Initial Modeling of the Measurement Concepts in the ISO Vocabulary of Terms in Metrology

Alain Abran, Asma Sellami

Accepted for publication at IWSM 2002, Magdeburg, Germany

Abstract

The field of software metrics is usually discussed from the perspective referred to as 'measurement theory'. However, in other disciplines, the domain of knowledge referred to as 'metrology' is the foundation for the development and use of measurement instruments and measurement processes. This paper presents an initial modelling of the sets of measurement concepts documented in the ISO International Vocabulary of Basic and General Terms in Metrology. In particular, this modelling illustrates the various levels of abstraction of the concepts as well as the relationships across related concepts and sub-concepts. We refer to this representation type as the topology of the concepts within the ISO Vocabulary. These models will provide the basis for analysing the current status of the field of 'software metrics' and to suggest improvements along the classical path of the field of metrology.

1. Introduction

Over recent decades, hundreds of 'software metrics' have been proposed by researchers and practitioners for measuring software products and software processes [1,2,3,4,5,6,8,9]. Most of these metrics have been designed based on the intuition of the researchers or on an empirical basis, or both, and they have most often been characterised by the ease with which some entities of the development process can be counted. In their analysis of some of these metrics, researchers have most often used the concepts of 'measurement theory' as the foundation for their analytical investigation. However, while totally relevant 'measurement theory' deals with only a subset of the classical set of concepts of measurement; 'software metrics' researchers, by focussing solely on 'measurement theory', have investigated mainly the representation conditions, the mathematical properties of the manipulation of numbers, and the proper conditions for such manipulations [8,9]. Our survey of the literature on software metrics has not, however, come up with references to the classical concepts of metrology in these investigations into the quality of the metrics proposed to the software engineering community.

In the scientific fields, including engineering, as well as in other fields such as business administration and a significant number of the social sciences, measurement is one of the number of analytical tools. Measurement in these other sciences is based on a large body of knowledge; such a body of knowledge, built up over centuries and millennia, is commonly referred to as the field of 'metrology'. This domain is supported by government metrology agencies which are to be found in most industrially advanced countries. For this research, we have selected a single document as our basis for analysis of the key measurement concepts related to metrology, that is, the ISO document that represents the official national and international consensus on the vocabulary of basic and general terms on metrology [7].

While this key ISO document is widely known in the field of metrology, it is almost unknown in the 'software metrics' community; consequently, most of its concepts are not being used, either by the 'metrics' designers proposing their metrics as measurement instruments to the software engineering community, or by the users of these 'metrics'.

The objective of this paper is therefore to introduce this set of metrology concepts to the software engineering community, the goal being, that once these metrology concepts become better known in this community, they will be used for the design of new software measurement instruments, for the evaluation of current 'metrics' proposals, as well as and for the design of improvements to current software 'metrics'.

This ISO Vocabulary follows some of the concepts of traditional presentation of vocabularies, with terms described individually in textual information, and with a single level of classification of the terms defined. This mode of representation is challenging in terms of assembling the full set of inter-related terms. To improve the presentation and the understanding of this complex set of inter-related concepts, which, up to now, has been referred to as 'metrology', this paper proposes to use the software engineering technique of 'modelling'.

Section 2 presents first a high-level model of the set of concepts in this ISO Vocabulary. Then, in subsequent sections, the lower-level models of each related sub-set of metrology concepts are presented. The last section suggests how such metrology concepts can be used for both the design of new measurement instruments and for verifying and validating the current set of proposed 'metrics'.

2. High level model of the ISO vocabulary on metrology

The ISO document (International Vocabulary of Basic and General Terms of Metrology) represents the international consensus on a common and coherent terminology for the set of concepts of metrology. This ISO document does not follow strictly the usual structure of dictionaries or glossaries whereby all the terms are presented, and documented, on the basis of their alphabetical ordering: the metrology terms are first subdivided into a set of six categories organised as distinct chapters (see Table 1). Within each chapter, the 120 terms are presented next in an *"approximate order of increasing complexity"* [line 7, page 29], and their definitions, in a textual format. This makes an overall understanding difficult, since it does not provide direct maps of the relationships across the terms, and impairs the understanding of the full set of relationships over the 120 distinct but related measurement concepts. Basically, it is expected that readers of this ISO document study the textual descriptions very carefully and reconstruct the logic that links all these terms which deal with various aspects of measurement, that is, that they reconstruct the topology of the related concepts, and sub-concepts, at different levels of abstractions.

Table 1: Categories of terms in metrology (ISO 1993)

Categories	Number of terms = 120
1. Quantities and units	22
2. Measurements	9
3. Measurement results	16
4. Measuring instruments	31
5. Characteristics of the measuring instruments	28
6. Measurement standards – Etalons	14

In summary, this ISO document does not provide its readers with any model which would facilitate the positioning of concepts relative to other concepts by specifying the logical links and the interrelationships of the terms. In this paper, we have elected to build models of these relationships across the terms, based on an analysis of their textual definitions and relationships as defined by their semantics. The high-level model of the set of categories in Table 1 is presented in Figure 1. This model, and the sub-models presented later on, corresponds to our current understanding of the topology integrated into the vocabulary of this specialised area of the body of knowledge related to metrology.

To represent the relationships across the elements of the categories in Table 1, the classical representation of a production process was selected: e.g. input, output and control variables, as well as the process itself inside the box. In Figure 1, the output is represented by the 'measurement results' and the process itself by the ‘measurement’ in the sense of measurement operations, while the control variables are the 'Etalons' and the 'quantities and units'. This set of concepts represent then the 'measuring instrument', and the measurement operations are themselves influenced as well by the 'characteristics of the measuring instruments'.

It is to be noted that in the Vocabulary, the term 'measurements' when used as a single term corresponds to the 'set of operations' for measuring; this translates in French into 'mesurage'. To be noted also is that, in all figures and tables in this paper, a term taken directly from the ISO

Vocabulary will be appear in regular character letters, while terms representing concepts not specifically listed will appear in *italics*; for instance, in Figure 1, we have added the term 'Input', which is not included in any of the six categories of the ISO Vocabulary. Sometimes in the ISO Vocabulary, a term has an additional qualifier added in parentheses to facilitate understanding and prevent misreading of the specific interpretation given to this term in the ISO document; for instance, (measurable) quantity, in Table 2. Finally, the ISO vocabulary sometimes proposes two expressions for the same set of concepts; the two expressions are then included in the vocabulary and are joined by a forward slash (/); this means that the two terms can be used interchangeably, e.g. 'Quantity of dimension one / Dimensionless quantity' in Table 2. When two terms appear in a Figure and they are not joined by a /, then they represent two distinct terms in the ISO Vocabulary; for instance 'measurand' and 'measurement signal' in figure 4 are two distinct terms.

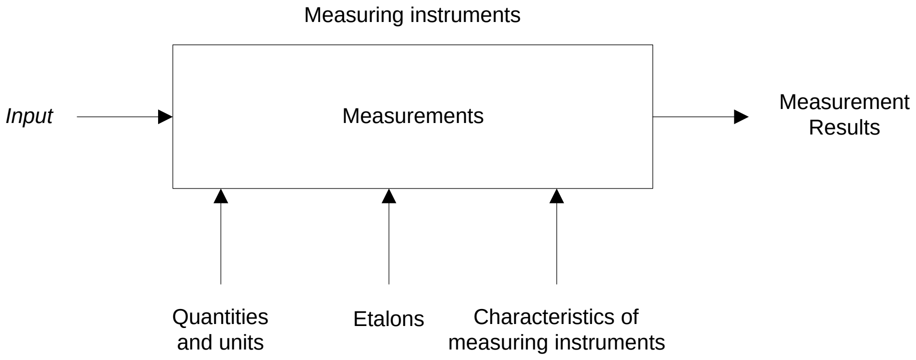

Figure 1: Process model of the categories of metrology terms in ISO 1993

3. Quantities and units

Figure 2 presents the modelling of the first category of measurement concepts specified in the Vocabulary document, that is, 'quantities and units'. We have modeled this category on the basis of four sub-concepts of quantity we identified within the set of terms in this category: systems of quantities, dimension of a quantity, unit (of measurement) and the value of a quantity. The detailed topology of this model is then presented in Table 2 positioning all the 22 terms defined in this category are listed.

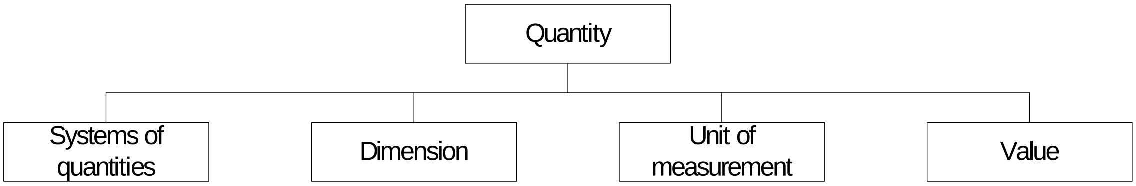

Figure 2: High level topology of 'Quantities and Unit'

Table 2: 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 Derived quantity	Quantity of dimension one / Dimensionless quantity	Symbol of a unit System of units Coherent (derived) unit Coherent system of units International system of units/ SI Base unit Derived unit Off-system unit Multiple of a unit Submultiple of a unit	True value Conventional true value Numerical value Conventional reference scale / Reference-value scale

4. Measurement

The second set of sub-concepts is in the 'measurements' category, defined as the measurement process itself. Figure 3 presents the modeling of this category. In this sub-model the hierarchy of the levels is defined from the most general towards the specific. For instance, the metrology terms that include all the aspects of measurement (theoretical and practical) and that are referred to collectively as the science of measurement in the metrology literature, contain the 'principle of measurement', which represents its scientific basis for measurement. From the principle of measurement, the 'method of measurement' in the general sense is then instantiated by a measurement as a set of operations .

The detailed topology of the measurement process is instantiated in a 'measurement procedure', and is presented in Figure 4, again as a process model having several inputs, many control variables and an output representing the 'results of measurement'. To represent it as a process model, we have added the term '*operator*' which appears in a note to the term 'measurement procedure'.

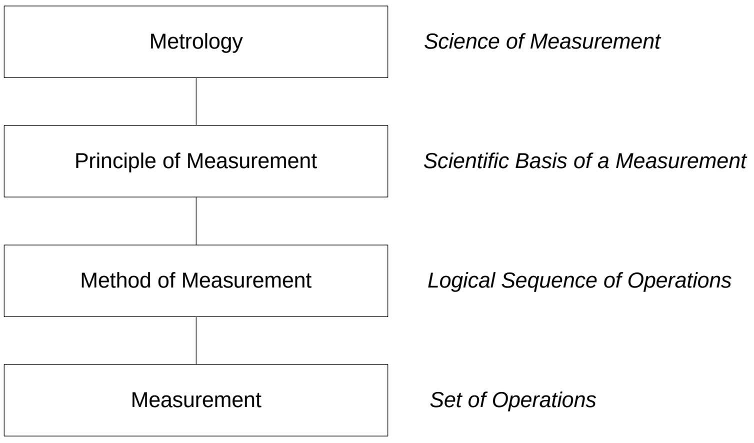

Figure 3: Measurement foundations - high-level topology

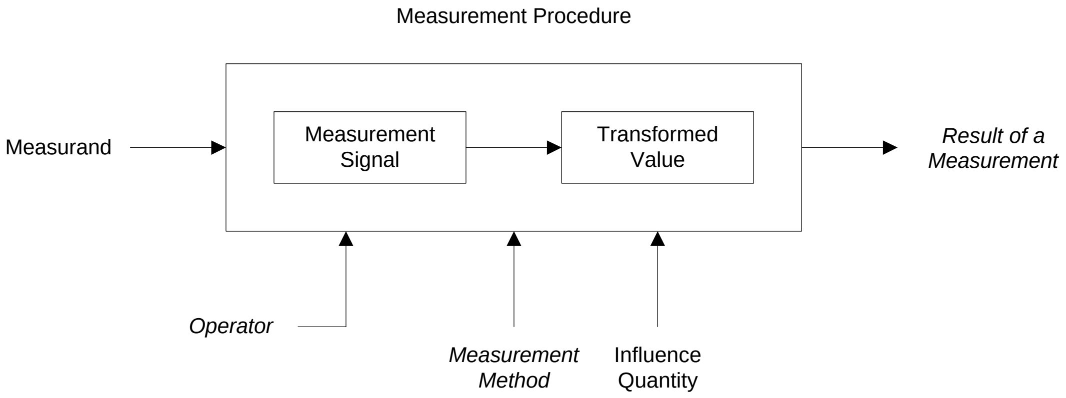

Figure 4: Measurement process - detailed topology of sub-concepts

To carry out a measurement exercise, an operator should design and follow a 'measurement procedure' which consists of a set of operations, described specifically, for the performance of particular measurement according to a given measurement method. The instantiation of a measurement procedure handles a 'measurement signal', and produces a transformed value to which represents a given measurand. The result of the measurement can have been influenced by an 'influence quantity' during the measurement process: for example, the temperature of a micrometer during the measurement of the length of a particular object.

5. Measurement Results

The third category, 'measurement results', is presented next in the form of a structured table according to the types of measurement results, the modes of verification of the measurement results and information about the uncertainty of measurement – Table 3. Again, this structure is our own.

Table 3: Detailed topology of 'Measurement Results' Vocabulary

Result of a Measurement		
Types of measurement results	***Modes of verification of measurement results***	**Uncertainty of measurement**
Indication (of a measuring instrument) Uncorrected result Corrected result	Accuracy of measurement Repeatability (of results of measurements) Reproducibility (of results of measurements)	Experimental standard deviation Error (of measurement) Deviation Relative error Random error Systematic error Correction Correction factor

6. Measuring Instruments

Figure 5 presents the first set of concepts within the ISO Vocabulary category that refer to 'measuring instruments'. The high-level topology of a 'measuring chain' (Figure 5) is then further detailed in Figures 6 and 7. All measuring system elements from input to output constitute a 'measuring chain', Figure 5. The set of instruments and other equipments assembled for measurement constitute the 'measuring system', which is detailed in Figure 6.

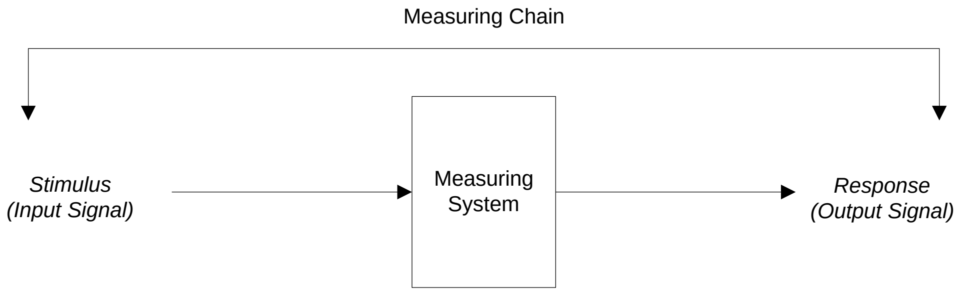

Figure 5: Measuring Chain

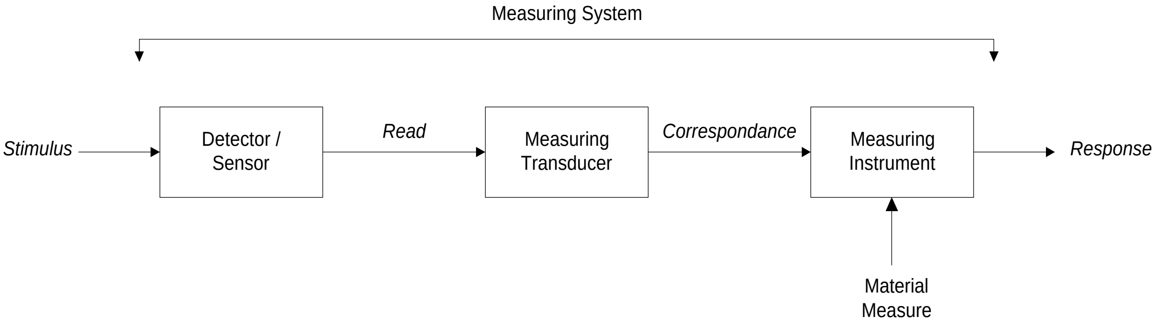

Figure 6: Measuring System

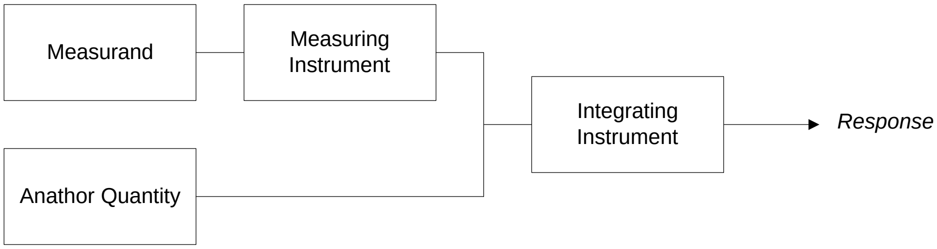

Figure 7: Integrating Instrument

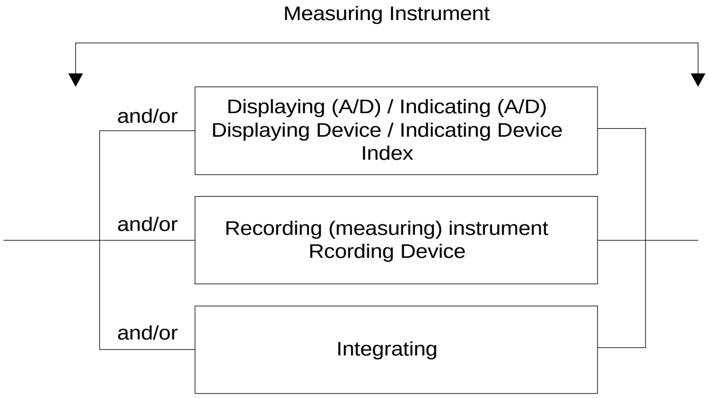

Figure 8: Details of a 'Measuring Instrument'

Figure 6 presents a more detailed view of a measuring system: following a stimulus or an input signal, the detector (or sensor) will detect the presence of the signal. If there is a signal, the instriment will indicate a value of a quantity associated with it. Following a reading, the measuring transducer provides an output quantity having a determined relationship to the input quantity. If there is another quantity, an integrating instrument will determine the value of the measurand by integrating a quantity with respect to this other quantity – Figure 7). The output will be indicated on a display device, and maybe recorded as well in some record device – Figure 8.

When there is more than one measuring system, a totalizing (measuring) instrument determines the value of a measurand by summation of the partial values of the measurand obtained simultaneously or consecutively from one or more sources – Figure 9.

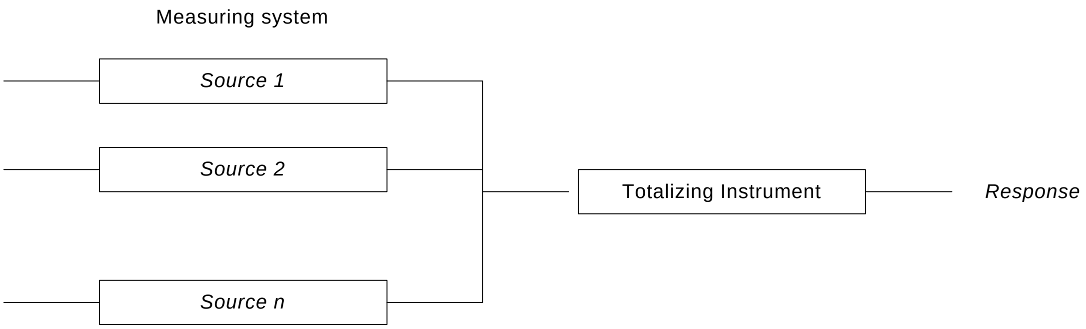

Figure 9: Model of a totalizing measuring instrument

Figure10 presents a detailed topology of the structure of the concepts within the 'scale' sub-category, according to the type of scale, scale length, the range of indication and scale division as well as scale numbering.

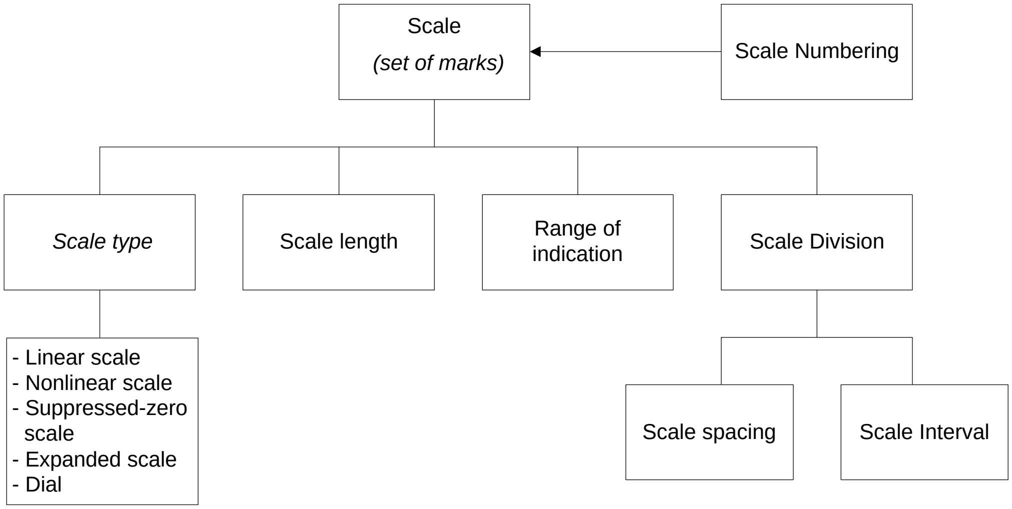

Figure 10: Detailed topology of 'Scale'

The 'Measuring Instruments' category of terms also contains the set of concepts on the type of operations required for the use of a particular instrument by an operator: gauging, adjustment, and user adjustment.

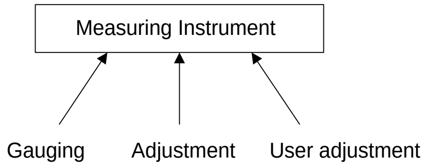

Figure 11: Operations on 'Measuring Instruments'

7. Characteristics of measuring instruments

Table 4 presents a detailed topology of the fifth category of metrology terms addressing the 'characteristics of the measuring instruments'. This table is structured according to the quantitative and qualitative characteristics of a measuring instrument, as well as a functionality test to be performed at the moment of the utilisation and control of the instrument, and a measuring range, which represents a set of measurement values within which the measuring instrument error is expected to operate (e.g. within specified limits, such as nominal range, span and nominal value).

Table 4: Detailed topology of the 'Characteristics of Measuring Instruments'

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

8. Measurement Standard - Etalons

Finally, Table 5 presents a detailed topology of the 'Measurement Standard – Etalon' category of metrology terms', which are intended to produce a unit of one or more quantity values to be used as references. Generally, a reference standard is necessary, from which to derive measurement and for its usefulness in a context requiring an official status (national or international) or a largely recognized basis (primary or secondary). The transfer standard is used as an intermediary to compare standards.

Table 5: Detailed topology of 'Measurement Standards / Etalon'

(Measurement) Standard Etalon	Conservation of a (Measurement) Standard
International (Measurement) Standard	Traceability
National (Measurement) Standard	Calibration
Primary Standard	Reference Material (RM)
Secondary Standard	Certified Reference Material (CRM)
Reference Standard	
Working Standard	
Transfer Standard	
Travelling Standard	

9. Summary

The domain of knowledge referred to as ‘metrology’ is the foundation for the development and use of measurement instruments and measurement processes; the ISO Vocabulary of metrology terms contains the international consensus on the set of metrology terms. A vocabulary is usually presented in a textual format, like that of a standard dictionary where the terms are classified only on the basis of their alphabetical order; the ISO Vocabulary of 120 metrology terms introduces, in addition, a high-level classification of these terms based on a set of six concepts, in an 'increasing order of complexity' within each concept.

To facilitate the understanding of the relationships across the 120 individual measurements concepts in all categories and at different levels of abstraction, this paper has presented first a high-level model of the ISO Vocabulary classification, followed by more detailed models of how the individual terms fit into this high-level model.

In the context of software engineering, this paper represents an initial attempt at modelling the measurement concepts documented in this ISO International Vocabulary. In particular, this initial modelling has illustrated both the different levels of abstraction of the concepts as well as the relationships across related concepts and sub-concepts. We have sometimes referred to this representation type as the topology of the concepts within this ISO Vocabulary.

Further work is required to include all measurement concepts in this modelling effort, and to ensure full coherence and consistency of representation. This refined modeling representation will next be used to investigate which of these concepts have indeed been discussed in the software engineering metrics literature, in addition to the traditional perspective referred to as ‘measurement theory’. In a subsequent stage, we will investigate how these metrology concepts can help in understanding the current maturity status of the field of software 'metrics' and contribute to its continuous process improvement.

10. References

[1] A. Abran, R. Dumke, ‘A Framework of the Software Measurement Domain: Current Situation and Future Directions’, International Workshop on Software Measurement – IWSM 97, 1997.

[2] S. R. Chidamber, C. F. Kemerer, ‘A Metrics Suite for Object Oriented Design’, IEEE Transactions on Software Engineering. Vol. 20, No. 6, June 1994, pp 476-493.

[3] E. Dimitrov, R, R. Dumke, E. Foltin, M. Wipprecht, ‘Conception and Experience of Metrics Based Software Reuse in Practice’, International Workshop on Software Measurement (IWSM) Lac Supérieur, Québec, 1999.

[4] T. Fetcke, A. Abran, R, A. Dumke, ‘Generalized Representation for Functional Size Measurement Methods’, International Workshop on Software Measurement – ISWM 2001, Montréal, Canada, August 28-29, 2001.

[5] R. Dumke, E. Foltin, P. Bourque, ‘Issues when Evaluating Software Measurement Tools Based on Existing Standards’, Forum on Software Engineering Standards (SES’96). Montréal, 1996.

[6] R. Dumke, M. Lother, A. Abran, ‘An Approach for Integrated Software Measurement Processes in the IT Area’, 4th European Conference on Software Measurement and ICT Control in co-operation with DASMA (FESMA-DASMA). Heidelberg, Germany, 2001.

[7] ISO, *ISO: International Vocabulary of Basic and General Terms in Metrology,* International Organization for Standardization, Geneva, 1993.

[8] Zuse, H. *A Framework of Software Measurement*. New York, 1997.

[9] M. Hitz, B. Montazeri, ‘Chidamber and Kemerer's Metrics Suite: A Measurement Theory Perspective’, IEEE Transactions on Software Engineering. Vol. 22, No. 4, pp 267-271, April 1996.