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Cloud Computing Service Metrics Description

NIST Cloud Computing Reference Architecture and Taxonomy Working Group
NIST Cloud Computing Program
Information Technology Laboratory

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Reports on Computer Systems Technology

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1 Executive Summary

With cloud computing in the mainstream, there is a preponderance of cloud based services in the market and the choices for consumers increase daily. However, comparing the service offerings between cloud service providers is not a straightforward exercise. To be successful in procuring cloud services, one must have requirements that are clear, create service level agreements (SLA) which reflect these requirements and be measureable in order to validate the delivery of these services along with their performance and remedies.

As part of the decision making framework for moving to the cloud, having data on measurable capabilities, for example - quality of service, availability and reliability, give the cloud service customer the tools and opportunity to make informed choices and to gain an understanding of the service being delivered. NIST's definition of cloud computing describes a "Measured Service" as being one of the five essential characteristics of the cloud computing model. To describe a "measured service", one needs to identify the cloud service properties that have to be measured and what their standards of measurement or metrics are.

A metric provides knowledge about characteristics of a cloud property through both its definition (e.g. expression, unit, rules) and the values resulting from the observation of the property. For instance, a customer response time metric can be used to estimate a specific response time property (i.e. response time from customer to customer) of a cloud email service search feature. It also provides the necessary information that is needed for to reproduce and verify observations and measurement results.

In this context, the role of that metrics play is very important to support decision-making as well as:

- Selecting cloud services
- Defining and enforcing service agreements
- Monitoring cloud services
- Accounting and Auditing

Metrics for cloud computing services can be described using the model proposed in this document. The model represents the information needed to understand the targeted cloud property and which constraints should be applied during observation. The Cloud Service Metric model (CSM) describes the higher level concepts of the abstract metric definitions for a specific cloud service property; service uptime is a prime example. Definitions for abstract metrics contain parameters and rules to express a formal understanding the property of interest. The CSM model also contains concrete metric definitions that are based on abstract metric definitions. Concrete metric definitions add specific values to rules and parameters that make the metric usable for a given scenario.

A scenario represents a particular use case in which metrics play a role. Stakeholders need to have a way to understand, assess, compare, combine and make decisions about cloud service properties. This means that for a given scenario (e.g. choosing a cloud service or setup a service agreement), a stakeholder needs to be able to get information on cloud service properties, which when measured (observed) will guide the stakeholder along the proper course of action. The scenario and cloud service property will determine the metric (standard of measurement) to be used.

2 Introduction

2.1 Audience

This document proposes a framework that identifies and characterizes the information and relationships needed to describe and observe properties of cloud services that are representative, accurate and reproducible. This information can be used in a variety of ways including, collection, comparison, gap analysis, and assessment or description of metrics at the technical or business levels. These metrics can connect information intended for decision-making, for the service agreements between provider and customer, for the runtime performance measurement and the underlying properties within the providers system.

This document may be used as a source of information to better understand metrology within the context of cloud services, and as a framework to describe, collect and access information related to metrics. The measurement process and methodology necessary for performing the measurement of a given cloud property is not the focus of this document.

The targeted audience of this document includes but is not limited to:

- U.S. Government agencies
- Cloud service customers
- Cloud service auditors
- Cloud service providers

2.2 Background

Cloud computing shifted the use of compute resources from asset-based physical resources to service-based virtual resources. NIST in its definition of cloud computing [2] describes a "Measured Service" as being one of the five essential characteristics of the cloud computing model. Providing data on measurable capabilities (such as; quality of service, security features, availability and reliability) gives the cloud service customer the opportunity to make informed choices and to gain understanding of the state of the service being delivered. It also gives the cloud service provider the opportunity to present the properties of their cloud services to the cloud service customer.

However cloud metrology is not necessarily well understood. Common terminologies (i.e. the definition of measurement, metric, and related concepts) or sets of measurement artifacts (i.e. unit of measurement, metric) often have several definitions, which makes it very difficult for the cloud service customer to compare services or rely on third party tools to monitor the health of the service. It also makes it difficult for the provider to show that the service is performing correctly or to allow its service to enter into a complex cloud service chain or federation.

Organizations, like U.S. agencies, need a way to consistently define sets of metrics on which they can rely, trust and share. This has the net-effect of increasing the overall confidence in the results of measurements of selected cloud service properties. This effect also increases the support of the decision-making process during the different stages of the cloud service lifecycle.

It is critical to have the capacity to represent what needs to be measured, how the measurement results are used, and how they impact business and technical decisions.

Cloud metrology is vast and takes into account many different components including:

- The definition of metrics and their use.
- The definition of measurement processes and methods.
- The calibration of measurement tools.
- The measurement operations.
- The processing of measurement results and associated consequences.

This document's primary focus is on the first item and introduces an approach to define and represent the concepts and uses of measurement within the context of cloud services and their underlying components.

3 Definitions

Currently, the terminology of cloud service measurements is not well defined. Different stakeholders in the Information and Communication Technology (ICT) community use the same terms with slightly different (or sometimes contradicting or overlapping) meanings. This may be due to wide variety of ICT's technology domains (i.e. Software, Telecommunication, Manufacturing), each using its own language. It could also come from the lack of a common process to define new terminology. This leads to great confusion among cloud service providers, customers, carriers and other cloud stakeholders.

The use of well-defined and understood terms within a given domain will enable the stakeholders to communicate more efficiently. It reduces the risk of the misinterpretation of information and facilitates the combination and comparison of information.

To bring clarity to the vocabulary of cloud service measurements, some of the core terms used in the document are defined below.

3.1 Abstract Metric

An abstract standard of measurement used to assess a property. The standard of measurement describes what the result of the measurement means, but not how the measurement was performed. The Abstract Metric is not used by itself, but is instantiated using a Metric.

3.2 Abstract Metric Definition

A collection of elements that defines the expression of a specific metric for a given metric category like a blueprint

3.3 Cloud Service Property

A property of a cloud service to be observed. A property may be expressed qualitatively or quantitatively.

3.4 Concrete Metric Definition

A collection of elements that complete an abstract metric definition by linking the metric to its primary abstract metric and assigning specific values to the rule(s) and parameter(s) defined in the abstract metric definition

3.5 Context

The circumstances that form the setting for an event, statement, or idea, in which the meaning of a metric can be fully understood and assessed.

3.6 Measurement

Set of operations having the object of assigning a Measurement Result.

Note: Based on the definition of Measurement in ISO/IEC 15939:2007 [6]. Also used here to describe an actual instance of execution of these operations leading to the production of a Measurement Result instance.

3.7 Measurement Result

Value that expresses a qualitative or quantitative assessment of a property of an entity.

Note: Based on the definition of Measurement Result in ISO/IEC 15939:2007 [6]

Note: The term measure is **not** used in this document. Measure is defined with so many divergent definitions it is difficult to use. Section 9 "Definitions Survey" shows a sample of the definitions related to "measure".

3.8 Metric

A standard of measurement that defines the conditions and the rules for performing the measurement and for understanding the results of a measurement.

Note: A metric implements a particular abstract metric concept.

Note: A metric is to be applied in practice within a given context that requires specific properties to be measured, at a given time(s) for a specific objective.

3.9 Observation

Measurement based on a metric, at a point in time, on a measurement target.

3.10 Unit of Measurement

Real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number [7].

Note: part of an Abstract Metric

4 The Role of Metrology in Cloud Services

Metrology – the science of measurement – is important for cloud computing not just for the measurement of properties of cloud services, but also to gain a common understanding of the properties themselves.

Physical properties can be measured using a standardized metrology process. Software properties measurement has some associated standards like functional size measurement methods [3][4][5] that are not exactly at the level of physical metrology.

Metrics are used to understand a particular measurement (or type of measurement) of a cloud service property and to understand the property itself by providing a standard for describing a measurement and measurement result.

Figure 1 shows the relationship between a property and a metric. Cloud services have properties that represent characteristics of the service. The understanding of these properties is very important to determine the service capabilities. One way to understand these properties is with metrics. The use of a metric through an observation results in measurement results to estimate the property of an element. For instance a customer response time metric can be used to estimate a specific response time property (i.e. response time from customer to customer) of a cloud email service search feature.

A metric provides knowledge about aspects of the property through its definition (e.g. expression, unit, rules). It also provides the necessary information for reproducibility and verification of observations and measurement results.

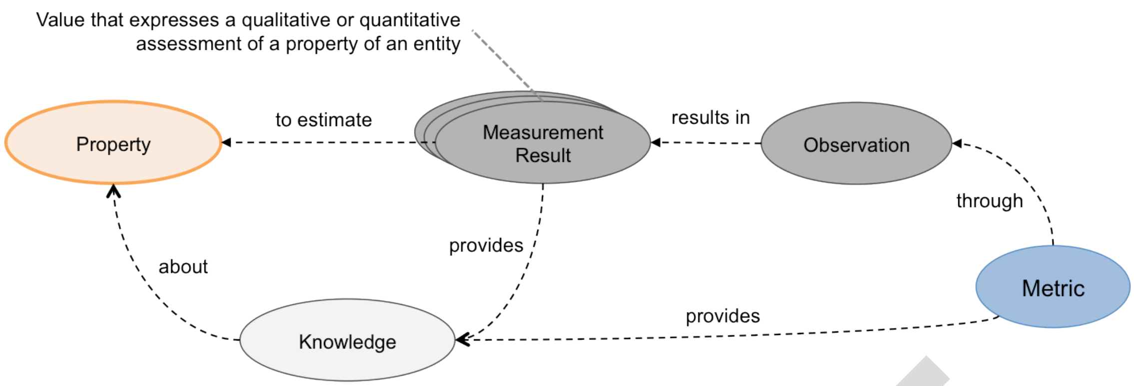

Figure 1 Metric and Property

In this manner cloud metrics help providers communicate the properties of their cloud services that are measurable, help customers and providers agree on what will be provided, and allow cloud service features to be measured to ensure the agreement is met (and therefore the customers requirements are met).

Cloud system can leverage metrics – standards for measurements – for many different purposes. For instance metrics can be used at different layers of a cloud computing system (e.g. hardware layers, logic layers, governance layers or service layers). They can also be used at different stages of the cloud computing services life cycle (e.g. procurement, operation, audit and retirement).

4.1 The Cloud Service Trifecta

The use of metrics for cloud computing systems at the service interface can be broken down into three general areas, service selection, service agreement, and service verification. Metrics are essential, not just to understand each of these areas, but to connect these three distinct parts of the cloud procurement process. The three aspects of the trifecta are described below.

4.1.1 Metrics for Selecting Cloud Services

Metrics are essential at the stage of deciding what cloud offering should be best suited to meet the business and technical requirements. The customer of cloud services should be able to select and use metrics and their underlying measures to assess and decide which offering would be best. Solutions like the Service Measurement Index (SMI), [8] produced by the Cloud Services Measurement Initiative Consortium (CSMIC), could be used to determine which metrics are relevant to the selection of a particular cloud offering.

Figure 2 shows how metrics are used to understand the factors and properties necessary for distinguishing and deciding between two different cloud offerings. Such metrics may be used to provide data on actual cloud operations (e.g. performance, responsiveness, scalability, availability…) as produced by some independent auditing or monitoring of the provider when servicing its current customers. The use of these metrics may also result in an assessment on the readiness and ability of a cloud service provider to ensure some level of service quality prior to and independently from actual operations (e.g. various aspects of security, accessibility, customer support, financial flexibility).

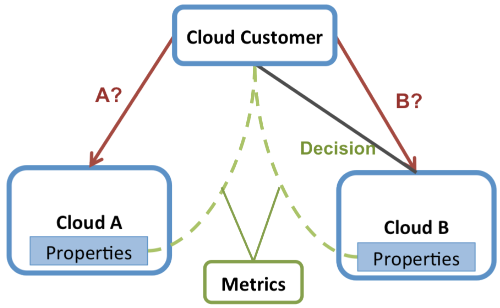

Figure 2 Cloud Service Selection

4.1.2 Metrics for Service Agreements (SAs)

A Service Agreement (SA) represents a binding agreement between the provider and customer of a cloud service. Among the elements that it contains are the description of the service, the rights and responsibilities of both the provider and the customer and terms definition. It also contains essential information related to the measurement of different aspects of the cloud service (e.g., its business level objectives or its performance level). The definition and usage of appropriate metrics with their underlying measures are essential components of the Service Level Agreement (SLA) and Service Level Objectives (SLO), which are constituents of the SA. The references [9] and [10] describe, in detail, the importance of and need for metrics in SLAs. At this point, the metrics are used to set the boundaries and margins of errors the provider of the service abides by and sets their limitations. For instance these metrics could be used at runtime for service monitoring and balancing, or remediation (e.g., financial). Using a standardized set of metrics or metric templates in SAs makes it easier and quicker to define SLAs and SLOs, and to compare them with others.

Figure 3 illustrates the use of metrics to support an SLA document that defines the expectations of the two parties – cloud customer and cloud provider, allowing them to understand the characteristics of the specific service (cloud offering) being provided.

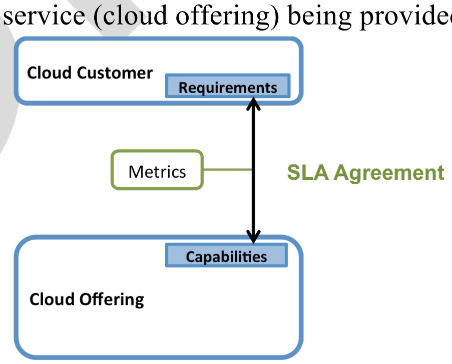

Figure 3 Cloud Service Agreement

4.1.3 Metrics for Service Measurement

Once the customer purchases a cloud service, it is necessary to ensure the service level objectives are being met. If they are not met, a pre-determined remedy needs to be initiated.

Figure 4 illustrates the service being delivered to the cloud customer from the cloud provider. In this case, metrics are used when monitoring the service level objectives defined in the service agreements.

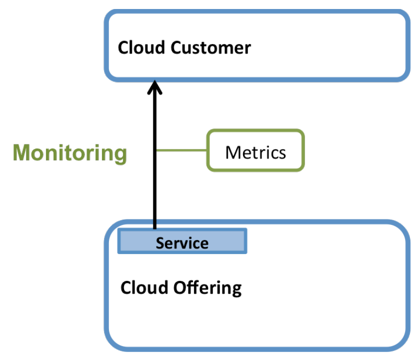

Figure 4 Cloud Service Objectives Monitoring

4.2 Other Metrics

Metrics can also be used internally to the cloud service itself. These metrics are more technical and used only by the cloud service provider to monitor and to understand the internal performance of their cloud system. References [11] and [12] discuss to specifications that show potential representations and usages of measurement concepts that can be used in cloud computing systems. Measurement results based on metrics for internal use may not be available to the cloud customer.

In addition, other parts of the cloud ecosystem can be influenced through the use of metrics like accounting, auditing and security. In the case of accounting, metrics are for instance linked to the amount of usage of a particular service. In the case of auditing, metrics are linked to the certification assessment of selected cloud service properties. Finally, cloud metrics can be used to negotiate/monitor the customer's requirements based on the agreed SLA.

4.3 Scenario

Stakeholders need to have a way to understand, assess, compare, combine and make decisions about cloud service properties. This means that for a given instance, i.e. scenario (e.g. choosing a cloud service or setting up a service agreement), a stakeholder needs to be able to get information on cloud service properties, which when measured (observed) will aid the stakeholder in selecting the proper course of action. The scenario and cloud service property will determine the metric (standard of measurement) to be used. The metric relies on the abstract metric definitions that are related to the selected cloud service property. The measurement (observation) of the cloud service property through the metric will result in measurement results.

Figure 5 shows the scenario concept:

- The **Scenario** represents a particular use case (business process decision making, application monitoring, Service Level Agreements, etc.).
- The **Abstract Metric** describes the base concept on which the Metric is based.

- The **Metric** adds the data necessary to use the abstract metric.
- The **Measurement Result** is data that results from making a measurement that follows a given metric.

More specifically, stakeholders (e.g. cloud customer or cloud provider) define the scenario for which the metric will be needed. The scenario represents:

- The expectations of an underlying business or operational process (e.g. SLA or Operation)
- How the metrics are used to assist in such a process
- What acceptable levels of the measured properties are

The scenario also includes the way the selected metrics are applied – what resource or service they support, under which conditions are their evaluation triggered and the frequency of the evaluation.

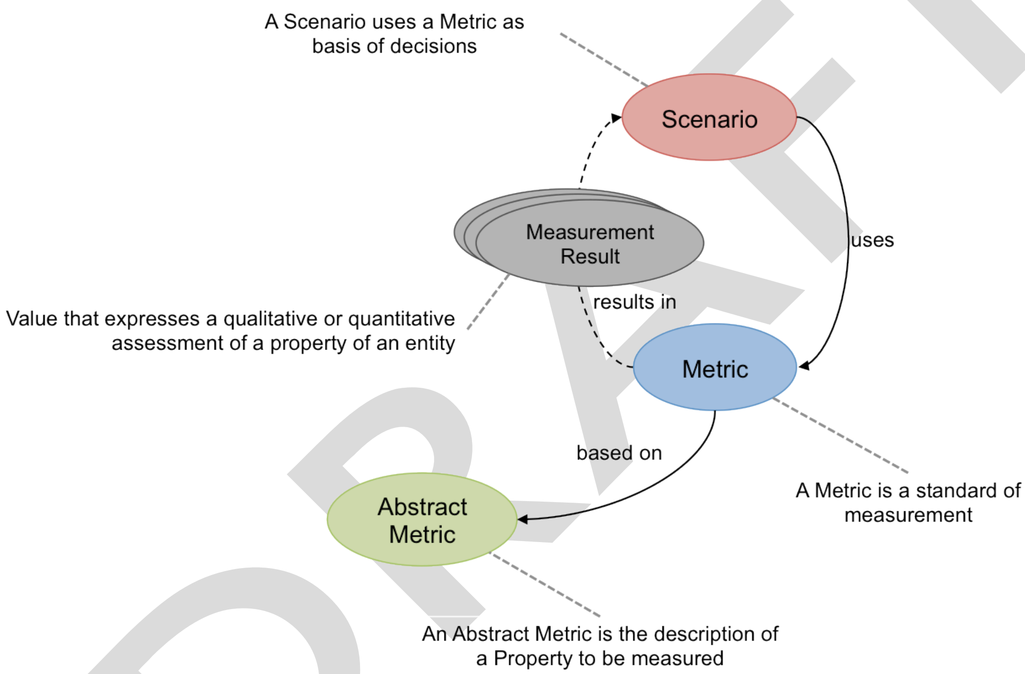

Figure 5 Scenario and Metric

In other words, a metric is a standard set of procedures and rules that generates values for its associated abstract metric. In practice, the metric is applied within a given scenario that determines specific conditions, such as a specific resource(s) being measured, at a given time(s) for a specific objective.

Possible scenarios could be the application of an availability metric for a performance objective of 99% in an SLA scenario or the application of an accessibility metric for a usability objective of value "high" in a decision process scenario.

5 Cloud Service Metric Model

Understanding of the relationships between different data elements of cloud service metrology is very important in order to create meaningful and traceable metrics. This section introduces the Cloud Service Metric model (CSM), its general concept and a full element description of the foundation diagram that describes a Metric definition.

5.1 Cloud Service Metric Ecosystem

As explained in the earlier *Section 3,* a metric is a fundamental concept that should provide information on how to understand a property being considered and how to estimate its value through observations.

The information that comprises the metric ecosystem can be broken down into these specific aspects:

- The description and definition of a standard of measurement *(e.g. metric for customer response time) – CSM*
- The addition of the context of the standard of measurement *(e.g. objectives and applicability conditions of the customer response time metric) – CSM Context*
- The use of the standard of measurement to define observations *(e.g. the observation of response time property based on the customer response time metric) – CSM Observation*
- The use of the standard of measurement in a scenario *(e.g. the selection and use of the customer response time metric in an SLA scenario) – CSM Scenario*

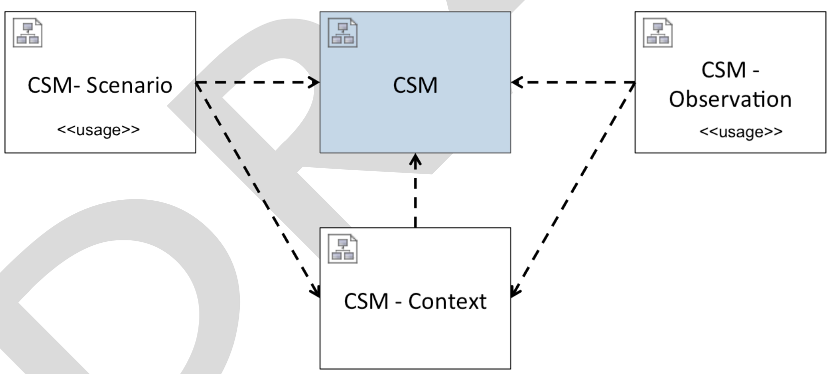

Figure 6 Cloud Service Metric Ecosystem Model

Figure 6 shows the breakdown of these different aspects and their relationships. The CSM box contains the description and definition of the standard of measurement. The CSM can be enhanced with information from the CSM Context; it contains elements that describe the environment of a particular standard of measurement. The CSM Scenario relies on the CSM and the CSM Context and contains elements that describe use cases that rely on standards of measurement. The CSM Observation relies on the CSM and the CSM Context and contains elements that are used during measurement operations.

In this document, only the CSM concept model is explained. The remaining concepts that compose the CSM Ecosystem model are the topics of other documents.

5.2 Model Characteristics

The following are characteristics that were considered important when developing the CSM model.

5.2.1 Consistent Representation of Information

Information related to metrics should be represented in a consistent, repeatable way in order to efficiently organize it, share it and use it.

5.2.2 Explicit Relationships

Concepts like metrics should be represented in such a way that the relationships among them, if any, are explicit. This clarifies the effects these concepts have on one another and their importance.

5.2.3 Repository of Definitions

There should be a way to organize metrics so they are reusable, searchable and derivable.

5.2.4 Comparability

The properties of the different concepts should allow its user to have enough information to efficiently compare them to find and understands either similarities or differences.

5.2.5 Flexibility and Adaptability

The concept model should be sufficiently flexible and adaptable to allow for easy integration with other metric models. These models could be complementary to the concept model (e.g. represent measurement methods and process).

5.2.6 Composability

The metrics should allow metrics definitions and instances to be reusable. Thus one should be able to use one or more metrics to build a composite metric. This metric that is composed of underlying metrics builds upon the information they contain. This results in metrics that could possibly be composed of underlying metrics of different kind (e.g. qualitative and quantitative). This consideration will be discussed in *Section 8*.

5.3 Cloud Service Metric Diagram

This subsection formally describes the CSM diagram, its elements, what these elements are composed of and the way they are connected to each other.

Figure 7 introduces the CSM concept as a UML class diagram [13]. The purpose of the CSM model is to capture the information needed to describe and understand a metric. The metric is used for gaining knowledge about, and measuring cloud service properties.

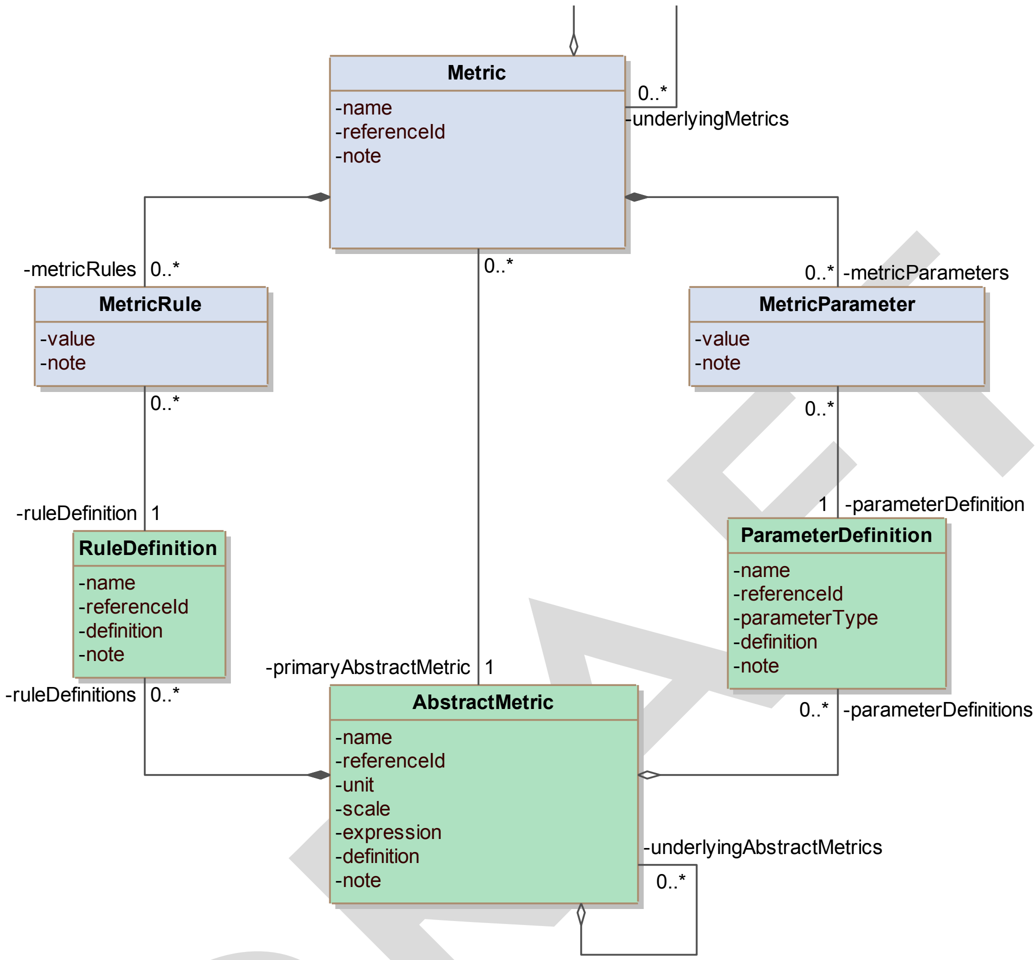

Figure 7 Cloud Service Metric (CSM)

5.4 Cloud Service Metric Element Definitions

The different elements of the CSM model are described below. In this section the use of the terms class, attribute and association and the model itself conform to the UML 2.0 specification. The classes are described in the following order:

- AbstracMetric
- RuleDefinition
- ParameterDefinition
- Metric
- MetricRule
- MetricParameter

Within each class, the attributes are described, then the associations between the class and other classes. The attributes are described following the order of the diagram.

5.4.1 AbstractMetric Class

The AbstractMetric class holds the basic information necessary to understand the measurement of a property to be observed, but does not include the additional information (e.g. context, target) to actually use the metric.

5.4.1.1 AbstractMetric Attributes

name

The name of the AbstractMetric.

(e.g. TimeDuration)

referenceId

A unique identifier for the abstract metric defined by convention.

(e.g. AM001)

unit

The unit that will be associated with the AbstractMetric.

(e.g. second)

Note that not every AbstactMetric is associated with a scalar unit. For instance, AbstractMetrics whose scale is nominal or ordinal (i.e. qualitative) could be associated with a list of elements (e.g. low, medium, high for data sensitivity) or a more complex construct.

scale

Information on how the measurement value can be interpreted and what sort of operations can be performed on it. It is based on the theory of scales of measurement [14].

The scale also reflects the kind of the AbstractMetric, i.e. qualitative or quantitative.

> **Quantitative** - A metric that has values of numeric type, with the semantics of a quantity. The expression (or formula) that determines how such a value is calculated is of numeric output with a quantitative meaning *(e.g. speed = distance / duration is of quantitative kind)*. The **interval** and **ratio** scales are viewed as quantitative.
>
> **Qualitative -** A metric that has either nominal or ordinal values. When ordinal, the metric usually expresses a "score" *(e.g. on a scale from 1 to 10)*. When nominal, it expresses a quality *(e.g. "good", "average", "bad")*. There is usually an expression (or formula) associated with each possible value, which is of qualitative nature. The **nominal** and **ordinal** scales are viewed as qualitative

Allowed values:

- Nominal – Qualitative
- Ordinal – Qualitative
- Interval – Quantitative
- Ratio – Quantitative

expression

The function used to assemble the underlying AbstractMetrics and the ParameterDefinitions that compose the AbstractMetric. RuleDefinitions can also be part of the expression. In its simplest form, the expression is a literal but it can also be a more formal expression language.

(e.g. expression = Sum(ResponseTime)/n where “ResponseTime” is an underlying AbstractMetric element and “n” is a ParameterDefinition element)

definition
A formal description of the AbstractMetric.

note
Additional information or comments related to the AbstractMetric.

5.4.1.2 AbstractMetric Associations

ruleDefinitions
An AbstractMetric may have zero or more RuleDefinions associated with it. RuleDefinitions may be part of the expression of an AbstractMetric to constrain it.

parameterDefinitions
An AbstractMetric may have zero or more ParameterDefinitions associated with it. ParameterDefinitions may be part of the expression of an AbstractMetric.

underlyingAbstractMetrics
Shows any AbstractMetrics that are used as a base for the AbstractMetric being defined. underlyingAbstractMetrics are part of the expression of an AbstractMetric.

5.4.2 RuleDefinition Class

A RuleDefinition element is used to further constrain some parts of an AbstractMetric element and indicate possible method(s) for measurement. For instance an “AvailabilityDuringBusinessHour” Metric element could be defined with a scope that constrains some piece of a generic “Availability” AbstractMetric element that limits the observation period to defined business hours.

5.4.2.1 RuleDefinition Attributes

name
The name of the RuleDefinition.
(e.g. whenStart RuleDefinition for a TimeDuration AbstractMetric)

referenceId
A unique identifier for the abstract metric defined by convention.
(e.g. RD001)

definition
A formal description of the RuleDefinition element.

note
Additional information or comments related to the RuleDefinition.

5.4.3 ParameterDefinition Class

A ParameterDefinition element is used to define a parameter needed in the expression of an AbstractMetric. A ParameterDefinition may be used by more than one AbstractMetrics.

5.4.3.1 ParameterDefinition Attributes

name
The name of the ParameterDefinition.
(e.g. measurementTimeframe)

referenceId
A unique identifier for the ParameterDefinition defined by convention.
(e.g. PD001)

parameterType
The type of the ParameterDefinition, the way it should be interpreted.
(e.g. integer, string)

definition
A formal description of the ParameterDefinition.

note
Additional information or comments related to the ParameterDefinition.

5.4.4 Metric Class

Defines the concrete standard of measurement for a specific cloud service property, It is based on the AbstractMetric concept, adding the specific parameters, and rules which are required to use the AbstractMetric.

5.4.4.1 Metric Attributes

name
The name of the Metric.
(e.g. CustomerResponseTime)

referenceId
A unique identifier for the metric defined by convention.

note
Additional information or comments related to the Metric.

5.4.4.2 Metric Associations

primaryAbstractMetric

The primary AbstractMetric that the Metric implements.

metricRules
A Metric is associated with zero or more MetricRules. These MetricRules are one piece of the implementation of an AbstractMetric through its RuleDefinitions association.

metricParameters
A Metric is associated with zero or more MetricParamters. These MetricParameters are one piece of the implementation of an AbstractMetric through its ParameterDefinitions association.

underlyingMetrics
Shows any Metrics that are used as a base for the Metric being described.

5.4.5 MetricRule Class

The element that represents a concrete rule of the Metric based on information from the Metric's primary AbstractMetric element.

5.4.5.1 MetricRule Attributes

value
The value of the rule defined by the associated RuleDefinition.
(e.g. value could be "scheduled maintenance" for the associated ruleDefinition observation_exclusion)

note
Additional information or comments related to the MetricRule.

5.4.5.2 MetricRule Associations

ruleDefinition
A MetricRule is dependent on a single RuleDefinition. This RuleDefinition is selected from the ruleDefinitions of the Metric's primaryAbstractMetric element.

5.4.6 MetricParameter Class

The element that represents a concrete parameter of the Metric based on information from the Metric's primary AbstractMetric element.

5.4.6.1 MetricParameter Attributes

value
The value of the parameter defined by the associated ParameterDefinition.
(e.g. value could be 30 for the associated parameterDefinition measurement_timeframe)

note
Additional information or comments related to the MetricParameter.

5.4.6.2 MetricParameter Associations

parameterDefinition

A MetricParameter is dependent on a single ParameterDefinition. This ParameterDefinition is selected from the parameterDefinitions of the Metric's primaryAbstractMetric element.

6 How to Use the CSM Model

The CSM model defines the fundamental elements needed to describe standards of measurement (i.e. metrics). These elements are organized into two parts. The first part represents the elements that make up the abstract definition of a particular metric (e.g. Service Availability). This is the abstracted model for a category of metrics. The second part represents the elements that make up a specific instantiation of this abstract metric.

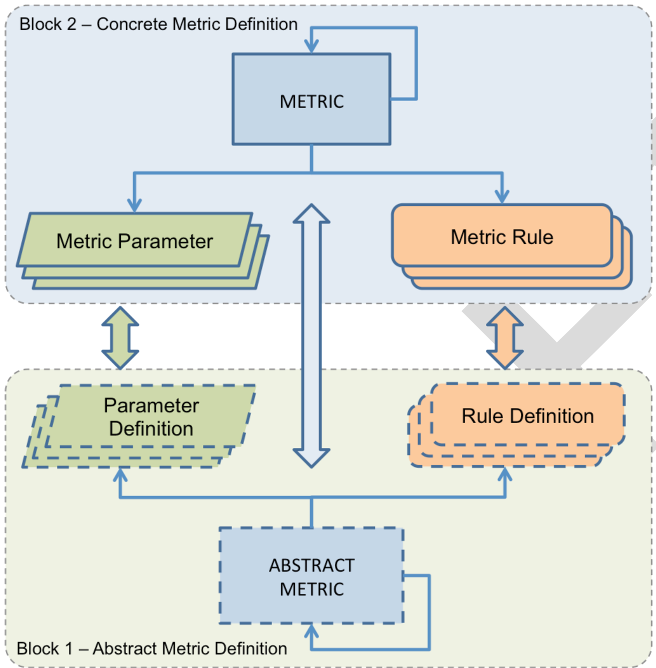

Figure 8 CSM Definitions Blocks

Figure 8 displays another perspective of the CSM concept. This perspective doesn't go into as much details for each element of the CSM as in Figure 7. Instead it displays the CSM at a higher viewpoint to show how the CSM can be organized into 2 sets of constituents, Abstract and Concrete Metric Definitions blocks.

In block 1, for a given metric category, the abstract metric definition of a metric is composed of AbstractMetric(s) and associated ParameterDefinition(s) and RuleDefinition(s). This abstract metric definition represents the collection of elements that defines the expression of a specific metric for a given metric category like a blueprint. For instance in the availability metric category which expresses the availability property of a cloud service, one can define several metrics like service uptime percentage or number of successful http requests. Each of these metrics can be expressed with a set of attributes like unit, scale, expression; a set of parameters and a set of rules and that constrain the definition. The rule definition and parameter definition elements describe what the rules and parameters are about, not what values they have. This allows one to add a rule for availability that expresses downtime exclusion without setting a specific value for that exclusion. This is the role of the concrete metric definition.

In block 2, the concrete metric definition of a metric is composed of a Metric and associated MetricParamter(s) and MetricRule(s). A concrete metric definition completes an abstract metric definition by linking the metric to its primary abstract metric and assigning specific values to the rule(s) and parameter(s) defined in the abstract metric definition block. This way multiple concrete metric definitions can leverage the same abstract metric definition.

Figure 9 displays the process followed to define metrics from a different viewpoint. The CSM model defines the core concepts and elements that constitute a standard of measurement. Specific instances of a subset of these elements (Figure 8 block 1) are then used to create an abstract metric definition. Then for a given abstract metric definition, implementation metrics are created using instances of another subset of the CSM elements (Figure 8 block 2).

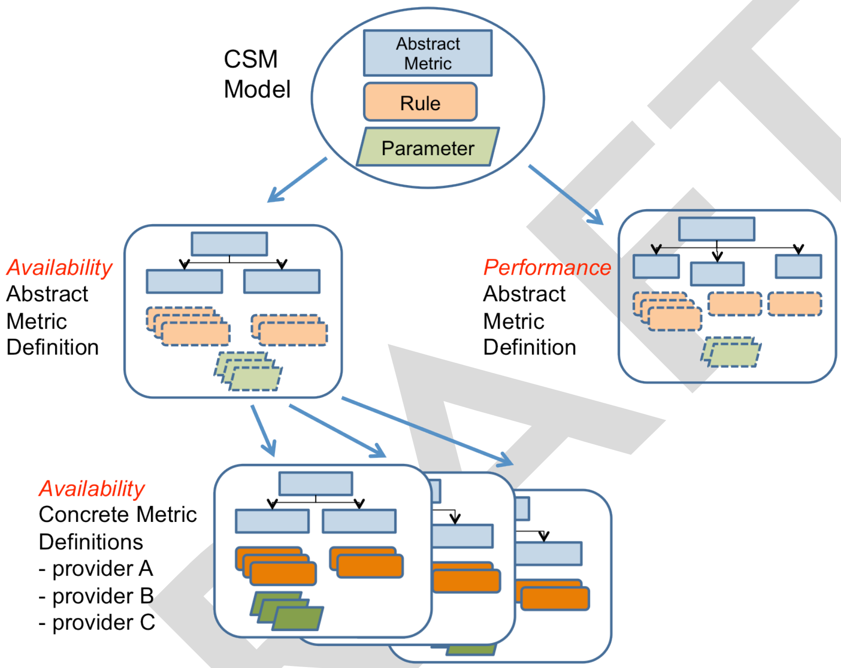

Figure 9 Metric Definition Process

7 Measurement Uncertainty

In metrology, the result of a measurement is not meaningful if a statement of the uncertainty of the measurement is not specified. This statement allows users to assess the quality of the measurement results and to build confidence to compare results and use them within the range of the measurement uncertainty.

The International Vocabulary of Metrology (VIM) [7] defines measurement uncertainty as

> *A non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used*

> *NOTE 1 Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated*

systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

NOTE 2 The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

NOTE 3 Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

NOTE 4 In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

In the context of cloud services, it is critical that the consumer of a measured resource be confident about the measurements operated on that resource. These measurements will feed metrics that could be used against thresholds to determine the range the acceptable results and trigger possible consequences.

The current CSM model starts addressing this aspect of metrology with an attribute “uncertainty” that is contained in the CSM Observation model.

8 Other Considerations

8.1 Metrics used for Property Composition

A key aspect of the CSM model is its extensibility, which permits metric definitions to be composed from other metric definitions. This is an effort to limit the duplication of information without too much of an increase on complexity. CSM allows qualitative or quantitative metrics to be defined and composed. This can affect the estimation – measurement results – of a particular property in several ways like its uncertainties.

8.2 Calibration & Measurement Standard (Etalon)

Once new metrics and unit of measurements have been defined for cloud service properties that can be reusable and comparable, the next step could be the calibration of the measurement systems used for measurement of cloud service properties against established measurement standards. This would enable a better alignment of the understanding and comparison of the properties that compose different cloud service offerings.

9 Conclusion

Metrics are a critical aspect of the selection, operation and use of cloud services. Metrics allow stakeholders to gain a better understanding of cloud service properties through consistent, reproducible and repeatable observations. Metrics can be used for a wide range of objectives from decision making to operation. For instance key performance indicator metrics can be used to measure specific achievements whereas benchmark metrics can be used as reference to compare features against one another.

Metrics need to be well defined and understood so that the different stakeholders involved in cloud computing (i.e. cloud service customer and cloud service provider) can rely on them with confidence. The Cloud Service Metric (CSM) model proposed in this document is one approach to addressing this challenge. The CSM defines a small set of concepts and links them together to define what a metric is, what it is composed of and what constrains its expression. The model can be logically broken down into two parts. The first part addresses the definition of abstract metrics. It specifies what the abstract metric is about, if it is composed of underlying abstract metrics, if it is expressed with additional parameters and if there are core rules that constrain it. The second part addresses the definition of concrete metrics. It specifies what primary abstract metric a metric is based on, what values for parameters and rules should be applied to the abstract metric parameters and rules definition.

The CSM model can be extended and integrated into other models that address other aspects of the metric ecosystem like the context of a metric, the observation and measurement results based on a metric or the scenarios that make use of metrics. These other aspects will be explored in future work.

Annex A - Definitions Survey

Table 1 presents a sample collection of measurement terms and definitions coming from different domains including, information technology, software, software engineering and physical. The terms that were sampled are measure, metric, key performance indicator, benchmark, measurement and measurement unit. As result, the table shows that across and among domains there are many different definitions for the same term. Most of these definitions tend to have the same concepts in their descriptions however a few mix the terms and definitions. For instance the OMG SIMM document defines measure as "a method assigning comparable numerical or symbolic values to entities in order to characterize an attribute of the entities" and measurement as "a numerical or symbolic value assigned to an entity by a measure" and other documents used the same definitions but inverted the terms so in the case of the ISO/IEC 15939 document measurement is defined as "Set of operations having the object of determining a value of a measure" and measure as "variable to which a value is assigned as the result of measurement".

Table 1 - A sample of measurement related terms and definition in the IT space

Term	Source	Title	Organization	Category	Description
			measure		
base measure	ISO/IEC 15939	Systems and software engineering - Measurement process	ISO/IEC	software engineering	measure defined in terms of an attribute and the method for quantifying it
measure	ISO/IEC 15939	Systems and software engineering - Measurement process	ISO/IEC	software engineering	variable to which a value is assigned as the result of measurement
measure	ISO/IEC 15939	Systems and software engineering - Measurement process	ISO/IEC	software engineering	make a measurement
measure	NIST SP 500-209	Software Error Analysis	NIST	software engineering	The numerical value obtained by either direct or indirect measurement; may also be the input, output, or value of a metric.
measure	IEEE 1061	IEEE Standard for a Software Quality Metrics Methodology	IEEE	software engineering	(A) a way to ascertain or appraise value by comparing it to norm. (B) to apply a metric
measure	SAMATE	SAMATE Project	NIST	software assurance	we use measure for more concrete or objective attributes
measure	SMM	Structured Metrics Metamodel (SMM)	OMG	software engineering	a method assigning comparable numerical or symbolic values to entities in order to characterize an attribute of the entities
quantity	JCGM 200:2012	International vocabulary of metrology - Basic and general concepts and associated terms	BIPM	metrology	property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference
			metric		
base metric	DSP1053_1.0.1	Base Metric Profile	DMTF		a metric provided directly without a dependency on other metric values
direct metric	IEEE 1061	IEEE Standard for a Software Quality Metrics Methodology	IEEE	software engineering	a metric that does not depend upon a measure of any other attribute
interval metric	DSP1053_1.0.1	Base Metric Profile	DMTF		metric that apply to a time interval. An example of an interval metric is the average CPU utilization of a server over the past hour
metric	GFD-R-P.098	Usage Record - Format Recommendation	OGF	web service	This attribute identifies the method of measurement used for quantifying the associated resource consumption if there are multiple methods by which to measure resource usage
metric	IEEE Std 610.12-1990	IEEE Standard Glossary of Software Engineering Terminology	IEEE	software engineering	a quantitative measure of the degree to which a system, component, or process possesses a given variable
metric	NIST SP 500-209	Software Error Analysis	NIST	software engineering	The definition, algorithm or mathematical function used to make a quantitative assessment of product or process.
metric	*www.prosci.com/metrics.htm*	-	-	*business*	*A metric is nothing more than a standard measure to assess your performance in a particular area.*

Term	Source	Title	Organization	Category	Description
metric	IEEE 1061	IEEE Standard for a Software Quality Metrics Methodology	IEEE	software engineering	see software quality metric
metric	SAMATE	SAMATE Project	NIST	software assurance	we use metric for more abstract, higher-level, or somewhat subjective attributes
metric	GB917 rev3	SLA Handbook	TMForum		a commonly identified and measurable concept
metric	ITIL 2011 glossary	glossary and abbreviations	ITIL	IT service management	Something that is measured and reported to help manage a process, IT service or activity.
metric	Merriam-Webster Dictionary		Merriam-Webster Dictionary		
software metric	Wikipedia	Software Metric	Wikipedia	software	a software is a measure of some property of a piece of software or its specifications
software quality metric	IEEE 1061	IEEE Standard for a Software Quality Metrics Methodology	IEEE	software engineering	a function whose inputs are software data and whose output is a single numerical value that can be interpreted as the degree to whichsoftware possesses a given attribute that affects its quality
summation metric	DSP1053_1.0.1	Base Metric Profile	DMTF		a type of counter metric that reflects the accumulation of a value
watermark metric	DSP1053_1.0.1	Base Metric Profile	DMTF		a type of aggregation metric used to capture the minimum or maximum value recorder for a monitored value
			key performance indicator		
key performance indicator	ITIL 2011 glossary	glossary and abbreviations	ITIL	IT service management	A metric that is used to help manage an IT service, process, plan, project or other activity. Key performance indicators are used to measure the achievement of critical success factors. Many metrics may be measured, but only the most important of these are defined as key performance indicators and used to actively manage and report on the process, IT service or activity. They should be selected to ensure that efficiency, effectiveness and cost effectiveness are all managed.
key performance indicator	GB917 rev3	SLA Handbook	TMForum		in a telecom concept, metric close to telecom technologies and devices
			benchmark		
benchmark	Oxford Dictionaries		Oxford Dictionaries		a standard or point of reference against which things may be compared or assessed
benchmark	Wikipedia		Wikipedia	computer	the act of running a computer program, a set of programs, or other operations, in order to assess the relative performance of an object, normally by running a number of standard tests and trials against it
benchmarking	Oxford Dictionaries		Oxford Dictionaries		evaluate or check (something) by comparison with a standard
benchmarking	Wikipedia		Wikipedia	business	the process of comparing one's business processes and performance metrics to industry bests or best practices from other industries
			measurement		
estimator	GB917 rev3	SLA Handbook	TMForum		method to obtain or compute a measured value of a metric (alsothe value itself)
measurement	Journal of research NBS Vol. 86, No 3, May-June 1981	Foundation of Metrology	NBS	metrology	A measurement is a series of manipulations of physical objects or systems according to a defined protocol which results in a number. The number is proported to uniquely represent the magnitude (or intensity) of some quantity embodied in the test object. This number is acquired to form the basis of a decision effecting some human goal or satisfying some human need to satisfaction of which depends on the properties of test object
measurement	JCGM 200:2012	International vocabulary of metrology - Basic and general concepts and associated terms	BIPM	metrology	process of experimentaly obtaining onr or more quantity values that can reasonably be attributed to a quantity
measurement	ISO/IEC 15939	Systems and Software Engineering - Measurement Process	ISO/IEC	software engineering	Set of operations having the object of determining a value of a measure
measurement	SMM	Structured Metrics Metamodel (SMM)	OMG	software engineering	a numerical or symbolic value assigned to an entity by a measure
			measurement unit		
unit of measure	SMM	Structured Metrics Metamodel (SMM)	OMG	software engineering	a quantity in terms of which the magnitudes of other quantities within the same total order can be stated
measurement unit	JCGM 200:2012	International vocabulary of metrology - Basic and general concepts and associated terms	BIPM	metrology	real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number

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