measurements for the quality measures, and applying the decision criteria.

Task 4.1: Make measurements

The selected software product quality measures shall be applied to the software product and components, according to the evaluation plan, resulting in values on the measurement scales.

Task 4.2: Apply decision criteria for quality measures

The decision criteria for the software product quality measures shall be applied to the measured values.

Task 4.3: Apply decision criteria for evaluation

The set of decision criteria shall be summarized into sub characteristics and characteristics, producing the assess results as a statement of the extent to which the software product meets quality requirements.

Activity 5: Conclude the evaluation

In this activity the software product quality evaluation is concluded, reviewing the evaluation results and creating the evaluation report.

Task 5.1: Review the evaluation result

The evaluator and the requester shall carry out a joint review of the evaluation results.

Task 5.2: Create the evaluation report

Once the results are reviewed, the evaluation report is created, including the requirements of the evaluation, the results from the measurements and analyses performed, any limitations or constraints, the evaluators and their qualifications, etc.

Task 5.3: Review quality evaluation and provide feedback to the organization

The evaluator shall review the results of the evaluation and the validity of the evaluation process, indicators and measures applied. Feedback from the review should be used in order to improve the evaluation process and evaluation techniques (evaluation modules).

Task 5.4: Perform disposition of evaluation data

When the evaluation is completed the data and evaluation items shall be disposed according to requirements of the requester, returning, archiving or destroying them in a secure way, depending on the type of data.

The MCDMA hierarchy of the system uses ISO/IEC 25010 quality model as basis for comparison of PARIS ranking results. The decision matrix with normalized weights for each sub characteristic, and scores for each software product are established. The main procedural steps of the proposed algorithm for comparisons of the quality of software products are as follows:

Step 1. Establish the hierarchy of the decision making process from ISO/IEC 25010 quality model with the objective of maximizing the quality of the chosen software product.

Step 2.Identify the number of products to include in the evaluation.

Step 3.Generate random numbers to establish the decision maker's weight for each characteristic.

Step 4.Establish the normalized importance weight vector for the experiments.

Step 5.Generate random numbers to establish the matrix of the decision maker's final scores for each software product against each sub characteristic.

Step 6.Establish the decision matrix for the comparisons combining the vector in step 4 and the matrix in step 5.

Step 7.Simultaneously apply PARIS steps to the matrix in step 6.

Step 8.Compare the ranking results.

D.The PARIS Method

Suppose that multiple criteria decision making analysis problem has I alternatives $a_i = (a_1, ..., a_i)$, $i \in \{ i = 1,...,I \}$, and J criteria $g_j = (g_1, ..., g_j)$, $j \in \{ j = 1,..., J \}$, and the importance weight of each criterion (ω_j, $j \in \{ j = 1,..., J \}$) is known. The procedural steps of PARIS method for evaluation of the alternatives with respect to the decision criteria are presented as follows [6-9]:

Step 1. Construction of decision matrix $X = (x_{ij})_{ixj}$

$$X = \begin{pmatrix} a_1 \\ \vdots \\ a_i \end{pmatrix} \begin{pmatrix} \overset{g_1}{x_{11}} & \cdots & \overset{g_j}{x_{1j}} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \quad (1)$$

where $X = (x_{ij})_{ixj}$ represents the decision matrix and x_{ij} is the value of ith alternative with respect to jth indicator g_j.

In exceptional decision problems, if there are negative values in the decision matrix, first, the decision matrix is transformed by $x^t_{ij} = x_{ij} - \min_j x_{ij}$, then, the values of x^t_{ij} are used in the next procedural steps.

Step 2. Normalization of the decision matrix $R = (r_{ij})_{ixj}$

$$R = \begin{pmatrix} a_1 \\ \vdots \\ a_i \end{pmatrix} \begin{pmatrix} \overset{g_1}{r_{11}} & \cdots & \overset{g_j}{r_{1j}} \\ \vdots & \ddots & \vdots \\ r_{i1} & \cdots & r_{ij} \end{pmatrix}_{ixj} \quad (3)$$

If the evaluation attribute g_j is a benefit criteria, then

$$r_{ij} = \frac{x_{ij}}{x_j^{\max}}, \; i = 1,..., I, \; j = 1,..., J \quad (3)$$

If the evaluation attribute g_j is a cost criteria, then

$$r_{ij} = \frac{x_j^{\min}}{x_{ij}}, \; i = 1,..., I, \; j = 1,..., J \quad (4)$$

where x_{ij} are the evaluation indices and $i = 1,..., I$, number of alternatives, and number of criteria, $j = 1,..., J$.

$$x_i^{max} = \max_j \left\{ x_{1j}, x_{2j}, ..., x_{ij} \right\}, \; x_i^{min} = \min_j \left\{ x_{1j}, x_{2j}, ..., x_{ij} \right\} \quad (5)$$

Upon normalizing criteria of the decision matrix, all elements x_{ij} are reduced to interval values [0, 1], so all criteria have the same commensurate metrics.

Step 3. Computation of the weighted normalized matrix $Z = (z_{ij})_{ixj}$

$$Z = \begin{pmatrix} a_1 \\ \vdots \\ a_i \end{pmatrix} \begin{pmatrix} \overset{g_1}{z_{11}} & \cdots & \overset{g_j}{z_{1j}} \\ \vdots & \ddots & \vdots \\ z_{i1} & \cdots & z_{ij} \end{pmatrix}_{ixj}$$

$$z_{ij} = \omega_j r_{ij} \quad (6)$$

where ω_j is the criterion weight of attribute g_j, and $\sum_{j=1}^{J} \omega_j = 1, \; j = 1..., J$.

Step 4. Computation of the weighted summation of the evaluation indices

$$\pi_i^{\omega} = \sum_{j=1}^{J} \omega_j r_{ij}, \; i = 1,..., I, \; j = 1,..., J \quad (7)$$

Step 5. Rank the alternatives according to decreasing values of π_i^{ω}. The alternative with the highest appraisal score is the best choice among the candidate alternatives.

Step 6. Determination of the elements of reference ideal solution (z_j^*)

$$z_j^* = \{z_1^*, ..., z_j^*\} = \{(max_i\, z_{ij} \mid j \in B), (\min_i z_{ij} \mid j \in C\} \quad (8)$$

Step 7. Computation of distance from the reference ideal solution (z_j^*)

$$\pi_i^* = \sum_{j=1}^{J} (z_j^* - z_{ij}),\ i = 1, ..., I,\ \ j = 1, ..., J \quad (9)$$

Step 8. Rank the alternatives according to increasing values of π_i^*. The alternative with the lowest appraisal score is the best choice among the candidate alternatives.

Step 9. The relative distance from each evaluated alternative to the reference ideal point is calculated to determine the ranking order of all alternatives.

$$R_i = \sqrt{(\pi_i^{\omega} - \pi_i^{\omega,\max})^2 + (\pi_i^* - \pi_i^{*,\min})^2} \quad (10)$$

Step 10. Rank the alternatives according to increasing values of R_i. The alternative with the lowest appraisal score is the best choice among the candidate alternatives.

III. Application

In this study, an empirical multiple criteria decision making analysis problem is considered to evaluate five software product quality alternatives by integrating objective weighting procedure (randomly generated normalized weights) with PARIS method. This software product quality evaluation and selection problem is considered to determine the most suitable software product alternative.

The evaluation criteria (characteristics and their associated sub characteristics) for selecting the appropriate software product are defined based on the ISO/IEC 25010 quality model as shown in Table 1, Table 5, and Table 9. A typical decision making tree for any decision problem is developed by identifying the goal, alternatives and criteria as shown in Fig 1. The goal, which is software product evaluation and selection, is on the first line of the tree. The evaluation criteria are on the second line and the alternatives are on the third line. Software product alternatives were quantitatively assessed by evaluation criteria for the multiple criteria decision making analysis problem.

The applicability of the proposed model on the software product quality assessment process is implemented using the ISO/IEC 25010 quality model. Following the procedural steps of the proposed algorithm, first, the hierarchy of the decision making model from ISO/IEC 25010 quality model with the objective of maximizing the quality of the chosen software product was established as shown in Table 1, Table 5, and Table 9.

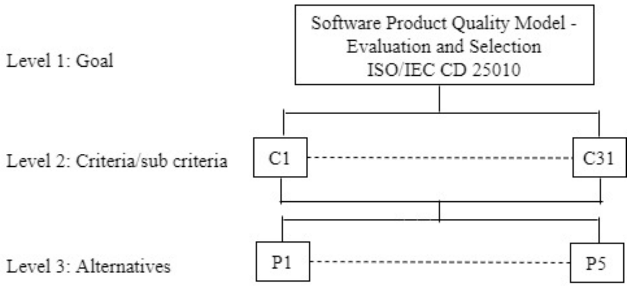

Fig 1. Hierarchy designed for optimum software product quality evaluation

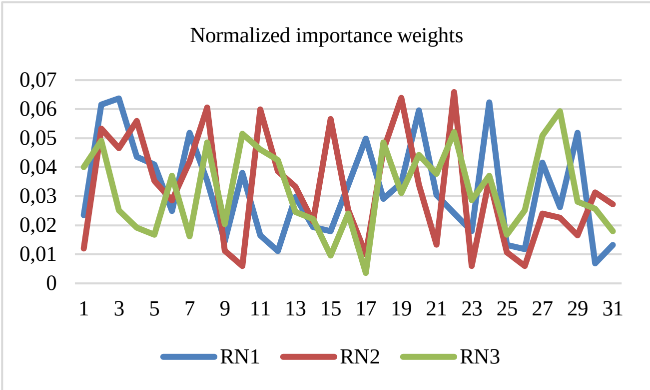

Fig 2. Normalized importance weight vectors

Five experimental synthetic products were identified to include in the evaluation and selection process. Random numbers (RN1, RN2, RN3) were generated to establish the decision maker's weight vectors for each sub characteristic in the decision matrix as shown in Table 13. The normalized importance weight vectors were established for the quantitative experiments as shown in Fig 2.

Again, random numbers were generated to establish the matrix of the decision maker's final scores for each software product against each sub characteristic. The decision matrix was established for the comparisons combining the weight vector and the decision matrix. Finally, simultaneously, PARIS steps were applied to the decision matrix with different datasets. Quantitative ranking results with full data are provided in Tables 1-16. Full data tables for random numbers (RN2 and RN3) are not included for ease of readability, but full data on final ranking results for comparisons are given in Table 14, Table 15 and Table 16.

Following the computational procedure for software product quality assessment and selection, the robustness of the proposed method was tested by using three different datasets with three different importance weight vectors. The multiple criteria decision making analysis models (π_i^{ω} , π_i^* , R_i) have produced different ranking schemes for the same datasets with same weight vectors for sensitivity analysis procedure. However, the MCDMA models (π_i^{ω} , π_i^* , R_i) have produced consistent ranking schemes for datasets 1 and 3 with three different weight vectors for sensitivity analysis procedure. As a result of the experimental studies, dataset 2 with RN2 weight vector has produced different ranking orders in sensitivity analysis.

IV. Conclusion

The main contribution of this article is to provide a systematic quantitative multi-criteria decision analysis process mapping study of the software product quality assessment model. Software product quality characteristics are defined according to the ISO/IEC 25010 standard. Accordingly, according to internal and external quality criteria, thirty-one sub- characteristics considered to handle software product quality evaluation were selected as relevant dimensions.

The main contribution of this paper is to provide a systematic quantitative multiple criteria decision analysis process mapping study of software product quality assessment model. Software product quality characteristics are identified based on the ISO/IEC 25010 standard. Accordingly, according to internal and external quality criteria, thirty-one sub characteristics are selected as relevant dimensions which are taken into consideration for addressing software product quality assessment.

Software industry does not have a quantitatively structured mechanism for measuring the quality characteristics, and further evaluating software product quality. Therefore, the proposed model tries to contribute to the development of an objective software product quality assessment model. The software quality assessment procedure, based on ISO/IEC 25010 - software product quality model, contributes to addressing multidimensional issues in controlling, improving, managing, and evaluating software product quality.

The proposed process evaluation model can generate a quantitative software product quality evaluation model based on the dimensions of the software product characteristics. Here, necessary software product measures are measured and further analyzed to provide feedback to address software product quality. The proposed model can help the software industry establish effective objective assessment models of software product quality and thus serve as an agreement of software product quality requirement. The ranking results obtained show that for three different datasets and three different weight vectors, MCDMA method applied may produce different ranking results as shown in Table 14 to Table 16. Finally, a software product quality evaluation model with multiple criteria decision making analysis is recommended to evaluate and select software products. The model can be applied to address the complexity involved in other decision making problems, including fuzzy environment and its applications.

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Table 1. Decision Matrix for Dataset 1

Model	Characteristics	Sub characteristics	Random Numbers	Normalized Weights RN1	Alternatives				
					P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	34	0,0235	9	30	85	61	80
		Functional Correctness	89	0,0616	79	74	27	41	94
		Functional Appropriateness	92	0,0637	18	99	82	84	4
	Performance Efficiency	Time-behaviour	63	0,0436	76	16	27	84	35
		Resource Utilization	59	0,0409	83	77	51	44	87
		Capacity	36	0,0249	47	21	18	22	2
	Compatibility	Coexistence	75	0,0519	6	91	4	92	64
		Interoperability	51	0,0353	88	19	51	6	53
	Usability	Appropriateness Recognisability	21	0,0145	40	49	59	17	50
		Learnability	55	0,0381	12	64	23	27	52
		Operability	24	0,0166	16	61	18	30	86
		User Error Protection	16	0,0111	95	51	69	38	32
		User Interface Aesthetics	43	0,0298	5	4	47	48	8
		Accessibility	28	0,0194	20	19	56	10	76
	Reliability	Maturity	26	0,018	22	96	47	88	25
		Availability	49	0,0339	77	84	21	29	89
		Fault Tolerance	72	0,0499	30	10	75	2	80
		Recoverability	42	0,0291	98	33	84	42	96
	Security	Confidentiality	50	0,0346	50	51	24	90	74
		Integrity	86	0,0596	32	45	44	2	82
		Non-Repudiation	44	0,0305	14	94	93	82	33
		Accountability	35	0,0242	12	67	89	18	16
		Authenticity	26	0,018	80	6	67	82	85
	Maintainability	Modularity	90	0,0623	94	6	60	71	69
		Reusability	19	0,0132	38	73	90	5	20
		Analyzability	17	0,0118	20	52	42	88	88
		Modifiability	60	0,0416	29	63	6	3	76
		Testability	38	0,0263	30	3	80	51	48
	Portability	Adaptability	75	0,0519	13	39	94	51	56
		Installability	10	0,0069	94	69	94	26	20
		Replaceability	19	0,0132	77	53	39	92	26
		Sum	1444	1	1404	1519	1666	1426	1706

Table 2. Normalized Matrix for Dataset 1

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	0,1059	0,3529	1	0,7176	0,9412
		Functional Correctness	0,0616	0,9294	0,8706	0,3176	0,4824	1,1059
		Functional Appropriateness	0,0637	0,2118	1,1647	0,9647	0,9882	0,0471
	Performance Efficiency	Time-behaviour	0,0436	0,8941	0,1882	0,3176	0,9882	0,4118
		Resource Utilization	0,0409	0,9765	0,9059	0,6	0,5176	1,0235
		Capacity	0,0249	0,5529	0,2471	0,2118	0,2588	0,0235
	Compatibility	Coexistence	0,0519	0,0706	1,0706	0,0471	1,0824	0,7529
		Interoperability	0,0353	1,0353	0,2235	0,6	0,0706	0,6235
	Usability	Appropriateness Recognisability	0,0145	0,4706	0,5765	0,6941	0,2	0,5882
		Learnability	0,0381	0,1412	0,7529	0,2706	0,3176	0,6118
		Operability	0,0166	0,1882	0,7176	0,2118	0,3529	1,0118
		User Error Protection	0,0111	1,1176	0,6	0,8118	0,4471	0,3765
		User Interface Aesthetics	0,0298	0,0588	0,0471	0,5529	0,5647	0,0941
		Accessibility	0,0194	0,2353	0,2235	0,6588	0,1176	0,8941
	Reliability	Maturity	0,018	0,2588	1,1294	0,5529	1,0353	0,2941
		Availability	0,0339	0,9059	0,9882	0,2471	0,3412	1,0471
		Fault Tolerance	0,0499	0,3529	0,1176	0,8824	0,0235	0,9412
		Recoverability	0,0291	1,1529	0,3882	0,9882	0,4941	1,1294
	Security	Confidentiality	0,0346	0,5882	0,6	0,2824	1,0588	0,8706
		Integrity	0,0596	0,3765	0,5294	0,5176	0,0235	0,9647
		Non-Repudiation	0,0305	0,1647	1,1059	1,0941	0,9647	0,3882
		Accountability	0,0242	0,1412	0,7882	1,0471	0,2118	0,1882
		Authenticity	0,018	0,9412	0,0706	0,7882	0,9647	1
	Maintainability	Modularity	0,0623	1,1059	0,0706	0,7059	0,8353	0,8118
		Reusability	0,0132	0,4471	0,8588	1,0588	0,0588	0,2353
		Analyzability	0,0118	0,2353	0,6118	0,4941	1,0353	1,0353
		Modifiability	0,0416	0,3412	0,7412	0,0706	0,0353	0,8941
		Testability	0,0263	0,3529	0,0353	0,9412	0,6	0,5647
	Portability	Adaptability	0,0519	0,1529	0,4588	1,1059	0,6	0,6588
		Installability	0,0069	1,1059	0,8118	1,1059	0,3059	0,2353
		Replaceability	0,0132	0,9059	0,6235	0,4588	1,0824	0,3059
		Sum	1	16,5176	17,871	19,6	16,776	20,071

Table 3. Weighted Normalized Matrix for Dataset 1

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	0,0025	0,0083	0,0235	0,0169	0,0222
		Functional Correctness	0,0616	0,0219	0,0205	0,0075	0,0114	0,026
		Functional Appropriateness	0,0637	0,005	0,0274	0,0227	0,0233	0,0011
	Performance Efficiency	Time-behaviour	0,0436	0,0211	0,0044	0,0075	0,0233	0,0097
		Resource Utilization	0,0409	0,023	0,0213	0,0141	0,0122	0,0241
		Capacity	0,0249	0,013	0,0058	0,005	0,0061	0,0006
	Compatibility	Coexistence	0,0519	0,0017	0,0252	0,0011	0,0255	0,0177
		Interoperability	0,0353	0,0244	0,0053	0,0141	0,0017	0,0147
	Usability	Appropriateness Recognisability	0,0145	0,0111	0,0136	0,0163	0,0047	0,0139
		Learnability	0,0381	0,0033	0,0177	0,0064	0,0075	0,0144
		Operability	0,0166	0,0044	0,0169	0,005	0,0083	0,0238
		User Error Protection	0,0111	0,0263	0,0141	0,0191	0,0105	0,0089
		User Interface Aesthetics	0,0298	0,0014	0,0011	0,013	0,0133	0,0022
		Accessibility	0,0194	0,0055	0,0053	0,0155	0,0028	0,0211
	Reliability	Maturity	0,018	0,0061	0,0266	0,013	0,0244	0,0069
		Availability	0,0339	0,0213	0,0233	0,0058	0,008	0,0247
		Fault Tolerance	0,0499	0,0083	0,0028	0,0208	0,0006	0,0222
		Recoverability	0,0291	0,0271	0,0091	0,0233	0,0116	0,0266
	Security	Confidentiality	0,0346	0,0139	0,0141	0,0066	0,0249	0,0205
		Integrity	0,0596	0,0089	0,0125	0,0122	0,0006	0,0227
		Non-Repudiation	0,0305	0,0039	0,026	0,0258	0,0227	0,0091
		Accountability	0,0242	0,0033	0,0186	0,0247	0,005	0,0044
		Authenticity	0,018	0,0222	0,0017	0,0186	0,0227	0,0235
	Maintainability	Modularity	0,0623	0,026	0,0017	0,0166	0,0197	0,0191
		Reusability	0,0132	0,0105	0,0202	0,0249	0,0014	0,0055
		Analyzability	0,0118	0,0055	0,0144	0,0116	0,0244	0,0244
		Modifiability	0,0416	0,008	0,0175	0,0017	0,0008	0,0211
		Testability	0,0263	0,0083	0,0008	0,0222	0,0141	0,0133
	Portability	Adaptability	0,0519	0,0036	0,0108	0,026	0,0141	0,0155
		Installability	0,0069	0,026	0,0191	0,026	0,0072	0,0055
		Replaceability	0,0132	0,0213	0,0147	0,0108	0,0255	0,0072
		Sum	1	0,3889	0,4208	0,4615	0,395	0,4726

Table 4. Distance from Reference Ideal Solution for Dataset 1

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	0,0211	0,0152	0	0,0066	0,0014
		Functional Correctness	0,0616	0,0017	0,003	0,0161	0,0122	-0,002
		Functional Appropriateness	0,0637	0,0186	-0,004	0,0008	0,0003	0,0224
	Performance Efficiency	Time-behaviour	0,0436	0,0025	0,0191	0,0161	0,0003	0,0139
		Resource Utilization	0,0409	0,0006	0,0022	0,0094	0,0114	-6E-04
		Capacity	0,0249	0,0105	0,0177	0,0186	0,0175	0,023
	Compatibility	Coexistence	0,0519	0,0219	-0,002	0,0224	-0,002	0,0058
		Interoperability	0,0353	-8E-04	0,0183	0,0094	0,0219	0,0089
	Usability	Appropriateness Recognisability	0,0145	0,0125	0,01	0,0072	0,0188	0,0097
		Learnability	0,0381	0,0202	0,0058	0,0172	0,0161	0,0091
		Operability	0,0166	0,0191	0,0066	0,0186	0,0152	-3E-04
		User Error Protection	0,0111	-0,003	0,0094	0,0044	0,013	0,0147
		User Interface Aesthetics	0,0298	0,0222	0,0224	0,0105	0,0102	0,0213
		Accessibility	0,0194	0,018	0,0183	0,008	0,0208	0,0025
	Reliability	Maturity	0,018	0,0175	-0,003	0,0105	-8E-04	0,0166
		Availability	0,0339	0,0022	0,0003	0,0177	0,0155	-0,001
		Fault Tolerance	0,0499	0,0152	0,0208	0,0028	0,023	0,0014
		Recoverability	0,0291	-0,004	0,0144	0,0003	0,0119	-0,003
	Security	Confidentiality	0,0346	0,0097	0,0094	0,0169	-0,001	0,003
		Integrity	0,0596	0,0147	0,0111	0,0114	0,023	0,0008
		Non-Repudiation	0,0305	0,0197	-0,002	-0,002	0,0008	0,0144
		Accountability	0,0242	0,0202	0,005	-0,001	0,0186	0,0191
		Authenticity	0,018	0,0014	0,0219	0,005	0,0008	0
	Maintainability	Modularity	0,0623	-0,002	0,0219	0,0069	0,0039	0,0044
		Reusability	0,0132	0,013	0,0033	-0,001	0,0222	0,018
		Analyzability	0,0118	0,018	0,0091	0,0119	-8E-04	-8E-04
		Modifiability	0,0416	0,0155	0,0061	0,0219	0,0227	0,0025
		Testability	0,0263	0,0152	0,0227	0,0014	0,0094	0,0102
	Portability	Adaptability	0,0519	0,0199	0,0127	-0,002	0,0094	0,008
		Installability	0,0069	-0,002	0,0044	-0,002	0,0163	0,018
		Replaceability	0,0132	0,0022	0,0089	0,0127	-0,002	0,0163
		Sum	1	0,341	0,3091	0,2684	0,3349	0,2573

Table 5. Decision Matrix for Dataset 2

Model	Characteristics	Sub characteristics	Random Numbers	Normalized Weights RN1	Alternatives				
					P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	34	0,0235	98	19	95	31	46
		Functional Correctness	89	0,0616	16	86	48	52	6
		Functional Appropriateness	92	0,0637	24	88	50	64	26
	Performance Efficiency	Time-behaviour	63	0,0436	96	11	35	85	68
		Resource Utilization	59	0,0409	59	56	60	11	28
		Capacity	36	0,0249	88	3	68	80	52
	Compatibility	Coexistence	75	0,0519	34	33	20	63	25
		Interoperability	51	0,0353	4	29	5	70	8
	Usability	Appropriateness Recognisability	21	0,0145	77	25	32	56	47
		Learnability	55	0,0381	43	56	84	3	20
		Operability	24	0,0166	37	66	37	5	68
		User Error Protection	16	0,0111	86	98	80	10	59
		User Interface Aesthetics	43	0,0298	44	69	5	87	83
		Accessibility	28	0,0194	98	12	79	54	7
	Reliability	Maturity	26	0,018	73	33	66	91	70
		Availability	49	0,0339	97	73	51	40	71
		Fault Tolerance	72	0,0499	68	43	40	63	91
		Recoverability	42	0,0291	62	4	67	90	89
	Security	Confidentiality	50	0,0346	47	29	54	10	20
		Integrity	86	0,0596	84	12	88	33	26
		Non-Repudiation	44	0,0305	61	43	69	45	92
		Accountability	35	0,0242	39	95	60	38	34
		Authenticity	26	0,018	14	65	99	86	83
	Maintainability	Modularity	90	0,0623	91	9	58	50	13
		Reusability	19	0,0132	7	66	16	53	40
		Analyzability	17	0,0118	45	53	58	13	95
		Modifiability	60	0,0416	39	51	62	45	75
		Testability	38	0,0263	19	65	49	81	92
	Portability	Adaptability	75	0,0519	52	20	96	68	95
		Installability	10	0,0069	45	23	49	22	89
		Replaceability	19	0,0132	40	77	80	39	86
		Sum	1444	1	1687	1412	1760	1538	1704

Table 6. Normalized Matrix for Dataset 2

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	1	0,1939	0,9694	0,3163	0,4694
		Functional Correctness	0,0616	0,186	1	0,5581	0,6047	0,0698
		Functional Appropriateness	0,0637	0,2727	1	0,5682	0,7273	0,2955
	Performance Efficiency	Time-behaviour	0,0436	1	0,1146	0,3646	0,8854	0,7083
		Resource Utilization	0,0409	0,9833	0,9333	1	0,1833	0,4667
		Capacity	0,0249	1	0,0341	0,7727	0,9091	0,5909
	Compatibility	Coexistence	0,0519	0,5397	0,5238	0,3175	1	0,3968
		Interoperability	0,0353	0,0571	0,4143	0,0714	1	0,1143
	Usability	Appropriateness Recognisability	0,0145	1	0,3247	0,4156	0,7273	0,6104
		Learnability	0,0381	0,5119	0,6667	1	0,0357	0,2381
		Operability	0,0166	0,5441	0,9706	0,5441	0,0735	1
		User Error Protection	0,0111	0,8776	1	0,8163	0,102	0,602
		User Interface Aesthetics	0,0298	0,5057	0,7931	0,0575	1	0,954
		Accessibility	0,0194	1	0,1224	0,8061	0,551	0,0714
	Reliability	Maturity	0,018	0,8022	0,3626	0,7253	1	0,7692
		Availability	0,0339	1	0,7526	0,5258	0,4124	0,732
		Fault Tolerance	0,0499	0,7473	0,4725	0,4396	0,6923	1
		Recoverability	0,0291	0,6889	0,0444	0,7444	1	0,9889
	Security	Confidentiality	0,0346	0,8704	0,537	1	0,1852	0,3704
		Integrity	0,0596	0,9545	0,1364	1	0,375	0,2955
		Non-Repudiation	0,0305	0,663	0,4674	0,75	0,4891	1
		Accountability	0,0242	0,4105	1	0,6316	0,4	0,3579
		Authenticity	0,018	0,1414	0,6566	1	0,8687	0,8384
	Maintainability	Modularity	0,0623	1	0,0989	0,6374	0,5495	0,1429
		Reusability	0,0132	0,1061	1	0,2424	0,803	0,6061
		Analyzability	0,0118	0,4737	0,5579	0,6105	0,1368	1
		Modifiability	0,0416	0,52	0,68	0,8267	0,6	1
		Testability	0,0263	0,2065	0,7065	0,5326	0,8804	1
	Portability	Adaptability	0,0519	0,5417	0,2083	1	0,7083	0,9896
		Installability	0,0069	0,5056	0,2584	0,5506	0,2472	1
		Replaceability	0,0132	0,4651	0,8953	0,9302	0,4535	1
		Sum	1	19,575	16,926	20,409	17,917	19,678

Table 7. Weighted Normalized Matrix for Dataset 2

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	0,0235	0,0046	0,0228	0,0074	0,0111
		Functional Correctness	0,0616	0,0115	0,0616	0,0344	0,0373	0,0043
		Functional Appropriateness	0,0637	0,0174	0,0637	0,0362	0,0463	0,0188
	Performance Efficiency	Time-behaviour	0,0436	0,0436	0,005	0,0159	0,0386	0,0309
		Resource Utilization	0,0409	0,0402	0,0381	0,0409	0,0075	0,0191
		Capacity	0,0249	0,0249	0,0008	0,0193	0,0227	0,0147
	Compatibility	Coexistence	0,0519	0,0280	0,0272	0,0165	0,0519	0,0206
		Interoperability	0,0353	0,0020	0,0146	0,0025	0,0353	0,004
	Usability	Appropriateness Recognisability	0,0145	0,0145	0,0047	0,006	0,0106	0,0089
		Learnability	0,0381	0,0195	0,0254	0,0381	0,0014	0,0091
		Operability	0,0166	0,0090	0,0161	0,009	0,0012	0,0166
		User Error Protection	0,0111	0,0097	0,0111	0,009	0,0011	0,0067
		User Interface Aesthetics	0,0298	0,0151	0,0236	0,0017	0,0298	0,0284
		Accessibility	0,0194	0,0194	0,0024	0,0156	0,0107	0,0014
	Reliability	Maturity	0,018	0,0144	0,0065	0,0131	0,018	0,0139
		Availability	0,0339	0,0339	0,0255	0,0178	0,014	0,0248
		Fault Tolerance	0,0499	0,0373	0,0236	0,0219	0,0345	0,0499
		Recoverability	0,0291	0,0200	0,0013	0,0217	0,0291	0,0288
	Security	Confidentiality	0,0346	0,0301	0,0186	0,0346	0,0064	0,0128
		Integrity	0,0596	0,0568	0,0081	0,0596	0,0223	0,0176
		Non-Repudiation	0,0305	0,0202	0,0142	0,0229	0,0149	0,0305
		Accountability	0,0242	0,0100	0,0242	0,0153	0,0097	0,0087
		Authenticity	0,018	0,0025	0,0118	0,018	0,0156	0,0151
	Maintainability	Modularity	0,0623	0,0623	0,0062	0,0397	0,0342	0,0089
		Reusability	0,0132	0,0014	0,0132	0,0032	0,0106	0,008
		Analyzability	0,0118	0,0056	0,0066	0,0072	0,0016	0,0118
		Modifiability	0,0416	0,0216	0,0283	0,0343	0,0249	0,0416
		Testability	0,0263	0,0054	0,0186	0,014	0,0232	0,0263
	Portability	Adaptability	0,0519	0,0281	0,0108	0,0519	0,0368	0,0514
		Installability	0,0069	0,0035	0,0018	0,0038	0,0017	0,0069
		Replaceability	0,0132	0,0061	0,0118	0,0122	0,006	0,0132
		Sum	1	0,6379	0,5301	0,6593	0,6054	0,5645

Table 8. Distance from Reference Ideal Solution for Dataset 2

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	0	0,019	0,0007	0,0161	0,0125
		Functional Correctness	0,0616	0,0502	0	0,0272	0,0244	0,0573
		Functional Appropriateness	0,0637	0,0463	0	0,0275	0,0174	0,0449
	Performance Efficiency	Time-behaviour	0,0436	0	0,0386	0,0277	0,005	0,0127
		Resource Utilization	0,0409	0,0007	0,0027	0	0,0334	0,0218
		Capacity	0,0249	0	0,0241	0,0057	0,0023	0,0102
	Compatibility	Coexistence	0,0519	0,0239	0,0247	0,0355	0	0,0313
		Interoperability	0,0353	0,0333	0,0207	0,0328	0	0,0313
	Usability	Appropriateness Recognisability	0,0145	0	0,0098	0,0085	0,004	0,0057
		Learnability	0,0381	0,0186	0,0127	0	0,0367	0,029
		Operability	0,0166	0,0076	0,0005	0,0076	0,0154	0
		User Error Protection	0,0111	0,0014	0	0,002	0,0099	0,0044
		User Interface Aesthetics	0,0298	0,0147	0,0062	0,0281	0	0,0014
		Accessibility	0,0194	0	0,017	0,0038	0,0087	0,018
	Reliability	Maturity	0,018	0,0036	0,0115	0,0049	0	0,0042
		Availability	0,0339	0	0,0084	0,0161	0,0199	0,0091
		Fault Tolerance	0,0499	0,0126	0,0263	0,0279	0,0153	0
		Recoverability	0,0291	0,009	0,0278	0,0074	0	0,0003
	Security	Confidentiality	0,0346	0,0045	0,016	0	0,0282	0,0218
		Integrity	0,0596	0,0027	0,0514	0	0,0372	0,042
		Non-Repudiation	0,0305	0,0103	0,0162	0,0076	0,0156	0
		Accountability	0,0242	0,0143	0	0,0089	0,0145	0,0156
		Authenticity	0,018	0,0155	0,0062	0	0,0024	0,0029
	Maintainability	Modularity	0,0623	0	0,0562	0,0226	0,0281	0,0534
		Reusability	0,0132	0,0118	0	0,01	0,0026	0,0052
		Analyzability	0,0118	0,0062	0,0052	0,0046	0,0102	0
		Modifiability	0,0416	0,0199	0,0133	0,0072	0,0166	0
		Testability	0,0263	0,0209	0,0077	0,0123	0,0031	0
	Portability	Adaptability	0,0519	0,0238	0,0411	0	0,0151	0,0005
		Installability	0,0069	0,0034	0,0051	0,0031	0,0052	0
		Replaceability	0,0132	0,007	0,0014	0,0009	0,0072	0
		Sum	1	0,3621	0,4699	0,3407	0,3946	0,4355

Table 9. Decision Matrix for Dataset 3

Model	Characteristics	Sub characteristics	Random Numbers	Normalized Weights RN1	Alternatives				
					P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	34	0,0235	86	42	93	62	90
		Functional Correctness	89	0,0616	31	23	67	96	74
		Functional Appropriateness	92	0,0637	17	38	98	31	89
	Performance Efficiency	Time-behaviour	63	0,0436	59	89	6	61	9
		Resource Utilization	59	0,0409	27	3	2	6	71
		Capacity	36	0,0249	20	30	90	64	99
	Compatibility	Coexistence	75	0,0519	88	86	2	9	41
		Interoperability	51	0,0353	79	63	37	43	62
	Usability	Appropriateness Recognisability	21	0,0145	64	98	13	34	22
		Learnability	55	0,0381	2	54	48	49	90
		Operability	24	0,0166	59	63	48	36	48
		User Error Protection	16	0,0111	27	3	37	45	1
		User Interface Aesthetics	43	0,0298	69	10	63	83	21
		Accessibility	28	0,0194	62	28	94	78	64
	Reliability	Maturity	26	0,018	58	64	77	62	5
		Availability	49	0,0339	96	61	48	47	50
		Fault Tolerance	72	0,0499	60	81	84	70	94
		Recoverability	42	0,0291	63	10	45	97	22
	Security	Confidentiality	50	0,0346	67	51	56	75	65
		Integrity	86	0,0596	88	69	5	60	34
		Non-Repudiation	44	0,0305	19	76	62	99	45
		Accountability	35	0,0242	63	77	98	75	96
		Authenticity	26	0,018	11	23	49	73	28
	Maintainability	Modularity	90	0,0623	77	77	68	45	24
		Reusability	19	0,0132	78	46	94	54	25
		Analyzability	17	0,0118	22	15	25	9	17
		Modifiability	60	0,0416	7	59	70	84	94
		Testability	38	0,0263	43	75	11	34	29
	Portability	Adaptability	75	0,0519	88	43	46	90	99
		Installability	10	0,0069	70	99	77	89	76
		Replaceability	19	0,0132	81	10	75	18	50
		Sum	1444	1	1681	1566	1688	1778	1634

Table 10. Normalized Matrix for Dataset 3

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	0,9247	0,4516	1	0,6667	0,9677
		Functional Correctness	0,0616	0,3229	0,2396	0,6979	1	0,7708
		Functional Appropriateness	0,0637	0,1735	0,3878	1	0,3163	0,9082
	Performance Efficiency	Time-behaviour	0,0436	0,6629	1	0,0674	0,6854	0,1011
		Resource Utilization	0,0409	0,3803	0,0423	0,0282	0,0845	1
		Capacity	0,0249	0,202	0,303	0,9091	0,6465	1
	Compatibility	Coexistence	0,0519	1	0,9773	0,0227	0,1023	0,4659
		Interoperability	0,0353	1	0,7975	0,4684	0,5443	0,7848
	Usability	Appropriateness Recognisability	0,0145	0,6531	1	0,1327	0,3469	0,2245
		Learnability	0,0381	0,0222	0,6	0,5333	0,5444	1
		Operability	0,0166	0,9365	1	0,7619	0,5714	0,7619
		User Error Protection	0,0111	0,6	0,0667	0,8222	1	0,0222
		User Interface Aesthetics	0,0298	0,8313	0,1205	0,759	1	0,253
		Accessibility	0,0194	0,6596	0,2979	1	0,8298	0,6809
	Reliability	Maturity	0,018	0,7532	0,8312	1	0,8052	0,0649
		Availability	0,0339	1	0,6354	0,5	0,4896	0,5208
		Fault Tolerance	0,0499	0,6383	0,8617	0,8936	0,7447	1
		Recoverability	0,0291	0,6495	0,1031	0,4639	1	0,2268
	Security	Confidentiality	0,0346	0,8933	0,68	0,7467	1	0,8667
		Integrity	0,0596	1	0,7841	0,0568	0,6818	0,3864
		Non-Repudiation	0,0305	0,1919	0,7677	0,6263	1	0,4545
		Accountability	0,0242	0,6429	0,7857	1	0,7653	0,9796
		Authenticity	0,018	0,1507	0,3151	0,6712	1	0,3836
	Maintainability	Modularity	0,0623	1	1	0,8831	0,5844	0,3117
		Reusability	0,0132	0,8298	0,4894	1	0,5745	0,266
		Analyzability	0,0118	0,88	0,6	1	0,36	0,68
		Modifiability	0,0416	0,0745	0,6277	0,7447	0,8936	1
		Testability	0,0263	0,5733	1	0,1467	0,4533	0,3867
	Portability	Adaptability	0,0519	0,8889	0,4343	0,4646	0,9091	1
		Installability	0,0069	0,7071	1	0,7778	0,899	0,7677
		Replaceability	0,0132	1	0,1235	0,9259	0,2222	0,6173
		Sum	1	20,242	18,323	20,104	20,721	18,854

Table 11. Weighted Normalized Matrix for Dataset 3

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	0,0218	0,0106	0,0235	0,0157	0,0228
		Functional Correctness	0,0616	0,0076	0,0056	0,0164	0,0235	0,0181
		Functional Appropriateness	0,0637	0,0041	0,0091	0,0235	0,0074	0,0214
	Performance Efficiency	Time-behaviour	0,0436	0,0156	0,0235	0,0016	0,0161	0,0024
		Resource Utilization	0,0409	0,0090	0,001	0,0007	0,002	0,0235
		Capacity	0,0249	0,0048	0,0071	0,0214	0,0152	0,0235
	Compatibility	Coexistence	0,0519	0,0235	0,023	0,0005	0,0024	0,011
		Interoperability	0,0353	0,0235	0,0188	0,011	0,0128	0,0185
	Usability	Appropriateness Recognisability	0,0145	0,0154	0,0235	0,0031	0,0082	0,0053
		Learnability	0,0381	0,0005	0,0141	0,0126	0,0128	0,0235
		Operability	0,0166	0,0221	0,0235	0,0179	0,0135	0,0179
		User Error Protection	0,0111	0,0141	0,0016	0,0194	0,0235	0,0005
		User Interface Aesthetics	0,0298	0,0196	0,0028	0,0179	0,0235	0,006
		Accessibility	0,0194	0,0155	0,007	0,0235	0,0195	0,016
	Reliability	Maturity	0,018	0,0177	0,0196	0,0235	0,019	0,0015
		Availability	0,0339	0,0235	0,015	0,0118	0,0115	0,0123
		Fault Tolerance	0,0499	0,0150	0,0203	0,021	0,0175	0,0235
		Recoverability	0,0291	0,0153	0,0024	0,0109	0,0235	0,0053
	Security	Confidentiality	0,0346	0,0210	0,016	0,0176	0,0235	0,0204
		Integrity	0,0596	0,0235	0,0185	0,0013	0,0161	0,0091
		Non-Repudiation	0,0305	0,0045	0,0181	0,0147	0,0235	0,0107
		Accountability	0,0242	0,0151	0,0185	0,0235	0,018	0,0231
		Authenticity	0,018	0,0035	0,0074	0,0158	0,0235	0,009
	Maintainability	Modularity	0,0623	0,0235	0,0235	0,0208	0,0138	0,0073
		Reusability	0,0132	0,0195	0,0115	0,0235	0,0135	0,0063
		Analyzability	0,0118	0,0207	0,0141	0,0235	0,0085	0,016
		Modifiability	0,0416	0,0018	0,0148	0,0175	0,021	0,0235
		Testability	0,0263	0,0135	0,0235	0,0035	0,0107	0,0091
	Portability	Adaptability	0,0519	0,0209	0,0102	0,0109	0,0214	0,0235
		Installability	0,0069	0,0166	0,0235	0,0183	0,0212	0,0181
		Replaceability	0,0132	0,0235	0,0029	0,0218	0,0052	0,0145
		Sum	1	0,4766	0,4314	0,4734	0,4879	0,4439

Table 12. Distance from Reference Ideal Solution for Dataset 3

Model	Characteristics	Sub characteristics	Normalized Weights RN1	Alternatives				
				P1	P2	P2	P4	P5
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	0,0235	0,0018	0,0129	0	0,0078	0,0008
		Functional Correctness	0,0616	0,054	0,056	0,0452	0,0381	0,0435
		Functional Appropriateness	0,0637	0,0596	0,0546	0,0402	0,0563	0,0423
	Performance Efficiency	Time-behaviour	0,0436	0,028	0,0201	0,042	0,0275	0,0412
		Resource Utilization	0,0409	0,0319	0,0399	0,0402	0,0389	0,0173
		Capacity	0,0249	0,0202	0,0178	0,0035	0,0097	0,0014
	Compatibility	Coexistence	0,0519	0,0284	0,0289	0,0514	0,0495	0,041
		Interoperability	0,0353	0,0118	0,0165	0,0243	0,0225	0,0168
	Usability	Appropriateness Recognisability	0,0145	-8E-04	-0,009	0,0114	0,0064	0,0093
		Learnability	0,0381	0,0376	0,024	0,0255	0,0253	0,0145
		Operability	0,0166	-0,005	-0,007	-0,001	0,0032	-0,001
		User Error Protection	0,0111	-0,003	0,0095	-0,008	-0,012	0,0106
		User Interface Aesthetics	0,0298	0,0102	0,0269	0,0119	0,0062	0,0238
		Accessibility	0,0194	0,0039	0,0124	-0,004	-1E-04	0,0034
	Reliability	Maturity	0,018	0,0003	-0,002	-0,006	-1E-03	0,0165
		Availability	0,0339	0,0104	0,019	0,0222	0,0224	0,0217
		Fault Tolerance	0,0499	0,0348	0,0296	0,0288	0,0323	0,0263
		Recoverability	0,0291	0,0138	0,0267	0,0182	0,0055	0,0237
	Security	Confidentiality	0,0346	0,0136	0,0186	0,017	0,0111	0,0142
		Integrity	0,0596	0,036	0,0411	0,0582	0,0435	0,0505
		Non-Repudiation	0,0305	0,026	0,0124	0,0157	0,0069	0,0198
		Accountability	0,0242	0,0091	0,0057	0,0007	0,0062	0,0012
		Authenticity	0,018	0,0145	0,0106	0,0022	-0,006	0,009
	Maintainability	Modularity	0,0623	0,0388	0,0388	0,0415	0,0486	0,055
		Reusability	0,0132	-0,006	0,0016	-0,01	-4E-04	0,0069
		Analyzability	0,0118	-0,009	-0,002	-0,012	0,0033	-0,004
		Modifiability	0,0416	0,0398	0,0268	0,024	0,0205	0,018
		Testability	0,0263	0,0128	0,0028	0,0229	0,0156	0,0172
	Portability	Adaptability	0,0519	0,031	0,0417	0,041	0,0305	0,0284
		Installability	0,0069	-0,01	-0,017	-0,011	-0,014	-0,011
		Replaceability	0,0132	-0,01	0,0103	-0,009	0,0079	-0,001
		Sum	1	0,5234	0,5686	0,5266	0,5121	0,5561

Table 13. Random numbers and normalized weights vectors (RN1, RN2, RN3)

Model	Characteristics	Sub characteristics	Random Numbers RN1	Normalized Weights RN1	Random Numbers RN2	Normalized Weights RN2	Random Numbers RN3	Normalized Weights RN3
Software Product Quality Model in ISO/IEC 25010:2011	Functional Suitability	Functional Completeness	34	0,0235	18	0,012	67	0,0401
		Functional Correctness	89	0,0616	80	0,0533	82	0,0491
		Functional Appropriateness	92	0,0637	70	0,0466	42	0,0251
	Performance Efficiency	Time-behaviour	63	0,0436	84	0,0559	32	0,0192
		Resource Utilization	59	0,0409	53	0,0353	28	0,0168
		Capacity	36	0,0249	43	0,0286	62	0,0371
	Compatibility	Coexistence	75	0,0519	63	0,0419	27	0,0162
		Interoperability	51	0,0353	91	0,0606	81	0,0485
	Usability	Appropriateness Recognisability	21	0,0145	17	0,0113	34	0,0204
		Learnability	55	0,0381	9	0,006	86	0,0515
		Operability	24	0,0166	90	0,0599	77	0,0461
		User Error Protection	16	0,0111	58	0,0386	71	0,0425
		User Interface Aesthetics	43	0,0298	50	0,0333	41	0,0246
		Accessibility	28	0,0194	32	0,0213	37	0,0222
	Reliability	Maturity	26	0,018	85	0,0566	16	0,0096
		Availability	49	0,0339	38	0,0253	40	0,024
		Fault Tolerance	72	0,0499	15	0,01	6	0,0036
		Recoverability	42	0,0291	69	0,0459	81	0,0485
	Security	Confidentiality	50	0,0346	96	0,0639	52	0,0311
		Integrity	86	0,0596	51	0,034	74	0,0443
		Non-Repudiation	44	0,0305	20	0,0133	63	0,0377
		Accountability	35	0,0242	99	0,0659	87	0,0521
		Authenticity	26	0,018	9	0,006	48	0,0287
	Maintainability	Modularity	90	0,0623	54	0,036	62	0,0371
		Reusability	19	0,0132	16	0,0107	28	0,0168
		Analyzability	17	0,0118	9	0,006	42	0,0251
		Modifiability	60	0,0416	36	0,024	85	0,0509
		Testability	38	0,0263	34	0,0226	99	0,0593
	Portability	Adaptability	75	0,0519	25	0,0166	47	0,0281
		Installability	10	0,0069	47	0,0313	43	0,0257
		Replaceability	19	0,0132	41	0,0273	30	0,018
		Sum	1444	1	1502	1	1670	1

Table 14. PARIS ranking results from three different datasets using normalized weight vector 1 (RN1)

	Dataset 1						Dataset 2						Dataset 3					
	π_i^{ω}	R	π_i^{*}	R	R_i	R	π_i^{ω}	R	π_i^{*}	R	R_i	R	π_i^{ω}	R	π_i^{*}	R	R_i	R
P1	0,3889	5	0,341	5	0,1183	5	0,6379	2	0,3621	2	0,4965	2	0,4766	2	0,5234	2	0,0159	2
P2	0,4208	3	0,3091	3	0,0733	3	0,5301	5	0,4699	5	0,6087	5	0,4314	5	0,5686	5	0,0799	5
P3	0,4615	2	0,2684	2	0,0157	2	0,6593	1	0,3407	1	0,4739	1	0,4734	3	0,5266	3	0,0205	3
P4	0,395	4	0,3349	4	0,1097	4	0,6054	3	0,3946	3	0,5305	3	0,4879	1	0,5121	1	0	1
P5	0,4726	1	0,2573	1	0	1	0,5645	4	0,4355	4	0,573	4	0,4439	4	0,5561	4	0,0622	4
	P5 is ranked as optimal alternative						P3 is ranked as optimal alternative						P4 is ranked as optimal alternative					

Table 15. PARIS ranking results from three different datasets using normalized weight vector 2 (RN2)

	Dataset 1						Dataset 2						Dataset 3					
	π_i^ω	R	π_i^*	R	R_i	R	π_i^ω	R	π_i^*	R	R_i	R	π_i^ω	R	π_i^*	R	R_i	R
P1	0,1979	5	0,1736	5	0,0602	5	0,6281	1	0,3719	1	0,4833	1	0,2426	2	0,7574	2	0,0081	2
P2	0,2142	3	0,1573	3	0,0373	3	0,5702	5	0,4298	5	0,543	5	0,2196	5	0,7804	5	0,0406	5
P3	0,2349	2	0,1366	2	0,008	2	0,6259	2	0,3741	2	0,4856	2	0,2409	3	0,7591	3	0,0105	3
P4	0,201	4	0,1705	4	0,0558	4	0,5941	3	0,4059	3	0,5184	3	0,2483	1	0,7517	1	0	1
P5	0,2405	1	0,131	1	0	1	0,5768	4	0,4232	4	0,5362	4	0,2259	4	0,7741	4	0,0317	4
	P5 is ranked as optimal alternative						P1 is ranked as optimal alternative						P4 is ranked as optimal alternative					

Table 16. PARIS ranking results from three different datasets using normalized weight vector 3 (RN3)

	Dataset 1						Dataset 2						Dataset 3					
	π_i^ω	R	π_i^*	R	R_i	R	π_i^ω	R	π_i^*	R	R_i	R	π_i^ω	R	π_i^*	R	R_i	R
P1	0,6627	5	0,581	5	0,2016	5	0,5978	3	0,4022	3	0,5529	3	0,8121	2	0,1879	2	0,0272	2
P2	0,717	3	0,5267	3	0,1248	3	0,5564	4	0,4436	4	0,5964	4	0,7351	5	0,2649	5	0,1361	5
P3	0,7863	2	0,4574	2	0,0267	2	0,679	1	0,321	1	0,4669	1	0,8066	3	0,1934	3	0,035	3
P4	0,6731	4	0,5706	4	0,1869	4	0,5518	5	0,4482	5	0,6011	5	0,8313	1	0,1687	1	0	1
P5	0,8052	1	0,4385	1	0	1	0,6103	2	0,3897	2	0,5398	2	0,7564	4	0,2436	4	0,106	4
	P5 is ranked as optimal alternative						P3 is ranked as optimal alternative						P4 is ranked as optimal alternative					