Kim, H., and Fox, M.S., (1994), "Formal Models of Quality and ISO 9000 Compliance: An Information Systems Approach", American Quality Congress (AQC) Conference, American Society for Quality Control, Las Vegas NV.

FORMAL MODELS OF QUALITY AND ISO 9000 COMPLIANCE:

AN INFORMATION SYSTEMS APPROACH

Henry M. Kim & Mark S. Fox
Department of Industrial Engineering
University of Toronto
4 Taddle Creek Road
Toronto, Ontario CANADA
M5S 1A4

SUMMARY

In this paper, a formal approach is taken to organize the body of knowledge about quality. The body of knowledge thus formalized is structured into: TOVE Quality Ontology, and the ISO 9003 Micro-Theory. The TOVE Quality Ontology represents a prototype formalization, researched from ISO 9000 and other quality management references, but independent of any one source. And the ISO 9003 Micro-Theory consists of axioms for determining ISO 9003 compliance. The TOVE Quality Ontology and the ISO 9003 Micro-Theory are used in conjunction with a computer-based model of a lamp-making company to test the ISO 9003 compliance of the company. ISO 9003 compliance tests are run on different configurations of the model of this company. Since TOVE is based upon a generic, re-usable methodology of modeling an enterprise, the TOVE Quality Ontology and the ISO 9003 Micro-Theory can be applied to a model of any organization constructed using such a methodology to test ISO 9003 compliance.

INTRODUCTION

A systematic approach to quality management, that is a systems perspective of quality— total quality management (TQM) is a commonly-used term for this approach— is a key factor in the drive to achieving world-class behavior and delighting the customer [Sullivan 90]. In this paper, a formalization of this systems perspective of quality is pursued; that is, the terminology, concepts and structures about quality are systematically identified and classified. Moreover an information systems approach— one in which this formalization is coded in a computer language— is used to show how this formalization can be used to automate ISO 9003 compliance verification.

The systems approach to any endeavour requires rigorous methodology. Systems thinking entails classification of objects according to common characteristics, and identification of hierarchical relationships of these classifications; identification of the nature of interrelationships and interdependencies between objects; and recognition of both cause and effect and synergism between objects [Turner et. al. 93]. An ontology of a given subject is defined as "A formal description of entities, properties, relationships, and roles that someone familiar with the concept normally associates with it... Ontological engineering is the process by which a domain is analyzed to ascertain the ontological primitives."[1], and represents formalized output of the systematic thinking about that subject. Development of ontologies for the purpose of representing qualitative knowledge within a computer is a discipline of research within the field of artificial intelligence. And Godfrey of the Juran Institute has listed information systems for quality as one of the ten clear quality trends for the next ten years [Godfrey 93]. Hence an ontology of quality serves to represent the terminology, concepts, and structures on the subject of quality, such that this can be represented as a new type of quality information within the computer: The type of information that is used not merely for computation and display— as traditional quality information systems are used— but also the type of information with which reasoning and inferences— simulating intelligent decision-making capability— can be made.

Ultimately the usefulness of this information systems approach to quality is two-fold:

1. To formally organize the body of knowledge about quality.
2. To use this formalization to reason about product, process, or system-wide quality, so that better quality management decisions can be made.

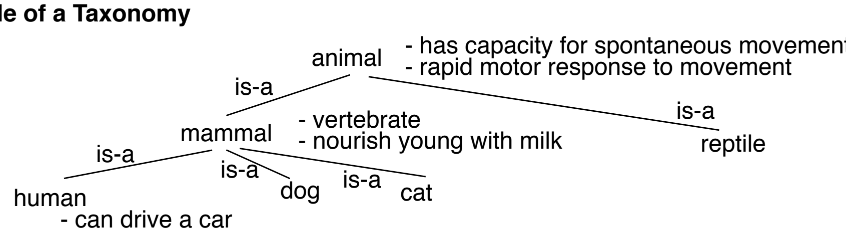
ONTOLOGICAL ENGINEERING

> "All knowledge-based systems refer to entities in the world, but in order to capture the breadth of human knowledge, we need a well-designed global ontology that specifies at a very high level what kind of things exist and what their general properties are."[2]

Gruber outlines that the ontological engineering process entails associating human-readable terms in the universe of discourse (the domain) to computer-readable classes (A collection of entities organized as one because they share common properties), relations (relationships between these entities), and functions; and stating formal axioms (roles within the domain) that constrain the interpretation and proper use of these terms [Gruber 93]. Thus the ontological engineering process creates a data model of terms of the domain, and specifies axioms that define and constrain the terminology (definitions in a formal language such as first-order logic).

One of the first steps in creating an ontology is the development of a data model composed of classification hierarchy of terms (e.g. objects and their properties), a taxonomy, a tree structure displaying *is-a* relationships in a hierarchical manner. Figure 1 is an example of a taxonomy. Note that we easily deduce that human *is-a* animal, even though it is not explicitly stated. Note also that properties of animal are inherited to human, such that these are implied to apply to human. That such deductions and implications are possible show that a taxonomy implies more beyond what is stated. Because a taxonomy organizes the terms within the domain, and associates implicit information about the terms, it is an invaluable construct for ontological engineering.

Figure 1: Example of a Taxonomy



The axiomatization entails defining and constraining the interpretation of the terms of the data model. So for example, *All animals have capacity for spontaneous movement*, or *There exists a human who can drive a car* are examples of axioms about animals. This example shows that the number of axioms about a domain really are unbounded. The concept of minimal ontological commitment, though, is a way of bounding the number of axioms

[Newell 82][Gruber 93]. This restricts axioms to those required to minimally describe a domain, and focused upon definitions. Thus the ontology offers only minimal commitment to give details or facilitate problem solving about the domain; another set of axioms, as different from the ontology axioms, can be developed for details or problem solving. In the example, *All animals have capacity for spontaneous movement* is an axiom that meets this minimal commitment criterion and belongs in the ontology, since this axiom is one which defines animal as separate from plant or mineral. *There exists a human who can drive a car* is an axiom that is not germane to the description of the animal domain, and does not belong in the animal ontology.

A more formal dissertation of the domain beyond the ontology is the micro-theory of that domain. A micro-theory of a domain consists of:

- ontology
- locally consistent semantics
- axioms that describe details about the domain, or can facilitate problem solving within the domain

This entails formalization beyond that which is required to just describe a domain. For one, a more complete body of knowledge, required to solve a problem in that domain or to describe in greater detail a subset of the domain, needs to be axiomatized. Moreover it must be ensured that the way the terms are used and the meaning of the terms in these more complete axioms are consistent with that of the ontology of the domain. So for example the animal ontology can be combined with axioms such as *There exists a human who can drive a car* and *No animal other than human can move with the aid of mechanical devices* to develop a micro-theory of animal transportation.

TOVE QUALITY ONTOLOGY

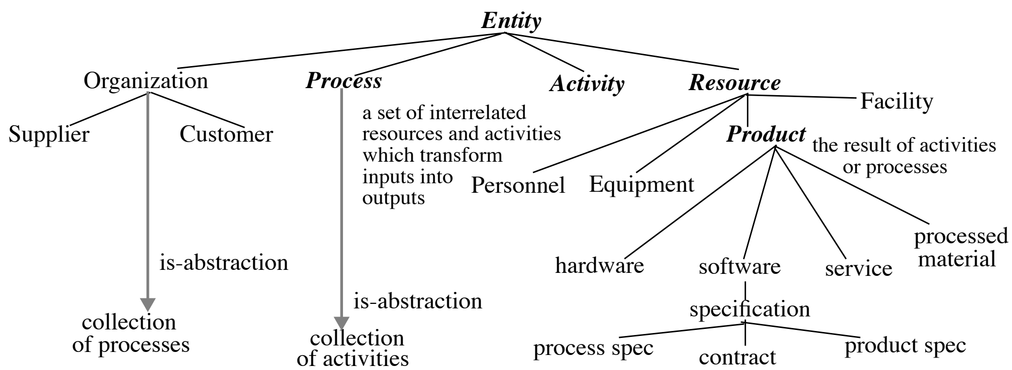
TOVE Effort

The formalization of quality knowledge is performed within the context of TOVE Enterprise Ontology project at the Enterprise Integration Laboratory at the University of Toronto. The project focus is to construct generic, re-usable ontologies spanning various types of enterprise knowledge. The Toronto Virtual Enterprise (TOVE) Enterprise Ontology is implemented on top of C++ using the ROCK™ knowledge representation tool from the Carnegie Group. The TOVE Enterprise Ontology currently spans knowledge of quality, costing, organization, agility, time-based competition, activity/states, time, causality, and resources. The TOVE testbed provides an environment for analyzing enterprise ontologies, and defines a virtual enterprise model and accompanying tools for browsing, visualizing, simulating, and deductively querying about the enterprise [Fox et. al. 93]. Hence the formalization described in this paper is called the TOVE Quality Ontology.

Partial Data Model of TOVE Quality Ontology

In order to formalize the body of knowledge about quality, one term must first be defined. This is the definition for any “thing”, for which its quality is a relevant factor. The term used in the ISO 9000 is entity: *In this standard, the term entity includes the term product, but extends further to cover, for example, activity, process, organization, or person*[3]. The specific entities mentioned in the definition should also be defined. These facilitate the development of a taxonomy for entity.

Figure 2: Entity Taxonomy



This taxonomy displays a portion of the data model of the TOVE Quality Ontology. Note that the definitions for process and product are given in terms of activities and resources. In fact all the other terms in the taxonomy are defined in terms of activities and resources. Hence these two terms, along with the term, entity, are primitive terms in the TOVE Quality Ontology, with which other terms are defined.

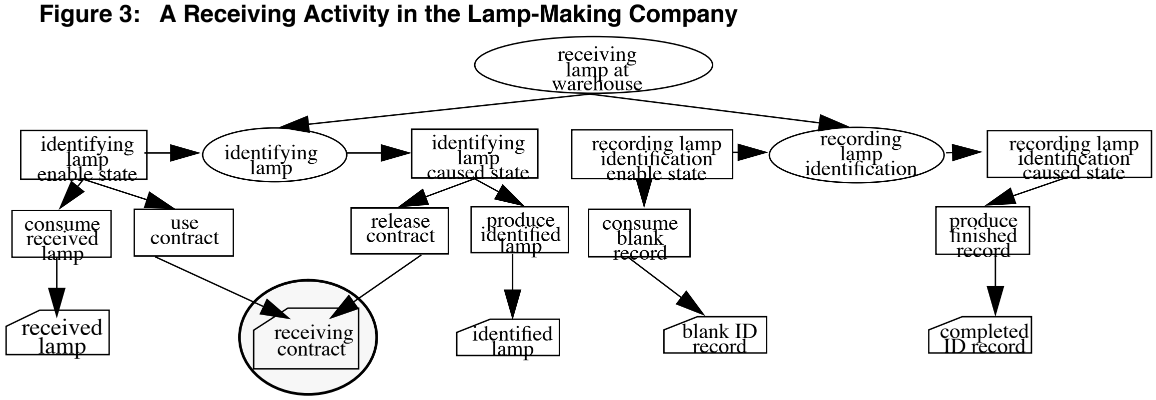
Excerpt of TOVE Quality Ontology

A sample axiom from the TOVE Quality Ontology is:

- In order for a specification to be deemed a contract: There must exist a supplier-customer relationship between two organizations, and the customer organization must provide a set of specifications to the supplier.

Shown below is an activity from the enterprise model from the TOVE testbed. Note that this activity uses and releases a receiving contract. An example of how this enterprise model interacts with the TOVE Quality Ontology is this: Within the TOVE testbed environment, whether the receiving contract is indeed a contract, as defined by the TOVE Quality Ontology, can be tested by checking whether the properties associated the receiving contract satisfy the axiom stated above. If it does not, then the analysis capability of the TOVE testbed can state why it is not.

Figure 3: A Receiving Activity in the Lamp-Making Company



Usefulness of TOVE Quality Ontology

The entity taxonomy shown and the axioms that define the terms in the taxonomy are necessary in order to formally describe quality: In order to assess the quality of something, it must be possible to ascertain what that something is, what kind of a thing it is, or what are the activities that must be performed to create that something. The objects required to answer the above questions then naturally form the rudiments of the TOVE Quality Ontology. The prototype TOVE Quality Ontology contains constructs to meet the first purpose of this paper: To formally organize the body of knowledge about quality.

With this prototype, the second purpose can be addressed: To use this formalization to reason about product, process, or system-wide quality, so that better quality management decisions can be made. By organizing more specific axioms about quality— e.g. what makes one product "better"— asking relevant questions useful for management decision-making, and reasoning about the answers is possible. Fulfillment of this purpose is the impetus for developing the ISO 9003 Micro-theory.

ISO 9003 COMPLIANCE MICRO-THEORY

Decision-Making about ISO 9003 Compliance using the Information Systems Approach

One of the basic tenets of quality management is that the quality of an entity cannot be improved unless its quality can be measured. Customer surveys can measure product or service quality, and statistical process control can measure process quality. The ISO 9000 standards aim to define threshold specifications for quality systems. Since the TOVE Quality Ontology relates all entities within an organization, and the TOVE model is a model of an organization, ascertaining quality about the organizational quality system should be pursued. The ISO 9003— one of the ISO 9000 standards, which presents a model of a quality system for quality assurance in final inspection and test— has been chosen to formalize a specific body of quality knowledge. This formalization is realized in the ISO 9003 micro-theory.

The ISO 9003 compliance micro-theory consists of a consistent set of syntax and semantics to represent the ISO 9003 requirements, an ontology of terms and structures of the ISO 9003, and axioms on how an organization can be ISO 9003 compliant. The ISO 9003 micro-theory can be used in conjunction with the TOVE Quality Ontology and the TOVE enterprise model to show decision-making capability about quality; the primary decision being whether the TOVE enterprise model is ISO 9003 compliant.

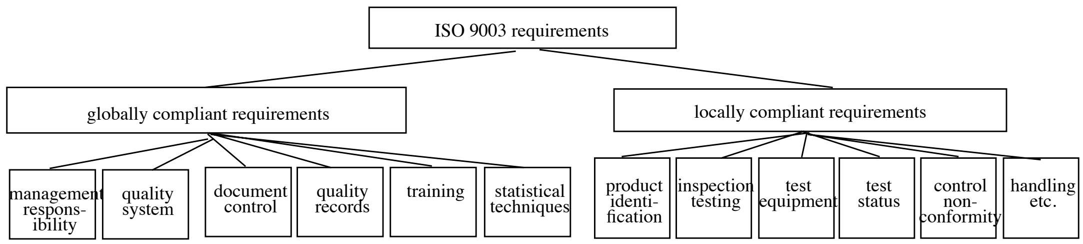
This information systems approach for ISO 9003 compliance has following merits:

- Since both the information systems model and the ISO 9003 compliance micro-theory are abstractions of reality, these cannot take place of a thorough manual audit. However nonconformities identified using these models are likely to be the major ones. The major nonconformities identified thusly can be corrected without an expensive external auditor, and may minimize several iterations of audits.
- Moreover the enterprise model/ISO 9003 micro-theory program interaction can be performed anytime that a quality audit is needed. Thus it is much more flexible, responsive, and cost-effective than time-consuming manual audits.

Excerpt of ISO 9003 Micro-Theory

The ISO 9003 Micro-theory classifies ISO 9003 requirements into requirements that can be met by just one process of an enterprise (locally compliant requirements), and requirements that require several or all processes of the enterprise (globally compliant requirements). This classification of ISO 9003 requirements into two types is suggested by [Lamprecht 93].

Figure 4: Taxonomy of ISO 9003 Requirements



An exempler axiom from the micro-theory is: In order for the product identification process to be ISO 9003 compliant:

- a contract between the supplier and the organization must be a resource used in the product identification process, and
- an identified product must be output of the product identification process, and
- a record of the product being identified must be an output of the product identification process.

CONCLUSION

The actual working implementation solves the problem of ISO 9003 compliance by: Interaction between the TOVE Quality Ontology, ISO 9003 Micro-Theory, and the TOVE Enterprise Model, facilitated in the Prolog software which supports query and inference. The query *Is TOVE ISO 9003 Compliant?* activates an examination of the set of activities and resources of the TOVE enterprise model for compliance to one of the ISO 9003 requirements (expressed as a set of axioms in the ISO 9003 Micro-Theory). After conducting the examination of all the requirements, and verifying that the TOVE enterprise model does indeed have the requisite activities and resources, an answer *YES!* to the query is returned. The basis of this, of course, is the logical formalization of quality knowledge, presented in this paper.

By formalizing this body of knowledge, these benefits have been accrued:

1. Clearly identified terminology: the TOVE Quality Ontology
2. Precise definition of these terms
3. The ability to use this formalization to make deductions and decisions about quality

The ISO 9003 Micro-Theory is built upon some assumptions. The additional requirements of the ISO 9001, as well as the other quality standards in the ISO 9000 (such as ISO 9004 for internal standards, and ISO 9000-3 for standards for supply and maintenance of software) provide a concrete source for creating a micro-theory of ISO 9000. As far as the assumptions, these will be iteratively relaxed as more refined axioms for the micro-theory are defined.

Beyond the ISO 9000, some future quality domains to be formalized may include: Baldridge Awards (for organizational quality), costs of poor quality (for process quality), and theories of product quality and quality improvement. In the same informations systems approach displayed in this paper, terms, relationships and structures of these domains will be analyzed and codified, generic quality knowledge can be extracted and added onto the quality ontology, and a micro-theory of the domain can be put forth. This iterative enhancement of the TOVE Quality Ontology through repeated development of micro-theories will always use the

TOVE Enterprise Ontology as a test-bed to evaluate the TOVE Quality Ontology and the micro-theories.

ACKNOWLEDGEMENTS

This research is supported, in part, by the Natural Science and Engineering Research Council of Canada, Digital Equipment Corp., Micro Electronics and Computer Research Corp., and Spar Aerospace.

FOOTNOTES

1. Fox, M.S., *Ontological Engineering*, Class Notes, Department of Industrial Engineering, University of Toronto, Toronto, Ontario M5S 2Z3, 1992.

2. Rich, Elaine, and Knight, Kevin, *Artificial Intelligence*, New York: McGraw-Hill, Second Edition 1991, pp. 292.

3. International Organization for Standards, *ISO 9000 International Standards for Quality Management*, Geneva: ISO Central Secretariat, 1991, pp. 30, 34-5.

REFERENCES

[Fox et. al. 89] Fox, M.S., Reddy, Y.V., Husain, N., McRoberts, M., *Knowledge-Based Simulation: An AI Approach to Systems Modeling and Automating the Simulation Life-Cycle*, in Artificial Intelligence, Simulation, and Modeling, by: Widman, L.E., John Wiley & Sons, 1989.

[Fox et. al. 93] Fox, M.S., Chionglo, J.C., Fadel, F.G., *A Common-Sense Model of the Enterprise*, in Proceedings of the Industrial Engineering Research Conference 1993.

[Godfrey 93] Godfrey, A. Blanton, *Ten Clear Trends for the Next Ten Years*, Quality Quotes Vol. 19, Spring 1993, No. 2, pp. 15-18.

[Gruber 93] Gruber, Thomas R., *Towards Principles for the Design of Ontologies Used for Knowledge Sharing*, Technical Report KSL 93-4, Knowledge Systems Laboratory, Computer Science Department, Stanford University, Stanford, CA 94305.

[ISO 91] International Organization for Standards, *ISO 9000 International Standards for Quality Management*, Geneva: ISO Central Secretariat, 1991.

[Lamprecht 93] Lamprecht, James L., *Implementing the ISO 9000 Series*, Marcel Dekker Inc., 1993, pp. 26.

[Marca & McGowan 88] Marca, D.A., and McGowan, C.L., *SADT: Structured Analysis and Design Technique,* New York: McGraw-Hill Co., 1988.

[Newell 82] Newell, A., *The Knowledge Level*, Artificial Intelligence, 18(1), pp. 87-127, 1982.

[Sullivan 90] Sullivan, Lawrence P., *Total Quality Management in the Automotive Industry Worldwide*, Notes from Management Briefing Seminars, University of Michigan, Ann Arbor, Michigan, August, 1990.

[Turner et. al. 93] Turner, W. C., Mize, J. H., Case, K. E., Nazemetz, J. W., *Quality Control*, Introduction to Industrial and Systems Engineering, pp. 212-47, Englewood, NJ:Prentice-Hall, Third Edition, 1993.

LCS: 640:90:000