Towards a Data Model for Quality Management Web Services: An Ontology of Measurement for Enterprise Modeling

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Abstract. Though the WWW is used for business process automation to lower costs and shorten leadtimes, arguably its use has been limited for another metric of business success: Improving quality. A promising advancement to the WWW is the development of the Semantic Web, which relies upon using machine process-able domain knowledge represented in ontologies. Therefore, one promising area of research and application is the development of ontologies used as data models to provide quality management services on the Semantic Web. In this paper, the TOVE Measurement Ontology is presented as a formal model of a fundamental domain, which needs to be represented to provide these services. Measurement is fundamental for representing quality because before quality is evaluated and managed, it must first be measured. An assessment system for measuring attributes of an entity, activities for measurement, and quality as conformance to requirements are the core concepts represented in the ontology. The formal representation of measurement is emphasized over detailing context of ontology use, since this is an issue not heavily examined by the ontology community and one that needs to be detailed in order develop data models to provide Semantic Web based quality management services.

1 Introduction

Using Internet technologies to enable novel business processes and link globally disparate entities has led to benefits such as lowered transaction costs and leadtimes. However, what about quality? Though technologies can be used to automate rote operational business processes, quality management processes are often knowledge intensive. It is difficult then to abstract processes' steps, and automate them to

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computer readable instructions. A (computational) enterprise model[1], "a computational representation of the structure, activities, processes, information, resources, people, behavior, goals, and constraints of a business, government, or other enterprise" [1], can be used to encode organizational knowledge. An expressive model represents rich knowledge required for some quality management business processes. A precise model represents this knowledge such that computers can interpret instructions and data as intended by the encoders.

Ontology-based enterprise models are expressive and precise (minimize ambiguity in interpretation). An ontology is a data model that "consists of a representational vocabulary with precise definitions of the meanings of the terms of this vocabulary plus a set of formal axioms that constrain interpretation and well-formed use of these terms" [2]. An ontology can also be considered an explicit representation of shared understanding [3]: Since precise definitions and axioms exist, proper interpretations by and sharing with a computer or a decision maker that did not develop the definitions and axioms are possible.

Yahoo! [4] and *VerticalNet* [5] use ontologies commercially. In Tim Berners-Lee's vision of the Semantic Web [6], computers on the web will automatically find and interpret semantics of key terms and rules, represented in ontologies, necessary for providing web services. If this vision is realized, there are huge implications for businesses. IBM states the provision and use of web services as part of "dynamic e-business, the evolution of our e-business strategy" [7]. Potentially, some quality management functions can be performed as web services, and these in turn can be enabled using quality management ontologies.

Though not explicitly designed for use on the Semantic Web, Kim [8] identifies measurement, traceability, and quality management system as domains fundamental to represent to describe quality. In particular, according to the definition of quality as "conformance to requirements" [9], a more definitive statement about the quality of an entity is possible after measurements are taken and conformance to requirements, evaluated. For instance, Federal Express' quality motto was "measure, measure, measure" [10].

In this paper then, an ontology of measurement is detailed to provide evidence that enterprise models constructed using the ontology can someday enable and automate business processes for provision of quality management web services. In particular, the representations themselves are detailed rather than the context of their uses. This paper is organized as follows. In §2, the ontological engineering methodology used is introduced. In §3, development of ontology representations according to the steps of the methodology is presented. Finally in §4, concluding remarks are made, along with statements about how this work can be extended to provide quality management services via the Semantic Web.

2 Methodology

Shown below is an overview of the methodology [11] used to engineer the TOVE Measurement Ontology.

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[1] Hereto forth, 'enterprise model' refers to computational enterprise model.

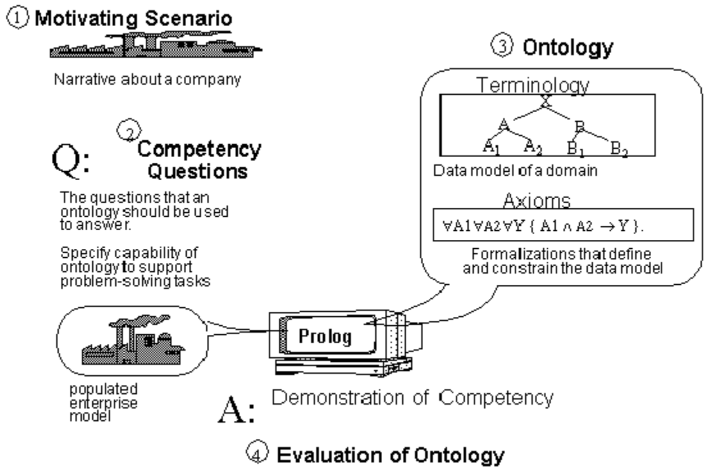

Fig. 1. TOVE Ontological Engineering Methodology

A *Motivating Scenario* is a detailed narrative about a specific enterprise, where emphasis is placed on problems or tasks it faces. When the Motivating Scenario is analyzed, enterprise-independent, generic concepts are abstracted and serve to characterize *Informal Competency Questions* in natural language. Terms with which such queries can be composed comprise the *Terminology*, or data model, of the ontology. Queries re-stated using the terminology are called *Formal Competency Questions*. Answers to these questions can be automatically deduced if *Axioms* that define and constrain the terminology are developed in a formal language with restrictive syntax and semantics, such as First-Order Logic. In this methodology, ontologies are defined using building block ontologies that formalize core enterprise concepts. So, axioms of the measurement ontology are defined using its own terms and/or those from the TOVE Core Ontologies —a collective term for ontologies of activity-state, causality, time, resource, and organizational structure. Deductions using the axioms constitute a *Demonstration of Competency*, which can be implemented in a declarative language like Prolog. If this ontology is used as a schema to construct a populated enterprise model for the specific enterprise analyzed in the Motivating Scenario, the demonstration of competency serves as query-based analysis to solve the enterprise's problems.

3 Measurement Ontology

3.1 Motivating Scenario

BHP Steel is an industrial collaborator for the TOVE Measurement Ontology development. The following excerpt describes its losses with respect to cost, time, and revenue when products of unacceptable quality (called non-prime products) are produced. The key concept abstracted from this excerpt is the following: *There must be a systematic way of describing how a particular physical characteristic is to be* *measured and this description must be used to meet the customer expectations of quality* (**C1**)[2].

- As raw materials are transformed by the different production units of BHP Steel's supply chain, non-prime products may be produced. These are the products whose physical properties do not satisfy necessary tolerance specifications. Non-prime products lead to lost revenue due to re-grading and scrapping, increased costs due to additional rework, carrying of excess inventory to meet delivery promises, and increased variability of leadtime performance.

The next excerpt describes BHP Steel's need to understand and improve its inspection system, the collection of activities that assesses whether a product is non-prime. The key concept is the following: *Quality assessment is made through a system of activities that perform measurement; this is a view of measurement as an activity* (**C2**).

- If products are consistently found to be non-prime, this is an indication that there is something faulty in the production unit. A cause for this occurrence is suspected to be an inadequate inspection processes.

The following excerpt specifies what is entailed in determining a product as non-prime. The key concept is the following: *Every quality assessment is a decision that begins with a value of measurement at a given point in time* (**C3**).

- Especially when the product is shipped to the customer, it is essential that the product satisfy the tolerance specifications of the customer. Therefore, the product's physical characteristics are measured, compared against tolerance specifications, and a decision about whether the product is non-prime is made.

3.2 Informal Competency Questions

Measurement Description System. In order to elaborate (C1), the transformation of the relationship between an entity and its attributes into the more tractable domain of terms, numbers and operators must be modeled. Relationships that describe quality can be represented as requirements on an entity, expressed as a series of equations, A⊗B, where A and B denote qualitative or quantitative measurements upon attributes, and ⊗ denotes a comparison operator. The following then are informal competency questions (ICQ's) about requirements:

- Is this a quality requirement? (**ICQ-1**)
- What are the physical characteristics that are measured? (**ICQ-2**)

In measuring physical characteristics, one important aspect is sampling, which occurs when a subset of a population of an evaluated entity is measured, rather than the whole population [12]. The following are some questions for representing sampling:

- Is every entity that is produced measured? (**ICQ-3**)

[2] stands for Concept #1

- If the product is a batch, is a sample taken from that batch and measured? (**ICQ-4**)
- If a sample is taken and measured, is the value for the measurement some aggregate (e.g. average) of the measurement upon individual units of that sample? (**ICQ-5**)
- Or, is the value of the measurement a measure of whether or not individual units of the sample passed or failed a certain threshold (e.g. % of widgets of the sample which are <10cm)? (**ICQ-6**)

In order to measure, there must be a way to systematically describe a measurement. This description system must minimally include the appropriate attributes of an entity to measure, as well as each of the attributes' mean (μ), distribution (connoted by its standard deviation, σ), and comparison operator ($\otimes$) for comparing measured values against μ and σ. Hopefully, the value of a measurement for a physical characteristic falls within certain tolerance specifications, which can be described with μ, σ and $\otimes$. So, the following can be asked:

- What ought to be the measured value; that is, what is the expected value for that physical characteristic? (**ICQ-7**)
- What are the tolerance specifications for a physical characteristic that is measured? (**ICQ-8**)

Measurements are ambiguous without their relevant units of measurements. So, the following can be asked:

- What is the unit of measurement for a physical characteristic of an entity? (**ICQ-9**)

Measurement Activities. In order to elaborate (C2), the following questions about measurement and inspection can be asked.

- Is this an activity that performs measurement? (**ICQ-10**)
- Is this an inspection activity? (**ICQ-11**)

Measurement Points. In order to elaborate (C3), the elemental piece of information needed to make a quality assessment decision can be represented as the value of a measurement taken at a point in time. Following are questions about quality that build on this.

- What is the measured value for a physical characteristic at a given point in time? (**ICQ-12**)
- What are the measured values for a physical characteristic during a given period of time? (**ICQ-13**)
- Is an entity of "good" quality at a given point in time? (**ICQ-14**)
- Is an entity of "bad" quality at a given point in time? (**ICQ-15**)
- Is an entity of conforming quality over a given period of time? (**ICQ-16**)

These questions need to be expressed more formally using terms from the TOVE Measurement Ontology, which are shown next.

3.3 Terminology & Formal Competency Questions

Measurement Description System. To formally express (ICQ-1) and (ICQ-2), the following terms are included in the TOVE Measurement Ontology:

quality_requirement(Qr) **(Term-1)**
<Qr> A quality related organizational constraint
measured_attribute(At) **(Term-2)**
<At>[3] A physical characteristic for an entity that has a bearing on the quality of the entity

To formally express (ICQ-3) to (ICQ-6), the relationship between an attribute <Atr> of a *resource*—e.g. 'arm length' of an 'arm assembly'—and a measured attribute <At> of a set or batch (also called a *traceable resource unit* or *tru*) of that resource—e.g. 'average arm length' of the measured sample from a 'lot of arm assemblies'—is represented. tru and resource are terms from the TOVE Core Ontologies.

- samples_attribute(Atr,At) **(Term-3)**

There are two additional issues regarding sampling.

- *sample size*: How many individuals in a set are measured in order to model the characteristics of the set? Sample size type <Sz> can be classified as one of:
  - *sample*: set size > sample size > 1
  - *unit sample*: set size > sample size = 1
  - *unit population*: set size = sample size = 1
  - *population*: set size = sample size > 1
- *sampling plan*: When determining an aggregate value from the sample, does it refer directly to the actual attribute that is physically measured—e.g. 'average arm length'—or is the reference indirect—e.g. '# nonconforming of a sample'? In statistics, the former sampling plan type <Sp> is called *variable sampling*, the latter, *attribute sampling*.

So the following are represented:

- has_sample_sizing(At,Sz) (**Term-4**)
- has_sampling_plan(At,Sp) (**Term-5**)

To formally express (ICQ-7) to (ICQ-8), a standard mean value μ <Mu> for what the value of a measured attribute <At> must be is represented as well as a function of μ and σ^2 ($f(\mu,\sigma^2)$) and an operator ($\otimes$). Then, the value of each measurement can be compared to this function, so that some evaluation of "acceptability" of the entity measured can be made. The challenge for representation is the following: How can $f(\mu,\sigma^2)$ and $\otimes$ be represented when measured values are not of ratio scale? Although σ^2 cannot be represented non-numerically, $f(\mu,\sigma^2)$ can, if it is assumed that $f(\mu,\sigma^2)$ is a subset of the range of all possible measured values. For a measured attribute <At>, this subset is given a generic term called a *specification set* <SL>, where elements of this subset denote "acceptable" measurement values:

[3] A variable or parameter of a term is denoted within <> brackets when the term is defined. <At> denotes that 'At' is one of the variables of the term *measured attribute*, e.g. if At='average widget length' for the expression measured_attribute(At) then this is read as "average widget length is a measured attribute."

- has_standard_value(At,Mu) (**Term-6**)
- has_specification_set(At,SL) (**Term-7**)

To formally express (ICQ-9), a description system for a measured attribute <At> that describes a unit of measurement <U> is represented:

- has_unit_of_measurement(At,U) (**Term-8**)

Below is a data model of the Measurement Description System represented in the TOVE Measurement Ontology.

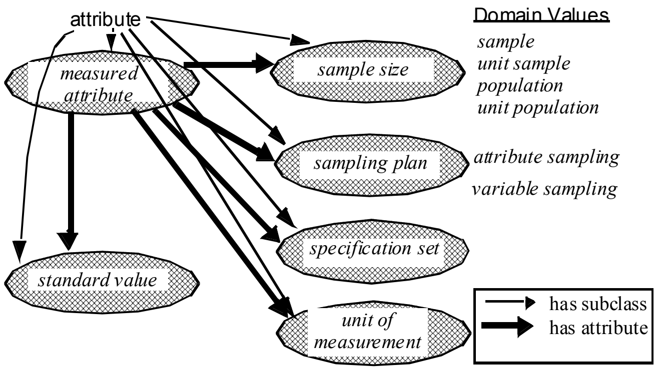

Fig. 2. Measurement Description System Data Model

Measurement Activities. The simplest measurement action is the measurement of one measured attribute of one tru at one point in time. When this measurement is performed using a special resource <R> called a *measuring resource*, this activity <A> is a *primitive measure* activity. A primitive measure activity or an aggregation of primitive measure activities is a *measure* activity. An *inspection and test* activity is a form of a measure activity. The following terms then are used to formally express (ICQ-9) and (ICQ-10).

- measuring_resource(R) (**Term-9**)
- primitive_measure(A) (**Term-10**)
- measure(A) (**Term-11**)
- inspect_and_test(A) (**Term-12**)

Measurement Point. To formally express (ICQ-12) and (ICQ-13), the result of a measurement activity is represented using a *measurement point* <Mp>, which relates the value of the measurement, and concomitantly the measured attribute <At>, the time of measurement <Tp>, and tru measured <Rt>.

- measurement_pt(Rt,At,Mp,Tp) (**Term-13**)

If a measurement point is assessed to be "acceptable"—i.e. the point is an element within the specification set—then a *conformance point* <Q> is represented along with the related tru <Rt>, measured attribute <At>, and time of measurement <Tp>. If it is not "acceptable" then a *nonconformance point* with the same related variables is represented.

- conformance_pt(Q,Rt,At,Tp) **(Term-14)**
- nonconformance_pt(Q,Rt,At,Tp) **(Term-15)**

A given quality requirement <Qr> on an entity <X> can then be written as a composition of conformance points—e.g. "X meets its quality requirements if all measurement points for a measured attribute of various trus whose measurements related to X's quality during a given time period are conformance points." The following term then represents the concept that "quality is conformance to requirements."

- conforming_quality(X,Qr) (**Term-16**)

With these terms that describe measurement points, (ICQ-14) to (ICQ-16) can be formally expressed. Informal competency questions can now be stated formally since the terminology with which the questions can be re-posed are developed.

3.4 Formal Competency Questions

For brevity, only some of the competency questions are presented, and in the following manner:

- The informal competency question is stated.
- The informal competency question is re-stated in English with the terminology developed from the ontology
- The competency question is stated formally in First-Order Logic.

For consistency with other TOVE ontologies, the situation calculus [13] is used to represent measurement ontology expressions. In situation calculus, each perturbation to the modeled world changes the world from one *situation* <s> to another. If the truth value of a term that describes an entity in this world or a relationship between entities varies from situation to situation, then the term is a *fluent* <*f*>. A fluent *holds* in a given situation if the term is true in that given situation. So, ontology expressions are of the form *holds*(*f*,s).

Measurement Description System.

- Is this a quality requirement? Does there exist a quality requirement 'θρ'[4] in a situation 'σ'?

$$holds(\text{quality\_requirement}(\theta\rho),\sigma). \qquad \textbf{(CQ-1)}^{5}$$

- What are the physical characteristics that are measured? Does there exist a measured attribute <At> for a tru 'κ' in a situation 'σ'?

$$\exists At\ [holds(\text{tru}(\kappa),\sigma) \wedge holds(\text{has\_attribute}(\kappa,At),\sigma) \wedge holds(\text{measured\_attribute}(At),\sigma)]. \qquad \textbf{(CQ-2)}$$

[4] Facts or constants (as opposed to variables) expressed in competency questions are denoted within single quotes. For example, 'σ' and 'sample_population' are constants that are bound to variables.

[5] Stands for Competency Question #1, which is the formal representation of Informal Competency Question #1

has_attribute(X,At) is from Core Ontologies: an object <X> has an attribute named <At>.

- If the product is a batch, is a sample taken from that batch and measured? That is, for a measured attribute ‘α’ of a tru ‘κ’ in a given situation ‘σ’, does it have a ‘unit sample’ or ‘sample’ sample sizing plan?

$$\begin{array}{l} holds(\text{tru}(\kappa),\sigma) \wedge holds(\text{has\_attribute}(\kappa,\alpha),\sigma) \wedge \\ \quad holds(\text{measured\_attribute}(\alpha),\sigma) \wedge \\ (\ holds(\text{has\_sample\_sizing}(\alpha,\text{unit\_sample}),\sigma) \vee \\ \quad holds(\text{has\_sample\_sizing}(\alpha,\text{sample}),\sigma)\ ). \end{array} \quad \textbf{(CQ-4)}$$

- What are the tolerance specifications for a physical characteristic that is measured? For a measured attribute ‘α’ in a given situation ‘σ’, does there exist a specification set (expressed as an interval [$<T_1>$,$<T_2>$] or a list {$<W_i>$}?

$$\begin{array}{l} \exists T_1 \exists T_2 \exists \{W_i\}\ [holds(\text{measured\_attribute}(\alpha),\sigma) \wedge \\ (\ holds(\text{has\_specification\_set}(\alpha,[T_1,T_2]),\sigma) \vee \\ holds(\text{has\_specification\_set}(\alpha,\{W_i\}),\sigma)\ )\ ]. \end{array} \quad \textbf{(CQ-8)}$$

Measurement Activities.

Is this an activity that performs measurement? Is ‘α’ a measure activity in a situation ‘σ’?

$$holds(\text{measure}(\alpha),\sigma). \quad \textbf{(CQ-10)}$$

Measurement Points.

What are the measured values for a physical characteristic during a given period of time? What are the measurement points <Mp> for a measured attribute ‘κ’ of an entity ‘ξ’ for time points <Tp> within the duration [‘τ_1’,τ_2’] for a given situation ‘σ’?

$$holds(\text{measurement\_pt}(\xi,\kappa,Mp,Tp),s) \wedge Tp \geq \tau_1 \wedge Tp \leq \tau_2 \rightarrow f(Tp,Mp). \quad \textbf{(CQ-13)}$$

Where f(Tp,Mp) is just a graphing function that plots Tp vs. Mp.

Is an entity of conforming quality over a given period of time? For all time points <Tp> within a given time duration [‘τ_1’,τ_2’] for a given situation ‘σ’, does there always exist a conformance point <Q> for different trus <Rt> comprised of resource ‘ξ’, for the attribute ‘κ’?

$$\begin{array}{l} \forall Rt \forall Tp\ [Tp \geq \tau_1 \wedge Tp \leq \tau_2 \wedge \tau_1 < \tau_2 \wedge holds(\text{has\_tru}(\xi,Rt),s) \rightarrow \\ \quad \exists Q\ holds(\text{conformance\_pt}(Q,Rt,\kappa,Tp),\sigma)\ ]. \end{array} \quad \textbf{(CQ-16)}$$

Next, some of the axioms required to deduce answers to these questions are stated.

3.5 Axioms

Measurement Description System. A *quality requirement* is stated as a *primitive term*—a term that is instantiated and stated as a fact in the populated enterprise model. All *definition* axioms of an ontology are ultimately formally defined in terms of primitive terms. By applying *constraint* axioms, proper use of primitive terms is enforced. Primitive terms are populated (instantiated) as *ground terms*; e.g. a fact that 'widget119' is a resource is represented as a ground term, resource(widget119), which is an instance of the primitive term, resource(R). The term, *measured attribute*, is also a primitive term. In the TOVE Measurement Ontology, the quality of an activity is evaluated by the quality of resources associated with that activity; and the quality of a resource (prototypical product) is gauged by the quality of trus comprised of individual units of that resource. The following axioms express this:

A measured attribute must be an attribute of a tru. (**Cons-1**)[6]

A measured attribute must be sampled from an attribute of a resource.

$$\forall At \forall s\ [\ holds(\text{measured\_attribute}(At),s) \rightarrow \exists Atr \exists R\ (\ holds(\text{samples\_attribute}(Atr,At),s) \wedge holds(\text{has\_attribute}(R,Atr),s) \wedge holds(\text{resource}(R),s)\ )\ ].$$

<At> measured attribute **(Cons-2)**
<Atr> attribute sampled for At
<Rt> tru for which At is an attribute
<R> resource for which Atr is an attribute
<s> an extant or hypothetical situation

In order to express the above constraint, the term, *samples attribute*, is also represented as a primitive term. These axioms ensure valid answers for (CQ-1) and (CQ-2). Additional such constraints constrain the use of the primitive terms, *has sample sizing*, *has sampling plan*, *has standard value*, *has specification set*, and *has unit of measurement*. The following axiom ensures valid answers for (CQ-8).

All measured attributes must have a specification set, and the standard value for that measured attribute must be an element of the specification set.

$$\forall At \forall Mu \forall s\ [holds(\text{has\_standard\_value}(At,Mu),s) \rightarrow \exists T_1 \exists T_2 (holds(\text{has\_specification\_set}(At,[T_1,T_2]),s) \wedge T_1 \leq Mu \leq T_2) \vee \exists \{W_i\}\ (holds(\text{has\_specification\_set}(At,\{W_i\}),s) \wedge Mu \in \{W_i\})\ ]$$

<At>a measured attribute **(Cons-3)**
[<T_1>,<T_2>] upper and lower bounds of a specification set for a measured attribute of ratio scale
$\{W_i\}$ a set of "acceptable" values for the measured attribute
<Mu>the standard value for At
<s>an extant or hypothetical situation

Measurement Activities. A *primitive measure* activity is a *primitive activity* (an activity without any sub-activities) that *uses* a *measuring resource* (a primitive term) to measure the measured attribute of a *consumed* tru.

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6 Stands for Constraint #1

$$\forall A\,\forall s\,\exists R\,\exists At\,\exists Rt\ [\ \text{holds}(primitive\_activity(A),s) \wedge \\ \text{holds}(use\_res\_tru(A,R),s) \wedge \\ \text{holds}(measuring\_resource(R),s) \wedge \\ \text{holds}(consume\_res\_tru(A,Rt),s) \wedge \\ \text{holds}(has\_attribute(Rt,At),s) \wedge \text{holds}(tru(Rt),s) \wedge \\ \text{holds}(measured\_attribute(At),s)\ ) \\ \rightarrow \text{holds}(primitive\_measure(A),s)\ ].$$

(Defn-1)[7]

<At> measured attribute
<A> primitive measure activity
<Atr> attribute sampled for At
<Rt> tru for which At is an attribute
<R> resource for which Atr is an attribute
<s> an extant or hypothetical situation

- primitive_activity(A) is from Core Ontologies
- use_res_tru(Ax,Rx) and consume_res_tru(Ax,Rx) are from Core Ontologies. If an activity <Ax> uses a resource or tru <Rx>, then it does not materially change Rx; if <Ax> consumes <Rx>, then it changes a fundamental property of <Rx>. Note <A> ⊆ <Ax>, <R> ⊆ <Rx>, and <Rt> ⊆ <Rx>.

Then, any *measure* activity can be composed from primitive measure activities; i.e. it is a primitive measure activity or an aggregation of measure activities (**Defn-2**). This definition ensures an answer for (CQ-10).

Measurement Points. A *measurement point* is defined to be the *value* for the measured attribute of a tru that is measured by a primitive measure activity at a *time point* included in the *activity duration* for that primitive measure activity. Using the axiom below, (CQ-13) can be answered.

$$\forall Rt\,\forall At\,\forall Mp\ \forall s\,\exists T\,\exists Tp\ [\ \text{holds}(measured\_attribute(At),s) \wedge \\ \text{holds}(has\_attribute(Rt,At),s) \wedge \\ \text{holds}(has\_attribute\_value(Rt,At,Mp),s) \wedge \\ \exists A\ (\ \text{holds}(tru(Rt),s) \wedge \text{holds}(consume\_res\_tru(A,Rt),s) \wedge \\ \text{holds}(primitive\_measure(A),s) \wedge \\ activity\_duration(A,T) \wedge has\_point(T,Tp)\ ) \rightarrow \\ \text{holds}(measurement\_pt(Rt,At,Mp,Tp),s)\ ].$$

(Defn-3)

<Rt> a tru for which there exists a measurement point
<At> a measured attribute of Rt
<Tp> time point for which Mp is the measurement point for Rt
<Mp> value of that measurement point
<T> time period in which the measurement takes place
<A> the primitive measure activity that ascertains the measurement point

[7] Stands for Definition #1

<s> an extant or hypothetical situation
has_attribute_value(X,Atx,V) is from the Core Ontologies: An object <X> has a value <V> for its attribute <Atx>. Note <Rt> ⊆ <X>, <At> ⊆ <Atx>, and <Mp> ⊆ <V>.
activity_duration(Ax,Tx) is from the Core Ontologies: Any activity <Ax> is performed during a time period <Tx>. Note <A> ⊆ <Ax> and <T> ⊆ <Tx>.
has_point(Tx,Tpx) is from the Core Ontologies: Time points <Tpx> are within the time period <Tx>. Note <T> ⊆ <Tx> and <Tp> ⊆ <Tpx>.

A *conformance point* is defined as a measurement point of a tru that lies within the specification set (**Defn-4**). Otherwise, that measurement point is a *nonconformance point* (**Defn-5**).

Then, conformance points of other entities like resources, activities, or even organization agents can be defined in terms of conformance points of trus. For example, conformance points of an activity can be defined in terms of conformance points of trus produced by the activity, and conformance points of an organization agent can be defined in terms of conformance points of trus produced by activities performed by that agent.

3.6 Quality Management Analysis

In the TOVE Core Ontologies, an *agent constraint* is a special fluent that represents a constraint upon an *organization agent,* which must be satisfied in order for that agent to achieve some goal. For instance, ISO 9000 compliance can be represented as goal that is achieved if a set of quality-related agent constraints upon an enterprise is satisfied. The following is the formal representation:

$$\text{Holds}(agent\_constraint(Oa,c(\underline{X})),s) \leftrightarrow \Phi(Oa,\underline{X},s).$$

<s> a given situation
<Oa> an organization agent which seeks to achieve a goal in situation s
<X̲> entities that must be represented in order to represent the constraints on Oa; X̲ is a vector with none, one, or more entities **(Defn-6)**
<c(X̲)> predicate name for the agent constraint
<Φ(A,X̲,s)> a first-order logic expression for the constraint described as c(X̲)

Since a key concept set before developing the Measurement Ontology is that *every quality assessment is a decision that begins with a value of measurement at a given point in time*, it follows that a quality requirement should be expressed as a composition of conformance and nonconformance points. Regardless of how it is expressed, if an agent constraint that constrains an entity <X>, is satisfied in situation <s> and is a quality requirement <Qr>, then the entity is evaluated as *of conforming quality* with respect to that quality requirement.

$$\forall X \forall Qr \forall s\ [\text{holds}(conforming\_quality(X,Qr),s) \leftrightarrow \text{holds}(agent\_constraint(X,Qr),s) \wedge \text{holds}(quality\_requirement(Qr),s)\ ]. \quad \textbf{(Defn-7)}$$

With these axioms, (CQ-16) can be answered. In fact, it looks like a prototypical quality requirement: Within time interval [‘τ_1’,‘τ_2’], all measurements for the attribute ‘κ’ of batches (or lots) of the resource ‘ξ’ must be within specs.

Then quality analysis using the TOVE Measurement Ontology can follow the same steps used to construct the ontology:

1. *Motivating Scenario*: Write a narrative about a specific quality issues related to an entity.
2. *Informal Competency Questions*. Write out the quality requirements for the entity informally in natural language.
3. *Terminology*: Organize useful terminology from existing ontologies.
4. *Formal Competency Questions*: State informally stated quality requirements as a First-Order Logic expression using ontology terminology, especially conformance and nonconformance points.
5. *Axioms*: Organize the axioms that constrains or defines the relevant terminology.
6. *Answer Competency Questions*: If the facts about an entity are represented as ground terms—e.g. *holds*(measured_attribute(average_length),s10) and *holds*(measurement_pt (tru123,average_length,2, 10),s10)—axioms are applied to ground terms to deduce whether a quality requirement is satisfied.

For brevity, the demonstration of competency is not shown. It can be found in [8].

4 Conclusion

First, though the WWW is used for business process automation to lower costs and shorten leadtimes, its use is limited for another metric of business success: Improving quality. Second, a promising advancement to the WWW is the development of the Semantic Web, which relies upon using machine process-able domain knowledge represented in ontologies. Therefore, one promising area of research and application is the development of ontologies as data models to provide quality management services on the Semantic Web. In this paper, the TOVE Measurement Ontology is presented as a formalization of a fundamental domain, which needs to be represented to provide these services. The following summarize the generic concepts represented:

- A system for assessing measurements includes the appropriate *measured attribute*, as well as its *standard value* (μ), *sampling plan* and *size*, *specification set* of “acceptable values” of $f(\mu,\sigma^2)$, and *unit of measurement*. Measurement of attributes are recorded as *measurement points* in time that are assigned a value as a result of some *measure* activity. These representations are the basic ones necessary to model any form of measurement.
- Quality can be represented as some composition of *conformance points*, which are “conforming” *measurement points* with respect to some *quality requirement*.

Representing quality requirements, measurement points, and conformance points makes it possible to model and assess any entity within an enterprise as of *conforming quality*.

These concepts are formally represented by: Posing competency questions, analyzing the domain of measurement, stating assumptions, and developing terminology and axioms.

The main contribution of this paper is that representations themselves and the methodology used to develop them are detailed. These have been emphasized over discussions of other important issues such as related works in measurement modeling [14], mechanics of providing web services (e.g. use of software agents [15]), and whether ontologies and the Semantic Web will even be commercially adopted [16][17] In this paper, the content of quality management ontologies are disseminated over the context of their uses.

The "content vs. context" dichotomy serves as a framework for future work. For content, formally representing other domains fundamental to quality management such as traceability and the quality management system is planned, as is applying these ontologies for providing a quality management service—automatic ISO 9000 compliance evaluation. For context, an interesting research area is in ontological engineering methodologies for the Semantic Web. The ontological engineering community has known that in order for ontologies to be adopted, they must be competent for "local," known applications yet re-usable for "foreign," unknown applications in order to justify the substantial effort in knowledge representation. However, possible emergence of the Semantic Web as a readily accessible infrastructure means that assumptions about "foreign" applications inherent in many existing methodologies —e.g. that those using others' ontologies are ontological engineers, who have reasonable knowledge of the domain represented in shared ontologies—may not necessarily hold, inasmuch as the accessibility of the WWW enabled access to documents by those whom the documents' authors could not have anticipated as readers. The opportunity then is in researching development of adaptive and flexible ontologies.

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