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OntoEng: A Design Method for Ontology Engineering in Information Systems

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Abstract. This paper addresses the design problem relating to ontology engineering in the discipline of information systems. Ontology engineering is a realm that covers issues related to ontology development and use throughout its life span. Nowadays, ontology as a new innovation promises to improve the design, semantic integration, and utilization of information systems. Ontologies are the backbone of knowledge-based systems. In addition, they establish sharable and reusable common understanding of specific domains amongst people, information systems, and software agents. Notwithstanding, the ontology engineering literature does not provide adequate guidance on how to build, evaluate, and maintain ontologies. On the basis of the gathered experience during the development of V^4 Telecoms Business Model Ontology as well as the conducted integration of the related literature from the design science paradigm, this paper introduces OntoEng and its application as a novel systematic design method for ontology engineering.

Keywords: OntoEng, Design Method, Ontology Engineering, Design Science, Computational Ontology, Digital Business Model, Information Systems and Computing.

1 Introduction

Ontology is a constructed model, or a theory of a particular domain demonstrating a real-world phenomenon. Recently, the research on ontologies shows it to be a growing and important field in the Information Systems and Computing (ISC) discipline. The underlying message of ontology innovation is that through its employment, information systems design and utilization as well as their semantic integration would be improved. This is because ontologies are the backbone of knowledge-based systems and they establish sharable and reusable common understanding of specific domains amongst people, information systems, and software agents.

Although the fundamental course of action of building or engineering ontologies has lately received considerable attention, but few methodologies have been proposed and the literature does not provide adequate guidance on how to engineer ontologies throughout their life span. There are probably four main reasons; firstly, ontology research is still an evolving field within ISC. Secondly, the majority of the proposed methodologies that do exist are only examined from artificial intelligence and knowledge engineering perspectives. Thirdly, most of these methodologies are domain-dependent and therefore limited in their utility. Lastly, proposals mostly originate from software engineering where the design method in each is skeletal; that is structured into broad phases giving little guidance to ontology engineering practices.

Yet, if they are going to provide more disciplined design and be regarded as a true engineering practice (i.e. not a craft), ontology design needs to encapsulate precise standardized activities and comprehensive systematic methodologies in addition to well-defined design criteria, techniques, and tools (Fernandez et al., 1997). Particularly in information systems, it is important now to achieve that by delineating ontology engineering principally from the design science paradigm. Indeed, if a study of a specific ontology is to be considered proper design science research, it is imperative that the study evolves a *qualified ontology* based on a *reliable design method*. However, the scheme to construct design artifacts is still very broad. In IS design science research, two main and general processes are identified as *build* and *evaluate* (March and Smith, 1995; Hevner et al., 2004). Apparently, they need further methodical decomposition suitable for different types of artifacts. Hitherto, there is a need to define inclusive design methodology with appropriate level of granularity that would allow smooth and consistent ontology engineering developments in the field of information systems.

The main purpose of this research is to take a further step. This paper aims to integrate the gathered experience during the development of V^4 Telecoms Business Model Ontology with relevant literature, and ultimately extends recent thinking relating to ontology engineering from the design science viewpoint. Fundamentally, "OntoEng" is developed as a novel design method for engineering ontologies from scratch in the field information systems. OntoEng not only introduces design and development phases, but also importantly explains different steps and activities within and across phases as well as their chronological order. Within the design iterative activities, the study explores the sort of potential research approaches that can be incorporated and employed. In addition, it explicitly identifies the anticipated outcomes from each design activity; allowing more controllable ontology engineering practices. Moreover, an application of OntoEng is conducted to practically validate the constructed design method and is presented here to show and illustrate OntoEng competency and use.

The remainder of this paper is structured as follows. In the next section, we provide a concise theoretical background concerning ontology and ontological engineering. Thereafter we examine major related research. Next, we introduce the OntoEng; the constructed design method. We then discuss an illustrative case that represents an empirical application of OntoEng as a design method on business models of mobile networks and telecommunication service providers. Before presenting our conclusions, we discuss OntoEng and its evolution and application more from the design science paradigm showing its main distinctive features and contributions.

2 Background: Ontology and Ontology Engineering

Ontology is a term that has been originated in philosophy and refers to the systematic explanation and study of the nature of existence, or being. The term has been borrowed by the information systems and computing disciplines (e.g. Bunge, 1977; Wand and Weber 1990; Guarino and Welty, 2002) and changed somewhat, but despite its recent extensive use in these disciplines, the term has no universal definition. In a practical sense, ontology is a formal and explicit specification and representation (Chandrasekaran et al., 1999) of classes of objects (i.e. concepts) as well as their properties (i.e. relationships), rules (i.e. constraints and axioms), and semantics (i.e. meanings). One of the most cited definitions of the concept is that of Gruber (1993) which defines the notion of ontology as an "explicit specification of a conceptualization" (p.1). The inclusion of the term 'explicit' in this definition highlights *knowledge externalization* as one of the main characteristics and reasons for ontology developments. Moreover, since one of the primary activities during ontology developments is merging, synthesizing, and categorizing a domain's knowledge in a hierarchy (or a taxonomy), we believe that an ontology is also principally addressing the *knowledge combination* mode and the definition of Genesereth and Nilsson (1987) supports this by underlining the term ontology as a formal combined knowledge. They define the term, however, as a "body of formally represented knowledge based on conceptualization" (p.3).

Interestingly, both definitions emphasize 'conceptualization' as a key attribute of an ontology. In essence, conceptualization implies abstraction which signifies that an ontology represents only knowledge regarded as core in any specific domain. Gruber (1993) depicts abstraction as a simplified view of the real-world that we hope to represent for some purpose, but since no precise abstraction level is determined as optimal across different situations, it is normally determined subjectively by ontology developers. Although, factors such as purpose, simplicity, understandability, and inclusiveness of an ontology give indications of which level of abstraction is appropriate.

In addition to 'shared', 'explicit' and 'conceptualized', 'formal' is the fourth keyword that is characteristic in defining ontologies. These four hallmarks are presented in Benjamins et al. (1998) definition and they describe ontology as a "formal, explicit specification of shared conceptualization" (p.2).

Ontology has gained a particular recognition in the domain of Information Systems Analysis and Design (e.g. Wand and Weber, 2002; Wyssusek, 2004). Information systems that make use of explicit and formally defined ontologies have been described as ontology-driven systems (Guarino, 1998). Such ontologies, however, are referred to by terms as *IS ontologies* (e.g. Smith, 2003), or *computational ontologies* (e.g. Kishore and Sharman, 2004).

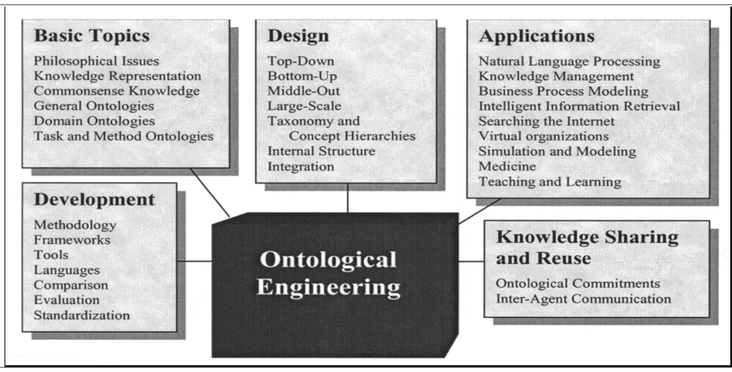

Figure 1. Themes of Ontological Engineering (Adapted from Devedzic, 2002)

Ontological engineering on the other hand is a subfield that covers issues related to ontology development and use throughout its life cycle (Gomez-Perez et al., 2004). Basically, it covers the set of activities conducted during conceptualization, design, implementation and deployment phases of ontologies (Devedzic, 2002). In the related literature, ontology engineering is discussed in different contexts and from different perspectives reflecting the diverse themes included under its umbrella (see Figure 1).

3 Related Research

There are few approaches or methodologies for constructing ontologies (e.g. Uschold and King, 1995; Gruninger and Fox, 1995; Fernandez-Lopez et al., 1999; Noy and McGuinness, 2001; Pinto and Martins, 2004). Based on the experience gathered in developing the *Enterprise Ontology*, Uschold and King (1995) report four main stages for ontology developments: identifying purpose, building the ontology (ontology capture, ontology coding, and integrating existing ontologies), evaluation, and documentation. Within the domain of business process modeling and based on the experience in the development of the *TOVE ontology* (TOronto Virtual Enterprise), Gruninger and Fox (1995) propose six activities for ontology building: capture of motivating scenarios, formulation of informal competency questions, specification of the terminology of the ontology with a formal language, formulation of formal competency questions using the terminology of the ontology, specification of axioms and definitions for the terms in the ontology within the formal language, and finally establishing conditions for characterizing the completeness of the ontology.

Methonology (Fernandez et al., 1997; Gomez-Perez, 1998; Fernandez-Lopez et al., 1999) is a methodology that has been developed within the domain of artificial intelligence which enables the engineering of ontologies at the knowledge level. Methonology distinguishes three types of activities: development, project management, and support. Development activities are specification, conceptualization, formalization, implementation, and maintenance. While project management activities include control and quality assurance, support activities encompass knowledge acquisition, integration, evaluation, documentation, and configuration management. Noy and McGuinness (2001) develop the 'Ontology

Development 101' methodology which includes simple guidelines based on iterative design to help developers and others in creating ontologies using basically Protégé and Ontolingua tools or environments. According to Pinto and Martins (2004), the ontology development life cycle consists of two types of activities. The first includes specification, conceptualization, formalization, implementation, and maintenance activities and the second contains the activities of knowledge acquisition, evaluation, and documentation.

4 Research Methods

The research paradigm followed is that of design science research, with the aim of analytically designing and developing a methodology for ontology engineering in information systems. Design science research, although not new, has lately received increasing attention by information systems and computing researchers. It has been argued that the design science research paradigm could usefully complement the behavioral science pattern -the mainstream IS research- within the cycle of information systems research (Hevner et al., 2004; Iivari, 2007; March and Storey, 2008; Land et al., 2008). The increasing interest in design science has been coupled with that of *design theory* which has lately been emphasized by, for example, Walls et al. (1992) and Gregor and Jones (2007).

Contrasting behavioral science research that aims to provide *truth*; that is principled explanations of phenomena, the employed design science research produces artifacts (i.e. utilities) that address the so-called *wicked problems* (Hevner et al., 2004; Pries-Heje and Baskerville, 2008). While OntoEng is the main artifact in the context of this paper, the engineering of ontologies from scratch in the field of ISC is the tackled wicked problem.

Within the design science paradigm, we have specifically incorporated, and build upon, the following existing research domains to develop the OntoEng design method: (1) Ontology engineering methodologies (e.g. Uschold and King, 1995; Pinto and Martins, 2004), (2) Ontology design and evaluation methods (e.g. Gruber, 1995; Gomez-Perez, 2001, Wand and Weber, 2002; Guarino and Welty, 2002), and (3) IS design and development methodologies (e.g. Avison and Fitzgerald, 2006; Kuechler and Vaishnavi, 2008). An analysis of these approaches led to the foundation on which we built OntoEng. However, it has then been iteratively refined and extended mainly as a result of experience during use in developing the V^4 Telecoms BM Ontology.

From a methodological standpoint, OntoEng could be best portrayed as a *multimethod* or *pluralist* design methodology, as many different research approaches are incorporated. In developing a Telecoms BM ontology in practice, we use OntoEng as a design method, within which we utilize different well-established research approaches in the field of ISC. For example, we principally employed ethnographic content analysis (see Agar, 1980) technique in a manner similar to grounded theory (see Glaser and Strauss, 1967) throughout the *conceptualization* design activity. While for *validation* purposes, we employed case study research (see Yin, 2008). Other methods and tools are used and these are discussed in details in section 5 where we introduce an empirical application of OntoEng.

A multimethod approach is beneficial because, as Mingers (2001) argues, results are richer and more reliable if different research methods are combined together. We agree with Mingers since different related research methods have their own advantages and drawbacks but when appropriately combined together, they can provide enhanced value. Mingers (2001) organizes the designs of pluralist research into five non-mutually exclusive clusters as: sequential, parallel, dominant (imperialist), multimethodology, and multilevel. In our application concerning the Telecoms BM ontology, OntoEng is a *multimethodology* design method. Nonetheless, OntoEng can take the form of any pluralist research designs as appropriate, in future uses and applications.

5 The OntoEng: A Systematic Design Method

Based on our empirical investigations as well as an extensive review of the literature addressing ontologies and ontological engineering including their development methodologies, environments, design principles, and evaluation, we have iteratively drawn upon, synthesized, organized, and extended the ideas in the literature to develop the V^4 Business Model (BM) ontology for mobile networks and telecommunication service providers (see Al-Debei et al., 2008a,b; Al-Debei and Avison, 2009; Al-Debei and Fitzgerald, 2010). On the basis of our experience from developing the V^4 Telecoms BM Ontology we have defined a systematic design method that we term 'OntoEng' which we propose as an ontology engineering method that provides complete guidance for engineering ontologies from scratch.

OntoEng is an iterative design method that encompasses five phases comprising twelve design activities. These are specified in Figure 2 (column 1). For each activity we identify the potential research methods, techniques, and/or tools that are likely to be deployed (column 2). In addition, we define the sort of outcomes that are generated after conducting each design activity (column 3). The design activities of OntoEng are comprehensive, as are the outcomes, whereas the specified research methods, techniques and tools are just examples, as there will probably be others that could be utilized in different circumstances. Figure 2 provides an overview of the final version of OntoEng. In the next section that overview is expanded upon.

6 An Empirical Application of the OntoEng: V^4 Telecoms Business Model Ontology

In this section we provide more illustration through a practical application of the constructed design method. We discuss OntoEng in detail; not only theoretically, but also empirically through its use to engineer the V^4 business model ontology for telecommunication providers and their products-services.

6.1 Planning Phase

This phase consists of three main design activities: specification, planning, and the establishment of design principles and evaluation criteria. In the following subsections, we provide a detailed explanation relating to these design activities and their employment in the practical application.

Specification and Planning. One of the most influential and decisive stages in ontology engineering practices is planning. At this early stage, ontology developers *specify* what sort of ontology they are going to build, verify and indicate its significance and importance along with the intended users, and define its boundaries.

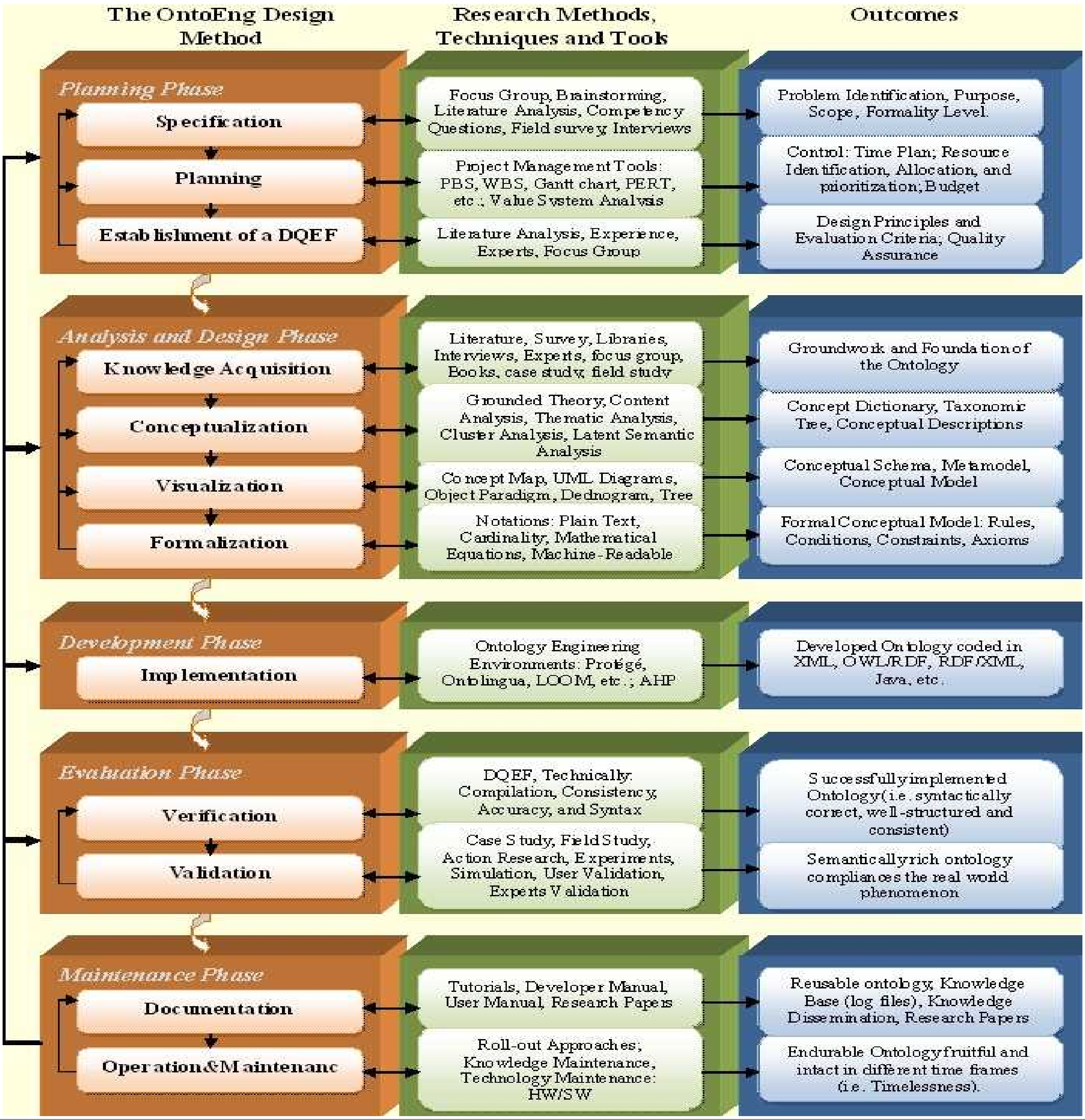

Figure 2. The OntoEng Framework

It is also important to identify the formality level of the ontology. However, any changes to the themes established in the specification design activity may have profound consequences; thus, it is highly recommended to make these ideas as stable as possible. Having requirements specified, ontology engineers can then conduct the *planning* design activity more easily, accurately, and pragmatically. By planning, we mean establishing time plan, resource (e.g. technological, organizational, tangible, intangible) identification, allocation, and arrangements, in addition to a budget. These actions should help in controlling ontology engineering projects.

At this stage during our ontology engineering practice, we dealt with four main issues: awareness of the problem, purpose, scope, and competency questions. Based on interviewing practitioners as well as conducting extensive review and analysis of the related literature, we established that the problem is that IS/IT telecom managers are facing ill-structured decisions regarding the design of business models for mobile and telecom networks and their ICT services. Weak designs of business models make it very hard to translate technological innovations into economic values so as to achieve strategic goals and objectives. However, we also found that an accurate, comprehensive, justified, and well-designed ontology of telecoms business models is lacking within information systems research. Hence, with an ultimate aim of automating the design, evaluation, and change of telecoms business models in order to make it more intelligent, faster, and more disciplined, we addressed this fundamental issue and developed an ontology that identified the business model components, properties, rules, and semantics in the telecom sector. This ontology is of value for telecoms IS/IT or business developers and managers dealing with strategic planning and analysis. Moreover, we found it more appropriate to define the ontology level of formality as semi-formal to ensure satisfactory communication and understanding by both technical and managerial audiences. Specification design activity is followed by planning where we prepared realistic time, resource, and budget plans.

Establishment of a Design Quality and Evaluation Framework (DQEF). It is important to set up a quality system that incorporates objective criteria to guide the design process and also to evaluate the constructed design artifact. In our view, this step affects the quality of the final artifact as well as its validity. The evaluation process in particular ensures that the ontology is semantically rich and syntactically correct, thus, it performs correctly in the real world. Despite its importance, this area is still insufficiently explored. In fact, this design activity (DQEF) is not mentioned or discussed by other methodologies concerning ontology development. Rather, it is only examined as a stage following ontology implementation and development. Despite the absence of this activity in other ontology design methodologies, there is a limited amount of literature tackling this important domain (e.g. Gruber, 1995; Gomez-Perez, 2001). An analysis of the literature tackling the design principles and evaluation criteria of ontologies has led to the identification of the following six criteria.

A- Clarity. An ontology needs to successfully and objectively communicate the intended meaning of defined terms (Gruber, 1995). Defined terms are concepts describing the domain, which will most likely be nouns (i.e. objects), or verbs (i.e.

relationships). Creating a list of these terms is important (Noy and McGuinness, 2001), as well as documenting their definitions in natural language (Gruber, 1995).

Wand and Weber (1993, 2002), followed by Shanks et al. (2008), argue that the clarity and validity of the ontological expressiveness require the absence of the following deficiencies:

• *Construct overload*: two or more ontological constructs map to one modeling (i.e. grammatical) construct.

• *Construct redundancy*: two or more modeling constructs map to one ontological construct.

• *Construct excess*: an existing modeling construct does not map to any existing ontological construct.

• *Construct deficit*: an existing ontological construct does not map to any existing modeling construct.

The rationale behind the importance of *ontological clarity* is that it affects human understanding of the represented phenomenon (Shanks et al., 2002).

B-Coherence. Gruber (1995) argues that an ontology should be coherent, "if a sentence that can be inferred from the axioms contradicts a definition or example given informally, then the ontology is incoherent" (p.3). Gomez-Perez (2001) agrees, but depicts *coherence* in terms of *consistency*. However, she explains that "a given definition is consistent if and only if the individual definition is consistent and no contradictory sentences can be inferred using other definitions and axioms" (p.394).

C- Conciseness. According to Gomez-Perez (2001) an ontology is concise if and only if it does not contain unnecessary definitions, and explicit or implicit (i.e. can be inferred) redundancies amongst existing definitions and axioms. However, we understand "unnecessary definitions" as those definitions adding no value to the understanding of the phenomenon under investigation.

D- Preciseness. Precision is a key factor determining the usefulness and the shared agreement of ontologies in general. It entails avoiding what is so-called 'encoding bias' by founding conceptualization at the *knowledge-level* rather than the *symbol-level* (Gruber, 1995). In other words, representation decisions should not be made based only and dominantly on the convenience of notation. We particularly highlight the value of this criterion when dealing with the business model domain. The concept is criticized for being confused mainly with corporate strategy and business process modeling. Hence, the resulting ontology should be precise enough. That is shaping the boundaries and identifying the elements of the business model concept, as well as resolving any conflict it has with other concepts.

E-Completeness. We believe that it is more convenient to verify the completeness of an ontology in an inverse way; that is by asking questions of "what is missing?" type. Incompleteness means that one or more central parts or hallmarks of the investigated phenomenon are not set out explicitly or cannot be inferred through established definitions and axioms (Gomez-Perez, 2001).

F- Customizability. In the language of Gruber (1995), customizability is *minimal ontological commitment* and *extendibility*, while for Gomez-Perez (2001) it is *expandability*. However, we argue that semantically all of these notions denote customizability as giving better indication for the entire meaning. We support Gruber's view (1995) that an ontology is a conceptual foundation that should be designed in a way that leaves room for different users to monotonically instantiate and specialize the ontology so as to fit their particular settings. In other words, an ontology needs to be designed in a way that gives its different users the ability to expand the existing shared vocabulary without altering the existing ones (Gomez-Perez, 2001).

However, it is worth mentioning that customizability or expandability does not mean completing an incomplete ontology, rather it means taking the ontology to a deeper level of detail that characterize a particular user (e.g. telecoms provider). Further, engineering a customizable ontology requires a deliberate design that takes into consideration minimal ontological commitments. Ontological commitment is minimized when an ontology engineer(s) defines only constructs (objects and relationships) that are critical and crucial to the communication of knowledge consistent with theory (Gruber, 1995). This would lead to a sufficiency state where the representation level is adequate.

Nonetheless, we understand that achieving the ideal situation where all of the above criteria are completely satisfied is a challenge. Our experience supports the view that designing an ontology requires, to some extent, tradeoffs (Gruber, 1995) amongst the criteria.

6.2 Analysis and Design Phase

The next phase in OntoEng is analysis and design. It includes knowledge acquisition, conceptualization, visualization, and formalization design activities. This phase is core in ontology engineering and thus is discussed here in a more detailed manner.

Knowledge Acquisition and Conceptualization. Knowledge acquisition is essential as a foundation for any ontology as it refers to the acquisition of the basic knowledge needed to build an ontology. Conceptualization on the other hand is required to structure the domain knowledge into a *conceptual model* which demonstrates the problem and its solution (Fernandez et al., 1997). This stage is equivalent to the *requirement analysis* phase that normally occurs during the development of information systems and often involves the use of conceptual models (Wand and Weber, 2002).

This section describes the creation of a concept dictionary (see Fernandez-Lopez et al., 1999), a taxonomic tree, and conceptual descriptions with respect to the phenomenon under investigation. In developing the V^4 Telecoms BM ontology, we iteratively acquire and analyze related information and knowledge for the purpose of enumerating the key concepts in the Telecoms Business Model Ontology by creating a concept dictionary for *objects* and *relationships*. This is followed by categorizing these concepts, and the objects in a class hierarchy, to build a taxonomic tree of the Telecoms Business model innovation. Finally, we develop an initial conceptual model for our ontology by utilizing both; the created taxonomic tree of the objects, and the concept dictionary of the relationships. We follow methods from knowledge and ontology engineering domains while also draw upon content analysis techniques.

Essentially, ontologies have been proposed to build knowledge-based systems by reusing and integrating related knowledge (Pinto and Martins, 2004). Thus, we utilize two main sources of data to build a Telecoms BM ontology: (1) empirical data through conducting eighteen semi-structured interviews with key practitioners (managers) in the telecommunication industry; and (2) archived data, i.e. literature that we started with as a first iteration. The literature of business models tackles ontology-related issues in discrete and different manners. While research into business model components provides insights about the classes of objects, the eBusiness conceptual modeling and ontology research extends the information relating to components and includes the relationships.

Despite the general usefulness of the literature as a data source, the BM ontology-related literature is not well organized or consistent; in fact, it can be characterized as incoherent as a whole. This is because instead of building on each others work, researchers tend to propose new-labeled components which are often semantically similar to those existing in literature. Others have misused and confused the BM notion with other concepts such as corporate strategy and ICT-enabled business processes. Moreover, the issue of classifying the business model components in a semantically precise manner has been almost ignored. This is a major limitation since "an effective ontological engineering depends on defining a "good" set of classes to describe the domain" (Parsons and Wand, 2008, p.841). Thus, making a constructive use from the related literature is no easy task, but is very necessary. It requires a deliberate analysis that attempts to overcome the shortcomings of the existing literature and provides a unified and comprehensive ontology.

To do so, we start by identifying and collecting literature concerning the application or the examination of the business model concept in the mobile and telecommunications domain. After our initial exploration and examination, we found the collected literature insufficient for two-reasons. First, a lack of research into business models and mobile-telecommunications has been found. Second, the mobile-telecommunications research addresses the BM concept from a very high level of abstraction without investigating in-depth its constituent elements. Therefore, we start expanding our portfolio and including literature tackling the business model concept in general and more widely in the digital economy as opposed to just the mobile-telecommunications sector. This proved beneficial since the ontological aspects of the BM concept are common amongst different digital domains. This step allows us to create a comprehensive portfolio with deeper levels of details. On the other hand, extending our portfolio imposes an important challenge as well; it compels us to deal with a more confused and blurred views toward the concept than if we are only examining the business model in the telecom domain.

Thereafter, we started the second iteration; i.e. field investigation in the form of a quantitative case study research. Data were collected through a variety of techniques including semi-structured interviewing, documentation review, and observation. This triangulation across various methods in the conducted data collection course of action is useful since it allows 'cross-checking' which strengthens the collected data validity, provides 'multiple perspectives', and supplies more 'complementary' data and information (Orlikowski, 1993). We carried out semi-structured interviews with eighteen (18) key practitioners at one of the leading international telecommunications service providers. The BM serves the strategic level of any digital organization, and therefore managerial representatives from business management, IS/IT, engineering, marketing/sales, and finance domains were engaged as interviewees. Interviews were recorded and on average lasted about (90) minutes. The interviews were transcribed, verified, and then analyzed.

Although not all questions were predetermined, our interview framework guide was fairly tight. The primary themes discussed focused on the topics of BM arrangements along with their rationales from the perspective of telecom operators as a whole as well as their ICT services. Themes included the definition of products and services along with their target segments, communication and collaboration with value network actors, resource allocation and configuration, the creation of core competencies, costing and pricing, customer relationship management and intelligence, and services offering related issues. Many respondents put forward fruitful examples and we extend our information base in the course of collecting extensive and appropriate secondary data. We utilize internal business data such as archival documents, business and annual reports, organizational charts, presentation materials, and proposals. External secondary data such as telecoms websites has been also drawn on.

However, building our ontology by reusing and refining the BM ontological-related knowledge within and outside the domain of telecommunications combines and adds to the two reuse processes identified by Pinto and Martins (2004) which are (1) Fusion/Merging; and (2) Composition/Integration. We now add our process as a third one and term it Synthesis/Refinement.

The research process, which includes data collection, coding, and analysis, is not linear. It proceeds in an iterative way similar to the grounded theory method (see Glaser and Strauss, 1967). In our view, each conducted interview, collected document and collected research paper represents a *case* where related aspects in it are coded and analyzed within-case and across-cases. The collected data were analyzed and coded semantically following ethnographic content analysis technique (see Agar, 1980) where the role of the investigator is in allowing categories, i.e. concepts, to emerge out of data by understanding the underlying themes in the materials being analyzed (see Figure 3). Thus, we employed content analysis to classify textual material semantically and provide more relevant and manageable data (Weber, 1990). To indentify useful classes, we followed *cognitive economy* and *inference* criteria proposed by Parsons and Wand (2008). These two main factors are calculated to enable capturing relevant knowledge about a domain effectively and efficiently. Subclasses have been introduced if one or more of the following conditions is true (Noy and McGuinness, 2001): (1) subclasses are found to have additional properties that the superclasses do not have; (2) having different restrictions; or (3) participate in different relationships to the superclasses.

The first level of detail that has been examined is the *dimensions* of the telecoms business models along with their properties. At this stage we tried to understand and identify the comprehensive but tight basic concepts or upper-level concepts of the business models and their interactions. The second level of detail concerns the *building blocks* or the constituent elements of these dimensions and their interdependencies. This level is essential since it provides more control and offers a better way to manage telecoms business models. However, the iterative process that includes collecting, coding and analyzing data has been ended when the trend has become that new cases are adding no significant value to the Telecoms BM ontology but are repeating what has already been identified. At the final stage of data collection, analysis, and concepts enumeration, the portfolio consisted of ninety-two (92) cases: (18) interviews, (13) documents and (61) research papers.

Concepts	Synonyms in Literature	Description
Products/Services	Services (Viscio and Pasternak, 1996); product (Horowitz, 1996); products (Hamel, 2000); value model (Petrovic et al, 2001); product or service (Alt and Zimmermann, 2001); product and service (Applegate and Collura, 2001); value proposition (Pigneur, 2002); ……… ; value proposition (Lambert, 2008).	This class holds a description about core products and services. This mainly includes name, type, function, and technical/nontechnical requirements of services.
Intended Value Elements	Value proposition (Linder and Cantrell, 2000); value model (Petrovic et al, 2001); value proposition (Alt and Zimmermann, 2001); brand and reputation (Applegate and Collura, 2001); value proposition (Chesbrough and Rosenbloom, 2002); ……… ; intended value (Ballon, 2007).	This class mainly embarasses the sort of value(s) the telecom intends to provide their customers with (utilitarian, hedonic, quality, economy, etc.).
………	………………	………………
Properties	**From**	**To**
enables	Value Configuration	Core Competencies
	Core Competencies	Intended Value Elements
	………	………
deliveredTo	Products/Services	Target Segments
encapsulates	Relationships	Flows and Communications
………	………………	………………

Figure 3. Examples of the Concept Dictionary (Objects and Properties Enumeration).

Founded on the gained experience, we consider that determining the ontology depth in terms of its hierarchy is not an easy task. Nevertheless, based on our examination of the empirical data collected along with literature tackling business model concept (knowledge source), and more importantly by referring to the design and evaluation criteria of ontologies presented in the previous subsection, we found it more convenient to classify business model components in three levels of *Part-Whole* relations (see Shanks et al., 2008). In this research, we call these levels: *thing: telecoms business model*, *dimensions*, and *building blocks* where the latter is related to the former using what is so-called *part-of* structuring relation (see Figure 4). This hierarchy along with its level of details addresses the established design criteria in general, and *customizability* feature in particular.

Retrospectively, the strategy followed in building our ontology could be classified as *middle-out* rather than the classical top-down or bottom-up approaches. Uschold and Gruninger (1996), who identify those three strategies, argue that although the top-down approach provides a better control for the level of detail in any ontology, it could result in imposing arbitrary high level categories which in turn may affect the stability of the ontology. In our research, this approach has been excluded since we might at the end find challenges in meeting our evaluation criteria in general. The bottom up approach has also been excluded because it principally contradicts the *customizability* design and evaluation criteria. According to Uschold and Gruninger (1996), a bottom-up approach results in an ontology that includes a very high level of detail which makes it hard to identify commonalities between related concepts and also increases the risk of inconsistencies, i.e. *coherence*. The middle-out strategy balances the levels of detail as details only arise as necessary since basic concepts, i.e. higher level concepts, are specified in advance and are more stable having naturally evolved.

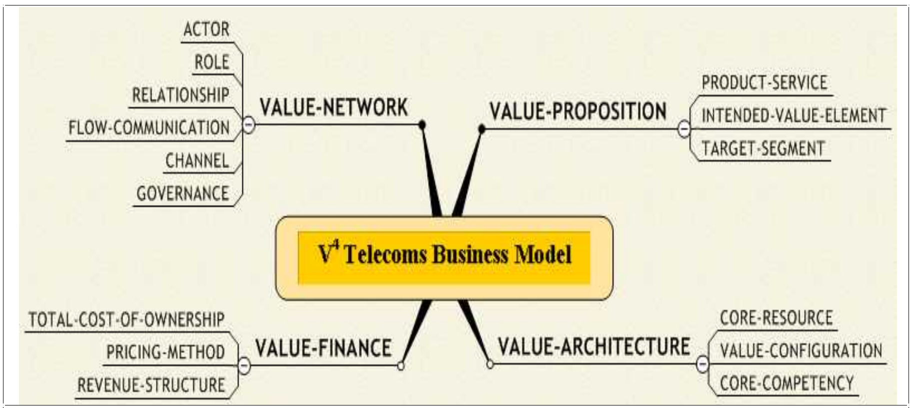

Figure 4. Taxonomic Tree of the V⁴ Telecoms BM Ontology

Visualization and Formalization. The main aim of this stage is to provide an appropriate graphical representation and formalization of our conceptualized ontology. That is utilizing the concept dictionaries, taxonomic trees and the conceptual descriptions made at the prior stage to generate a more formal metamodel or conceptual model that is clearly visualized and shows cardinality rules and domain-range axioms.

To date, there is no generally accepted or mature notation for representing ontologies. Ontology engineers are sometimes using their own notation systems. Most often, which is similar to our case, they utilize Unified Modeling Language (UML) notation for representation purposes. UML is a platform-independent software engineering notation. It is primarily used to provide a metamodel of object-oriented design. Its ability to represent class/subclass hierarchies, relationships between classes/subclasses, and axioms that specify constraints makes it significance in representing ontologies (Kogut et al., 2002), and UML is almost a *de facto* standard for modeling businesses and their computational support systems (Burton-Jones and Meso, 2002), in this context. To show its capabilities, Eriksson and Penker (2000), for example, demonstrate how UML modeling language is also very useful in representing business models in the same way as their software models.

As UML facilitates producing visually rich and easy to use models, there is a strong interest and call in the ontological engineering domain to use it for ontology representation (Cranefield and Purvis, 1999; Guizzardi et al., 2004). This attention however is understandable since UML is a well-established and standardized graphical notation in analysis and design phases (Kogut et al., 2002), and according to Cranefield and Purvis (1999) has a large and rapidly expanding user community.

In this research, we use UML class diagram along with the cardinality notations to represent and formalize the V^4 Telecoms BM ontology in the form of conceptual model (see Figure 5). At this stage, according to Wand and Weber (2002) conceptual models are useful in (1) supporting communications between users and the development team; (2) helping system analysts in understanding the domain under investigation; (3) providing rich input for the design and implementation processes; and (4) documenting the original system requirements for future reference.

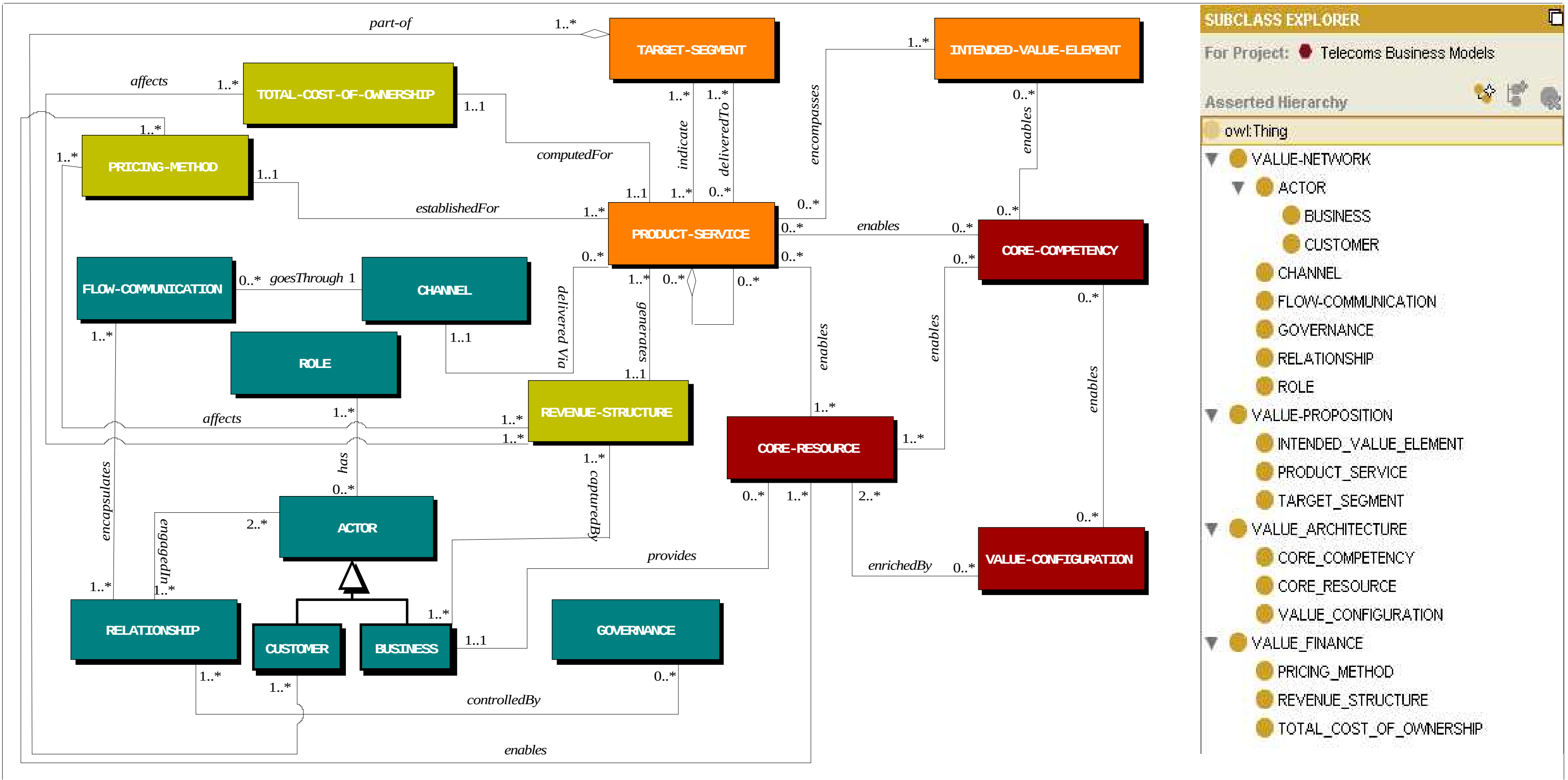

Figure 5. Conceptual Model: UML and OWL Representation

6.3 Development Phase

This phase is concerned with the real implementation of the ontology using one of the ontology engineering environments or any other development platform.

Implementation. At this stage, we are concerned with a process called forward engineering (Fernandez-Lopez and Gomez-Perez, 2003) in which we translate the constructed conceptual model into an implemented ontology (see Figure 6).

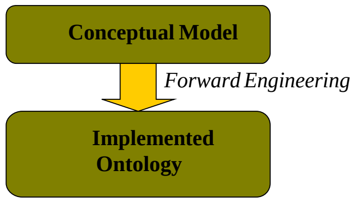

Figure 6. Forward Engineering Process

However, the main question here is which ontology-engineering environment to use? Corcho et al. (2003) provide a comprehensive review of the major environments and tools developed for ontological engineering purposes. They classify these environments into two clusters called first and new generations. First-generation ontology-engineering environments, e.g. *Ontolingua Server*, *Ontosaurus*, and *WebOnto* have been criticized for having strong relationships with specific languages and for not providing expandability facilities. These issues, it is argued, have been resolved in the new-generation environments such as *Protégé-OWL*, *WebODE*, and *OntoEdit*.

Amongst the new-generation environments, Protégé-OWL -which is developed at Stanford University- is chosen and used as the development platform for engineering the V^4 Telecoms BM ontology. This is because Protégé is a new-generation environment, it is authorized by the World Wide Web Consortium (W3C), and it has been recognized as a leading ontology-engineering environment for more than a decade (Knublauch, 2005). It is also an open source integrated environment, a standalone application, and enjoys an extendible architecture with several plugins (Corcho et al., 2003).

However, after implementing the ontology in Protégé-OWL, we represent it using RDF/XML (see Figure 7) language given that it is a general-purpose language for representing information in the web. Representing our ontology in RDF/XML makes it formal and gives flexibility to different telecom operators and other beneficiaries to use or reuse the V^4 Telecoms BM ontology in different applications.

```
.......
.......
<owl:ObjectProperty rdf:about="http://www.owl-ontologies.com/TelecomsBMO.owl#affectsRevenue">
    <rdfs:domain>
      <owl:Class>
        <owl:unionOf rdf:parseType="Collection">
          <owl:Class rdf:about="http://www.owl-ontologies.com/TelecomsBMO.owl#PRICING_METHOD"/>
          <owl:Class rdf:about="http://www.owl-ontologies.com/TelecomsBMO.owl#TOTAL_COST_OF_OWNERSHIP"/>
        </owl:unionOf>
      </owl:Class>
    </rdfs:domain>
    <rdfs:range rdf:resource="http://www.owl-ontologies.com/TelecomsBMO.owl#REVENUE_STRUCTURE"/>
  </owl:ObjectProperty>
.......
......
```

Figure 7. Example of the Implemented Ontology in RDF/XML

6.4 Evaluation Phase

This phase includes two main design activities: verification and validation. We now discuss them showing their significance and also their differences.

Verification and Validation. Evaluation is decisive since it assesses the extent of success of the constructed ontology. In other words, it ensures that the created ontology is successfully implemented and performs correctly in the real world. However, evaluation is a broad term that encompasses both verification and validation (Fernandez et al., 1997; Gomez-Perez, 2001). While *verification* mainly refers to technical activities that ensure the syntactic correctness and cleanness of an ontology, *validation* refers to the process of ensuring that an ontology corresponds to the phenomenon that it is supposed to represent. However, having built the design quality and evaluation framework in a very early stage in the produced ontology engineering method (i.e. OntoEng) allows the evaluation process to start early. Evaluation of the V^4 Telecoms BM ontology in this research is a continuous process. In each and every design activity, we are referring to and ensuring a satisfactory level of all of the criteria described in the established design quality and evaluation system. However, the identification of this particular stage comes from the need to evaluate the entire constructed ontology in a cohesive manner.

For verification, this paper employs Protégé tools and plugins to technically verify that our ontology is clean and implemented correctly. Tools such as *Run ontology tests, Check Consistency, SWRL Rule Validation,* and *WonderWeb OWL Ontology Validator* are used for technical verification purposes in relation to consistency, accuracy, and syntax.

For validation, in addition to the established Design Quality and Evaluation Framework (DQEF), we employ a retrospective case analysis with the aim of providing practical validation of our V^4 Telecoms BM ontology. We examine two cases of mobile services: NTT DoCoMo’s i-mode services and iPhone services. Data were gathered through published materials and case studies pertaining to these two services.

As a subsequent step, we utilize the quantitative content analysis approach. Bryman and Bell (2007) define it as an approach to the analysis of texts and documents in which the researcher seeks to quantify content in terms of predetermined categories in a systematic and replicable manner. The approach is appropriate at this point of the research as the assorted BM hierarchy is already defined within the ontology. At this stage, the research turns deductive since the designed theory (i.e. ontology) represents a hypothesis to be tested using qualitative content analysis.

The process of quantitative content analysis involved data coding and analysis. All data are examined and coded. We use an interpretive approach and thus code the generated text in terms of subjects and themes. This is logical given that the phenomenon of interest (i.e. Telecoms BM ontology) is already established in the prior phases. The coding procedure could be depicted as ‘targeted’, since it relies on mapping the generated data to the predetermined categories within the constructed ontology. Based on this analysis, we develop a logical representation from multiple sources of data. In sight of our experience, we agree that quantitative content analysis is transparent, objective, and systematic.

However, for both within case and across-cases, coding and analysis activities are iterative mainly because the BM dimensions including their building blocks are substantially interrelated and interdependent. Therefore we employ an iterative analysis process to ensure representation of the generated data from the case studies. However, in this iterative process, we experience many cycles of ‘re-sorting’ and ‘re-analysis’. This experience hopefully enables us to provide richer and more inclusive views of BM theory and practice through the developed ontology. It is worth mentioning here that the developed ontology presented within this paper is in its final version after being modified and revised following the evaluation phase.

6.5 Maintenance Phase

This is the last phase in OntoEng although the design process is iterative. We here discuss documentation as well as operation and maintenance as the two main design activities included within this phase.

Documentation and Operation & Maintenance. Documentation refers to the *theorize/justify* processes identified by March and Smith (1995). Ontology documentation is important since poor documentation of ontologies is one of the main barriers to effective knowledge sharing and dissemination. In addition, documentation plays a key role in facilitating ontologies maintenance, use, and reuse. Therefore, clarity and transparency are considered major issues affecting ontology and knowledge-base research usefulness and value.

We understand that design science research in general should be communicated to IS/IT developers and management audience alike and have documented our research with this in mind. Therefore, the way this research is documented is designed to address the needs of both technical and managerial audiences.

The operation activity is novel in this context and refers to the process in which the ontology is put into practice and is used. Maintenance is highly tied to the operation activity since it ensures that the ontology is fruitful and intact in different time frames of use. Maintenance is highly significant given that today’s environment is very turbulent and dynamic. Transformations could take place in the software tool used to implement the ontology, the hardware which accommodates the ontology, and, most importantly, the knowledge included within the ontology. While software and hardware maintenance are key to verify that the ontology successfully performs with the current and future technological trends, the latter (i.e. knowledge maintenance) is highly significant since it is the manner on which we validate that the ontology is constantly compliant with the real world phenomenon.

7 Discussion

OntoEng is a technology-oriented design artifact that we characterize as novel, innovative, and purposeful. Portrayed as *purposeful* implies that OntoEng would provide organizations and other stakeholders with recognizable utility since it provides additional improvements to a real-world phenomenon; that is ontology engineering. The importance of OntoEng however comes from the fact the *Design* implies the use of scientific principles in creating artifacts that perform predefined functions highly efficiently (Singh et al., 2006).

There is still a debate on what constitutes and characterizes IT or design artifacts in design science research (Benbasat and Zmud, 2003; Matook and Brown, 2008). Yet, Design artifacts are defined and classified by March and Smith (1995) and anchored by Hevner et al. (2004) as *constructs* of vocabulary and symbols, *models* representing reality with appropriate level of abstraction, *methods* in the form of algorithms and practices, and *instantiations* which are the implemented systems and/or their prototypes developed as proof-of-concepts. OntoEng is primarily a design *method* artifact, yet this research inclusively generates the four types of design science artifacts. Throughout this research, OntoEng enables the creation of *construct artifacts* (e.g. dimensions and building blocks of Telecoms BMs) as well as *model artifacts* (e.g. conceptual model of Telecoms BMs). Further, *instantiation* artifacts are also addressed in this research given that the V^4 Telecoms BM Ontology is implemented and represented using RDF/XML code.

Two main processes are specified to produce artifacts in IS design science research: *build* and *evaluate.* While building design artifacts demonstrates feasibility, they are evaluated against criteria of value to a community of intended users (March and Smith, 1995). In this paper, not only OntoEng has the conformity with these two general processes, but also effectively decompose them into measurable and controllable five phases including twelve design activities. OntoEng explores that build and evaluate processes are not linear but rather overlapping; given that evaluation is a continuous process where it starts by creating design principles and evaluation criteria at the very early stage. This implies that each prototype of the desired ontology should be assessed against the evaluation framework throughout each design activity. Additionally, when the prototype is implemented, the ontology needs to be completely verified and validated, and then adjusted if needed.

In IS design science research, change phenomenon should be also managed in the design method. This is because design artifacts are technology-oriented where technology is continuously evolving. Hence, it is not enough for artifacts to perform correctly in the real world for a certain period of time without being maintainable and scalable. Interestingly, OntoEng takes this fact into consideration and includes maintenance as the last design activity which could take the design back to any prior stage. With hindsight, we here argue that for design science research in general, *maintain* should be considered as the third main process alongside *build* and *evaluate*. On the other hand, documentation is also included within OntoEng design activities and is meant to refer to *theorize* and *justify* complementary processes in IS design science research.

Generally speaking, information systems design method is iterative where design processes form a loop which normally is iterated a number of times before the final artifact is created (Markus et al., 2002). This fact is also addressed in the proposed design method. OntoEng effectively addresses the iterative design process through its recursion points and allows the development of the other design artifacts based on evolving prototypes.

Hevner et al. (2004) establish seven guidelines to assist researchers, reviewers, editors, and readers to recognize the requirements for effective design science research. For the purpose of helping the aforementioned parties, we recapitulate and map the current research to the established requirements (see table 1).

Table 1. Mapping The OntoEng to Design Science Research Requirements		
Guideline	**Description: General**	**Description: OntoEng**
Guideline 1: Design as an artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an Instantiations.	Although this research examines all types of design artifacts, the key artifact present in this paper is OntoEng; a *method* artifact in design-science research.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.	OntoEng as a method artifact aims to address the design dilemma concerning ontology engineering in the field of ISC. OntoEng aims to make ontology building and engineering more effective, manageable, and creative process.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.	OntoEng is evaluated through its empirical application to develop V^4 Telecoms BM Ontology. OntoEng inclusiveness, use, and competency have been evaluated through its empirical application.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of design artifact, design foundations, and/or design methodologies.	The main contribution is in the area of ontology design and development methodologies. OntoEng is developed as systematic and comprehensive methodology for ontology engineering that adds to the topical related thinking. It also links design activities with research approaches, and provides explicit definitions of the outcomes. Moreover, OntoEng incorporates *maintain* as a third main process besides *build* and *evaluate* in design-science research.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.	This paper has theoretical foundations in knowledge engineering, software engineering, IS development, and IS design-science research. The experience gained throughout the development of a Telecoms BM ontology coupled with prior research in ontology engineering and design science serves as groundwork for this paper. Deficiencies of related research and the need to address the ontology engineering design problem from the design-science paradigm serve as motivation. OntoEng extends recent thinking relating to ontology engineering from the design-science paradigm. Its rigor is also demonstrated through the systematic iterative evolution and its approach, in addition to the empirical application on the OntoEng.
Guideline 6: Design a search process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.	OntoEng, as presented, signifies the resulted artifact following a number of design iterations. Prototypes followed the utilization of the existing literature and then the experience gained through the entire development of Telecoms BM ontology.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.	We document and present our results taking into consideration the needs of the varied audiences: managerial and technical. This paper is an example.

Actually, OntoEng synthesizes and extends the topical views relating to ontology engineering. It however has its own enhancements and distinctive features over the prior methodologies. To unambiguously explain that, we create table 2 within which a mapping between the OntoEng and other major existing methodologies is presented. However, this mapping only shows theme matching concerning design activities and does not reflect differences in terms of sequences, recursion points, iterations, types and perspectives of the ontology design phases and activities.

Table 2. Mapping The OntoEng to Prior Methodologies

OntoEng Design Method	Uschold and King (1995)	Gruninger and Fox (1995)	Methonology (e.g. Gomez-Perez, 1998)	Noy and McGuinness (2001)	Pinto and Martins (2004)
1. Planning Phase					
1.1 Specification	Identify purpose	Capture of motivating scenarios ;informal competency questions	Specification	Domain and scope determination (competency questions)	Specification
1.2 Planning			Control; and quality assurance		
1.3 DQEF					
2. Analysis and Design Phase					
2.1 Knowledge Acquisition	Capture and integrate existing ontologies		Knowledge acquisition; integration	Consider reusing existing ontologies	Knowledge Acquisition
2.2 Conceptualization		Informal terminology	Conceptualization	Enumerate important terms ;define class hierarchy and properties	Conceptualization
2.3 Visualization					
2.4 Formalization		Formal language terminology, competency questions, axioms, and definitions	Formalization	Define the facets of the slots	Formalization
3. Development Phase (3.1 Implementation)	Ontology coding		Implementation		Implementation
4. Evaluation Phase	Evaluation		Evaluation		Evaluation
4.1 Verification					
4.2 Validation		Completeness theorems			
5. Maintenance Phase			Maintenance		Maintenance
5.1 Documentation	Documentation		Documentation; configuration management		Documentation
5.2 Operation & Maintenance					

8 Conclusions

This paper puts forward OntoEng as a novel design methodology for ontology engineering in the field of information systems. OntoEng comprehensively defines five design phases and their twelve activities along with their succession and recursion points. Further, it explicitly links design activities with different useful research approaches and tools. It also unambiguously defines the deliverables of each design activity within ontology engineering practices.

OntoEng is formulated on the basis of the experience gained throughout the design of a BM ontology for telecommunications providers coupled with synthesizing literature relating to ontology engineering themes. OntoEng is an extension of the topical related views. It draws upon artificial intelligence, software engineering, knowledge engineering, and IS development thinking to address the design dilemma concerning ontology engineering from the design science paradigm.

This paper suggests that OntoEng is a significant contribution to design science research. By employing the OntoEng design method, ontology engineers would be more able to build, evaluate, and maintain high-quality ontologies in a systematic and creative manner. We also believe that this paper has important implications on theory and practice concerning design science as well as ontology engineering. We believe that in design science research, *maintain* should be regarded as a third main process complementing *build* and *evaluate*. This is because we consider that the delivered value is augmented, if the artifact is designed while bearing in minds its maintainability and scalability. Reflecting this belief, OntoEng successfully decomposes design science broad processes into more measurable design phases and activities that also extend the recent thinking relating to ontology engineering. Our further research however will include the utilization of OntoEng to engineer varied ontologies within a wide range of domains. We hope that this step will help in providing additional validation for OntoEng as a domain independent design method.

References

Agar, M. *The Professional Stranger: An Informal Introduction to Ethnography*, Academic Press, New York, NY, 1980.

Al-Debei, M. M., and Avison, D. "Business Model Requirements and Challenges in the Mobile Telecommunication Sector," *Journal of organizational transformation and social change*, Forthcoming 2009, pp. 1-27.

Al-Debei, M. M., and Fitzgerald, G. "The Design and Engineering of Mobile Data Services: Developing an Ontology based on Business Model Thinking," *International Federation for Information Processing (IFIP) WG 8.2+8.6 – Human Benefit through the Diffusion of IS Design Science Research,* March-April 2010 (forthcoming), Perth, Australia, pp. 1-21.

Al-Debei, M. M., El-Haddadeh, R., and Avison, D. "Defining the Business Model in the New World of Digital Business," *In Proceedings of the 14th Americas Conference on Information Systems,* AMCIS'08, 2008a, Toronto, Canada, pp. 1-11.

Al-Debei, M. M., El-Haddadeh, R., and Avison, D. "Towards a Business Model for Cellular Networks and Telecommunication Operators: a Theoretical Framework," *In Proceedings of the 13th Conference of the UK Academy for Information Systems,* UKAIS'08, 2008b, Bournemouth, UK, pp. 1-15.

Avison, D., and Fitzgerald, G. *Information Systems Development: Methodologies, Techniques and Tools*, McGraw-Hill, 4th edition.

Benbasat, I., and Zmud, R. "The Identity Crisis within the IS Discipline: Defining and Communicating the Discipline's Core Properties," *Management Information Systems Quarterly* (27:2), June 2003, pp. 183-194.

Benjamins, V. R., Fensel, D., and Perez, A. G. "Knowledge Management through Ontologies," *In Proceedings of the Second International Conference on Practical Aspects of Knowledge Management,* Basel, Switzerland, 29-30 October1998, pp. 1-12.

Bryman, A., and Bell, E. *Business Research Methods,* Oxford University Press, New York, NY, 2nd edition, 2007.

Bunge, M. *Treatise on Basic Philosophy: Vol. 3: Ontology I: The Furniture of the World,* Boston MA, Reidel, 1977.

Burton-Jones, A., and Meso, P. "How Good are these UML Diagrams? An Empirical Test of the Wand and Weber Good Decomposition Model," *In Proceedings of the Twenty-Third International Conference on Information Systems,* Barcelona, December 2002, pp. 101-114.

Chandrasekaran, B., Josephson, J.R., and Benjamins, V. R. "What are Ontologies, and Why do we Need them?," *IEEE Intelligent Systems and their Applications* (14:1), January/February 1999, pp. 20-26.

Cranefield, S. J. S., and Purvis, M. K. "UML as an Ontology Modeling Language," *In Proceedings of the Workshop on Intelligent Information Integration, 16th Int. Joint Conference on AI (IJCAI-99)*. Germany, 1999, pp. 1-8.

Corcho, O., Fernandez-Lopez, M., Gomez-Perez, A. "Methodologies, Tools and Languages for Building Ontologies. Where is their Meeting Point?," *Data & Knowledge Engineering* (46:1), July 2003, pp. 41-64.

Devedzic, V. "Understanding Ontological Engineering," *Communications of the ACM* (45:1), 2002, pp. 36-44.

Eriksson, H. E., and Penker, M. *Business Modeling with UML*, John Wiley, OMG Press, New York, NY, 2000.

Fernandez, M., Gomez-Perez, A., and Juristo, N. "Methonology: From Ontological Art towards Ontological Engineering," *In Proceedings of AAAI97 spring symposium series, workshop on ontological engineering*, Stanford, CA, 1997, pp. 33–40.

Fernandez-Lopez, M., Gomez-Perez, A., Pazos, J., and Pazos, A. "Building a Chemical Ontology using Methonology and the Ontology Design Environment," *IEEE Intelligent Systems and their Applications* (4:1), 1999, pp. 37-45.

Fernandez-Lopez, M., Gomez-Perez, A. "Overview and Analysis of Methodologies for Building Ontologies," *The Knowledge Engineering Review* (17:2), April 2003, pp. 129-156.

Genesereth, M. R., and Nilsson, N. J. *Logical Foundations of Artificial Intelligence*, San Mateo, CA: Morgan Kaufmann Publishers, 1987.

Glaser, B. G., and Strauss, A. L. *The Discovery of Grounded Theory*, Aldine, Chicago, IL, 1967.

Gomez-Perez, A. Knowledge sharing and reuse. In: Liebowitz J, editor. *The handbook of applied expert systems*. Boca Raton: CRC Press; 1998.

Gomez-Perez, A. "Evaluation of Ontologies," *International Journal of Intelligent Systems* (16:3), February 2001, pp. 391-409.

Gomez-Perez, A., Fernandez-Lopez, M., and Corcho, O. *Ontological Engineering with examples from the areas of Knowledge Management, e-Commerce and the Semantic Web*, Advanced Information and Knowledge Processing. Springer, 1st edition, 2004.

Gregor, S., and Jones, D. "The Anatomy of a Design Theory," *Journal of the Association for Information Systems* (8:5), May 2007, pp. 313-335.

Gruber, T. R. "A Translation Approach to Potable Ontology Specification," *Knowledge Acquisition* (5:2), 1993, pp. 199-220.

Gruber, T. R. "Toward Principles for the Design of Ontologies Used for Knowledge Sharing," *International Journal of Human Computer Studies* (43:5/6), 1995, pp. 907-928.

Gruninger, M., and Fox, M. S. "Methodology for the Design and Evaluation of Ontologies," *In Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing,* 1995, pp.1-10.

Guarino, N. *Formal Ontology in Information Systems*, Amsterdam, Netherlands: IOS Press, 1998.

Guarino, N., and Welty, C. "Evaluating Ontological Decisions with OntoClean," *Communications of the ACM* (45:2), February 2002, pp. 61-65.

Guizzardi, G., Wanger, G., Guarino, N., Van Sinderen, M. "An Ontologically Well-Founded Profile for UML Conceptual Models," *In Proceedings of the 16th International*

Conference on Advanced Information Systems Engineering (CaiSE). Springer-Verlag, Berlin, Lecture Notes in Computer Science, 2004, pp. 1-12.

Hevner, A. R., March, S. T., Park, J., and Ram, S. "Design Science in Information Systems Research," *Management Information Systems Quarterly* (28:1), March 2004, pp. 75-105.

Iivari, J. "A Pragmatic Analysis of Information Systems as a Design Science," *Scandinavian Journal of Information Systems* (19:2), 2007, pp. 39-64.

Kishore, R., and Sharman, R. "Computational Ontologies and Information Systems I: Foundations," *Communications of the Association for Information Systems* (14:8), 2004, pp. 158-183.

Knublauch, H. "Protégé OWL," Stanford: Stanford Medical Informatics, 2005.

Kogut, P., Cranefield, S., Hart, L., Dutra, M., Baclawski, K., Kokar, M., and Smith, J. "UML for Ontology Development," *The Knowledge Engineering Review* (17:1), August 2002, pp. 61-64.

Kuechler, B., and Vaishnavi, V. "On Theory Development in Design Science Research: Anatomy of a Research Project," *European Journal of Information Systems* (17:5), October 2008, pp. 489-504.

Land, F., Loebbecke, C., Angehrn, A. A., Clemons, E. K., Hevner, A. R., and Mueller, G. "Design Science in Information Systems: Hegemony, Bandwagon, or New Wave?," *In Proceedings of the Twenty Ninth International Conference on Information Systems,* Paris, December 2008, pp. 1-5.

March, S. T., and Smith, G. F. "Design and Natural Science Research on Information Technology," *Decision Support Systems* (15:4), December 1995, pp. 251-266.

March, S. T., and Storey, V. C. "Design Science in the Information Systems Discipline: An Introduction to the Special Issue on Design Science Research," *Management Information Systems Quarterly* (32:4), December 2008, pp. 725-730.

Markus, M. L., Majchrzak, A., and Gasser, L. "A Design Theory for Systems that Support Emergent Knowledge Processes," *Management Information Systems Quarterly* (26:3), September 2002, pp. 179-212.

Matook, S., and Brown. S. A. "Conceptualizing the IT Artifact for MIS Research," *In Proceedings of the Twenty Ninth International Conference on Information Systems,* Paris, December 2008, pp. 1-11.

Mingers, J. "Combining IS Research Methods: Towards a Pluralist Methodology," *Information Systems Research* (12:3), September 2001, pp. 240-259.

Noy, N. F., and McGuinness, D. L. "Ontology Development 101: A Guide to Creating your First Ontology," Stanford Medical Informatics, Stanford, 2001, pp. 1- 25.

Orlikowski, W. J. "Case Tools as Organizational Change: Investigating Incremental and Radical Changes in Systems Development," *Management Information Systems Quarterly* (17:3), September 1993, pp. 309-340.

Parsons, J., and Wand, Y. "Using Cognitive Principles to Guide Classification in Information Systems Modeling," *Management Information Systems Quarterly* (32:4), December 2008, pp. 839-868.

Pinto, H. S., and Martins, J. P. "Ontologies: How can they be Built?," *Knowledge and Information Systems* (6:4), July 2004, pp. 441-464.

Pries-Heje, J., and Baskerville, R. "The Design Theory Nexus," *Management Information Systems Quarterly* (32:4), December 2008, pp. 731-755.

Shanks, G., Tansley, E., Nuredini, J., Tobin, D., and Weber R. "Representing Part–Whole Relations in Conceptual Modeling: An Empirical Evaluation," *In Proceedings of the Twenty Third International Conference on Information Systems,* Barcelona, December 2002, pp. 89-100.

Shanks, G., Tansley, E., Nuredini, J., Tobin, D., and Weber R. "Representing Part–Whole Relations in Conceptual Modeling: An Empirical Evaluation," *Management Information Systems Quarterly* (32:3), September 2008, pp. 553-573.

Singh, R., Redmond, R., and Yoon, V. "Design Artifact to Support Knowledge-Driven Predictive and Explanatory Decision Analytics," *In Proceedings of the Twenty-Seventh International Conference on Information Systems,* Milwaukee, December 2006, pp. 101-116.

Smith, B. Ontology. In L. Floridi (Ed.), *The Blackwell Guide to the Philosophy of Computing and Information* (pp. 155-166). Malden, MA: Blackwell, 2003.

Uschold, M., and Gruninger, M. "Ontologies: Principles, Methods and Applications," *The Knowledge Engineering Review* (11:2), February 1996, pp. 93-136.

Uschold, M., and King, M. "Towards a Methodology for Building Ontologies," *In Proceedings of the Workshop on Basic Ontological Issues in Knowledge Sharing.* International Joint Conference on Artificial Intelligence, 1995. Also available as AIAI-TR-183 from AIAI, the University of Edinburgh, pp. 1-13.

Walls, J. G., Widmeyer, G. R., and El Sawy, O. "Building an Information System Design Theory for Vigilant EIS," *Information Systems Research* (3:1), March 1992, pp. 36-59.

Wand, Y., and Weber, R. "An Ontological Model of an Information System," *IEEE Transactions on Software Engineering* (16:11), November 1990, pp. 1282-1292.

Wand, Y., and Weber, R. "On the Ontological Expressiveness of Information Systems Analysis and Design Grammars," *Information Systems Journal* (3:4), 1993, pp. 217-237.

Wand, Y., and Weber, R. "Research Commentary: Information Systems and Conceptual Modeling—A Research Agenda," *Information Systems Research* (13:4), December 2002, pp. 363-376.

Wyssusek, B. "Ontology and ontologies in Information Systems Analysis and Design: A Critique," *In Proceedings of the Tenth Americas Conference on Information Systems*, York, New York, August, 2004, pp. 4303-4308.

Yin, R. K. *Case Study Research: Design and Methods,* Sage Publications, Inc., 4th edition, October 2008.