THE DEVELOPMENT OF A KNOWLEDGE SYSTEM FOR ISO 9001 QUALITY MANAGEMENT

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Abstract: Many researchers in knowledge management point out that the first step toward knowledge management is the management of documents. However, the complexity imbedded in some documents could present great difficulty for most methodologies to deal with. The knowledge content for building an excellent quality management system that complies with ISO 9001 falls into this category; this knowledge is characterized by multi-dimensionality and knowledge embedment through various procedures and forms. We applied Ontology, which is a new approach in AI for better presenting knowledge structure of a domain, to develop a system structure that will facilitate the development of a knowledge-based ISO 9001 quality management system. We use the real case of a Taiwanese chemical company that has a total of 175 ISO manuals to refer to when needed. This system is built with Protégé 2000 as the knowledge platform, and we follow the development process recommended by Ontology Engineering of Toronto Virtual Enterprise. One main feature of the system is its capability of understanding the semantic of documents, which is a vital part of the inference mechanism in answering user's queries.

1 INTRODUCTION

Many researchers in knowledge management indicate that the first step toward knowledge management of an organization is the management of documents. The conventional document management system is capable of finding lots of related information, but it may not be able to provide user with information that can satisfy users' exact needs. A great deal of efforts has been made on developing methodologies to overcome this problem. What seems to be lacking, however, is the ability for systems to understand the semantic of documents. Researchers in AI have recently tuned to ontology as a better approach for expressing shared conceptualization of a domain through knowledge structure and contents. The complexity and difficulty for business to manage and control procedures and documents to meet requirements of ISO 9001 has

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prompted us to study the application of ontology in this area.

ISO 9001 (Goetsch and Davis, 1998) contains quality documents that represent the standards required by the International Standard Organization for building an excellent quality management system, and its accreditation is sought by most organizations worldwide; especially those in international trade. These documents define requirements and standard procedures that are well recognized as the best practices in quality management. In a sense, these procedures represent the knowledge contents necessary for building an excellent quality management system. Due to its cross-departmental nature and the depth in penetrating various levels of management, these documents can be overwhelming for most management to remember. In addition, the amount of ISO 9001 contents may increase year after year; it adds a further problem to management to keep track of them.

The objective of this study is to develop an ontology-based system structure that will facilitate the development of an ISO 9001 knowledge management system. This system could help enterprises to overcome the difficult in managing and control the contents of an ISO-based quality system. We used information of a Taiwanese chemical company for the development, and applied TOVE (Toronto Virtual Enterprise) ontology engineering approach to construct the ISO ontology on Protégé 2000 (Gennari, 2003), (Noy, 2001), (Grosso, 1999), which was developed by Stanford Medical Informatics. The rest of this paper is arranged as follows. Section 2 provides a brief introduction of ontology and ontology engineering approaches. Section 3 examines the details of ISO 9001 documents and look into the issues associated in implementation. Section 4 introduces the system architecture. Section 5 explains the development of the ISO 9001 ontology, and is followed by the last section of conclusion.

2 ONTOLOGY AND ONTOLOGY ENGINEERING

Ontology is a "formal explicit expression of a shared conceptualization of a domain" (Uschold and Gruninger, 1996), it is one of the latest research frontiers of AI in searching for better knowledge representation of a domain, so that it can be easily shared and reused. In actual application, ontology consists of a set of vocabulary and the content theory to express entities and relationships between entities in a domain, which are normally expressed with: classes, slots, instances, and axioms. Classes represent the conceptual items of the domain. Slots are the relations or attributes of classes. Instances are the data that belong to classes and describe the objects in real world. Axioms are inference logics that serve as the reasoning mechanism.

There are two major approaches in developing enterprise ontology. The first one is proposed by M. Ushold et al. (Uschold and King, 1995), their ontology engineering is based on the experience of the Enterprise Ontology. The other is proposed by M. Gruninger et al. (Gruninger and Fox, 1995), (Kim and Fox, 2002), (Kim, 2002), (Kim, Fox, and Gruninger, 1999), which is based on the experience of the TOVE (TOronto Virtual Enterprise). Based on the evaluation by Fernandez Lopez (Fernandez, 1999), the former approach is more for the modelling of the operation of an enterprising, and the latter is more for the modelling of knowledge content of a domain, hence, one could conclude the latter can better accommodate needs of knowledge management users for our case. As a result, we decided to apply M. Gruninger et al.'s approach in this research; it will be termed TOVE ontology engineering in the later sections.

TOVE ontology engineering has six design phases: motivation scenario, informal competency question, terminology, formal competency question, axiom, and completeness theorem. The motivation scenario describes problems in application of a domain that motivate the application of ontology; it may also provide an expected solution to the problems. The informal competency questions transform motivation scenario into question forms, which the system must answer when completed. The terminology phase defines vocabularies and their meaning that are to be used in the ontology, which include all terms used for expressing knowledge content. The formal competency question applies terminology to formalize informal competency questions in natural language forms the system can understand. The axiom phase defines the inference logics to lay the foundation to facilitate search mechanism when the ontology is completed. The last phase, completeness theorem, is to demonstrate that the ontology can correctly answer all of the competency questions. Kim (Kim, Fox, and Gruninger, 1999) redefines the six phases into Motivational Scenario, Informal Competency Questions, and Ontology; with the Ontology phase being further broken down into 5 sub-phases: terminology, hierarchical model, predicate model, formal competency question, and axiom. While the terminology, formal competency question and axiom remain the same as before, hierarchical model describes the relationships of all terminologies in a hierarchical scheme, and Predicate model defines terms and relations of the hierarchical model in the format of first-order logic to further facilitate system development.

3 ISO 9001

The ISO 9001 standards are a set of international quality management system standards and guidelines, which was developed by International Organization for Standard for specifying requirements to achieve product conformance by a quality management system. While these requirements are generic and independent of any specific industry, they serve as the goals for the functioning of the overall quality management system and its various subsystems, which are to be developed and implemented by the management of enterprises. Each of these systems must be well documented in terms of its quality objectives, processes it serves, procedures required for each process and between them, and forms needed to verify performances. Basically, the documents of a quality management system of an enterprise consist of four major categories: quality policy, quality manual, process procedures, and quality records. Figure 1 shows the relationships of the four categories inside the triangle.

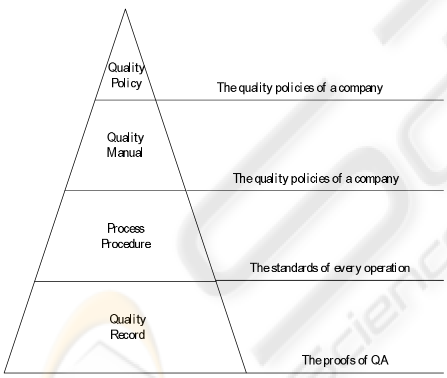

Figure 1: The four ISO 9001 document components

From top to bottom, they are quality policy, quality manual, process procedure, and quality records (Goetsch and Davis, 1998). Quality policy sits at the top level, it defines commitments to quality by top management, authorizes the organization to comply with requirements and continually improve, and provides framework for setting quality objectives of various levels of management. Quality manual is level 2, it defines and describes the scope of the quality management system, describes how processes interact to form the quality management system to insure quality assurance of the process, and achieve stated objectives in level 1. The process procedure, based on the scope and process interactions stated in quality manual, describes the procedures for planning, operation, and control of each process as well as that for the interaction of processes. Quality record consists of sets of forms, tables, or records, which serves to record actual data of process procedure of level 3 as a proof of the quality.

In terms of functionality, ISO 9001 covers five major functions: quality management system, management responsibility, resource management, production realization, and measurement, analysis and improvement. As shown in figure 2, these five functions are closely interrelated.

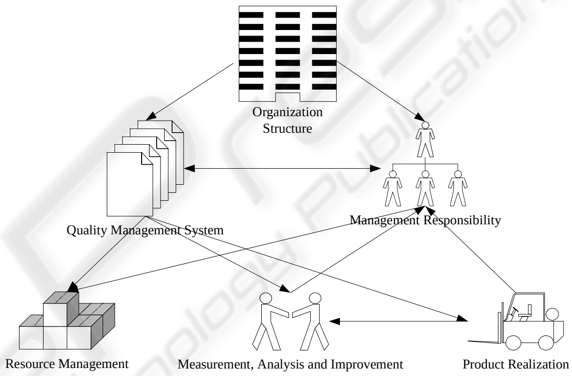

Figure 2: Interrelationships among five functions

A quality management system is built upon the structure of a company and must take into consideration responsibility of various levels of management. Management responsibility, on the other hand, must refer to the managerial structure and take into account system requirements at the same time. These two functions will in term affect the other three directly and/or indirectly as shown in the figure. These inter-webbed relationships and the fact that each individual unit must develop its own ISO documents, especially those that are related to quality records, process procedures, and quality assurance, could lead to the serious problem of inconsistency in contents and terminologies, because different departments may use different terms for the same meaning and vice versa. In our case, the company has developed a total of 175 ISO documents that must be referred to from time to time when needed and the inconsistency is not effectively dealt with. Another problem that is fronting the management is the fact that new issues and requirements are continually being developed by ISO, and that is becoming a major burden for many enterprises to maintain up-to-date requirements, let alone implementation. It is no wonder that Goetsch

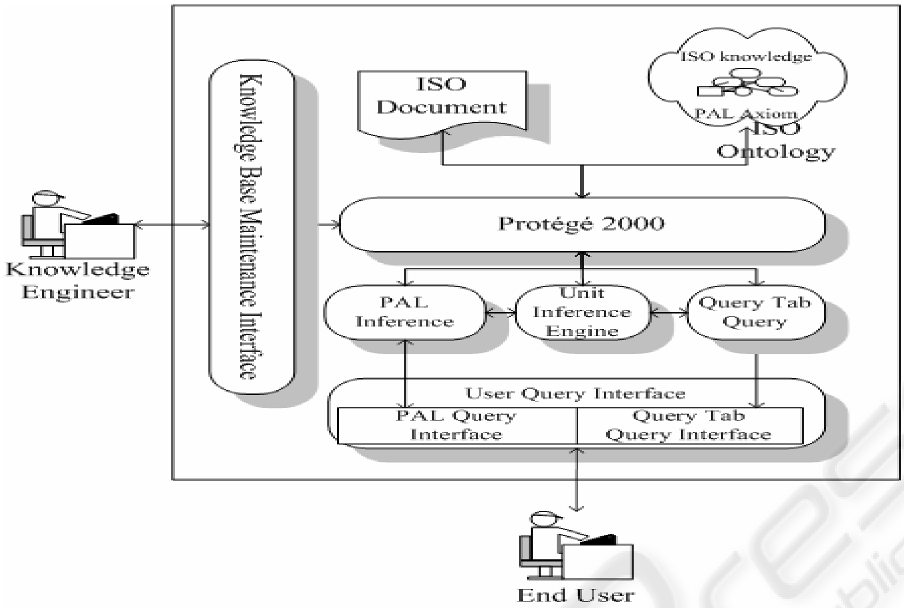

Figure 3: Architecture of the quality management system

and Davis's study concluded that it is very hard to understand all ISO 9001 requirements for most enterprises; because there are too many interrelationships among all requirements.

4 SYSTEM ARCHITECTURE

We employ Protégé 2000 as the platform for building the ontology-based quality management system (OQMS). Protégé 2000 is an ontology-based knowledge acquisition platform that can better deal with the issues of implicit relations, terminologies, document management, and unit integration. In addition, Protégé 2000 complies with Open Knowledge Base Connectivity Protocol, so that future integration with other systems would not be a problem. The proposed system architecture is shown in figure 3, which is composed of eight modules: User Interface, KB maintenance Interface, PAL Inference, Query Tab Query, Unit Inference Engine, Protégé 2000, Company Documents, and ISO ontology. Initially, knowledge engineers analyze knowledge contents from various ISO documents, and identify knowledge entities, their attributes, and their relationships with others to build the ISO ontology, which will be maintained by the knowledge engineers through the KB maintenance interface. The relevant company information and forms are collected and encoded as instances of the ontology. OQMS provides two types of query: PAL-based and Query Tab-based. The PAL-based query allows users to issue queries using the PAL (Protégé Axiom Language) logic form (Hou, Noy and Musen, 2002); its editor will translate those queries into PAL language for processing. The Query Tab is for general users, it provides a template query mode to allow users to fill out some specific fields. The PAL inference engine is the inference engine of our system. When performing reasoning instructions upon requests, it will refer to entities and their relationships of the ISO ontology for reasoning, and retrieve related documents from ISO Document. Protégé 2000 is the core module of our system. It provides a platform for saving identified knowledge structure of ISO documents and relevant company information; including various forms and detailed operation information. Users have the option of using the default interface of Protégé 2000 for maintaining ISO ontology and Company documents. ISO ontology represents the overall knowledge structure of all ISO 9001 documents. This structure contains knowledge identities, their attributes, and their interrelationships. Finally, ISO document consists of original contents that support the knowledge structure of the ISO Ontology. The contents may include company documents, various forms, detailed operating information, and other relevant documents.

5 ISO 9001 ONTOLOGY

The ISO 9001 Ontology is the core of the whole system, we follow TOVE ontology engineering for the development, and the following explains the various phases:

5.1 Motivation Scenario

It is the complexity and multi-dimensionality that is making ISO documents difficult to comprehend and manage while trying to build an excellent quality management system. The ontology we propose must be able to satisfy the needs of management in meeting requirements of ISO 9001, which include:

(1) Identifying ISO requirements at different levels, so that necessary procedure knowledge can be provided to meet these requirements.

(2) Defining terminologies of the overall system through a multi-naming mechanism, so that each term can have its precise meaning to achieve vocabulary consistency.

(3) Managing large number of documents to aid the needs of implementation and references.

5.2 Informal Competency Questions

From motivation scenario, we identify the following six informal competency questions for our case:

(CQ1) For a given job, what are the QA procedures that are needed to complete the job?

(CQ2) For a given job, what are the departments that are involved with the job?

(CQ3) For a given job, what are the quality records that are needed to complete the job?

(CQ4) For a given QA procedure, what are the departments that are involved with it?

(CQ5) For a given QA procedure, what are the quality records that needed to support it?

(CQ6) For a given unit, what are the QA procedures that are under its administration?

5.3 Ontology

As stated above, there are five steps in establishing the ontology: terminology, hierarchical model, predicate model, formal competency question, and axiom. However, due to space limit, we will only present part of hierarchical model and sample of formal competency question and axiom.

5.3.1 Hierarchical Model

Hierarchical model defines relationships among terms of the system. The hierarchical model of the organization of our case is shown in Figure 4, which indicates that there are five types of grouping: executives, division, department, team, and group. In this case, we classify all relations into two conventional relationships: is-a and has-slot. The is-a relation is applied to relate class and subclass, and has-slot relation is applied to all other relations.

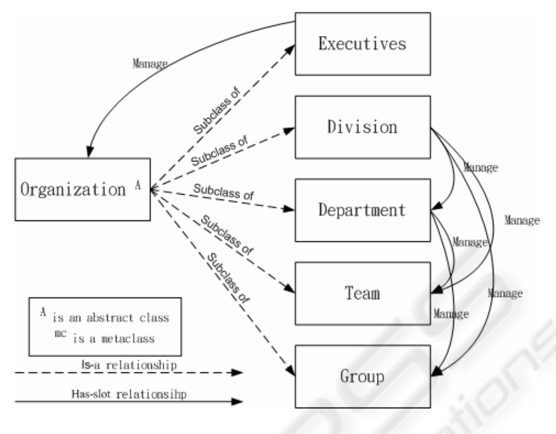

Figure 4: The hierarchical model of the organization

There are five “is-a” relationships, which are in dotted lines, to relate groupings to Organization, and, there are six “has-slot” relationship, which are in solid lines, to relate among themselves. Figure 5 is the hierarchical model for QA Procedure, Process, and Quality Record. A QA Procedure may contain more than one process; hence the “is-a” relation is applied between them. The same is true between Process and Operation Process and Decision Process. In addition, the “Operation Process” is related to “Process” with “Preceding Process” and “Succeeding Process” to indicate the processes before and after the given one of the process chain. Similarly, the “Decision Process” is related to “Process” with “Preceding Process”, “Succeeding Process without modification”, and “Succeeding Process with modification”. When performing a process, employees may need to use one or more quality forms as records, we use meta-class “QUALITY-DOC” to relate Process and Quality Record with “Use” and “Used by” as the two has-slot relationships. All quality records are instances of “QUALITY-DOC”, and each quality record may belong to more than one group of measurement records, which are subclasses of Quality Record, and has an “is-a” relationship with “QUALITY-DOC”.

5.3.2 Predicate Model

Predicate Model is the formal definition of classes and their relationships in First-Order Logic. Our system has in total 213 classes, and 723 relationships. In the following, we present only sample predicates.

(1) R: Filled Quality Record

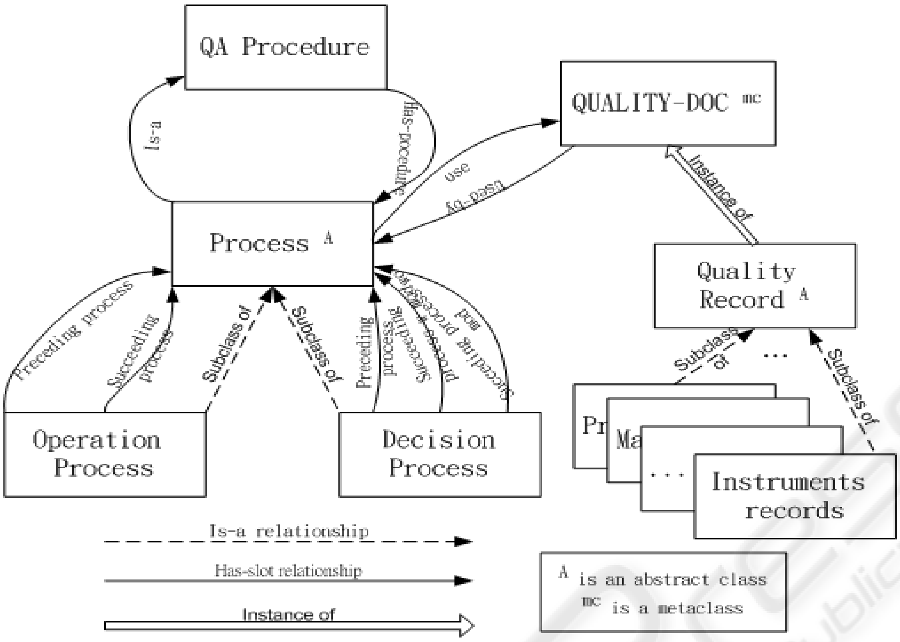

Figure 5: The hierarchical model of the QA procedure, process and quality record

Every filled quality record is an instance of the quality record that is a subclass of "Quality Record".

(2) *T: Empty Quality Record*
The "Quality Record" is an abstract class; every R is an instance of "QULAITY-DOC", and R has three common own-slots: preservation period, responsible department, and processes that need it.

(3) *P: QA Procedure*
P is an instance of "QA Procedure" class, it has four own-slots: name, related process, ISO code, version, and content.

(4) *U: Organization*
The "Organization" is an abstract class and has five classes: Executives, Division, Department, Team, and Group. U can be an instance of each of the five classes.

Some of their related expressions in predicate model are:

PT-1 Manage(U_1, U_2)
This predicate is valid if U1 is the superior of U2.

PT-2 QA-Procedure-Including-Process(P, OP)
This predicate is valid if a given QA procedure P includes the process OP.

PT-3 Process-Requiring-Quality-Record(OP, T)
This predicate is valid if the process OP requires filling quality record T.

5.3.3 Formal Competency Question

The above definition of predicate model can be expressed with first-order logic language to formulate the formal competency questions, some examples are:

(CQ1) When performing a job, which QA procedures are related to this job?

∃ P; *QA-Procedure-is-related-to- Keyword* (P, "Job")

(CQ 2) When performing a job, which departments are related to this job?

∃ U; *Department-is-related-to- Keyword* (U, "Job")

5.3.4 Axiom

We present following axioms that could assist in discovering relationships among QA processes, quality record, and department in order to solve the two competency questions:

Defn-1 QA-Procedure-is-related-to- Keyword(P, K)

(∀ P:QA-Procedure [(∨ (substring-of (K, (name P))) (∃ OP:Process
(∧ (QA-Procedure-Having-Process (P, OP))
(∨ (substring-of (K, (name OP)))
(∃ T:QUALITY-DOC
(∧ (Process-Using-Quality-Record(OP, T)) (substring-of(K, (:NAME T))))))))
≡ QA-Procedure-is-related-to-Keyword(P, K)])

Defn-2 QA-Procedure-is-related-to-Quality-Record (P, T)

(∀ T:QUALITY-DOC
(∃ P: QA Procedure
(∃ OP: Process
(∧ (Process-Using-Quality-Record(OP, T))
(QA-Procedure-Having-Process(P, OP)))))
≡ QA-Procedure-is-related-to-Quality-Record(P, T)])

Defn-3 QA-Procedure-is-related-to- Department (P, U)

(∀ U: Organization (∃ U_a: Organization
(∃ P: QA Procedure
(∨ (∃ OP: Process
(∧ (QA-Procedure-Having-Process(P, OP))
(∨ (Process-Execution-Department(OP, U))
(∧ (Process-Execution-Department (OP, U_a))
(Manage(U, U_a))))))
(∃ T: QUALITY-DOC
(∧ (QA-Procedure-is-related-to-Quality-Record(P, T))
(∨ (Quality-Record-Reserving-Department(T, U))
(∧ (Quality-Record-Reserving-Department (T, U_a))
(Manage(U, U_a))))))))
≡ QA-Procedure-is-related-to-Department(P, U)])

6 CONCLUSION

ISO 9001 certification is sought worldwide as a proof of excellence in quality of products and services provided by an enterprise. However, because of the involvement of many units and too much imbedded relationships in the system, it is a complicate and difficult job for management. We deal with this problem by designing an ontology-based system structure, and use a real case of a Taiwanese Chemical Company to develop an ISO 9001 quality knowledge system. We analyze the content of 175 ISO9001 documents to develop ISO ontology for the company, which contains 213 classes and 723 relationships. The system development process followed the TOVE ontology engineering and use Protégé 2000 as the platform for the knowledge base. The system is capable of modelling the metadata of ISO documents and relationships between documents, identifying units of management with various quality procedures, and supporting semantic search to allow for meaning-search rather than keyword based search for ISO documents.

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