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BY
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ANALYSIS OF THE WD-2502X STANDARDS APPROACH ON MEASUREMENT QUALITY

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ANALYSIS OF THE WD-25022, 25023, 25024 STANDARD APPROACHES ON MEASUREMENT OF DATA QUALITY BASED ON DIFFERENT ISO STANDARDS

Renee Leonardo Rabeya Cuartas

RESUME

La première version de la norme ISO/IEC 9126 a été publiée en 1991 en fournissant un cadre (framework) pour l'évaluation de la qualité de logiciel. Plus tard, en 2001, une mise à jour divisée en 4 parties a été livrée: modèle de qualité (ISO/IEC 9126-1), mesures internes (ISO/IEC 9126-2), mesures externes (ISO/IEC 9126-3) et mesures de qualité en utilisation (ISO/IEC 9126-4). Des chercheurs ont constatés qu'aucune des *mesures de base* (base quantities[1]) n'étaient définie correctement [2]. Afin d'améliorer cette version, la premier des séries d'ISO/IEC 25000 SQuaRE (Software product Quality Requirements and Evaluation) a été publié en 2005.

Dans la version actuelle (janvier 2014) des documents ISO de la série 25000 (SQuaRE) et plus précisément la série 2502x, il y a toujours des *mesures de base* qui ne sont pas encore définies pour des fins de mesure scientifique. La conséquence est qu'il n'est pas possible d'affirmer la cohérence des mesures d'une application à une autre ou d'une organisation à une autre. En science, cette cohérence est possible seulement si les exigences d'exactitude, de répétabilité et de reproductibilité sont respectées. L'objectif de cette recherche est de vérifier si les exigences d'exactitude, de répétabilité et de reproductibilité sont respectées pour les mesures de base (base quantities) (VIM).

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[1] Selon que l'on se réfère à la norme ISO 25021, ISO 15939 ou VIM (Vocabulary of International Metrology), les expressions sont respectivement Quality Measure Element (QME), «Base measure» ou « Base quantity». Dans ce document, il a été décidé d'utiliser l'expression «Base quantity».

ANALYSIS OF THE WD-25022, 25023, 25024 STANDARD APPROACHES ON MEASUREMENT OF DATA QUALITY BASED ON DIFFERENT ISO STANDARDS

Renee Leonardo RABEYA CUARTAS

ABSTRACT

The first version of ISO/IEC 9126 was issued in 1991 providing a framework for the software quality evaluation. In 2001, an update was delivered, composed of 4 parts: ISO/IEC 9126-1 Quality Model, ISO/IEC 9126-2 External Metrics, ISO/IEC 9126-3 Internal Metrics, and ISO/IEC 9126-4 Quality in use. As described in the article "Identification and analysis of attributes and base measures within ISO 9126" [2], some measures were presented at a fair level; the *base measures* Quality Measure Elements (QME) where not defined properly. As a result, to improve these measures, ISO/IEC 25000 SQuaRE (Software product Quality Requirements and Evaluation) first version was issued in 2005.

In the latest version (January 2014) of ISO documents regarding the subject (mainly 2502x series), there are *base quantities* that are not properly defined[2]. As a consequence, it is not possible to confirm the coherence among measures from one application to another or from one organization to another. In Science, this coherence is possible only if the requirements of accuracy, repeatability, and reproducibility are accomplished.

The objective of this research is to check if the requirements of accuracy, repeatability and reproducibility are accomplished for the *Base Quantities* (VIM).

Key Words: ISO/IEC 25022, ISO/IEC 25023, ISO/IEC 25024, ISO/IEC 21035, ISO/IEC 91026 SQuaRE series, SQuaRE, comparative, *Base Quantity,* accuracy, repeatability, reproducibility.

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[2] Depending on whether one refers to the standard ISO 25021, ISO 15939 or VIM (Vocabulary of International Metrology), expressions are respectively Quality Measure Element (QME), 'Basic measure' or 'Base quantity'. In this document it was decided to use the term 'base quantity'.

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LIST OF ABREVIATIONS

ISO: International Organization for Standardization

SQuaRE: Software Quality Requirements and Evaluation

QM: Quality Measure

QME: Quality Measure Element

IEC: International Electrotechnical Commission

CD: Committee Draft

BIPM: International Bureau of Weights and Measures

SC7: Subcommittee 7

WG6: Work Group 6

JCGM: Joint Committee for Guides in Metrology

TR: Technical Reference

INTRODUCTION

Software products and computer systems are developed to perform more and more a wide variety of business and personal functions. Measures and the quantify concepts in software engineering are not precisely defined; as a result the information is unreliable. However, the quality on the final software product is important to provide value in the form of the different services that are offered to the stakeholders, including the final users, and the developers. High quality software is essential to provide value to the stakeholders([5]).

In order to guarantee that the final product provides value, evaluation of the quality of software is imperative. This can be achieved by defining the necessary and desired quality characteristics associated with the stakeholder's business objectives. The quality characteristics and measurements can be useful not only to evaluate the product but also to define software quality requirements.

The objective of ISO / IEC 25000 SQuaRE series (Software Product Quality requirements and Evaluation) is to organize, and unify the series covering two main processes: software quality requirements specification and software quality evaluation, supported by the software quality measurement process.([16]). Within SQuaRE the ISO / IEC 250XX series replaces two related standards: ISO / IEC 9126 (Software Product Quality) and ISO / IEC 14598 (Software Product Evaluation)

More precisely, the idea of ISO/ IEC -2502X is to identify and measure the quality of the software. Because, in software engineering, software measures are often proposed without precise definition of the measurable concepts they attempt to quantify, the numbers obtained are challenging to reproduce and interpret in different measurement contexts, as it is "base quantity" defined in the following way in the Vocabulary of international metrology (VIM): "Base Quantity: quantity in a conventionally chosen subset of a given system of quantities, where no subset quantity can be expressed in terms of the others". The equivalent

expressions are “base measure” and “quality measure element (QME)” in other standards (ISO15939 and 25021 respectively). The lack of consistency when using base measures in data collection can affect both data preparation and data analysis. One of the ways to establish consistency of a measure is to determine if the measure is accurate, reproducible and repeatable as defined in VIM.([1]; [3]).

The rest of this document is organized as follows: Chapter 1 presents literature review on the subject. Chapter 2 presents the objective and the limits of this document. Chapter 3 describes the methodology followed to develop this document. Chapter 4 shows the list of *Base Quantities* and results related to the *Base Quantities* that meet the requirements of Accuracy, Repeatability, and Reproducibility, *Base Quantities* per standard, occurrences per standard, the amount of *Base Quantities* that are being defined, and the qualifiers. Chapter 5 presents the analysis of the information, the occurrence of the information and the interpretation of the results. Finally, chapter 6 presents the conclusion and recommendation for future work. There are 4 annexes: the first one is the master table of the base quantities, annex 2 is the complete list of the base quantities, annex 3 shows the base quantities definition match and finally annex 4 presents the list of the qualifiers.

CHAPTER 1

LITERATURE REVIEW

Literature review presents the most relevant documents that support this research. One of the first series of standards to standardize the software quality is the ISO/IEC 9126 series; the first version was issued in 1991 providing a framework for the evaluation of software quality. Then, in 2001 a revision was delivered dividing the series in 4 parts: ISO/IEC 9126-1 Quality Model, ISO/IEC 9126-2 External Metrics, ISO/IEC 9126-3 Internal Metrics, and ISO/IEC 9126-4 Quality in Use. This model has 6 product quality characteristics and 27 sub-characteristics as shown in the Table 1-1([6]).

Then, the ISO/IEC 25000 series was issued to replace the ISO/IEC 9126 series. The first edition of ISO/IEC 25000 SQUARE guide was issued in 2005, later in 2006, the ISO/IEC 25051:2006 requirements for quality of Commercial Off-The-Shelf (COTS) software product and instructions for testing was delivered; this standard defines requirements in order to test the documentation. Furthermore, the idea of these tests is to demonstrate that the requirements are compliant to the software; the documentation encloses a test plan, the description of the test cases, and the test results([17]).

Later, the ISO/IEC 25021 Quality Measure Elements was issued to define the initial set of QME to be used for developing and specifying QME for ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024 ([11]).

Then, the ISO/IEC 25010:2011 Quality model and guide was issued in 2011; compared to the quality model described in ISO/IEC 9126 series that has 6 characteristics (as shown in Table 1-1), this standard has eight product quality characteristics, and 31 sub-characteristics as shown in Table 1-2 ISO/IEC 25010:2011.

Finally, VIM “Vocabulaire International de Métrologie”, which means International Vocabulary of Metrology, first version was created in 1997 and it is intended to be a common reference for scientist and engineers, as well as people involved in measuring. It describes concepts used in different approaches, and promotes the harmonization of terminology used in metrology([3]).

The literature review will introduce each document that supports this research. First, ISO 9126 series will be introduced. Then, ISO/IEC 25000 series will be presented, as well as ISO/IEC 25010, ISO/IEC 25020, and ISO/IEC 25021 offering quality measure elements (QME) for ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024 that are currently under development. The ISO/IEC 15939 and VIM documents are presented to explain the measurement method to define the “Base Quantity”. Finally, the measurement methods and the selection criteria to meet the characteristics of accuracy, repeatability and reproducibility are described.

1.1 ISO/IEC 9126: 2003

ISO/IEC 9126: 2003 series is one of the first ISO series that delivers a framework to provide a suggested set of software quality metrics. The first version of the framework is composed of 6 characteristics and 27 sub-characteristics as shown in Table 1-1. Also, external and internal quality “metrics” were presented on this version (ISO/IEC 9126-2 and ISO/IEC 9126-3 respectively). ISO 9126 has four series: ISO/IEC 9126-1, ISO/IEC 9126-2, ISO/IEC 9126-3, and ISO/IEC 9126-4.

These series are mainly replaced by the ISO/ IEC 250XX series. The ISO 25023 Measurement of system and software product quality replaced the ISO/IEC 9126-2 external metrics and the ISO/IEC 9126-3 internal metrics, quality in use replaced the ISO/IEC 25022 Measurement of quality in use metrics. These standards series suggest a set of external and internal quality “metrics” to be used with the quality model.

The internal metrics measure the software from the developer point of view, and the external metrics measure the behavior of the computer-based system that includes the software; the quality in use metrics measures the effects of using the software in a specific context of use.

1.1.1 ISO/IEC TR 9126-1: 2003 Quality Model

ISO/IEC TR 9126-1: 2003 introduces the model for software quality characteristics and also shows how these characteristics are decomposed into sub-characteristics to be used among the subsequent ISO standard series. Presented in Table 1-1, ISO/IEC 9126-1 is a general framework of the quality model. The measures of the quality model are to be presented within ISO/IEC 9126-2, ISO/IEC 9126-3, and ISO/IEC 9126-4. This standard (TR) links the whole series categorizing the characteristics, sub-characteristics, and "metrics" (measures).

Table 1-1 ISO/IEC 9126 Characteristic and sub-characteristic ([6])

ISO/IEC 9126					
Functionality	**Reliability**	**Usability**	**Efficiency**	**Maintainability**	**Portability**
• Suitability • Accuracy • Interoperability • Security • Functionality Compliance	• Maturity • Fault Tolerance • Recoverability • Reliability Compliance	• Understandability • Learnability • Operability • Attractiveness • Usability Compliance	• Time Behaviour • Resource Utilization • Efficiency Compliance	• Analyzability • Changeability • Stability • Testability • Maintainability Compliance	• Adaptability • Installability • Co-Existence • Replaceability • Portability Compliance

This model defines 6 main characteristics and 27 sub-characteristics; each sub-characteristic includes a number of "metrics" proposed to quantify these characteristics and sub-characteristics. Those "metrics" are "quality measures" within SQuaRE and each quality measure has two or more "base quantities" (QME for ISO 25021).

1.1.2 ISO/IEC 9126-2 External metrics

ISO/IEC TR 9126-1:2003 defines the characteristics and sub-characteristics. ISO/IEC 9126-2 lists a number of "metrics" that help to measure these characteristics and sub-characteristics from the user point of view.

1.1.3 ISO/IEC 9126-3 Internal metrics

ISO/IEC TR 9126-1:2003 defines the characteristics and sub-characteristics. ISO/IEC 9126-3 lists a number of "metrics" that help to measure these characteristics and sub-characteristics from the developer point of view.

1.1.4 ISO/IEC 9126-4 Quality in use metrics

ISO/IEC TR 9126-1:2003 defines the characteristics and sub-characteristics. ISO/IEC 9126-4 lists a number of "metrics" that help to measure these characteristics when they are used dynamically.

1.2 SQUARE

SQuaRE is the acronym of Software product Quality Requirements and Evaluation. It is a reference model (guide and definitions). The series provide the details on the transition of ISO/IEC 9126 series to SQuaRE. More precisely, SQuaRE series describe:

- Terms and definitions,
- Reference models,
- General guide,
- Individual division guides, and
- Standards for requirements specification, planning and management, measurement and evaluation purposes. ([16])

These series are intended to unify the series that covers the software quality requirements and evaluation connected by the measurement process. Additionally, it can be used not only to define the software requirements but also to evaluate the final product. The ISO/IEC 25000 series are going to replace the ISO/IEC 9126 series, also based on ISO/IEC 15939. The following chapters are going to describe more in detail the standards constituting these series.

1.2.1 ISO/IEC 25000 Series

The overall objective of ISO / IEC 25000 SQuaRE (Software Product Quality requirements and Evaluation) is to organize, enhance and unify the series covering two main processes: requirements specification of software quality and evaluation of software quality, supported by the quality measurement process of the software.

Figure 1-1 presents the structure of the Quality Measurement division:

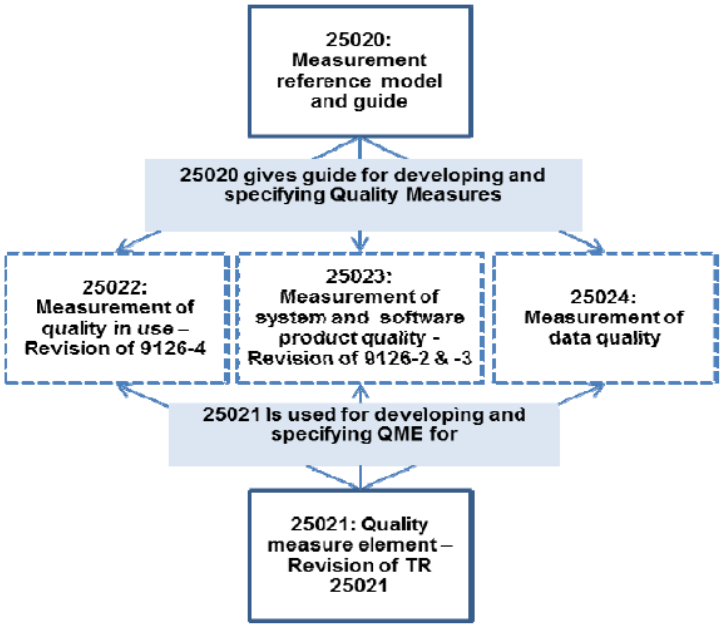

Figure 1-1 Structure of the Quality Measurement division([13])

ISO 25000 is divided into 6 main groups to cover different categories of the quality as follows:

- The ISO/IEC 2500n : Quality Management Division;
- The ISO/IEC 2501n : Data Quality Model;
- ISO/IEC 2502n: Data Quality Measures, as described in Figure 1-1;
- ISO/IEC 2504n : Division of quality evaluation;
- ISO/IEC 2503n : Quality Requirements;
- ISO/IEC 25050–25099: SQuaRE extension standards.

More precisely, the data quality measure series will be described as follows:

1.2.2 ISO/IEC 25010:2011

The ISO/IEC 25010 presents and defines the product quality model. The characteristics defined are related to computer systems and software products. The model for quality in use distinguishes five main characteristics which are divided into 11 sub-characteristics. The product quality model distinguishes eight main characteristics, each one divided into 31 sub-characteristics. The product quality characteristic are listed as shown in Table 1-2 ([5]).

Table 1-2 ISO/IEC 25010 Characteristics and sub-characteristics ([5])

ISO/IEC 25010							
Suitability (Functional suitability) •Functional appropriateness •Accuracy	**Performance Efficiency** (Performance efficiency) •Time behaviour •Resource utilisation	**Compatibility** (Compatibility) •Co-existence •Interoperability	**Usability** (Usability) •Appropriatenes s recognisability •Ease of use •User error protection •User interface aesthetics •Learnability •Accessibility	**Reliability** (Reliability) •Maturity •Availability •Fault tolerance •Recoverability	**Severability Secure** (Security) •Confidentiality •Integrity •Non-repudiation •Accountability •Authenticity	**Maintainability** (Maintainability) •Modularity •Reusability •Analysability •Modifiability •Testability	**Transferability** (Portability) •Adaptability •Installability •Replaceability

As shown in the Table 1-2, this new version has 2 more characteristics than ISO/IEC 9126. As a matter of fact, “Security” and “Compatibility” were added with their own sub characteristics. Furthermore, all the sub-characteristics where modified.

1.2.3 ISO/IEC 25020: 2007

The ISO/IEC 25020: 2007 Measurement reference model and guide sets requirements for the selection and construction of quality measures. It also supplies a reference model to measure the quality characteristics defined in ISO/IEC 2501n, the Quality Model Division. Also, it is a measurement guide and model for the ISO/IEC 25022, 25023, and 25024.

1.2.4 ISO/IEC 25021: 2012

This standard was issued in 2012, defining a set of Quality Measure Elements (QME) (Base quantities) to be used within all the SQuaRE series as well as all around the software lifecycle. The purpose of this standard is to define and/or design an initial set of QME to be used throughout the product life cycle for the purpose of Systems and Software Quality Requirements and Evaluation (SQuaRE). It also provides a set of rules to design a QME or verify the design of an existing QME([11]). In order to identify the way to quantify the QME, a Measurement Method should be applied to the property to quantify. For this reason, the standard describes a measurement method model.

ISO/IEC 25021:2012 is the latest version of this series, as shown in Figure 1-1 (Structure of the Quality Measurement division); this standard is a guideline intended to develop and specify QME (Base quantity) for ISO/IEC 25022, ISO/IEC 25023 and ISO/IEC 25024.

Described in a graphical way, Figure 1-2 shows the relationship between QME, Measurement method and property to quantify, and also their respective definition.

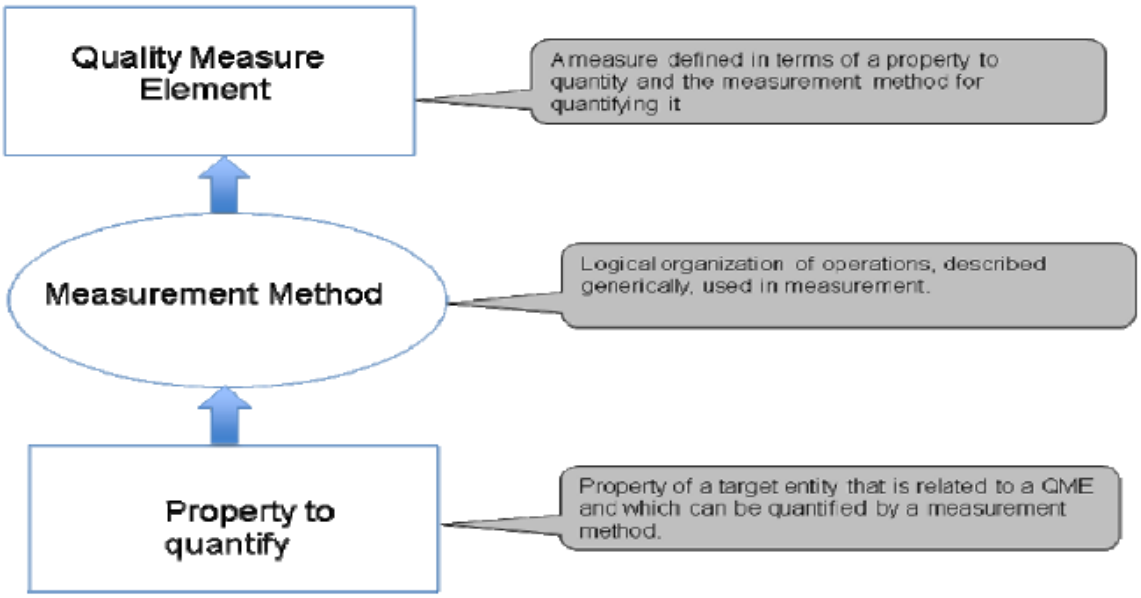

Figure 1-2 (ISO/IEC 25021:2012) Relationship between property to quantify, measurement method and QME([11]).

Figure 1-2 shows arrows going up in order to avoid misunderstanding, and clarify the way the flow should be, starting by the bottom. Furthermore, it shows dependency between each item described in the model; the inputs of the measurement method are the properties to quantify, followed by the measurement method quantifying the QME.

1.2.5 ISO/IEC 25022 (In development, latest version January 2014)

The ISO/IEC 25022 Measurement of quality in use is part of the SQuaRE series of international standards. This standard is intended to replace ISO/IEC 9126-4, and provides a set of measures for the characteristics of quality in use already defined in ISO/IEC 25010.

According to the International Standard Organization, ISO/IEC 25022 has the following changes:

- Measures are given for the revised quality model for quality in use in ISO/IEC 25010.

- Measures are categorized as highly recommended, recommended, or additional measures for reference ([12]).

Until January 2014, QME (Base quantities) were not properly defined. As a result, many comments were sent to WG6 for revision, because the QMEs were not defined based on ISO/IEC 25021 measurement method, meaning that there is still a lack of detailed description of the measures the standards attempted to quantify.

1.2.6 ISO/IEC 25023 (In development, latest version January 2014)

ISO/IEC 25023 Measurement of system and software product quality is intended to provide the required quality measures. Based on ISO ISO/IEC 25010:2011, and ISO/IEC 25021:2012, it is divided into the eight quality characteristics already mentioned in Table 1-2, also the terms and definitions present in ISO/IEC 25000 and ISO/IEC 25010.

The objective of this standard is to replace and integrate ISO/IEC 9126-2 external metrics and ISO/IEC 9126-3 internal metrics and to measure systems and software products, in each of the phases of the software product life cycle. According to ISO/IEC 25023, the external quality measures may be used to measure the quality of the system/software product, and can be used during operation or testing stages. The internal quality measures may be applied to a non-executable system/software product during its development stages. The relationship between this standard and the 2502n series is shown in Figure 1-1. ([13]; [16])

1.2.7 ISO/IEC 25024 (In development, latest version January 2014)

This International Standard takes into account large types of data: structured data, elementary data, aggregated data, stable or historical information on products, low-term-changing, and frequently-changing data. It can be applied in many types of information systems: monolithic information system, data warehouse, distributed information system, cooperative information system, and World Wide Web. It also aims to support the implementation of data integration

and federated data which come from different heterogeneous sources, by measuring the different level of data quality for each characteristic ([14]).

According to ISO/IEC 25024 it is oriented to:

- Allow organizations to measure data quality by using a basic set of quality measures, a basic set of target entities to which the measures are applied and a structured framework also useful for data documentation;
- Provide guidance for organizations defining their own measures for data quality requirements and evaluation;
- Provide guidance for organizations who want to maintain their own measures for data quality;
- Help identify the set of quality measure elements for each data quality characteristic ([14]).

Until January 2014, QME (Base quantities) were not properly defined. As a result many comments were sent to WG6 for revision, because the QMEs were not defined based on ISO/IEC 25021 measurement method, meaning that there is still a lack of detailed description of the measures the standards attempted to quantify.

1.3 ISO/IEC 15939: 2007

ISO/IEC 15939:2007 defines a measurement process described through model defining “measures”. Moreover, it is intended to describe how the measures and results are to be applied, and how to determine if the results are valid. It can be applicable to system and software engineering and management disciplines. ([15])

According to the International Standard Organization (ISO) “ISO/IEC 15939:2007 defines a measurement process applicable to system and software engineering areas”; ISO/IEC 15939 defines the relationship between the attribute (concept to quantify), measurement method and

base measure ((QME) or Base Quantity) as shown in Figure 1-3. Also, ISO/IEC 15939 on evaluation phase (construction of the measure), defines that a base measure is "a measure defined in terms of an attribute and the method for quantifying it" ([15]). In fact, the attribute is a property, the measurement method is the operation to measure this attribute, and the base measure the variable assigned by the method to one attribute. However, in real life, to obtain a base measure, a measurement method should be applied to an attribute ([1]).

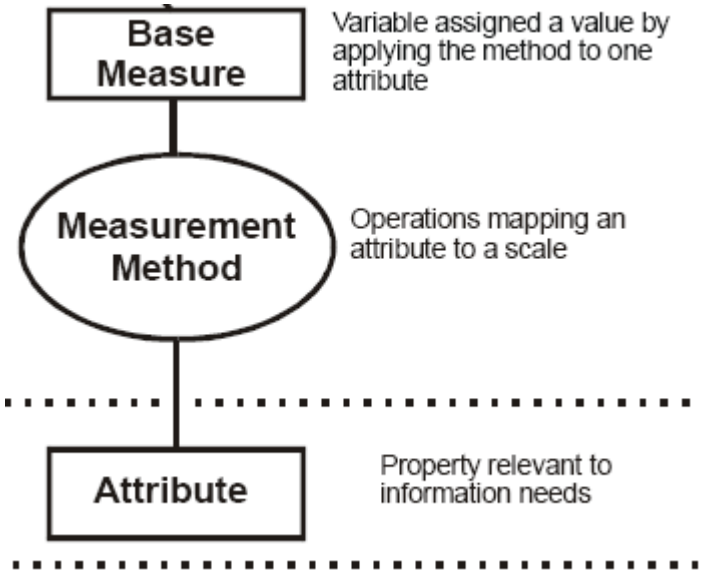

Figure 1-3 (ISO/IEC 15939:2007) Relationship between base measure, measurement method, and attribute ([1]).

1.4 International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM)

In 1997, the first version was issued by the Joint Committee for Guides in Metrology (JCGM); this committee is formed by eight organizations and chaired by the director of BIMP. Together they produced the e Guide to the Expression of Uncertainty in Measurement (GUM) and the International Vocabulary of Basic and General Terms in Metrology (VIM). Originally the JGM is integrated by 8 representatives:

- The International Bureau of Weights and Measures (BIPM),
- International Electrotechnical Commission (IEC),
- International Federation of Clinical Chemistry and Laboratory Medicine (IFCC),
- International Organization for Standardization (ISO),
- International Union of Pure and Applied Chemistry (IUPAC),
- International Union of Pure and Applied Physics (IUPAP),
- the International Organization of Legal Metrology (OIML),
- and International Laboratory Accreditation Cooperation (ILAC)([3]).

This vocabulary relates to metrology, the field of knowledge concerned with measurement. It is been created in French and English, the idea being to unify the terms between standards to have a common document with all the terms defined, for the standards to be used. It also covers the basic principles governing quantities and units.

According to VIM, the second edition needed reconsideration in the treatment of the concepts of measurement from an uncertainty Classical Approach, Traditional Approach or True-Value Approach to the Uncertainty Approach. In fact, the Classical Approach determines a value that is as close as possible to that single true value.

The third version and latest version, issued in 2006, will be used for this research in order to establish if *Base Quantities* meets the requirements of Accuracy, Reproducibility and Repeatability.

1.5 Measurement Method

As defined in ISO/IEC 25021, the Measurement Method is a: “Logical organization of operations, described generically, used in measurement” ([11]). The quality of the final product can be achieved through measurement; in order to get a high quality product, some standards must be approached.

Between the ISO standards, different measure terms are described, according to the document "Software Measurement Methods: An Analysis of Two Designs" by Desharnais and Abran 2012 ([1]), a summary mapping of the terms among VIM, ISO/IEC 15939, and ISO/IEC 25021 is shown in
Table 1-3. In fact, ISO/IEC 25021 is part of the ISO/IEC 25000 series (Product Quality Requirements and Evaluation), that where conceived to update the ISO/IEC 9126 series. ISO/IEC 25021, VIM and ISO/IEC 15939 adopted different vocabulary terms. For example, the following measurement-related terms, the corresponding ISO standard meaning, and their mapping table (Table 1-3):

- *Base Quantity is* defined in VIM as : "quantity in a conventionally chosen subset of a given system of quantities, where no subset quantity can be expressed in terms of the others"([3]);
- *Base Unit* is defined in VIM as *"*measurement unit that is adopted by convention for a base quantity" ([3]);
- *Measurement method* is a logical organization of operations, described generically used in measurement([3]; [11]; [15]);
- *Concept to quantify*: Concept that is related to a *Base Unit* and which can be quantified by a measurement method([3]);
- *Base Measure* is defined in ISO/IEC 15939 as "Variable assigned a value by applying the method to one attribute"([15]);
- *Attribute as is* defined in ISO/IEC 15939 as the "Property relevant to information needs"([15]) ;
- *Quality measurement element (QME)*: A measure defined in terms of property to quantity and the measurement method for quantifying it([11]);
- *Property to quantify is* defined in ISO/IEC 25021 as "Property of a target entity that is related to a QME and which can be quantified by the measurement method"([11]);

The following table (
Table 1-3) presents the different concepts used in the different standards

Table 1-3 Mapping between measurement-related terms ([1]).

VIM	ISO 15939	ISO 25021
Base quantity	Base measure	Quality measurement element
Base unit		
Measurement method	Measurement method	Measurement method
Concept to quantify	Attribute	Property to quantify

1.6 Requirements to apply scientifically a Base quantity

Similar definitions of accuracy, repeatability and reproducibility were found among ISO/IEC 15939, ISO/IEC 25021 and VIM. As a result, the comparative presented in

Table 1-4 matches each term and the corresponding definition. The definitions of the terms are very convenient and similar between them. However, for the purpose of this research, the terms as defined on VIM are going to be followed.

Table 1-4 Comparative between ISO/IEC 15939:2007, ISO/IEC 25021:2012 and VIM.

Characteristic	ISO/IEC 15939	ISO/IEC 25021	VIM
Accuracy	An accurate procedure produces results similar to the true (or intended) value of the base measure.	Not defined	Closeness of agreement between a measured quantity value and a true quantity value of the measurand.
Repeatability	The degree to which the repeated use of the base measure in the same Organizational Unit following the same measurement method under the same conditions.	Closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement.	Condition of measurement in a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time.

Reproducibility	The degree to which the repeated use of the base measure in the same Organizational Unit following the same measurement method under different conditions.	Closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement	Condition of measurement in a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects.

To be scientifically validated and recommendable based on best practices, the following conditions should apply:

1.6.1 Accuracy

Accuracy, as defined in ISO/ IEC 15939 refers to the procedure that produces the true value ([15]). On the other hand, VIM definition refers to the "measured quantity" and the "quantity value" these indicators represent the measurement result ([3]). Therefore, the definition of VIM will be followed all around this research. In fact, if the Quality Measure is not defined, there is no unit to measure, there is no base unit, and as a consequence, if there is no measurement method, there cannot be Accuracy.

According to ISO: 15939: 2007: "An accurate procedure produces results similar to the true (or intended) value of the base measure"([15]). In fact, systematic errors in the procedure may produce different results from what was initially envisioned to produce. Also, a misunderstanding in the procedure may produce different information captures and different results. Accidental errors inherent in the measurement method can produce errors in the final results.

Subjective methods may depend on human interpretation individually. However, these methods should be applied uniformly, and should be clear and simple for each individual user to avoid different interpretations.

To measure the accuracy, VIM: 2006 defines the condition from the classical approach: “closeness of agreement between a measured quantity value and a true quantity value of the measurand”([3]). It explains that the concept of “measurement accuracy” does not bring a numerical value. However, a measurement is accurate when it offers a smaller uncertainty.

Therefore, to be Accurate, a *Base Quantity* must be Reproducible and Repeatable. Moreover, the following conditions must be fulfilled:

- The *Base Quantity* must be specified according to the context of use and clearly visible in the measure, as it is described in VIM “base quantity: quantity is a conventionally chosen subset of a given system of quantities, where no subset quantity can be expressed in terms of the others” ([3]), Furthermore, it should be specified in the *Measurement Method* where the way measurement is done. Moreover, the steps on how to measure must be defined, and the *Base Measure* described;

- The *Base Unit* must be specified, as it is described in VIM “base unit: measurement unit that is adopted by convention for a base quantity” ([3]). Furthermore, the *Base Unit* depends on the *Base Quantity*, it cannot be defined by itself and as a consequence, if the *Base Quantity* and the *Measurement Method* are not defined properly neither the *Base Unit.*

- A *Measurement Method* should be clearly specified as defined in VIM : “measurement method : method of measurement generic description of a logical organization of operations used in a measurement” ([3]). Furthermore, the steps and the way of measurement, the way of obtaining the measure and the units associated must be clearly defined.

1.6.2 Repeatability

Repeatability, as defined in ISO/ IEC 15939, limits the measure to the "Organizational Unit"; it also refers to the "degree", and the conditions are not specified. On the other hand, VIM definition refers to "condition of measurement" and specifies the conditions of the measurement. In fact, it defines the degree in which the same base measure under the same measurement method can be repeated under the same conditions producing the same results.

ISO/IEC 25021:2012 defines repeatability as "Closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement."([11]).

In this case, the objective methods produce higher repeatability. On the other hand, random and subjective methods reduce repeatability.

To measure the repeatability, VIM: 2006 describes as a "set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time."([3]). Effectively, each Base quantity is going to be validated according to these conditions.

A *Base Quantity* to be *Repeatable* must be at least defined or be a scientific fact, according to the usage situation, this way, it is possible to repeat the Quality Measure multiple times regardless of the result.

1.6.3 Reproducibility

Reproducibility, as defined in ISO/IEC 15939, limits the measure to the "Organizational Unit", it refers to the "degree", and the conditions are not specified. On the other hand, VIM

definition refers to "condition of measurement" and specifies the conditions of the measurement. Therefore, the definition of VIM is more convenient and will be followed all along this research. In fact, as defined in chapter 3.4, if the Quality Measure is not defined, and there is no base unit, it could not be Reproducible.

The reproducibility of a measurement method, according to ISO/IEC 15939: 2007 defines the degree in which the same base measure under the same organizational unit under different conditions produces the same results.

According to ISO/IEC 25021:2012, reproducibility is defined as: "Closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement".

In this case, the objective methods produce higher repeatability. On the other hand, random and subjective methods reduce repeatability. Also, both definitions are very similar.

To measure reproducibility, VIM: 2006 describes as a "set of conditions that include different locations, operators, measuring systems, and replicate measurements on the same or similar objects." In addition, measuring different systems could use different measurement procedures.

A *Base Quantity* to be *Reproducible* must be defined, according to the usage situation, and must meet the following characteristics:

- The *Base Quantity* must be specified according to the context of use and clearly visible in the measure, as it is described in VIM "base quantity: quantity is a conventionally chosen subset of a given system of quantities, where no subset quantity can be expressed in terms of the others" ([3]), Furthermore, it should be specified in the *Measurement Method* where the way measurement is done. Moreover, the steps on how to measure must be defined and the *Base Measure* described;

- The *Base Unit* must be specified, as it is described in VIM "base unit: measurement unit that is adopted by convention for a base quantity"([3]). Furthermore, the *Base Unit* depends on the *Base Quantity*, it cannot be defined by itself, and as a consequence if the *Base Quantity* and the *Measurement Method* are not properly defined neither can the *Base Unit.*

As a conclusion, according to chapter 1.4 and as defined in VIM, it is a "Condition of measurement in a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects"; if there is no *Base Unit* defined*,* it won't be possible to replicate the measurements obtaining the same results without a unit to measure. As consequence, each location will produce a different result.

1.7 QME structure

The components of the QME's mentioned in the standards ISO/IEC-25022, ISO/IEC 25023, and ISO/IEC 25024 are categorized by the characteristics and sub characteristics in ISO/IEC 25010. On each table, present in each ISO/IEC standard, the following information is provided:

- ID: Identification code of quality measure;
- Name: Quality measure name;
- Description: The information provided by the quality measure;
- Measurement function and QMEs: Mathematical formula showing how the quality measure elements are combined to produce the quality measure. Each mathematical formula is composed of different items as defined in ISO/IEC 25021 (see Figure 1-4)

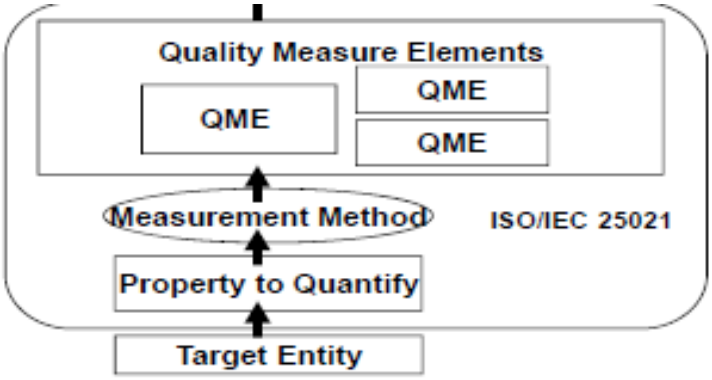

Figure 1-4 ISO/IEC 25021 Relationship among property to quantify, measurement method, QME and Quality Measure([11]).

- Target entity: defined in ISO/IEC 25021 as a "fundamental thing of relevance to the user, about which information is kept, and need to be measured", an example of target entity is a software artifact, documentation or code ([11]).

- Property to quantify (*Concept to Quantify*) defined in ISO/IEC 25021 as a "Property of a target entity that is related to a quality measure element and which can be quantified by a measurement method". In fact, the property to quantify should be the one which is most relevant to the measurement of information needed, the property to quantify its linked to one QME. For example: "Number of errors" is the QME, where "error" is the Base Quantity.

In the same way, the QME's are described on the master table (Annex I) and are explained more in detail in the following chapters. Also, another component that modifies the *Base quantities* is described as follows:

1.7.1 Qualifiers

An article wrote about ISO/IEC 9126 series in 2010 ([2]) also identifies "qualifiers" within each "quality measures". A qualifier characterizes some aspects of the "base quantity".

CHAPTER 2

OBJECTIVE AND SCOPE

2.1 Objective

The objective of this research is:

> To check the requirements of accuracy, repeatability, and reproducibility of the *Base Quantities* as defined in ISO International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM) in the ISO proposed documents (January 2014) in the series 2502x.

2.2 Scope

The scope of this document is to check the requirements of accuracy, repeatability and reproducibility in the following documents:

- ISO/CD 25022 (In development latest version January 2014),
- ISO/CD 25023 (In development latest version January 2014),
- And ISO/CD 25024 (In development latest version January 2014)

as defined in VIM:2006.

CHAPTER 3

METHODOLOGY

3.1 Compare different ISO measurement methodologies

After comparing and analyzing the different definitions among ISO/IEC 25021, ISO/IEC 15039, and VIM (as shown in Chapter 1.6), the document that is more appropriate to follow and that has complete definitions of: accuracy, repeatability, and reproducibility is VIM.

ISO/IEC 25021, ISO/IEC 15039, and VIM have similar definitions; however, for the purpose of this research, VIM - International Vocabulary of Metrology – Basic and General Concepts and Associated Terms is going to be followed for the following reasons:

- As its name states, it is an international vocabulary standard;
- It contains the definition of the terms to be consulted to support ISO/IEC standards;
- VIM facilitates the interpretation and the usage of the terms among the different ISO standards;
- It covers the basic principles governing quantities and units;
- It is composed of 8 international organizations :
    - the International Bureau of Weights and Measures (BIPM),
    - the International Electrotechnical Commission (IEC),
    - the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC),
    - the International Organization for Standardization (ISO),
    - the International Union of Pure and Applied Chemistry (IUPAC),
    - the International Union of Pure and Applied Physics (IUPAP),
    - the International Organization of Legal Metrology (OIML),
    - International Laboratory Accreditation Cooperation (ILAC).
- It relates to metrology, the field of knowledge concerned with measurement;

Also, these terms can provide the definition and the significance. Therefore, VIM is also an ISO guideline, mapping the term to a definition to be used as a reference among ISO / IEC standards.

3.2 Define the Base Quantity

Based on the article "Software Measurement Methods: An Analysis of Two Designs"([1]), and then following Chapter 1.5 the *Base Quantities* where defined among ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024, according to VIM description.

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3.3 Identify the Base Quantities

In order to identify the *Base Quantities,* an analysis has been made among ISO/IEC 25022 Measurement of Quality in Use, ISO/IEC 25023 System and Software Product Quality, and ISO/IEC 25024 Measurement of Data Quality; these documents are in development and the latest version was issued on January 2014. First, a list of the reference where each Base Quantity is mentioned was made and then, grouped by ISO / IEC Standard. Second, once the list was completed, a list of the Base Quantities is made and finally, a table of occurrences per ISO / IEC was added to the table.

3.4 Identify the conditions to apply

To be Accurate, Reproducible and Repeatable, a *Base Quantity* must meet the conditions already defined on Chapter 1.6: be Accurate (Chapter 1.6.1), Reproducible (Chapter 1.6.2) and Repeatable (Chapter 1.6.3). It is marked with "1" if the conditions are met; otherwise it is marked with "0".

3.5 Create the Comparative table

After having all the items gathered, they were put together in a master table for subsequent validation and analysis; the table is composed of the following items:

1- *Base Quantity:* This is the first field in the table and this field is defined in VIM as "quantity in a conventionally chosen subset of a given system of quantities, where no subset quantity can be expressed in terms of the others" ([3]) ;
2- *Base Unit:* this is the second field and is defined in VIM as *"*measurement unit that is adopted by convention for a base quantity" ([3]). In other words, it is the unit used to measure the *Base quantity*;
3- *Accurate, Repeatability, Reproducibility*: These fields are the third, fourth, and fifth and they define if the *Base Quantity* is accurate, repeatable, and reproducible with "1" if the condition is met, otherwise "0" according to the conditions already mentioned in Chapter 1.6;
4- *Occurrences*: this is the sixth field and shows how many occurrences of the *Base Quantities* were found on each ISO / IEC standard; also, at the end, it shows the total of occurrences;
5- *Reference* : this is the seventh field and it is the reference where the full quality measure is mentioned in the following format: ISO/ IEC (standard of reference) – (chapter number) (chapter name) [Metric ID] and then the full *base quantity* plus the qualifier;
6- Defined in *ISO/IEC 25021, VIM, ISO/IEC 15939, and Others*: these are the fields eight, nine, ten, and eleven. Marked by a "0" if it is not defined in the standard mentioned above or by a "1" if it is defined. Furthermore, the field "*Others"* shows the source where it is mentioned, other than in ISO/IEC 25021, 15939 or VIM.
7- Finally, the field *Justification*: this field describes why the "0" or the "1" was assigned to a *Base Quantity*; this field gives more details on the source of the definition. If there is, a Base measure, Base Unit or a Measurement Method is defined.

3.6 Statistics according to the results

After collecting the information, organizing the information, validating the conditions, and updating the master table, the statistics are presented.

3.7 Analyzing the Results

Finally, once the information is ready and the statistics are made, the analysis of the results and recommendations are presented.

CHAPTER 4

PRESENTATION OF THE RESULTS

In Chapter 3, the methodology was defined. This chapter also presents a comparison of the different measurement methodologies and how to define the *Base Quantities*. The results obtained once the methodology was applied are presented in this chapter.

This chapter presents: 1- the definition of the *Base Quantities* that were identified and listed among the ISO standards, 2- the list of the *Base Quantities* that meet the requirements of accuracy, repeatability and reproducibility, 3- the *Base Quantities* occurrences grouped by standard, 4- a list of the *Base Quantities* that are defined among ISO/IEC 25021, ISO/IEC 15939 and VIM, finally Qualifiers description.

4.1 List of the Base quantities (3.3 and 3.4)

Following the article "Identification and analysis of attributes and base measures with ISO 9126"([2]), the *Base Quantities* were identified among ISO/IEC 25022, ISO/IEC 25023 and ISO/IEC 25024. As a result, a total of 63 items were recognized as shown in the following table:

Table 4-1 List of *Base Quantities* among ISO/IEC 25022, 25023, and 25024.

Base Quantities		
Number of Accesses	Number of Data Values	Number of modifications
Number of Actions	Number of deliveries	Number of modules
Number of architecture components	Number of design features	Number of Operations
Number of Assets	Total amount of disk spaces	Number of people
Number of attributes	Total Duration	Number of processes
Number of authentication protocols	Number of Elements	Number of Questions
Number of authentication rules	Number of Entities	Number of records
Total bandwidth	Number of error messages	Number of requests
Number of breakdowns	Number of events	Number of Schemas
Number of cases	Number of faults	Size
Number of colour codings	Number of files	Number of software modules
Number of components	Number of functions	Number of Software products
Number of Contexts	Number of helps	Duration of special days
Amount of CPU time	Number of Interfaces	Number of systems
Number of cryptographic algorithms	Invested amount	Number of tasks
Number of customers	Number of installation	Number of test cases
Number of Data	Number of Items	Number of tests
Number of Data Files	Amount of memory space	Time
Number of Data Formats	Number of messages	Number of visitors
Number of Data Items	Number of metadata	Number of users
Number of data models	Number of Methods	Number of user errors

The 63 *Base Quantities* listed on Table 4-1, are the result of the analysis of the "Quality Measures" presented on ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024. The selection of these *Base Quantities* was made among a total of 204 measures applying the methodology described in Chapters 3.3 and 3.4.

4.2 Base quantities that meet the conditions of consistency (3.4 and 3.5)

Once the information was collected, organized and then prepared, the base quantities were checked with the conditions described in chapter 1.6, producing the following table:

Table 4-2 Cross-reference of Base quantities among the characteristics of accuracy, repeatability and reproducibility

Base Quantity	Accuracy	Repeatability	Reproducibility	Base Quantity	Accuracy	Repeatability	Reproducibility
Number of Accesses	0	1	0	Number of functions	1	1	1
Number of Actions	0	0	0	Number of helps	0	1	0
Number of architecture components	0	0	0	Number of Interfaces	0	1	1
Number of Assets	0	1	1	Invested amount	1	1	1
Number of attributes	1	1	1	Number of installation	1	1	1
Number of authentication protocols	0	1	1	Number of Items	0	1	1
Number of authentication rules	0	1	1	Amount of memory space	1	1	1
Total bandwidth	1	1	1	Number of messages	0	0	0
Number of breakdowns	1	1	1	Number of metadata	1	1	1
Number of cases	1	1	1	Number of Methods	0	1	0
Number of colour codings	0	1	1	Number of modifications	0	0	0
Number of components	0	0	0	Number of modules	0	1	1
Number of Contexts	1	1	1	Number of Operations	1	1	1
Amount of CPU time	1	1	1	Number of people	1	1	1
Number of cryptographic algorithms	0	1	1	Number of processes	1	1	1
Number of customers	1	1	1	Number of Questions	1	1	1
Number of Data	0	1	1	Number of records	1	1	1

Table 4-2 (continuation) Cross-reference of Base quantities among the characteristics of accuracy, repeatability and reproducibility

Base Quantity	Accuracy	Repeatability	Reproducibility	Base Quantity	Accuracy	Repeatability	Reproducibility
Number of Data Files	0	1	1	Number of requests	0	1	0
Number of Data Formats	0	1	1	Number of Schemas	0	0	0
Number of Data Items	1	1	1	Size	1	1	1
Number of data models	1	1	1	Number of software modules	0	0	0
Number of Data Values	0	1	0	Number of Software products	0	1	0
Number of deliveries	1	1	1	Duration of special days	0	1	0
Number of design features	0	1	0	Number of systems	0	0	0
Total amount of disk spaces	1	1	1	Number of tasks	1	1	1
Total Duration	1	1	1	Number of test cases	1	1	1
Number of Elements	0	0	0	Number of tests	1	1	1
Number of Entities	0	0	0	Time	0	1	1
Number of error messages	0	1	0	Number of visitors	0	0	0
Number of events	0	1	0	Number of users	1	0	0
Number of faults	0	0	0	Number of user errors	1	1	1
Number of files	0	0	0				

Table 4-2 presents the list of *Base Quantities* and the corresponding match among the characteristics of accuracy, repeatability, and reproducibility. This table shows 63 *Base Quantities* identified on ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024. In the second column named "Accuracy", the conditions defined in Chapter 1.6.1 were applied and as a result, if the condition is met, it is a "1" otherwise, it is a "0". The same analysis was applied

for “Repeatability” conditions defined in Chapter 1.6.2, and “Reproducibility” conditions defined in Chapter 1.6.3.

4.3 Base quantity per standard (3.4 and 3.5)

The following table presents the occurrences grouped by ISO/IEC standard:

Table 4-3 Occurrences among ISO/IEC 25022, 25023 and 25024

Base Quantity / ISO Standard	ISO/IEC 25022	ISO/IEC 25023	ISO/IEC 25024	Total
Number of Accesses		8	2	10
Number of Actions	2			2
Number of architecture components			4	4
Number of Assets		2		2
Number of attributes			4	4
Number of authentication protocols		2		2
Number of authentication rules		2		2
Total bandwidth		2		2
Number of breakdowns		1		1
Number of cases		5		5
Number of colour codings		2		2
Number of components		2		2
Number of Contexts	4			4
Amount of CPU time		2		2
Number of cryptographic algorithms		2		2
Number of customers	3			3
Number of Data		4		4
Number of Data Files			4	4
Number of Data Formats		2		2
Number of Data Items		10	62	72
Number of data models			5	5
Number of Data Values			25	25
Number of deliveries	1			1
Number of design features	2			2
Total amount of disk spaces		2		2
Total Duration	1	11		12

Table 4-3 (following) Occurrences among ISO/IEC 25022, 25023 and 25024

Base Quantity / ISO Standard	ISO/IEC 25022	ISO/IEC 25023	ISO/IEC 25024	Total
Number of Elements			18	18
Number of Entities			4	4
Number of error messages		2		2
Number of events		2		2
Number of faults		11		11
Number of files			8	8
Number of functions		37		37
Number of helps		2		2
Number of Installations		3		3
Number of Interfaces		4		4
Invested amount	3			3
Number of Items	2	6		8
Amount of memory space		2		2
Number of messages		2		2
Number of metadata			5	5
Number of Methods		2		2
Number of modifications		1		1
Number of modules		3		3
Number of Operations		3		3
Number of people	3			3
Number of processes		3		3
Number of Questions	2			2
Number of records			6	6
Number of requests		1		1
number of Schema			2	2
Size			4	4
Number of software modules		2		2
Number of Software products		2		2
duration of special days		2		2
Number of system		2		2
Number of tasks	12	11		23
Number of test cases		4		4
Number of test		2		2
Time	4	16	4	24
Number of users	9	13		22
Number of user errors	3			3
Visitors	1			1
Total	**52**	**197**	**157**	**406**

The ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024 quality models (up to January 2014), have a total of 21 quality characteristics, 40 sub-characteristics, more than 205 quality measures and 406 occurrences of *Base Quantities* plus attributes proposed to quantify these characteristics and sub-characteristics. These standards have the status of Committee Draft (CD), meaning that they are still in development and that they are not ready to be recognized as International Standards. One of the objectives of ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024 is to improve the definitions of the measures defined in the ISO/IEC 9126 series.

Table 4-4 Characteristics, Sub-characteristics, Quality Measures, and Base Quantities distribution among ISO/IEC 25022, 25023 and 25024.

ISO Standard	Characteristics	Sub-characteristics	Quality Measures	Base Quantities Ocurrences
25022	4	9	37	52
25023	8	31	103	197
25024	9		64	157
Total	21	40	204	406

Among the total of 406 occurrences of *Base Quantities* found in ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024 documents (listed in Annex II), as shown in Table 4-4. It can be identified that:

- From the total of 21 characteristics, ISO/IEC 25024 is the one with most characteristics (9 in total); however, it is also the one with no sub-characteristics;
- ISO/IEC 25022 is the standard with the least characteristics, also the one with least measures and *Base Quantities*.
- ISO/IEC 25023 is the standard with most *Base Quantities* (197) but at 49% from the total. It is also the one with most sub-characteristics and quality measures.

Among the *Base Quantities* the ones with more occurrences (top 7) are shown in Table 4-5

Table 4-5 Top 7 of Base Quantities with more occurrences per ISO standard

Base Quantity	ISO/IEC 25022	ISO/IEC 25023	ISO/IEC 25024	Total
Number of Data Items		10	62	72
Number of Functions		37		37
Number of Data values			25	25
Time	4	16	4	24
Number of Tasks	12	11		23
Number of User	9	13		22
Number of Elements			18	18
Total	25	87	109	221

The Base Quantities shown in Table 4-5 represent 54% of all the occurrences, from a total of 406. It can be inferred that:

- In the top 7 table, ISO/IEC 25024 is the standard with the most occurrences (109 in total), it represents 70% of the total of occurrences concentrated in 4 *Base Quantities* that are: "Number of Data Item" in first position, "Number of Data Values" in third position, "Time" and "Number of Elements";
- The Base Quantity "Number of Data Item" is the one with the highest rate, 18% out of the total of 406, meaning that it is being mentioned 72 times, among ISO/IEC 25023, and ISO/IEC 25024. Moreover, it is mentioned 62 times out of a total 157 base quantities declared on ISO/IEC 25024 which represents39% of the total;
- ISO/IEC 25022 is the one with lesser participation on the table representing only 11%. Furthermore, "number of tasks" is the base quantity with the highest rate on the table;

- ISO/IEC 25023 has the bigger amount of base quantities, and occurrences. Moreover, the occurrences are distributed among 41 base quantities declared on this standard. The base quantity mostly repeated is “Number of functions”;
- The difference between the first and the second base quantity in the table is 49%, in fact the first is almost doubles the second one.

4.4 Definition among ISO/IEC 25021, 15939 and VIM (3.6 and 3.7)

In order to check the accuracy, repeatability, and reproducibility, one of the first steps as defined in Chapter Requirements to apply scientifically a 1.6 is to search for the definition. In fact, it should be defined in some part this way, the users of these standards can resolve the doubts or ambiguities that may arise when applying the standards.

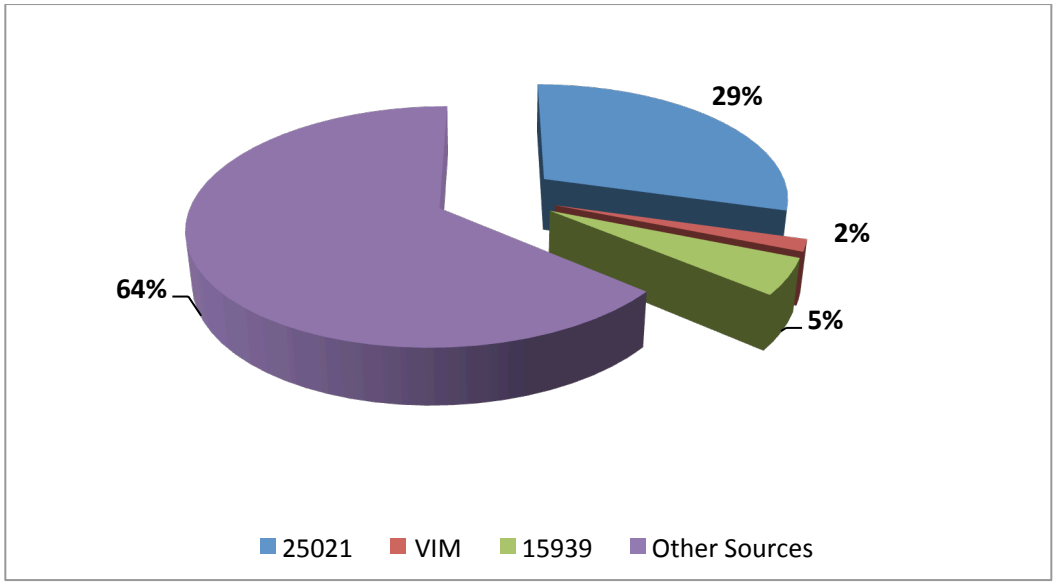

Figure 4-1 Definition rate among ISO/IEC 25021, 15939, VIM, and other sources.

As shown on Figure 4-1 (based on 0), 34% of the *Base Quantities* were found in the referenced standards (Chapter1) and 64% of the definitions were found in other sources of

ISO standards. In regards to “colour coding”, the definition was found on ISO 17724:2003, and it refers to the set of colors that are symbolically represented by a code([18]).

4.5 Qualifiers occurrences (3.6 and 3.7)

To understand the complexity of the interpretation of the “base quantities”, it is important to consider their combine use. Even if it is not the main objective of this research, combine use means the interpretation of a quality measure with more than one “base quantity” and “qualifier” as defined by Desharnais et Al. ([1]).In the ISO 9126 series, there is a total of 80 *Base Quantities* and 250 quality measures identified that include qualifiers that are not properly defined ([2]). In SQuaRE up to January 2014, there is a total of 63 base quantities and 204 quality measures. The qualifiers modifying the *Base Quantities* can be categorized as follows for the SQuaRE series:

1- Sentence qualifier (SQ): the “base quantity” could be defined properly (accurate, repeatable and reproducible). But because the qualifier is a long sentence difficult to understand, it is then difficult to interpret properly the “base quantity” with the sentence. For example: “number of data items having a value included in a specified interval” is more difficult to understand than just “Number of data items”;
2- One word qualifier (WQ): One word that qualifies the *Base Quantity*, for example: the “number of data items considered”. In this case “considered” is qualifying “data items”,
3- *Base quantity* with no qualifier: Just the Base Quantity. For example: “Total number of tasks”.

Based on the different definitions, the qualifiers were identified among the quality measures (see Annex IV). The distribution of the qualifiers per ISO/IEC standard is described on Table 4-6, showing the different types of qualifiers and the respective volume.

Table 4-6 Amount of qualifiers per ISO standard

Qualifier Type	ISO/IEC 25022	ISO/IEC 25023	ISO/IEC 25024	Total
SQ	27	170	143	340
WQ	18	22	11	51
No Qualifier	7	5	3	15
Total	**52**	**197**	**157**	**406**

ISO/IEC 25022, 25023, and 25024 have respectively 27, 170 and 143 base quantities with long sentences as qualifiers (SQ). Furthermore, only 15 base quantities out of 406 do not have qualifiers at all. The number of base quantities with one word qualifier (WQ) is 51. Also, ISO/IEC 25022 has proportionally a higher rate of base quantities with no qualifier.

CHAPTER 5

ANALYSIS OF THE RESULTS

5.1 Method, definition and reutilization

The analysis of the information obtained shows the following results about the methods and definitions:

- Starting from the comparative chart in Table 1-3, each different method has their own terminology.
- As shown in Table 1-4, each document has its own definition of accuracy, repeatability and reproducibility.

Some of the *Base quantities* are used more than one time in different quality measures, in the same ISO/IEC standard or between different standards. For example the *Base quantity* "Number of tasks" is mentioned in ISO/IEC 25022 and in ISO/IEC 25023 (12 and 11 times respectively). The analysis shows the following results about the use of base quantities:

- Reutilization of Base Quantities differs from one standard to another as shown on Table 5-1. The reutilization is three times more important with ISO/IEC 25024 than with ISO/IEC 25022.

Table 5-1 Distribution Rate of the base quantity per ISO/IEC standard.

ISO Standard	Base quantity	Occurrences	Distribution Rate
25022	15	52	3,5
25023	41	197	4,8
25024	15	157	10,5

Table 5-1 describes the total amount of base quantities per ISO/IEC standard, and the corresponding distribution rate. *Base Quantity* "Time" is the only one present in the three ISO/IEC standards, although not always clear for each one; sometimes it refers to duration or effort. It was found that "Data Item", "Task", "User", and "Access" are *base quantities* that comply with most of the requirements.

5.2 Accuracy, Repeatability, and Reproducibility rate

After acquiring all the information and applying the criteria described in chapter 1.6, the Table 4-2 was consolidated to determine if each *Base Quantity* meets the conditions of accuracy, repeatability and reproducibility.

Table 5-1 Amount of base quantities Accurate, Repeatable and Reproducible.

Requirement	1	0
Accuracy	28	35
Repeatability	49	14
Reproducibility	39	24

Considering that accuracy requires repeatability and reproducibility, 28 base quantities fulfill all the requirements according to Table 5-1.

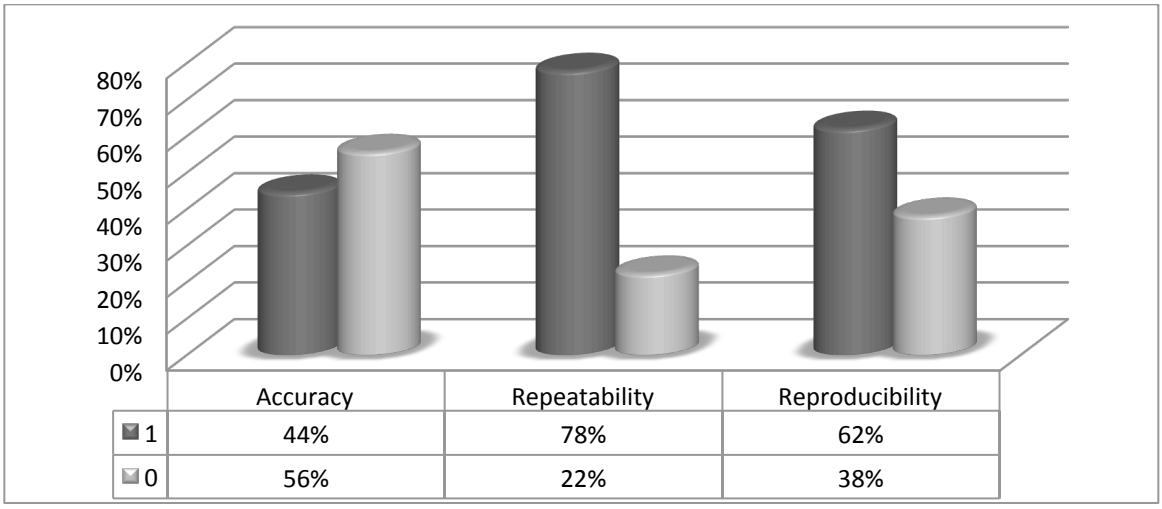

Figure 5-1 Comparative Percentage of accuracy, repeatability, and reproducibility.

After analyzing the results on Figure 5-1, it can be deduced that:

- The *base quantities* having the accuracy requirements have the lowest rate with 44%. There are more base quantities that do not meet the requirements of accuracy than those who meet the requirement of accuracy;
- The *base quantities* with the higher rate are the ones having the requirement of repeatability with 78%;
- Less than 50% of the *base quantities* fulfill all the requirements.

5.3 Analysis of the qualifiers

From the description made in Chapter 4.5 and the information gathered on Annex IV,

Table 5-2 shows the percentage by type of qualifier per ISO/IEC standard. The following analysis was developed:

Table 5-2 Percentage of qualifiers per ISO standard

Qualifier Type	ISO/IEC 25022	ISO/IEC 25023	ISO/IEC 25024	Total
SQ	52%	86%	91%	84%
WQ	35%	11%	7%	13%
No Qualifier	13%	3%	2%	4%

From Table 5-2, it can be identified that:

- The rate of *base quantities* with long sentences qualifiers (SQ) is 84%. Only 4% of the base quantities had no qualifier;
- ISO/IEC 25023 is the standard with more sentences (SQ), but in percentage ISO 25024 has relatively more sentence (SQ) than the two others ISO/IEC standards;
- ISO/IEC 25022 has the highest rate of base quantities with only one word qualifier (WQ) with 35%.

This is based on different qualifiers identified (see Annex IV) among 406 occurrences of qualifiers used by a base quantity (base quantity plus a qualifier). Table 4-6 shows the summary of the results, and Figure 5-2 shows the total rate per type of qualifier.

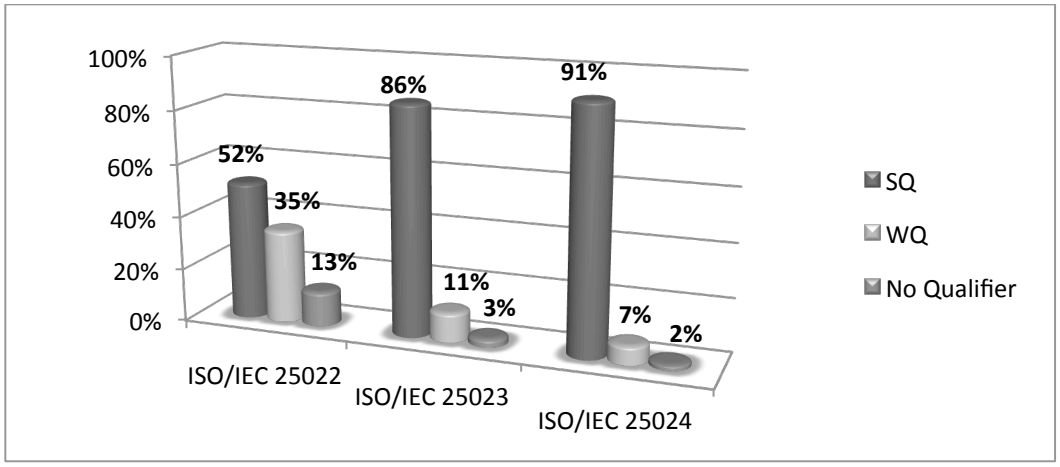

Figure 5-2 Qualifiers distribution rate

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

According to the article "Software Measurement Methods: An Analysis of Two Designs" [1] there is still a definition issue among ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024. The lack of adherence of the "base quantities" to metrology principles and characteristics are one of the major impediments of the overall applicability of ISO 9126 series.

After analyzing the "base quantities" as described in the January 2014 ISO/IEC 2502x series, it was found that:

- There is still a lack of detailed description of the measures the standards are attempting to quantify (Figure 4-1). It is not clear where are the *Base Quantities* defined. It should be a common document with the terms and definitions used among the ISO/IEC standards. There is not a unified document containing all the definitions among ISO/IEC 25022, 25023 and 25024. In fact, they are spread all among ISO 25021, ISO 15939, VIM and other standards.

- The current accuracy of the base quantities is below 50%, the repeatability and reproducibility under 78% and 62% respectively. This is a clear improvement when comparing with the ISO/IEC 9126 series (Figure 5-1). As an example, the *Base Quantity* "Number of Data values" is one of the most repeated on ISO/IEC 25024(Table 4-3), 25 occurrences in total and it is not defined by a measurement method in order to improve the accuracy and reproducibility. Additionally, the qualifiers modifying the Base Quantities are not properly defined, and homogenized. A qualifier could be a Base Quantity, a word, or a sentence that can change completely the context of the quality measure. Finally, it is difficult to understand the context of some *Base Quantities*; for

example “Number of Actions” meaning “actions” made by the end user or what type of “actions” it could represent in different contexts. The *Base Quantity* should be used in the same context to avoid misunderstanding.

- As for the “quality measures”, considering the high rate of base quantities with long sentence qualifiers (SQ), it can be deduced that it will be difficult to achieve the requirements of accuracy, repeatability and reproducibility with the proposed “quality measures” in those standards (Figure 5-2). The longer the qualifier is, the more difficult it is to understand; 84% of the qualifiers are long sentences modifying a *Base Quantity*.

The “base quantities” are not always clear, and also “qualifiers” added to each quality measure are not always clear. However, the effort to define the base quantities and quality measures can be observed. This is the actual **state of the art** of measurement in software engineering.

6.2 Future work

Further analysis and description on the qualifiers can be done in order to identify the source of each qualifier and guarantee their quality.. The qualifiers should be included in the list of definitions; this can facilitate the task and guarantee a common list with the definitions and context of use for the related standards. . It is not clear if the definition of the “qualifiers” should require the application of a measurement method; this still needs to be explored.

The task of defining the “base quantities” in the ISO 2502x series is not yet finished. In the next few months, there will be some improvement. A new study, based on the final documents, should be done.

ANEXE I

MASTER TABLE OF THE BASE QUANTITIES

List of the entire *Base Quantities* mentioned in ISO/IEC 25022, ISO/IEC 25023, and ISO/IEC 25024.

Including the following fields:

- Base Quantity
- Base Unit
- Accurate
- Repeatability
- Reproducibility
- Occurrences
- Reference
- Defined in
    - 25021
    - VIM
    - 15939
    - Others
- Justification

These fields are already defined in chapter 3.5.

Master Table Base Quantities.pdf

ANNEX II

COMPLETE LIST OF BASE QUANTITIES

This annex is the complete list of *Base Quantities* with the source and the ISO/IEC standard where it is mentioned. In this table, the following fields are included:

Base Quantity: Name of the *Base Quantity*
ISO Standard: ISO standard where it is mentioned
Reference: full description where it is mentioned

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List of Base Quantities.pdf

ANNEXE III

BASE QUANTITIES DEFINITION MATCH

In this annex, a matching table is shown. This table matches the definitions of the *Base Quantity* among ISO/IEC 25021, 15939, VIM and others.


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ANNEXE IV

LIST OF QUALIFIERS

In the table are listed the qualifiers identified among the ISO standards; this table includes the following fields:

Base Quantity : Name of the base quantity
ISO Standard : ISO Standard where the base quantity was identified
Reference: full link of the metric
Qualifier: the qualifier identified
Type of Qualifier: according to the description in Chapter 4.5 on the type of qualifier

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