Ontologies in Knowledge Management Support: A Case Study

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Information and knowledge are true assets in modern organizations. In order to cope with the need to manage these assets, corporations have invested in a set of practices that are conventionally called *knowledge management.* This article presents a case study on the development and the evaluation of ontologies that was conducted within the scope of a knowledge management project undertaken by the second largest Brazilian energy utility. Ontologies have different applications and can be used in knowledge management, in information retrieval, and in information systems, to mention but a few. Within the information systems realm, ontologies are generally used as system models, but their usage has not been restricted to software development. We advocate that, once assessed as to its content, an ontology may provide benefits to corporate communication and, therefore, provide support to knowledge management initiatives. We expect to further contribute by describing possibilities for the application of ontologies within organizational environments.

Introduction

Modern organizations face constant turbulence in their environment. A reduced life cycle of products and services and a highly integrated international market have led to a high degree of competitiveness. The 1980s saw the rise of this landscape just when economic restructuring forced companies to implement reorganization strategies. Furthermore, this organizational upheaval, combined with modern information technologies, opened a set of new possibilities regarding the actions of leading organizations. In this context, information and technology have become fundamental to corporate performance (Castells, 1996; McGee & Prusak, 1993). Following these developments, the issues of how a company could learn (Argyris, 1999; Senge, 1990), manage its own knowledge (Choo, 1998; Nonaka & Takeuchi, 1997), and preserve this knowledge (Lehner & Maier, 2000; Walsh & Ungson, 1991) have become topics of discussion.

Received March 31, 2008; revised April 16, 2009; accepted April 16, 2009

 • Published online 10 June 2009 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/asi.21120

In recent years, companies have made significant investments in knowledge management (KM) initiatives. Among the many techniques utilized, ontologies are an alternative that has been given an increased amount of attention (Grundstein & Barthès, 1996; O'Leary, 1998; Zack, 1999). Indeed, in examining a publication on KM from a major Information Science journal, we found studies that deal with the application of ontologies in KM projects (Holsapple & Joshi, 2004) and with the role of ontologies in Information Science (Fonseca, 2007).

Defining either KM or ontologies is no trivial task. The meaning of KM is not consensual. Wilson (2002), for instance, claims that knowledge is what the individual knows and involves mental processes, like understanding and learning, which take place in one's mind only. From this point of view, knowledge cannot be managed. On the other hand, ontology is a term that originated in philosophy and has been used in Information Science to describe a hierarchical structure based on concepts and relations. The issue of defining it, however, lies in the fact that different research communities adopt different perspectives: Computer Science, for example, Artificial Intelligence, Databases and Software Engineering; Information Science and Librarianship; Logic and Philosophy, to mention but a few (Obrst, Hughes, & Ray, 2006).

This article presents a study case on the utilization of ontologies in a KM project. The project is currently being conducted by one of the largest Brazilian electric utilities active both in the production and in the distribution of energy. Among other initiatives contemplated by the project is the development of an automated system for the handling of knowledge related to quality management. From the point of view of system modeling, the ontology corresponds to the representation component, named the *ontology-based model*. The term *model* is used in accordance with the characterization presented by Guarino (1998).

The purpose of this work is to add another instance on the research linking ontologies and KM. This article demonstrates that ontologies are, in many ways, a useful tool in KM applications and shows that their use is not limited to the development of automated systems. We advocate that ontologies can be successfully used in KM initiatives provided they are evaluated as to their content. The importance of this evaluation lies in the fact that, in general, a model for information systems (IS) is designed by professionals who are concerned with codification. Therefore, the result is that greater emphasis is given to implementation aspects, which are inadequate to represent reality in relation to people's needs and to allow usage in other contexts.

The contribution ontologies make to KM ultimately takes place through the improvement of corporate communication processes. Once we obtain positive results from the content evaluation process, the corresponding ontology works as a type of organizational language (Von Krogh & Roos, 1995), thus increasing communication and fostering KM initiatives. *Ontology content evaluation* is the user-centered process of verifying whether the knowledge acquired corresponds to that which is present in the environment where we accomplish the knowledge acquisition process.

It is worth mentioning that a detailed exposition of the KM project as well as of the respective system is beyond the scope of this article. Such questions are to be approached strictly when required in order to contextualize those benefits gained with the development processes and to evaluate the ontology for KM. In this article, KM is understood to be the set of administrative practices whose objective is to deal with corporate knowledge and which are aimed at providing for business needs.

The remaining part of the article is organized as follows: the second section deals with IS models, briefly describing their evolution and utilization. The third section presents the case study, describing the development stages and the ontology evaluation stages. The fourth section displays the results of the research, the resulting ontology, and ontology evaluation data. The fifth section discusses the results within the scope of KM, highlighting contributions toward meeting business needs. Finally, the sixth section offers conclusions regarding the possibilities for the utilization of ontologies in organizational environments.

Models for IS

Models are simplified representations of a reality that we expect to understand. The world is complex and models are produced to enable human comprehension to apprehend and organize facts. Models also are important entities and are an integral part of the scientific method. According to Frigg (2006), one of the ways to classify models is to consider the semantic issue, which deals with the functions of representation. From this point of view, models can be models of phenomena, theoretical models, or data models. Data models proliferate in organizations as a means of representing whatever must be codified and processed by IS.

IS has a relevant role in the consolidation of new administrative practices as they are aimed at providing for people's needs. IS development involves the creation of models to represent activities that take place in the organization. An organizational data model is "[...] an explicit representation of the structure, activities, processes, flows, resources, people, behavior, goals, and constraints of an organization" (Gandon, 2002, p. 42).

In IS development the stage in which models are created to furnish human comprehension is known as conceptual modeling. Conceptual models are created from abstractions of aspects of reality, be they from the perspective of an individual or from that of a group of people. Abstractions are a means of specifying the entities and the relations among entities within the domain of a field of knowledge that is of interest to the future system.

The remaining part of this section discusses models for IS, describing the evolution of data models through to conceptual models and, finally, to the ontology-based models.

Data Models and Conceptual Models

IS conceptual modeling as we know it is the result of research conducted in the last 50 years. The first initiatives for the specification of data models date from the late 1950s (Bosak et al., 1962; Young & Kent, 1958). Such initiatives were undertaken to create models that provided for the requirements of computational data structures.

In the 1960s, research on databases gave birth to three main data model types: the hierarchical model, the network model, and the relational model. These models are known as logic models, as they do not refer to physical aspects. However, logic models pose problems that limit their utilization in conceptual modeling (Mylopoulos, 1998). For example, in the relational model (Codd, 1970), a construct named *relation* is used to represent both entities and relationships among entities (Peckham & Maryanski, 1988). This fact generates comprehension problems and leads to modeling errors.

The first semantic models used in conceptual modeling appeared in the 1970s, within the work of the ANSI/X3/SPARC Committee for the standardization of database management systems. The most remarkable are the semantic data model (Abrial, 1974), the three-schema architecture (Jardine, 1976), the Entity Relationship (ER) (Chen, 1976), and the ER extension model (Codd, 1979), among others. The main characteristic of the semantic models, in comparison with the previous ones, is that they are easier to understand. The ER model, for instance, removes from the relation construct the overload that exists in relational models and, also, furnishes additional terms to be used as modeling primitives. Conceptual modeling arose from semantic data models developed for databases, but the ISO/TC97/SC5 Committee formed a group with the purpose of determining standards for IS conceptual modeling languages.

In the 1990s, proposals for object-oriented modeling became popular. Many consider these a category apart from that of data models. In fact, they have additional features in comparison with data models, but yet they bear similarities in their constructs, such as: objects vs. entities, attributes vs. properties, relationships vs. associations, classes vs. hierarchies (Milton, 2000). The Unified Modeling Language was

DOI: 10.1002/asi

an attempt to standardize the object-oriented notations that brought together other initiatives: the Booch Method (Booch, 1993), the Object-Modeling Technique (Rumbaugh et al., 1991), the Object Oriented Software Engineering (Jacobson et al., 1992), among others.

Over the years the creation of conceptual models has been motivated by the search for ever improved ways to represent reality in IS. According to Mylopoulos (1992, p. 3), conceptual modeling is "[. . .] the activity of formally describing some aspects of the physical and social world around us for purposes of understanding and communication." Nevertheless, semantic models used in conceptual modeling utilize a limited set of constructs for the task. The ER model, for instance, presupposes that part of the reality of interest to the system may be articulated by two concepts only: entity and relationship.

Smith and Welty (2001) point out the inconsistency in modeling during the early years of conceptual modeling as the main cause of interoperability problems in IS. An alternative for this type of problem is the ontology-based models. According to the authors, "[. . .] the provision, once and for all, of a common, robust reference ontology—a shared taxonomy of entities—might provide significant advantages over the ad hoc, case-by-case methods previously used" (Smith & Welty, 2001, p. 4).

Ontology-Based Models and Their Applications

Ontologies have been studied since the 1970s in Artificial Intelligence research. According to Smith (2003), the term first appeared in the Information Science literature in 1967, in work on data modeling conducted by Mealy.[1] In the 1990s, Web Semantic research increased the demand for ontologies for some kinds of applications, both to solve interoperability problems and to provide a common information structure. In fact, Vickery (1997) reports on a survey conducted on a multidisciplinary information service,[2] in which the term was found more than 500 times.

To understand those theoretical issues related to ontology in a more detailed manner, one must go beyond the goals of the present study. Several authors have studied the theme, both in Computer Science (Genesereth & Nilsson, 1987; Giaretta, 1995; Gruber, 1993; Guarino, 1995, 1998; Guarino & Sowa, 2000; Smith, 2003), and in Information Science (Gilchrist, 2003; Søerguel, 1997; Vickery, 1997; Wand, Storey, & Weber, 1999). Some noteworthy considerations that are relevant to the objectives of this article can be found in the remaining part of this section.

The study of ontologies is characterized by the coexistence of interdisciplinary approaches. Guizzardi (2005) mentions seven interpretations available in the literature of the term *ontology*: 1) a philosophical discipline; 2) an informal conceptual system; 3) a formal semantic account; 4) a specification of a conceptualization; 5) a representation of a conceptual system via logical theory; 6) a vocabulary used by a logical theory; 7) a specification (meta-level) of logical theory.

According to Smith (1998), from the philosophical point of view there can be only one ontology. In order to deal with the issue of term usage plurality, the author distinguishes two types of ontologies: the Real Ontology (R-ontology), which is about how the universe is organized and corresponds to a philosophical approach; and the Epistemological Ontology (E-ontology), related to the task of conceptualizing a domain. E-ontology supplies the need to express the ontology as an artifact within the scope of Software Engineering and of Knowledge Representation.

According to Guarino (1998), an ontology describes the meaning of the symbols adopted in IS and represents a specific vision of the world. The author classifies ontologies into two main dimensions, according to the impact they produce in IS. The time dimension corresponds to the utilization of ontologies in IS, be it in development-time or run-time. The structural dimension deals with the use of the ontology as a database component, as the user interface or as an application.

Fonseca (2007) distinguishes ontologies of IS from ontologies for IS. The author explains that in the former the ontology is used for conceptual modeling. In the latter, the ontology is an IS component that describes the vocabulary of a domain with the purpose of supporting the creation of conceptual schemes. This second approach corresponds to Guarino's view. Additional examples of ontologies of IS are the research conducted by Crubézy & Munsen (2004), Sycara & Paolucci (2004), Fonseca & Soares (2007), and Oberle, Voltz, Staab, & Motik (2004), among others. Additional examples of ontologies for IS are the research by Green & Roseman (2005), Fettke & Loss (2005), Holten, Dreiling, & Becker (2005), and Gemino & Fraser (2005), among others.

A diversity of initiatives for the use of ontologies in organizations can be found in the literature (Bernus, Nemes, & Williams, 1996; Fillion, Menzel, Blinn, & Mayer, 1995; Fox, 1992; Schlenoff, 1996; Uschold, King, Moralee, & Zorgios, 1998). Among the possibilities of ontologies for IS in KM, Lehner & Maier (2000) point out computer-based systems known as Organizational Memories. These systems have the capacity to collect and organize information systematically from several sources, creating a repository of organizational knowledge.

In general, an Organizational Memory architecture contains four levels: 1) the interface providing access to the data sources 2) the mediating ontology; 3) a multi-agent system; and 4) an interface for users. The ontology deals with the treatment of syntax and semantic inconsistencies in such a way that agents are capable of promoting the communication between those instances involved in the process and of representing the dynamic character of the corporate structures. These types of arrangements can be found in the proposals of Dieng et al., (1998), O'Leary (1998), Rabarijaona, Dieng,

[1]Mealy, G.H. (1967). Another Look at Data. Proceedings of AFIPS Conference. 31, 525–534. Washington: Thompson.

[2]Dialog. Retrieved January 20, 2003, from http://www.dialog.com/

DOI: 10.1002/asi

Corby, & Ouaddari, (2000), and Weinberger, Te'eni, & Frank (2008), among others.

Within the IS realm, the ontology must be evaluated as to its capacity to perform the function for which it has been designed. In general, evaluation issues are related to those mechanisms that promote the interaction of the ontology, the knowledge representation formalism considered, and the appropriateness of documentation. Proposals for evaluating ontologies are available (Brewster, Alani, Dasmahapatra, & Wilk, 2004; Gangemi, Guarino, Masolo, & Oltramari, 2001; Gómez-Pérez, 2004; Maedche & Staab, 2002; Porzel & Malaka, 2004; Velardi, Navigle, Cucchiarelli, & Neri, 2005), but a comprehensive, consensual, and standardized methodology does not seem to exist.

The next section presents the research in which the process of building an ontology is described. This ontology corresponds to the representation component of a system featuring characteristics similar to those of an Organizational Memory. The system is part of a comprehensive KM project developed within a large-sized corporation. As previously mentioned, the emphasis of the research does not rely on the system itself. The goal is to discuss the development process and the evaluation of the ontology in terms of possible applications in KM initiatives.

Ontology Development and Content Evaluation: A Case Study

The research was conducted in an organization named Companhia Energética de Minas Gerais (CEMIG), a Brazilian energy utility with nearly 11,000 employees, with around 6 million consumers and operating the longest energy distribution line in Latin America. This utility also has 46 hydroelectric power plants, two thermal plants, and one wind power plant. The company has a KM project that prioritizes three business needs: quality management, information security, and information on new energy sources. This study deals exclusively with the quality management policies implemented in the company.

The Quality Management Policy (QMP) sets the corporate guidelines regarding quality in a comprehensive manner. Designed over a period of 5 years, the QMP complies with international quality standards (ISO-9001, ISO-14001, and OHSAS-18001). The QMP includes three kinds of policies that represent corporate investment in quality, in the environment, and in health and safety: Office-QMP, Environment-QMP, and Occupational Health and Safety-QMP. They made it possible for the company to be listed, for the ninth consecutive year in 2008, in the Dow Jones Sustainability Index, which includes companies from around the globe.

This study was conducted in the unit responsible for corporate-level QMP deployment and maintenance. The ontology corresponds to an IS model aimed at collecting and organizing quality management knowledge that is, in fact, found in several different sources in the corporation. The following sections present, in detail, the procedures adopted for the development of the ontology and the evaluation of the ontology content.

Developing the Ontology

We planned the ontology to be built in three layers with the following names: abstract layer, organizational layer, and specific layer. The division into layers with different degrees of abstraction is aimed at enabling the reutilization of part of the ontology in future initiatives. The abstract layer contains generic concepts that may be reutilized in other contexts; the organizational layer contains concepts that may be utilized in different sectors of the organization; and the specific layer supplies for the specific requirements of the QMP.

The development of the ontology was comprised of the following stages: determining the scope, data collection, conceptualization, and implementation. In the remaining part of this section each stage of the process is described. The methodology adopted for building the ontologies is based on the work of Fernandez, Gomes-Perez, & Juristo (1997), Gandon (2002) and on complementary contributions by other authors.

Delimitation of scope within the organization. In order to determine the scope of the ontology, the following information was collected: the employees and the processes involved in the study, the objective of the ontology, and the sources of knowledge used.

We planned the research to be used by the company area responsible for the QMP. This unit comprises 30 university-level employees, from among whom eight specialists were selected to participate in the research. Next, processes that were seen as critical for the implementation of the QMP were selected: quality planning, the identification and monitoring of legal requirements, risk identification and assessment, registry and document control, training and raising awareness, treatment of nonconformities, preventive and corrective actions, internal verification and third-party audits, and critical analysis, among others.

The purpose of the ontology was determined as being the definition of a vocabulary of three types of terms: those representing the QMP (specific layer), those representing the organizational processes (organizational layer), and a third one representing all generic terms (abstract layer). Examples of the expected knowledge sources are: other ontologies, paper (and electronic) documents, employees, and information systems. The collection of data on the knowledge sources was aimed at gathering terms for the expected layers.

Data collection. We collected data for both abstract and organizational layers through a survey about top-level ontologies, organizational ontologies, and other resources. Both the context of the existing initiatives and the meaning of their terms were evaluated. We extracted terms from: 1) high-level ontologies (Knowledge Representation Ontology,[3]

[3]Retrieved May 20, 2004, from http://www.jfsowa.com/ontology/

DOI: 10.1002/asi

Interview summary				FORM n°
Member: Soraya		**Sector**: AQ	**Date**: 12/07/05	**form n°**:3-3
Goal of interview	Obtain general information about the department's operation, interviewee's attributions in the department and the department's attributions in the company.			
Summary: ...as a more concrete example of a core unit undergoing certification… because I follow other units, which are already certified, and in the process of undergoing certification and audits… the work tends to be more stable… but I follow a core unit in Montes Claros, which is DO/MC … it is an area in which they are certifying all units, they have several processes… invoicing processes, customer service processes… their scope is huge… ...				

FIG. 1. Portion of interview summary form with candidate-terms highlighted.

CYC Ontology,[4] and Suggested Upper Merged Ontology[5]); 2) organizational ontologies (Enterprise Ontology,[6] Comma Ontology,[7] and TOVE Ontology[8]); and 3) other sources (MIT Process Handbook Project[9] and The Workflow Management Coalition[10]). Next, we collected the data regarding each specific layer according to the following stages: interviews for collecting terms, document analysis, and interviews for the definition of terms.

We conducted two types of interviews for obtaining terms: 1) type 1 interview, semistructured, with the purpose of understanding the functions and the activities of the interviewee, as well as the documents used; 2) type 2 interview, semistructured, with the purpose of collecting data on IS used by the interviewee while working.

We conducted the type 1 interviews with the QMP specialists. We registered the interviews in forms named the Interview Summary. We marked candidate terms for ontology concepts as such in the form (Figure 1), based on subject analysis premises (Lancaster, Elliker, & Connel, 1989). Type 2 interviews were based on the Scenario Analysis (Rosson & Caroll, 2002). The narratives obtained were registered in forms named Scenario Reports. In an analogous manner, we marked the candidate terms as such in the form.

The document analysis focused on those that were relevant for the area's routine, such as: manuals, norms, reports, organization charts, and presentations, among others. We gathered together certain typical documents involved in the analyzed processes according to the data obtained in the type 1 interviews. The types of documents, their flow within the organization, and the related processes were described. This information was entered into a form named Document Analysis in order to facilitate the understanding of which role these documents played in the activities. Next, we performed the textual analysis of the paper or electronic documents, thus obtaining the candidate-terms applicable to the concepts in the ontology.

We conducted two types of interviews for the definition of terms: 1) the type 3 interview, with the goal of obtaining definitions from individuals of the applicable candidate-terms; 2) the type 4 interview, with the purpose of obtaining a consensus on the definitions of the candidate-terms.

Type 3 interviews aimed at obtaining intensional notions. We gave the employees a list of terms gathered during the type 1 and 2 interviews. We then asked them to provide definitions in their own natural language. Simultaneously, they were asked to furnish examples that were representative of each of those terms, so as to provide their extensional notion. The result of these activities was then entered into a form named Table of Individual Definitions.

Type 4 interviews were conducted in groups and promoted the discussion of the intensional notions. Concerning the definitions proposed, we considered three situations: 1) the term corresponds to one definition; 2) several terms correspond to one definition; and 3) one term corresponds to several definitions. Based on those discussions, consensual intensional and extensional notions were collected, which were then entered into a form named Table of Consensual Definitions (Figure 2).

Conceptualization. Once the set of terms and definitions representative of the domain have been obtained, we can start the conceptualization phase. As an intellectual activity undertaken by the person responsible for the modeling without the support of automated tools, conceptualization is the most important step in the construction of ontologies. This is an attempt to structure the shared mental models, or the consensual knowledge obtained through the process of collecting and organizing data, according to concepts and the relationships between them.

In order to structure the ontology, we adopted a middle-out approach (Uschold & Gruninger, 1996), a compound of bottom-up and top-down approaches. We identified core concepts of the domain and started to build the structure by specializing and generalizing these concepts simultaneously. According to Uschold and Gruninger (1996, p. 21), middle-out approaches "[. . .] result in stable models, and keep the level of details in control . . . reduce inaccuracies which in turn leads to less re-work." At first, the set of terms was organized

[4]Retrieved March 12, 2006, from http://www.opencyc.org/

[5]Retrieved June 10, 2005, from http://www.ieee.org/

[6]Retrieved December 15, 2005, from http://www-ksl-svc.stanford.edu/

[7]Retrieved February 20, 2006, from http://pauillac.inria.fr/cdrom/ftp/ocomma/comma.rdfs

[8]TOVE Ontology is not available online and terms were gathered from research articles.

[9]Retrieved March 12, 2006, from http://process.mit.edu/

[10]Retrieved March 10, 2006, from http://www.wfmc.org/

DOI: 10.1002/asi

Table of Consensual Definitions		**FORM n°**
Members: Eugênio, Anderson, Soraya, Beth, Selma, Eneli		**Members' Sectors:** AQ
Term ↓	**Individual intensional Notion 1** ↓	**Individual intensional Notion 2** ↓
Specific requirement	A requisite that is required only in a specific core unit	A requirement concerning a core unit and that is not foreseen in the documentation
Consensus →	A requisite concerning a specific situation of a core unit, not foreseen in the management system documentation and that must be provided for …	
Term ↓	**Individual intensional Notion 1** ↓	**Individual intensional Notion 2** ↓
Registry	Means of recording information, through any media, with no legal validity…	It is a document in which the several implementation activities are entered…

FIG. 2. Portion of the Table of Consensual Definitions.

FIG. 3. Portion of the Concepts and Relations table.

hierarchically into a taxonomy. Then other relations were established based on the representation requirements of the domain. The results were registered in a form named Table of Concepts and Relations (Figure 3), in which the data were organized for the implementation phase.

Implementation. The results of the conceptualization, or, that is, concepts and relations, were inserted into the Protégé[11] tool (Figure 4). The resulting implementation thus included the three planned layers (abstract, organizational, and specific). Following this, the results were exported from Protégé to the Resource Description Framework (RDFS). RDFS was chosen not only for its expressiveness but also because this representational language allows for the dissemination of the ontology through Web-based systems.

Simply stated, a formal ontology consists of classes, relations, and axioms. The role of the axioms is to constrain the interpretation of the terms in accordance with the needs of the system. The description of the activities related to the creation of the axioms is beyond the objectives of this research. Emphasis is placed on the vocabulary created during the construction of the ontology.

Evaluation of the Ontology

Despite the various initiatives for the evaluation of ontologies, we focus on the ontology content evaluation process. This process consists of verifying whether the knowledge acquired corresponds to that which is present in the environment where we accomplish the knowledge acquisition process. This verification is user-centered: it focuses on the expert who contributes to the knowledge acquisition process and is responsible for verifying whether the domain knowledge is properly represented by the ontology.

For the evaluation of the ontology, constructed in the manner described above, we utilized two types of instruments: a search engine prototype and a set of questionnaires for evaluation of the ontology.

The prototype consists of a search interface developed in Extended StyleSheet Language Transformation (XSLT),

[11]Retrieved May 18, 2008, from http://protege.stanford.edu

DOI: 10.1002/asi

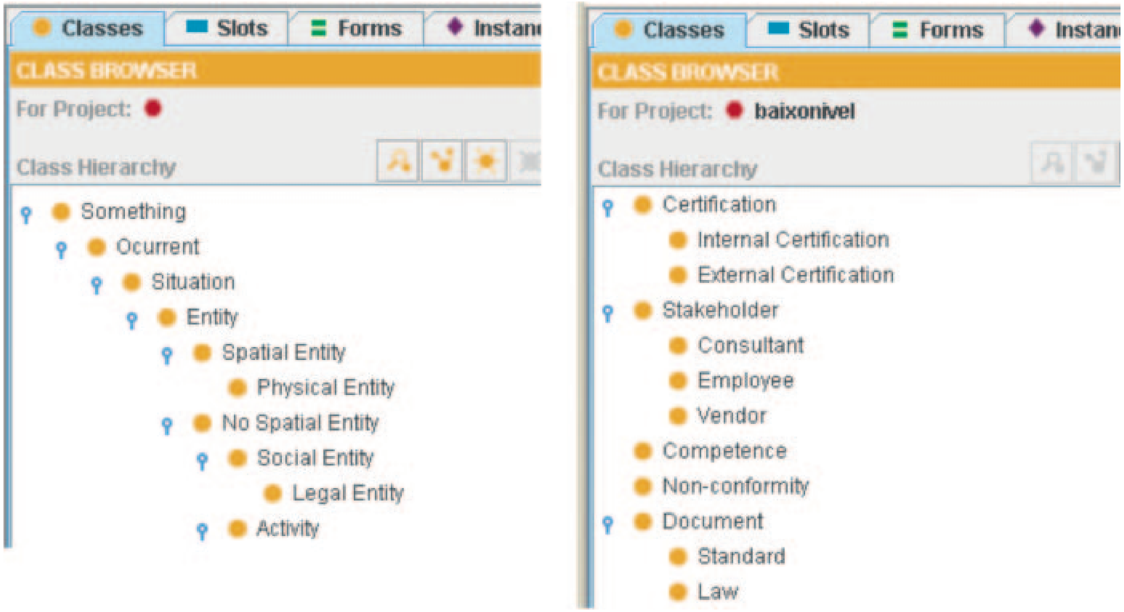

FIG. 4. Portion of the Protégé screen with the implemented ontology.

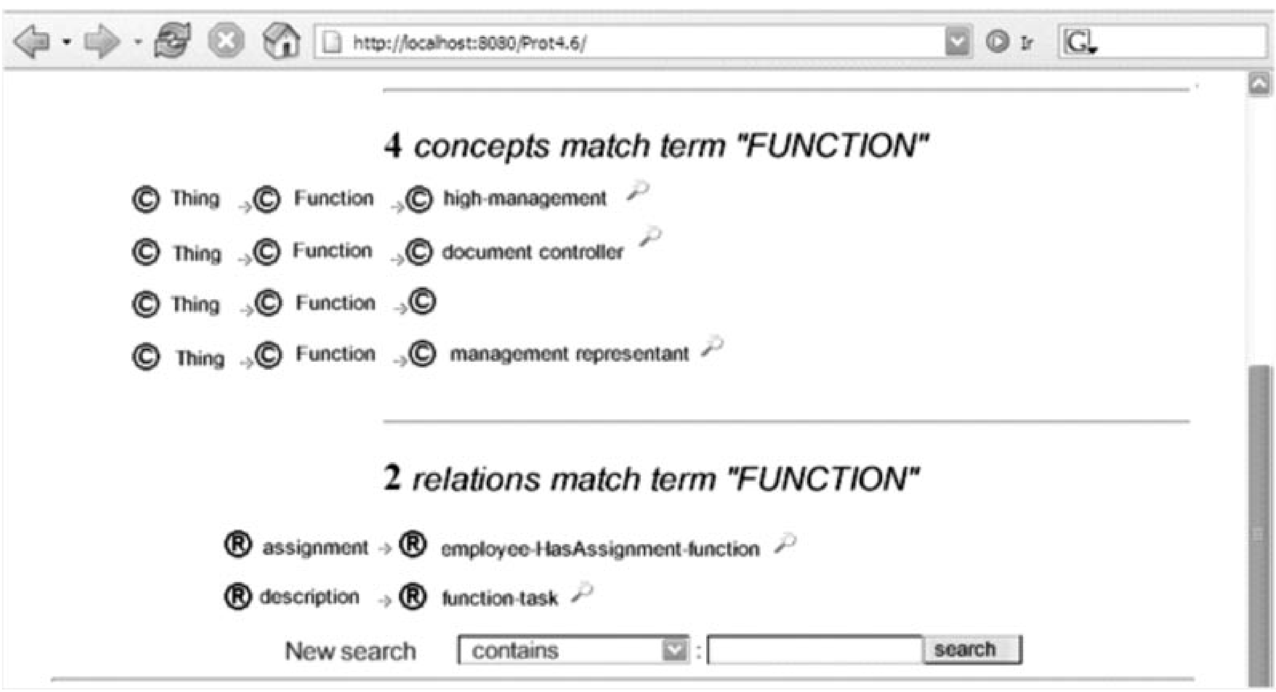

FIG. 5. Results screen, searched by the term "function".

which allows searches in the RDFS file exported by Protégé. This prototype makes the following functionalities available: 1) the search interface, which allows for searches for concepts and relations (Figure 5); 2) the concept hierarchy, which presents the taxonomy and hyperlinks for each term; 3) the hyperbolic vision, which helps the user to visualize the structure as a whole and understand the context of a concept during the searches.

The prototype was not conceived as a tool to be used by end-users but as an aid in the evaluation of the ontology. We presented specialists with the prototype and gave them a demonstration of its functionalities. The ontology evaluation was conducted by the same group of specialists involved in the earlier stages. After 1 week of using the prototype, we asked them to complete questionnaires.

The evaluation questionnaires are multidisciplinary, based on three orientations: 1) questionnaire 1, based on Competency Questions; 2) questionnaire 2, based on Information Quality criteria; 3) questionnaire 3, based on Educational Objectives.

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Read the possibilities bellow and indicate to what extent they meet your needs at work, according to the scale on the right. In this scale, 1 corresponds to "it does not meet my needs" and 5 corresponds to "it meets my needs".	
A list of all certified core sectors, by policy type	- 1 2 3 4 5 +
A list of all core sectors in the certification process, by policy	- 1 2 3 4 5 +
A list of all third party audits conducted by a consultant specialized in certification	- 1 2 3 4 5 +
A list of dates for certification renewals, by system, month and year	- 1 2 3 4 5 +

FIG. 6. Portion of questionnaire 1 (from a total of 20 questions).

The information is reliable.	- 1 2 3 4 5 +
The information is trustworthy.	- 1 2 3 4 5 +
The information features inconclusive credibility.	- 1 2 3 4 5 +

FIG. 7. Portion of questionnaire 2, credibility (from a total of 36 questions).

The information allows for judging the adequacy of conclusions.	- 1 2 3 4 5 +
The information allows for judging of facts based on internal parameters.	- 1 2 3 4 5 +
The information does not allow for proper conclusions.	- 1 2 3 4 5 +

FIG. 8. Portion of questionnaire 3, evaluation criterion (from a total of 25 questions).

Classes and relations	Defined classes	Defined slots	System classes	System slots
Abstract and organizational layers	109	-	15	34
Specific layer (QMP)	142	409		
Total	251	409	15	34

FIG. 9. Final ontology version metrics.

The Competency Questions (Fox, 1992) define the range of the ontology in such a manner that the recovery of information occurs within expected parameters. Questionnaire 1 (Figure 6) presented the specialists with questions that the ontology would be capable of answering and requested that they evaluate whether such questions met their expectations.

The Information Quality criteria are used to evaluate the usability of the systems as well as to propose criteria related to content. The criteria utilized were: proper volume, credibility, completeness, correctness, interpretation, objectivity, updating, relevance, and understanding (Kahn, Strong, & Wang, 1997; Lee, Strong, Kahn, & Olaisen, 1990; Parasuraman, Berry, & Zeitham, 1988; Wang, 2002). Figure 7 shows a portion of questionnaire 2.

The Taxonomy of Educational Objectives (Bloom, 1956), utilized in the field of education to verify whether specific content has been learned, was adapted for questionnaire 3 (Figure 8). The taxonomy establishes a hierarchy of learning objectives, which identifies what an individual is capable of learning about a given subject through a spectrum of six categories. The categories used are: knowledge, comprehension, application, analysis, synthesis, and evaluation.

Development and Evaluation of the Ontology: Results

The final version of the ontology contains ~250 classes and over 400 relations, distributed through three layers. Figure 9 shows the metrics of the final version and Figure 10 shows a portion of the resulting taxonomy.

We built two ontology versions during the research. The main difference between them was the number of slots, that is, the number of relations between concepts. In the first version, general relations were used in order to attend different business rules. However, the need to express specific rules and to deal with peculiarities of the implementation tool led us to build a second version. The rest of this section shows the results of the evaluation of the ontology organized according to the questionnaire orientations.

DOI: 10.1002/asi

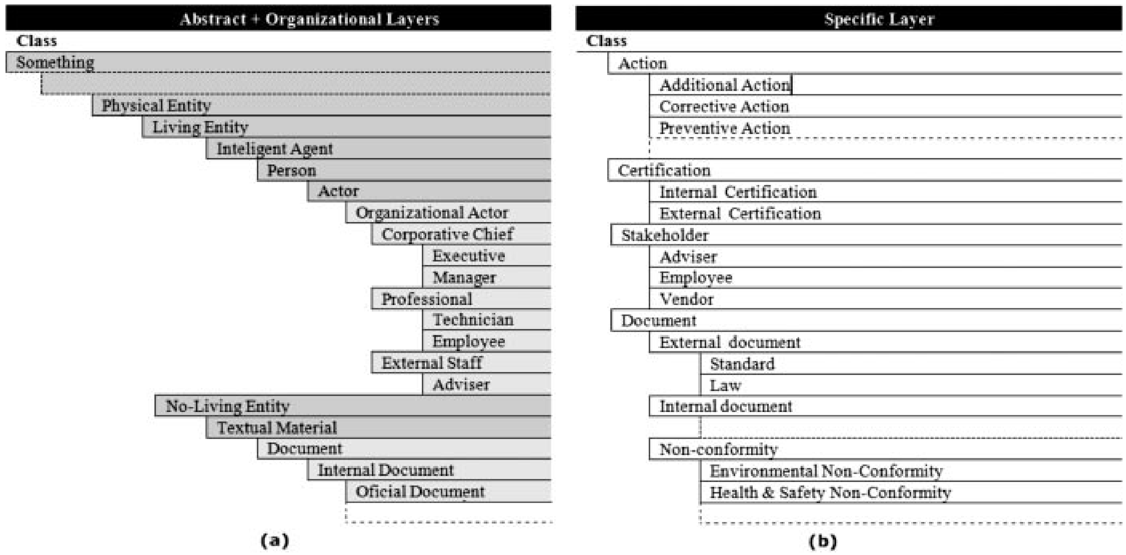

FIG. 10. In (a) portions of the organizational and abstract layers; in (b) the specific layer.

Scale	Meaning	Total of response per value
1	It does not comply	1
2	↓	11
3	↓	17
4	↓	35
5	It complies	62
Weighted mean of scale criteria 4.16		

Statement for questionnaire 1	Mean Value
A list of all core sectors in the certification process for each policy.	4.83
A list of all external audits conducted by a consultant specialized in certification.	4.50
A list of dates by month and year when the certification for each policy must be renewed.	4.50
A list of open Non-Conformity Reports for each core sector.	4.00
A list of employees who participate in internal certification processes per date.	3.50
A list of obsolete and invalid documents per date.	3.17
⋮	⋮
General mean value of responses..	**4.10**

FIG. 11. (a) Answers by criterion and criteria mean value; (b) Portion of data obtained in questionnaire 1.

The results for the Competency Questions dimension are shown in Figure 11a,b. Figure 11a shows a weighted mean (4.16) related to values assigned by participants according to the 1-to-5 scale in questionnaire 1. This value indicates that the results obtained were positive, that is, the model was able to answer the common questions present in the staff's work environment. We observed that 77% of the answers corresponded to high values on the scale (4 or 5).

Figure 11b depicts the following: a sample of assertions from questionnaire 1, the arithmetical mean value of responses according to a 1-to-5 scale, and a general mean value for all responses. The arithmetical mean value calculated for the questionnaire assertions (4.10) indicates that the needs of staff were met by knowledge in the ontology.

The results for the Information Quality dimension are presented in Figure 12a,b. Figure 12a depicts the total number of responses for each value using a 1-to-5 scale in questionnaire 2, where 1 corresponds to "I do not agree with the statement" and 5 corresponds to "I agree with the statement." Figure 12a also depicts a weighted mean value (4.26) related to values assigned by participants according to the 1-to-5 scale in questionnaire 2. The value obtained indicates that results were positive from an information quality viewpoint. 82% of the responses corresponded to high values on the scale.

Figure 12b depicts the following: a sample of assertions from questionnaire 2, the arithmetical mean value of responses according to a 1-to-5 scale, and a general mean value of all statements. The arithmetical mean value

Scale	Meaning	Total of responses per value
1	I do not agree	3
2	↓	4
3	↓	32
4	↓	72
5	I agree	105
Weighted mean value of scale criteria 4.26		

Direction	Statement of questionnaire 2	Mean Value
proper volume	The information volume is enough for your needs.	4.00
	The information volume does not attend to your needs.	4.33
	The information volume is neither large nor small.	3.17
mean for "proper volume" direction 3.83		
understanding	The information is easy to understand.	4.67
	The information is enough for your work.	4.83
	The meaning of the information is easy to understand.	4.50
mean value for "comprehension direction" 4.56		
General mean value of responses 4.26		

FIG. 12. (a) Criterion mean value and answers by criteria for questionnaire 2; (b) Portion of data obtained from questionnaire 2.

Scale	Meaning	Total of responses per value
1	I do not agree	2
2	↓	4
3	↓	25
4	↓	67
5	I agree	52
Weighted mean value of scale criteria 4.09		

Direction	Statements of questionnaire 3	Mean Value
knowledge	The principles of the subject considered are present.	4.17
	The terms and concepts used in your work are present.	4.50
	The procedures for your work are present.	4.17
	The terms and concepts used have little relation to your work. (I)	4.83
"Knowledge" direction mean vale.. 4.42		
evaluation	The information allows you to judge the adequacy of a conclusion.	3.83
	The information allows you to judge facts via internal guidelines.	3.33
	The information allows you to make judgments via external guidelines.	3.17
	The information does not allow you to judge the adequacy of a conclusion.	4.50
"Evaluation" direction mean value 3.71		
General mean value of responses 4.13		

FIG. 13. (a) Criteria mean value and answers by criteria; (b) Portion of data obtained from questionnaire 3.

calculated (4.26) indicates positive results. In relation to the dimensions, the mean values are: 3.83 for proper volume; 4.61 for credibility; 3.97 for completeness; 4.33 for correctness; 3.94 for interpretation; 4.22 for objectivity; 4.61 for updating; 4.50 for relevance; and 4.56 for understanding. These results indicated that the ontology was able to acquire relevant knowledge for participants and present this knowledge properly according to the criteria and dimensions.

The results for the Educational Objectives dimension are shown in Figure 13a,b. Figure 13a shows the following: the total number of responses of each value according to a 1-to-5 scale from questionnaire 3, where 1 corresponds to "I do not

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agree with the statement" and 5 corresponds to "I agree with the statement." Figure 13a also depicts weighted mean value (4.09) related to the values assigned by participants according to the 1-to-5 scale. The value obtained indicates that the results were positive. The ontology was able to acquire knowledge relevant to the staff's work. 79% of the responses corresponded to high values in the scale (4 and 5).

Figure 13b depicts the following: a sample of assertions from questionnaire 3, the arithmetical mean value of responses according to a 1-to-5 scale, and a general mean value for all assertions. The arithmetical mean value of the statements indicates positive results. In relation to dimensions, the mean values are: 4.42 for knowledge, 4.17 for comprehension, 4.5 for application, 4.13 for analysis, 3.88 for synthesis, and 3.71 for evaluation. These results indicate that the ontology was able to acquire knowledge according to the criteria and dimensions considered.

The results of the ontology content evaluation are satisfactory from the point of view of the proposed evaluation method. In the following section one of the issues discussed is the results of the evaluation within the scope of the KM project. This issue is addressed in a manner that clarifies the practical significance of the data obtained.

Discussion

With the case study having been presented, we believe in the significance of discussing issues regarding viability of the use of ontologies in KM activities based on the results obtained in the study. Abecker & van Elst (2004) classify the activities related to KM into two dimensions: the product-centered dimension, in which KM deals with the knowledge registered in documents as well as aspects of its storage and reutilization in IS; and the process-centered dimension, in which KM is considered a social communication process. This vision is the driver of the discussion of the use of ontologies in KM presented in this section. It is worth noting that the dimensions overlap and, therefore, so do the issues discussed here.

From the product-centered point of view, the main issues of interest for the organization are: the preservation of specialized knowledge and the development of IS to support quality management. Within the scope of IS development, issues regarding interoperability between systems are also discussed. From the process-centered KM point of view, the main issues of interest are: the use of the ontology evaluation results and the capability of the ontology to improve communication within the organization.

Preservation of Specialized Knowledge

With the effort to maintain specialized knowledge regarding quality management, the company intends to reduce costs deriving from failures in the certification processes. In this context, the terminological inconsistency of QMP control documents is one of the challenges of the KM project. The set of 15 control documents, called general procedures, provide guidance on the functioning of the QMP throughout the organization. In addition, each corporate unit may create new norm documents in order to adapt or modify a general procedure for a local context. Examples of documents subordinate to general procedures are: specific procedures, operation instructions, and specifications, among others. Over the 5 years in which the QMP has been developed and utilized, we have observed that the individual business units interpret in a distinct manner the meaning of the specialized terms used in the general procedures. This ambiguity is reproduced in local documents.

Activities that have been ongoing throughout the ontology construction process have contributed to a reduction of this ambiguity of terms. Still in the first phases of the process (data collection), documents were analyzed and contextualized based on interviews with specialists. During the discussion held to obtain consensual intensional and extensional notions, the specialists identified terminological inconsistencies in the control documents. According to the participants, the group interviews provided real opportunities to review and adjust the definitions used on a day-to-day basis. New terms were identified and defined, unused terms were discarded, and synonymous terms were entered.

IS for Quality Management

One of the ways of registering, maintaining, and disseminating specialized knowledge is the use of IS. The development of IS to support quality management is one of the main activities planned for in the KM project. The unit responsible for the QMP depends on a small group of professionals to meet the needs of a company with over 10,000 employees. The project calls for the development of specific IS for quality management in an effort to automate tasks, promote the dissemination of knowledge, and interconnect the geographically dispersed units of the company. Some typical KM systems are part of this effort, such as: repositories for lessons learned, repositories for best practices, control and feedback instruments, and cooperative systems, among others.

The main system planned makes use of the ontology-based model as a component of representation. This system is capable of capturing, organizing, disseminating, and reutilizing knowledge regarding quality management, which is registered in documents or in IS. From the point of view of KM, the goal of the system is to facilitate the search for day-to-day solutions, maintain a catalog of sources of know-how and of specialists, and to aid in the learning process. This system has characteristics similar to the Organizational Memory described in Ontology-Based Models and Their Applications (above. The standardization of terms found in the construction of the ontology allows for communication between system architecture agents.

The need to promote interoperability between IS in general is contemplated through the integration directives called for in companies' information strategic plans. However, in practice such planning is not always efficient in the long term, due to political, cultural, and technological factors, among others. Interoperability is a complex issue for which there is no simple solution. Within the scope of the KM project, ontologies were the basis for the approach taken. The ontology was constructed in three layers, as described in the third section: abstract, organizational, and specific. An effort was made to align the terms in the abstract layer with the top-level ontology (Sowa, 2000) or reference ontology (Guizzardi, 2005) terms obtained in well-founded initiatives. It is also worth noting the relevance of the specific level in the effort to standardize the quality management vocabulary for IS.

The Use of the Ontology Evaluation Results

From the technical judgment point of view, the evaluation of an ontology is essential in order to conduct a consistency verification in relation to the purposes for which the ontology was planned. Relevant from the KM activities point of view is the practical meaning of the positive results of the ontology evaluation presented in the fourth section. The proposed content evaluation process is centered on people, in contrast with the majority of evaluation methods available. People are responsible for verifying whether the knowledge of a domain is adequately represented by the ontology. In accordance with the method, positive results prove that the knowledge acquired is useful for the employees. In order for the evaluation scenario to be well founded it is necessary to contextualize the process within the scope of the business needs of the organization and to understand the use of the ontology in the workflow of the specialists.

As previously mentioned, ~5,000 employees are already working with processes certified by the QMP and the KM project seeks to expand this coverage. The QMP is implemented through an independent functional structure that is superimposed over the company organizational chart. In order to participate in the QMP, employees must understand their functions and their responsibilities in this structure, in addition to possessing the ability to undertake these actions. The dissemination of the ontology through the corporate intranet facilitated the access to knowledge regarding the QMP for the entire organization.

In this context, the ontology content evaluation came to be relevant as the knowledge represented in the ontology would be delivered throughout the organization. Primarily, this evaluation could be performed only by the experts who took part in the ontology building process to ensure that the knowledge acquired was equivalent to that which was available during the modeling process. If the domain experts could not evaluate the ontology content, situations could arise in which incorrect, incomplete, inconsistent, or low-quality knowledge could be delivered throughout the company. These experts participated in the creation of the QMP and are also responsible for its maintenance, thus assuring that they have the necessary expertise to perform the evaluation process.

The evaluation process became a part of the daily maintenance activities undertaken by the experts. The ontology is updated every time the dynamics of processes in the organization requires some purposeful changes. During each update, the ontology content is evaluated again by the experts, proving its adequacy before being delivered across the organization.

Communication Across the Organization

The issue of whether an ontology is capable of improving communication in an organization has pervaded every other issue dealt with to this point in the article. In this context, communication across the organization corresponds to the set of communication processes that occur in the social context of the organization, with the objective of meeting the needs of business operations. An improvement in the communication processes is essential in KM initiatives, as this allows for the dissemination of new knowledge and its incorporation into new products, services, and systems (Nonaka & Tackeuchi, 1997).

The dissemination of knowledge regarding quality management fostered debate and the exchange of experiences in the company in which the research was conducted. The ontology became a reference point for the creation of communities of practice, which had been planned as part of the KM project. A community of practice is an important feature for the production of knowledge in organizations, as it consists of a group of people brought together by common interests (Wenger, 1998). Within the scope of communities of practice, activities related to the construction of the ontology became an integral part of several of those tasks pertaining to the workflow of groups of employees: reaching a better understanding of the domain, reaching a unique and shared general agreement among the experts and users related to QMP, correcting inconsistencies in control documents that specify the QMP, and obtaining a common terminology to develop automated IS, among other benefits.

The members of a community of practice create a shared repertoire of resources, among which is a common vocabulary (Lave & Wegner, 1991). Issues related to vocabularies were discussed, in an informal manner, from the initial contact with the organization. The superintendent of the unit in which the case study was conducted reported that the QMP was transformed into a "language." This language facilitated communication among thousands of employees and, in a short period of time, the employees that were not familiar with the language would experience communication difficulties in the company. The need for an organizational language to improve communication in organizations is discussed in the literature (Davenport & Prusak, 2000; Eccles & Nohria, 1994; Von Krogh & Roos, 1995).

In order to refer to an ontology as a language, some clarifications are required. The ontologies for IS are called modeling languages or knowledge representation languages and, as such, have syntactic, semantic, and pragmatic components (Branchman & Levesque, 2004). A modeling language is a type of formal language, i.e., "a specific vocabulary used to describe a certain reality" (Guarino, 1998, p. 2). However, a modeling language does not correspond to an organizational

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TABLE 1. Opportunities for future research.

Activities related to the ontology	Opportunities of research for academics	Opportunities of actions for practitioners
Data Collection	Studies about information users, related to their needs and to their behavior in searching for and using information. Choo (1998) presents a comprehensive literature review on this subject, which is organized in two dimensions: the research objectives (integrative or task-oriented) and research orientation (systems-oriented or user-oriented).	– Do those professionals participating in KM projects have the preference to use only knowledge acquisition techniques adopted in their areas of origin? – Can the use of more than one knowledge acquisition technique be useful in the data collection stage? – Can the use of more than one knowledge acquisition technique result in more expressive models or only generate extra costs? – How do the studies about information users impact knowledge acquisition?
Conceptualization	Studies on how to obtain, organize and present facts that make up the reality in: – The Applied Ontology research field: top-level ontologies (Masolo et al., 2003; Grenon, Smith, & Goldberg, 2004); – The IS research field: evaluation of models according to ontological principles (Wand & Weber, 1990); – Philosophy, the Formal Ontology research field: philosophical principles to establish a theory of forms. Studies on Formal Ontologies date back to the works of Husserl (Edmund Gustav Albrecht Husserl, German philosopher, 1859 – 1938), but several contemporary philosophers have contributed to the subject (Bunge, 1977; Chisholm, 1996; Smith, 2003).	– Are the modeling activities conducted in an ad-hoc manner? Are they based in case-by-case methods? Can the resulting models be used in different contexts? – Do analysts and people responsible for modeling activities receive formal training in knowledge representation techniques? If so, is this training restricted to technological issues? – Do the modeling activities benefit from the reeducation of analysts and of people responsible for modeling activities? – Do the modeling activities benefit from the establishment of methodological guidelines? – Can these methodological guidelines be used by professionals acting in KM projects?
Implementation	Studies on the expressivity of representation languages (for example, RDFS), in other words, about the ability of these languages to support the representational needs in a domain (Milton, 2000; Guizzardi, 2005).	– Are there advantages in using web-oriented approaches (for example, RDFS) as opposed to the traditional approaches (for example, the structured approach of databases)? – Are there any computational or query efficiency limitations that recommend the use of either one of the approaches above? – Do these limitations undermine or influence the creation of models that are representative of the organizational reality?
Evaluation	Studies on the visualization of information. The purpose is to aid users to understand an ontology in the content evaluation process (Fluit, Sabou, & Van Harmelen, 2004; Chen, 2006).	– How to create forms of evaluation capable of dealing with the dynamics of an organizational environment? – How to create systematic procedures to permanently deal with the production and dissemination of new knowledge in the organization?

language, as the latter takes the advantage of the natural language used to share specialized knowledge.

Summary and Conclusions

The article presents a case study on the use of ontologies in KM conducted in an energy supply and distribution company. With the goal of contextualizing the use of ontology-based models, the role of data models and conceptual models is dealt with briefly. We provide a description of the research conducted at the company through the development stages and the evaluation of an ontology for quality management. The results obtained were presented and discussed, highlighting the contributions made by the ontology toward meeting the business needs of the organization.

In all the topics discussed, be they regarding the construction or the evaluation of an ontology, or even its utilization, the underlying issue is communication. Based on the results obtained in the case study, we concluded that ontologies made a contribution to KM in many ways, as, for instance: in the preservation of specialized knowledge, in IS development for KM support and interoperability, and in reaching a consensus by means of content evaluation.

Despite the considerations regarding modeling languages and their relation with natural languages, an ontology is an instrument capable of making a common language operational. This promotes improvements in communication in the organization. In fact, the ontology for quality management corresponds to a controlled vocabulary of terms and relations in that domain. This condition, however, does not conflict with the vision of an organizational language proposed by Von Krogh & Roos (1995) and others. In truth, such controlled vocabulary is a subset of the organizational language.

The research on ontologies is found in Software Engineering and in Knowledge Representation—areas that have the goal of IS development. Despite the differences between the approaches, the role of ontologies in this context is similar: to represent knowledge of a domain for use in an

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automated system. Despite that, the goal of the information system conceptual modeling stage is to create models of reality that promote a common understanding among people, or, that is to say, communication (Mylopolous, 1992). The absence of axiomatization in the case study does not limit the expressiveness of the results and is in consonance with a Knowledge Representation stream (Clancey, 1993). This stream emphasizes the need for consistent models of reality.

The case study demonstrates that contributions are made toward improvements in corporate communications as a result of the process of creating ontology-based models. In general, a model is not evaluated in relation to other possibilities of utilization in the organization. The model is used to implement IS, being then codified in a form that is difficult to be interpreted in other contexts. For KM application, it is essential that the results of the construction of the ontology-based model be evaluated as to its content and not just concerning technical issues. Knowledge must be evaluated in view of the fact that it will be used by people. It is also worth noting that the intermediary representations obtained during the construction of the ontology (see above) allow the results to be interpreted and utilized by people as they are being entered. Throughout the process, relevant concepts that describe the organization, its structure, its processes, its strategies, its resources, and its goals and context were defined.

The evaluation of the content of the ontology presented highly satisfactory results in the case study. It is worth noting that for this study to become a well-founded and easily generalized methodology, it must be tested in other units of the organization and even in other organizations. Nevertheless, this research represents a positive indicator for the viability of the research. In future projects the intention will be to obtain improvements in the sample and in the evaluation prototype. In addition to these improvements, we see other possibilities for future research. Indeed, the research relating ontologies and KM provides opportunities both for academics and for practitioners. Table 1 presents examples of this opportunities and relates them to stages of ontology construction and evaluation. In the column "Opportunities of research for academics" we offer brief comments and provide at least one reference for additional information. In the column "Opportunities of actions for practitioners" we pose questions to aid in searches for improvements in KM practices. We hope to provide grounds for future research and the use of ontologies in KM initiatives.

Acknowledgment

We thank Marcio Zola Santiago for constructive comments and support regarding the English version.

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DOI: 10.1002/asi