# Analysis of Software Measures Using Metrology Concepts – ISO 19761 Case Study

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**Abstract.** To help identify the strengths of proposed software measurement methods, this paper proposes an analytical approach based on metrology concepts documented in the ISO International Vocabulary of Basic and General Terms in Metrology. This approach is illustrated with a case study using one specific functional size measurement method recognized as an ISO standard: COSMIC-FFP (ISO 19761). The case study documents the metrology concepts addressed in this ISO standard, either in the design of this measurement method or in some of its practical uses. It illustrates, for instance, that the design of COSMIC-FFP encompasses a large number of related metrology concepts. It is suggested that such a review using metrology criteria be used to analyze other software functional size measurement methods, as well as other software measures suggested to industry.

## 1 Introduction

Hundreds of software measures have been defined in the software engineering domain and proposed to industry. However, only the following have successfully undergone the rigor of international standardization: the quality measures in the ISO 9126 series [8], and three functional size measurement methods, among them ISO 19761 – COSMIC-FFP [10]. Software functional size measures are used in particular to compare the productivity of software projects (internally or across organizations), for project effort estimation and for the control of functional changes over a project life cycle. The use of such standardized measures is important to ensure comparability of measurement results between projects and between organizations; indeed, it would not be relevant to compare numbers based on distinct (and not standardized) measurement methods. Without the use of standards, ideally those officially recognized internationally, software agreements between customers and suppliers are prone to a variety of interpretations and, often, to conflicts.

A large number of software measures are defined based on the intuition of their authors. When subjected to the scrutiny of researchers, they are often investigated only from the perspective referred to as "measurement theory" (i.e. their mathematical properties) [5, 6, 11]. However, in other science and engineering disciplines, it is the domain of knowledge referred to as "metrology" that is the foundation for the development and use of measurement standards, measurement instruments, and measurement processes [3].

In this paper, we propose to use our initial modeling [2] of the sets of measurement concepts documented in the ISO International Vocabulary of Basic and General Terms in Metrology – VIM [7] to investigate whether or not the full set of metrology-related concepts has been taken into account in the design and application of software measures. To illustrate this approach, one specific type of software measure, that is, COSMIC-FFP (ISO 19761), a functional size measurement (FSM) method, has been selected as a case study. This choice was based on the following criteria: 1) when compared to other types of software measures, FSM methods are supported by much more detailed operational descriptions than those for most other software measures; 2) only software measures of this type have undergone the rigor and scrutiny of international standardization and have reached the status of official ISO standard (it should be noted that the ISO 9126 series, with its set of definitions of quality measures, is an ISO technical report rather than an international standard per se).

This paper will therefore use ISO 19761 [10] for illustrative purposes to explore whether or not such a software measure encompasses most – if not all – of the classic metrology concepts.

The paper is organized as follows: Section 2 presents an overview of the metrology concepts documented in the VIM and of a specific FSM method, ISO 19761 standard (COSMIC-FFP). In section 3, metrology-related concepts are identified in the design of COSMIC-FFP; in section 4, measurement process-related concepts are described; and in section 5, measurement instrument-related and measurement results-related concepts using an RUP/COSMIC-FFP-related software prototype tool are presented. Section 6 contains a summary of this analysis of COSMIC-FFP with respect to metrology, along with some concluding observations.

## 2 Overview of VIM and COSMIC-FFP

### 2.1 Metrology - VIM

Metrology is the science of measurement [7] and includes the set of methods designed to perform the measurements and to provide a sufficient level of confidence in the measurement results. To carry out a measurement, it is necessary to compare an unknown quantity with a quantity of the same kind which has become a reference through quantification by a measuring instrument. Metrology encompasses all aspects of measurement (theoretical and practical) according to a measurement method design and in all domains of science and technology.

Six categories of metrology concepts are described in ISO VIM [7]:

1. Quantities and units
2. Measurements
3. Measurement results
4. Measuring instruments

5. Characteristics of the measuring instruments
6. Measurement standards – Etalon

Our initial modeling of the interrelated terms of this vocabulary, organized by category as above, is presented in Appendix A, either in the form of process models where appropriate, or in structured tables when the interrelated terms are, for instance, enumerative. In particular, the expression "topology of concepts" has been used to highlight the existence of links between related concepts. In this paper, we use the models and tables in Appendix A extensively to analyze not only the design of the COSMIC-FFP measurement method, but also the application of this FSM method.

Two of the six metrology categories of concepts are related to some aspects of the design of measurement methods, that is: "quantities and units" and "measurement standards - etalon". The other four categories are related not to the design of a measurement method itself, but rather to the application of a measurement design with a measuring instrument and to the quality characteristics of the measurement results provided by this measuring instrument (including the inherent related degree of uncertainty of the measurement results).

### 2.2 Overview of COSMIC-FFP

Software size can be assessed either by measures of length (for example, lines of source code in a module, pages in a requirements specification document) or functionality (for example, function points). Functional size measures can be derived directly from the specifications and can be obtained fairly early in the development life cycle, which makes them useful both for planning purposes and during the whole project life cycle.

The first generation of FSMs was developed in the late 1970s, followed by a large number of variants. It is only in the early 2000s that a second generation of such measures has emerged and been rapidly adopted as an international standard [10]: ISO/IEC 19761: 2003 COSMIC-FFP: A functional size measurement method. This FSM method is based on the application of a set of models, rules, and procedures to a given piece of software, as it is defined from the perspective of its Functional User Requirements – FURs. By design, the measurement results provided by this method are independent of the technology. This ISO FSM standard is suitable for measuring various types of software (business application software, real-time software or Web-based and Internet applications, and so on), independent of technologies, development, and implementation decision approaches. By design, and in conformity with ISO 14143-1 [9], the standard is independent of the implementation decisions embedded in the operational artifacts of the software to be measured and excludes both the software quality and technical characteristics.

COSMIC-FFP takes into account that software FURs can be decomposed into a set of functional processes, and that each of these functional processes constitutes a unique set of data movements and/or data manipulations (**Fig. 1**). The COSMIC-FFP software model distinguishes four types of data movement: entry, exit, read, and write, as identified in the context model (**Fig. 2**). By convention, all data movements move data contained in exactly one data group. Entries move data from the user across the boundary to the inside of the functional process; exits move data from inside the functional process across the boundary to the user; reads and writes move data from and to persistent storage.

In COSMIC-FFP, each data movement is assigned a single unit of measure of 1, which is, by convention, equal to 1 Cfsu (Cosmic functional size unit). The total size of the software being measured corresponds, therefore, to the addition of all data movements recognized by the COSMIC-FFP FSM method. See [1, 10] for the detailed measurement rules.

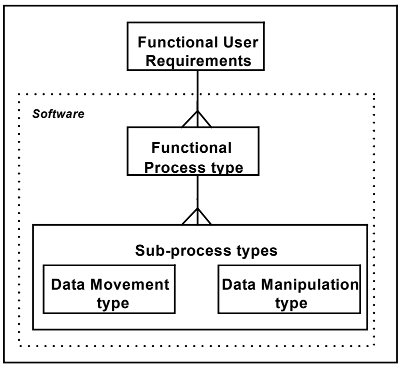


**Fig. 1.** A generic software model for measuring functional size [1]

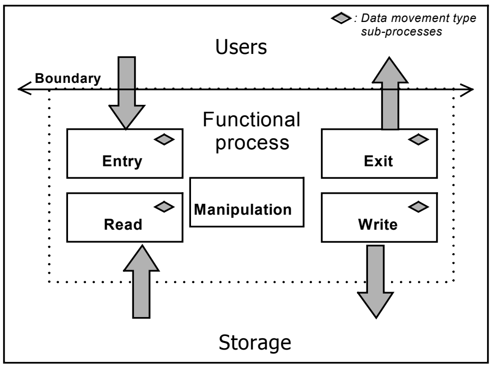


**Fig. 2.** COSMIC-FFP Movement types [1]

## 3 Analysis of COSMIC-FFP design

### 3.1 Quantities and units

The first analysis focuses on the design of COSMIC-FFP using the set of metrology concepts on "quantities and units", as described in Table A.1 of Appendix A. The results of this analysis are presented in Table 1. As can be observed from Table 1, the design of COSMIC-FFP allows quantification of a (measurable) quantity (that is, a movement of a single data group in a functional process) in well-defined units (that is, Cfsu). However, the COSMIC-FFP standard does not yet include any derived measure, and its system of quantities comprises a single base quantity, that is, the Cfsu itself.

The symbol for the base COSMIC-FFP quantity is the visual representation of "Cfsu", and this symbol is used to represent the unit of measurement, or 1 Cfsu. In the current state of the art for FSM, there is again only one unit of measurement, that is, there are no derived or off-system units.

It should be noted next from Table 1 that there are not yet either multiples or submultiples of a unit of measurement (like kilograms or centigrams). This lack of multiples and submultiples applies to the other ISO-recognized FSMs as well. Similarly, in COSMIC-FFP, there is only one level of granularity and formally recognized conventional reference scale, which is the level of a single data group movement, no matter how many attributes there are within this data group. The COSMIC Guide [1] recognizes, however, that some measurers might want to define their own – nonstandardized – finer levels of granularity (for example, at the level of data group attributes); however, there is not yet a consensus on this topic, and therefore there is not yet a basis on which to develop an international consensus for such a measurement convention.

In the last section of Table 1, the analysis of the set of concepts related to "value" (of a quantity) is more complex because, in our opinion, it includes concepts related both to the measurement method design and to its application in specific instances.

**Table 1.** Quantities and Units metrology concepts in COSMIC-FFP

| Metrology [7] | ISO 19761 [10] and COSMIC Implementation Guide [1] | Clause in ISO 19761 [10] |
|---|---|---|
| **System of quantities**<br><br>Base quantity<br>Derived quantity | (Currently, only one base quantity is included)<br>Cfsu<br>(none yet defined) | 2.5 COSMIC-FFP measurement phase |
| **Dimension of a quantity**<br>Quantity of dimension one / Dimensionless quantity | (not explicit)<br>(undetermined) | 2.7 Functional size measurement context |
| **Unit (of measurement)**<br>Symbol of a unit<br>System of units<br>Coherent (derived) unit<br>Coherent system of units<br>International system of units, SI<br>Base unit<br>Derived unit<br>Off-system unit<br>Multiple of a unit<br>Submultiple of a unit | = 1 Cfsu<br>= Cfsu<br>Not applicable<br>Not applicable<br>Not applicable<br>Not applicable<br><br>= 1 Cfsu<br>None<br>None<br>None yet defined<br>None yet defined | 2.5 COSMIC-FFP measurement phase |
| **Value (of a quantity)**<br>True value<br>Conventional true value<br><br>Numerical value<br><br>Conventional reference scale/ Reference-value scale | Value of functional size<br>Not yet explored<br>= In practice, obtained by expert judgment<br>= Result of a measurement: functional size<br>= Scale = a data group movement (independently of data movement type, and number of data attributes moved). Each data group movement is assigned a value of 1 Cfsu | 2.2 COSMIC-FFP measurement process model |

Finally, a “conventional reference scale/reference-value scale” represents particular quantities of a given kind, an ordered set of values, continuous or discrete, and is defined by convention as a reference for arranging quantities of that kind in order of magnitude. In COSMIC-FFP, this concept corresponds to the scale of a movement of a data group (entry, exit, read, and write, abbreviated by convention as “E” for entry, “X” for exit, “R” for read, and “W” for write). Each movement of a data group has a size of 1 Cfsu in COSMIC-FFP. There is, of course, a standard definition of what is recognized as a “data group” by COSMIC-FFP. In addition, it represents a discrete set of values composed of E = X = R = W = 1.

In COSMIC-FFP, the “numerical value” of the software to be measured corresponds to the addition (in the same software layer) of the individual values assigned to each identified movement of a data group. This addition provides the “numerical value” of the software to be measured. In short, “numerical value” and “conventional reference scale” are explicitly defined in the COSMIC-FFP standard [10].

### 3.2 Measurement standards – Etalon

In measurement for the sciences and for engineering, it is taken for granted that there should exist “measurement standards - etalons” for calibrating and verifying the measuring instruments and to ensure the consistency of measurement results across individuals, organizations, and nations. However, this metrology concept has not yet been discussed in the software measurement literature, nor has it been the focus of attention of practitioners. In software measurement, what could be close to this concept, and its related sub-concepts in Table A.4, are the case studies documented for a few of these software FSM methods.

## 4. Analysis of Measurement with COSMIC-FFP

In the VIM, the term “measurement” refers to the category of terms for the “set of operations” required to obtain a measurement result (see also Fig. A.1), and this is instantiated through the generic measurement process described in Fig. A.2.

This figure illustrates, with the use of a graphical representation of a process, different concepts related to the concept of “measurement”. It should be noted that, in metrology, the “quantity to be measured” by means of a set of operations (and a measuring instrument) is also called a “measurand”, that is, the input quantity that is applied to a measuring instrument (Fig. A.2).

As described in Fig. A.2, a measurement procedure requires, as input, a measurand, which corresponds in COSMIC-FFP to the FURs, and produces a measurement result which represents a numerical value of functional size. An instantiation of a measurement procedure for a specific measurement includes an operator to carry out the measurement process (here, the measurer), the measurement method itself (here, the standard method), and the influence quantities (here, conditions that could influence/ bias measurement results). The operator corresponds to the user of the method (the measurer). The COSMIC-FFP measurement method is explicit, and the influence quantities include, for example, user skills, capability of the given documentation to perform measurement, allocated time, etc.

In COSMIC-FFP, the quantity to be measured (the "measurand"), as determined by the software users through the functional requirements (FURs), will be transformed through the prescribed set of logical operations to provide a numerical value (a number representing software functional size). This number is associated with a size unit (Cfsu) to represent the measurement result (numeric value).

In the ISO standard for COSMIC-FFP [10], the standardized definitions of the concepts relevant to this method are specified in Clause 3, while the logical sequence of operations described as "measurement activities" are specified in Clause 6. In our opinion, these definitions and measurement activities should meet the metrology concepts for "principle of measurement" and "method of measurement" defined in the VIM [7]. However, these two VIM concepts, which correspond to the foundations of a measurement from a metrology perspective (Fig. A.1), are not described in finer levels of detail in the VIM with a view to verifying whether or not there is a full correspondence, in the COSMIC-FFP standard, of their underlying subconcepts.

It should also be noted that, in the software measurement literature, the concepts of "measurement signal" and "transformed value" are not discussed explicitly. Even though these two sets of terms are not discussed in the ISO standard [10], they are explicitly presented and discussed in the COSMIC guide for the implementation of the ISO 19761 standard [1]: they correspond to the set of concepts included in what is categorized as the "mapping phase" between the documentation of the FURs and their mapping to COSMIC-FFP. In an explicit way, this COSMIC guide [1] prescribes that the transformed value be obtained by the following sequence of operations:

*"The measurer should identify the boundaries of the software to be measured, identify all functional processes, triggering events and data groups, map them in the software context model using the COSMIC rules, identify the layers, identify the data movements in each function process and sub-process, and determine the COSMIC size measurement by adding the results."* [1].

A summary of these correspondences of measurement metrology concepts in COSMIC-FFP is presented in Table 2.

**Table 2.** Measurement metrology concepts in COSMIC-FFP

| Metrology [7] | COSMIC Implementation Guide of ISO 19761 [1] |
|---|---|
| Measurand | An FUR in an artifact of the software to be measured |
| Measurement signal | Mapping phase: measurement context and COSMIC-FFP software models |
| Measurement procedure | Measurement phase: rules and methods to be applied to the output of the Mapping phase as represented in the COSMIC-FFP generic software model |
| Measurement result | Functional size of the generic software model of the FUR: numerical value |
| Operator | The measurer |
| Method of measurement | See ISO 19761: COSMIC-FFP [10] |
| Influence quantity | For example: measurer expertise, quality of FUR documentation, time allocated for measuring, etc. |

## 5 Analysis of COSMIC-FFP Measuring Instruments and Measurement Results

To explore the metrology concepts relevant to the measuring instruments and measurement results, we use as a case study the prototype of COSMIC-FFP developed in the RUP-Rational Rose environment, as described in [4].

### 5.1 Measurement standards – Etalon

In scientific and engineering (and also commercial) environments, measurement is normally carried out using measuring instruments which are calibrated from reference standards/etalons. As illustrated in Fig. A.3, for example, the "measuring chain" represents the series of elements of a measuring instrument or system. In [4], the equivalent of a measuring chain is described as including the path of the measurement signal from the input as an FUR description of the Use Cases, the measurement prototype itself, and the output as the measurement results. More details of the mapping of this case study are presented in Table 3.

The notion of the measurement scale is also within the set of concepts related to the measuring instruments, and includes a dozen subconcepts, as illustrated in Fig. A.7. However, the application of these metrology concepts essentially depends on the presence of multiples and submultiples of a unit of measurement. Again, in the current state of the art of software FSM, these subconcepts are not present and therefore cannot be discussed here.

**Table 3.** Measuring Instrument metrology concepts and COSMIC-RUP prototype [4]

| **Metrology [7]** | **COSMIC – RUP Prototype [4]** |
|---|---|
| Measuring chain | FUR + COSMIC-RUP prototype + functional size results in [4] |
| Measuring system: | Complete set of elements of the software prototype + manual procedures |
| Detector | Prototype function which extracts the elements to be measured |
| Measuring transducer | The mapping solution between COSMIC and UML-RUP concepts in [4] |
| Measuring instrument | In the COSMIC-RUP prototype, the set of functionalities to implement the COSMIC-FFP measurement rules |
| Material measure | Measurement results, displayed on output screens and saved in memory |
| Integrating instrument | Not in the prototype (since it does not handle any 'other quantity') |
| Measurand | Set of FURs |
| Another quantity | Not in the prototype |
| **Details of a measuring instrument:** | |
| Displaying/ Indicating device (+index) | Display screens of measurement results |
| Recording instrument/ | Prototype function, which allows recording in the database |

| | |
|---|---|
| Recording device | |
| *Note: not all details appear in this table* | |

## 5.2 Measurement results

In all measurement instantiations, a measurement result is usually associated with a measurement uncertainty, because, in practice, no perfect measurement process exists. Measurement uncertainty is defined in metrology as a parameter characterizing the dispersion of the values that could reasonably be attributed to the measurand, that is, the interval centered on the measured value and in which it is very probable that the true value and the conventional true value will be found. In the current state of software FSM knowledge, the true value is generally obtained by consensus among measurement experts. The difference between the results obtained by a measurer (or by a measuring instrument) and by an expert represents the error.

In [4], the measurement results of a case study are presented; however, it is a small-scale case study only for the purpose of demonstrating the technical feasibility of the automation concept of the COSMIC-FFP standard in the RUP/Rational Rose environment. To obtain statistically significant results with information about the concepts included in the detailed topology of measurement results, much larger case studies will be required. Details of the mapping of this case study are presented in Table 4.

**Table 4.** **"**Measurement Results" metrology concepts and COSMIC-RUP prototype [4]

| **Metrology [7]** | **COSMIC – RUP Prototype [4]** |
|---|---|
| ***Measurement result types*** | |
| Indication | Detailed results, summarized, according to the proposed templates in [1] |
| Uncorrected result | Measurement results, prior to human intervention to add missing information |
| Corrected result | Revised measurement results, after addition of missing information |
| ***Mode of verification of results*** | |
| Accuracy of measurement | In [4], this characteristic is only tested with a small-scale case study. There are not enough cases to obtain significant statistically quantitative knowledge of this characteristic |
| Repeatability | A software tool normally provides the same results in repeatable conditions (needs to be verified by further experimentation) |
| Reproducibility | Same as above |
| Uncertainty of measurement and 8 other related concepts | Characteristic not yet explored |

## 5.3 Characteristics of measuring instruments

We have modeled the "characteristics of measuring instruments" from both the quantitative and qualitative viewpoints described in Table A.3.

### 5.3.1 Quantitative viewpoint

In the COSMIC-RUP prototype [4], several quantitative metrology concepts can be observed: for example, in the description of its operational conditions (that is, the FUR must be modeled according to an RUP process based on UML formalisms) and of its boundary conditions (that is, the prototype currently deals with only one software layer at a time). Further mappings are presented in Table 5.

**Table 5.** Quantitative viewpoint of "Characteristics of Measuring Instruments"

| Metrology [7] | COSMIC –RUP Prototype [4] |
|---|---|
| Rated operating conditions | It is necessary to model FURs according to an RUP process based on UML formalisms |
| Limiting conditions | The prototype deals currently with only one software layer at a time |
| Reference conditions | Example: a functional process must have more than 2 data movements |
| Instrument constant | The tool should preserve its metrological characteristics over time (even, for example, when there is a change of version in each of its software components) |
| Response characteristic | New levels of units of measurement have been defined in the tool (Ufsu and Sfsu), but the response characteristics have not yet been analyzed |
| Sensitivity | A particular case has been identified; for example, to indicate whether or not it is possible to categorize correctly the read or write movements. It is recognized that this categorization problem does not have any impact on the final size itself since the numerical value for each data group movement = 1 independently of its category (for example, sensitivity = none) |
| Discrimination (threshold) | 1 Cfsu, the minimum size of a change to an FUR |
| Resolution (of display device) | Not yet investigated |
| Dead band | Not yet investigated |

### 5.3.2 Qualitative viewpoint

In the COSMIC-RUP prototype [4], the results of the analysis between the qualitative viewpoint of "characteristics of measuring instruments" from Table A.3 are presented in Table 6. It must be noted here that the mappings with the concepts of the functionality test (use errors and control errors), and even the measuring range or working range concepts (nominal range, span, and nominal value) have not been explored, since the appropriate experimental conditions were not available. (See Table A.3 for the list of related metrology concepts).

**Table 6.** Qualitative viewpoint of Characteristics of Measuring Instruments

| Metrology [7] | COSMIC-FFP: automated tool with RUP [4] |
|---|---|
| Stability | Not yet investigated |
| Transparency | COSMIC-FFP/ RUP prototype is a transparent instrument for the measurement of a functional process |
| Drift | Not yet investigated |
| Response time | There is a time interval between the instant of the stimulus and the instant of the response |
| Accuracy of a measuring instrument | This was analyzed with only one case study, which was a small-scale one. More case studies should be constructed and the results analyzed to determine the accuracy of the results measured by the prototype, and under which set of conditions |
| Accuracy class (class of measuring instruments) | Not yet investigated |
| Freedom from bias | Not yet investigated |
| Repeatability | The prototype provides the same value for the same conditions of measurement |

# 6 Summary and conclusions

In software engineering, the analysis of software measures is usually discussed from the perspective of measurement theory. We have proposed an approach here for the analysis of some aspects of the strengths of software measures based on our modeling of the set of metrology concepts documented in the ISO International vocabulary of basic and general metrology terms (VIM). This was illustrated using one specific FSM method recognized as an ISO standard: COSMIC-FFP (ISO 19761).

The paper has documented the metrology concepts addressed in this ISO standard, either in the design of this measurement method or in some of its practical uses. In summary, it was observed that:

- On the one hand, the design of the COSMIC-FFP method covers a majority of the metrology concepts described in the VIM dealing with the design of measurement methods;
- On the other hand, much larger-scale case studies will be required for the study of the characteristics of measurement instruments as identified in the VIM.

Measurement is recognized as a fundamental concept in engineering and provides the information required to make key project decisions and take appropriate action. A very large number of software measures has been proposed to industry to describe the various characteristics of software in a quantitative manner, and much work remains to be done in the study of both the design of software measurement methods and the characteristics of measuring instruments for software measurement instrumentation in industry.

Indeed, most of the metrology concepts related to measuring instruments still have to be adequately explored by software engineers. It is suggested that the full set of metrology concepts documented in the VIM be used as criteria to analyze the strengths of other software FSM methods, as well as of other software measures suggested to industry.

## References


1. A. Abran, J. M. Desharnais, S. Oligny, D. St-Pierre, and C. Symons, "COSMIC FFP Measurement Manual - Version 2.2, The COSMIC Implementation Guide for ISO/IEC 19761: 2003," École de technologie supérieure – ETS, Montreal (Canada) 2003. Available free at: www.lrgl.uqam.ca/cosmic-ffp
2. A. Abran and A. Sellami, "Initial Modeling of the Measurement Concepts in the ISO Vocabulary of Terms in Metrology", 12th International Workshop on Software Measurement – IWSM, Magdeburg (Germany) Oct. 7-9 2002, in Software Measurement and Estimation, Shaker-Verlag, Aachen, 2002.
3. A. Abran, A. Sellami, and W. Suryn, "Metrology, measurement and metrics in software engineering," Ninth International Software Metrics Symposium – METRICS 2003, Sept. 3-5 2003, Sydney, Australia, IEEE Computer Society Press, Los Alamitos, 2003.
4. S. Azzouz and A. Abran, "A proposed measurement role in the Rational Unified Process (RUP) and its implementation with ISO 19761: COSMIC FFP," Software Measurement European Forum SMEF 2004, Rome, Italy, Jan. 28-30, 2004.
5. N. E. Fenton and S. L. Pfleeger, Software Metrics: A Rigorous and Practical Approach: 2nd ed., PWS Publishing Co., 1997.
6. M. Hitz and B. Montazeri, "Chidamber and Kemerer's Metrics Suite: A Measurement Theory Perspective," IEEE Transactions on Software Engineering, vol. 22, pp. 267 -271, 1996.
7. ISO, International Vocabulary of Basic and General Terms in Metrology. International Organization for Standardization – ISO, Geneva, 1993.
8. ISO, ISO/IEC 9126-1 to 3: 2001, Information Technology – Software Quality Characteristics and Metrics; Part 1: Quality model; Part 2: External metrics; Part 3: Internal metrics, International Organization for Standardization – ISO, Geneva 2001 to 2003.
9. ISO ISO/IEC 14143-1: 1998, Information technology -- Software measurement -- Functional size measurement -- Part 1: Definition of concepts, International Organization for Standardization – ISO, Geneva, 1998.
10. ISO ISO/IEC 19761: 2003, Software Engineering – COSMIC-FFP – A Functional Size Measurement Method, International Organization for Standardization – ISO, Geneva, 2003.
11. Zuse H., A Framework for Software Measurement, Walter de Gruyter, Germany, Berlin, 1997.

## Appendix A

The 6 categories of metrology concepts described in the ISO vocabulary of metrology [5] are:

1. Quantities and units: Table A.1
2. Measurements: Fig. A.1 and Fig. A.2
3. Measurement results: Table A.2
4. Measuring instruments: Fig. A.3, A.4, A.5, A.6 and A.7
5. Characteristics of the measuring instruments: Table A.3
6. Measurement standards – Etalon: Table A.4

A subset of the Tables and Figures from [8] are presented next.

**Table A.1.** Detailed topology of the Quantities and Units set of concepts

| **(Measurable) Quantity** | | | |
|---|---|---|---|
| **Systems of quantities** | **Dimension of a quantity** | **Unit (of measurement)** | **Value (of a quantity)** |
| Base quantity<br>Derived quantity | Quantity of dimension one/ Dimensionless quantity | Symbol of a unit<br>System of units<br>Coherent (derived) unit<br>Coherent system of units<br>International system of units<br>Base unit<br>Derived unit<br>Off-system unit<br>Multiple of a unit<br>Submultiple of a unit | True value<br>Conventional true value<br>Numerical value<br>Conventional reference scale/Reference-value scale |

**Table A.2.** Detailed topology of Measurement Results vocabulary

| **Result of a Measurement** | | |
|---|---|---|
| ***Types of measurement results*** | ***Modes of verification of measurement results*** | **Uncertainty of measurement** |
| Indication Uncorrected result<br>Corrected result | Accuracy of measurement<br>Repeatability<br>Reproducibility | Experimental standard deviation<br>Error (of measurement)<br>Deviation<br>Relative error<br>Random error<br>Systematic error<br>Correction<br>Correction factor |

**Table A.3.** Detailed topology of the Characteristics of Measuring Instruments

| ***Quantitative*** | ***Qualitative*** | ***Functionality test*** | | **Measuring Range** |
|---|---|---|---|---|
| | | ***Use*** | ***Control*** | |
| Rated operating conditions<br>Limiting conditions<br>Reference conditions<br>Instrument constant<br>Response characteristic<br>Sensitivity<br>Discrimination<br>Resolution<br>Dead band | Stability<br>Transparency<br>Drift<br>Response time<br>Accuracy of a measuring instrument<br>Accuracy class<br>Freedom from bias<br>Repeatability | Error (of indication)<br>Maximum permissible errors/ Limits of permissible error<br>Bias<br>Fiducial error | Datum error<br>Zero error<br>Intrinsic error | Nominal Range<br>Span<br>Nominal Value |

**Table A.4.** Detailed topology of Measurement Standards / Etalons

| **(Measurement) Standard Etalon** | **Conservation of a (Measurement) Standard** |
|---|---|
| International (Measurement) Standard<br>National (Measurement) Standard<br>Primary Standard<br>Secondary Standard<br>Reference Standard<br>Working Standard<br>Transfer Standard<br>Traveling Standard | Traceability<br>Calibration<br>Reference Material (RM)<br>Certified Reference Material (CRM) |

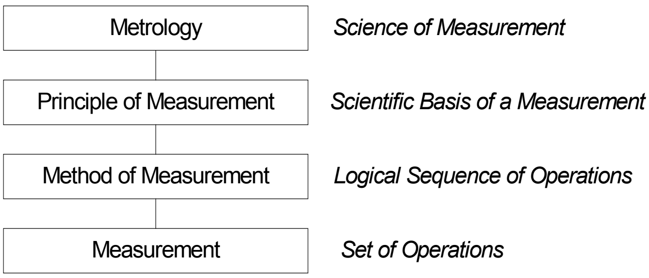


**Fig. A.1.** Measurement Foundations – High-level topology

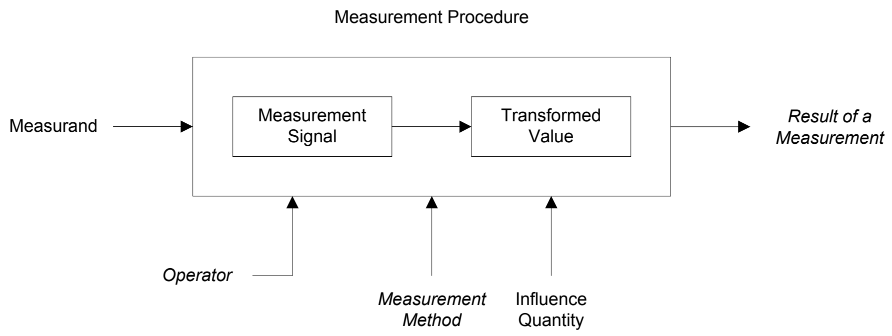


**Fig. A.2.** Measurement Process – Detailed topology of sub-concepts

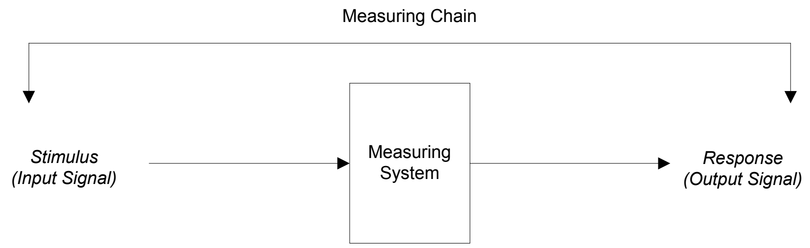


**Fig. A.3.** High-level topology of Measuring Instruments

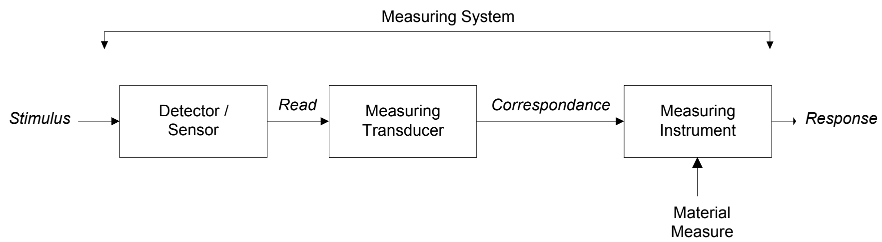


**Fig. A.4.** Detailed topology of a Measuring System

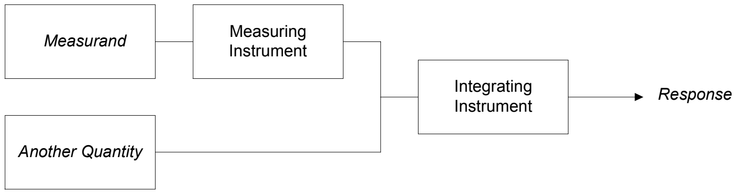


**Fig. A.5.** Integrating Instrument

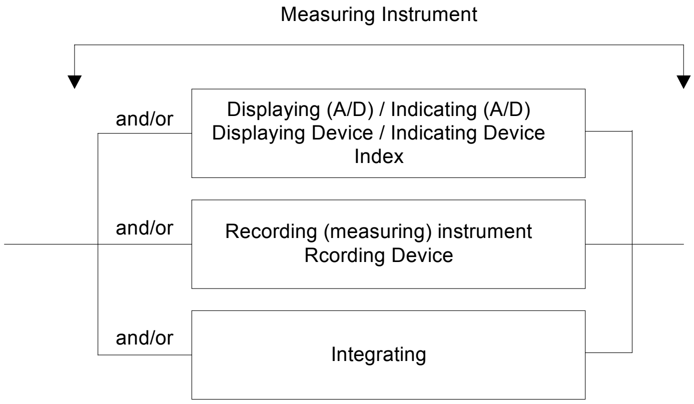


**Fig. A.6.** Details of a Measuring Instrument

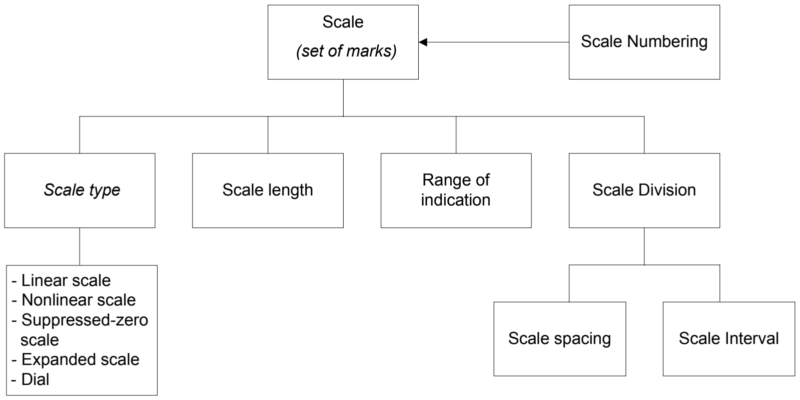


**Fig. A.7.** Set of concepts related to scale