Applications of Ontologies in Enterprise Modelling: A Systematic Mapping Study

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Abstract. Ontologies have been used in several fields as an engineering artefact with the main purpose of conceptualizing a specific object of study. Therefore, it is reasonable to think about using ontologies to support enterprise modelling. In this paper, we investigate the application of ontologies in enterprise modelling. We performed a comprehensive systematic mapping study in order to understand the usage of ontologies to enterprise modeling. We group the results by business areas, business segments, languages, environments and methodologies. We conclude that ontologies are applicable to assist enterprise modelling and have been used specially in Industry, Health and Environment and Government.

Keywords: Ontology; Enterprise Modelling; Systematic Review; Enterprise Architecture.

1 Introduction

Ontologies are used to conceptualize domain knowledge. They have been used in fields like knowledge management, artificial intelligence and bioinformatics, among others. In parallel, organizations have been working on modelling their business services and processes, information systems and technical infrastructure [1], [2]. The purpose of this paper is to understand how ontologies have been used to support enterprise modelling.

In this paper, we present a comprehensive literature review on the state-of-the-art in the research field of ontologies. The main objective of this research is to understand the use of ontologies in enterprise modelling. More precisely, this paper aims to answer the following research question: What are the uses of ontologies in enterprise modelling? To answer this question, 1079 ontology related papers were analyzed.

We organize this paper as follows. Section 2 describes the theoretical foundations. Section 3 describes the research methodology underlying our survey. Section 4 presents the results obtained. Section 5 presents the threats to validity of this paper. Finally, section 6 concludes the paper.

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2 Background

2.1 Ontology

Conceptual modelling (or ontology) describes information related to an application domain and includes the vocabulary, constraints and means to obtain information inferences [3]. The term "Ontology" has been used with different meanings, depending on the community [4]. However, in the computational sense, ontology represents an engineering artefact whose purpose is to conceptualize a specific object of study [5]. In this way, ontology is defined as an explicit, formal and shared specification of a specific concept [4].

Ontologies have been used in diverse fields, such as: knowledge management, information integration, cooperative systems, information retrieval, e-commerce, semantic web, among others [6]. According to [7], ontologies are used in Knowledge Engineering, Artificial Intelligence and Computer Science. For these authors, ontologies are also used in applications related to natural language processing, intelligent integration information, integration of databases, bioinformatics, and education.

2.2 Enterprise Modelling

Building an architectural model of an enterprise is a discipline that organizes and structures components from business and IT, and their relationships that seek to increase organizational performance through better management of complexity.

A business process model is part of enterprise modelling and can be defined as the operational representation of activities, sequences and routes, aiming to reach goals [8]. For these authors, the business process can be modelled in a single segment perspective (orchestration) or in a multiple segment perspective (coreography). This approach enables enterprise modelling: while orchestration describes the organizational internal process, the coreography handles the external process integration, that is, those processes shared by different organizations.

According to [9], business process modelling is an important resource for an efficient management, since models constitute the basis for communication, redesign, implementation and processes control. These authors state that the efficiency of organizational processes can be increased depending on a consistent documentation of the process steps.

2.3 Ontologies for Enterprise Modelling

An organization, in the information age, is compounded by other organizations which share the job, all of them connected to a central organization which holds strategic brands and technologies [10]. Considering ontologies as structures capable to organize information from concepts and their relationships [11], it would be reasonable to think about using ontologies to support enterprise modelling.

3 Research Method

This research aims to analyze publications related to the use of ontologies to enterprise modelling, by executing a systematic literature review, also known as systematic mapping study. According to [12], a systematic review is a means of evaluating and interpreting available research relevant to a particular research question, topic area, or phenomenon of interest. This kind of study comprises three consecutive phases: planning, execution and results. In order to ensure the validity of our literature review, we based this research on guidelines proposed by [12].

3.1 Planning

The main purpose of this phase is to deliver a protocol which drives the research efforts. There are four stages associated with the planning phase: (1) Research Background, (2) Research Questions, (3) Research Strategy and (4) Data Extraction Strategy.

Research Background. In this stage we analyzed the existing literature and identified definitions [11, 4], classifications [7], languages [3, 6, 5], environments and methodologies [13, 14] related to ontologies, and definitions [10], classifications [15], segments [9] and business units [8] related to Enterprise Modelling.

Research Questions. In this stage we defined the research questions addressed by this study. The main research question addressed by this study is: RQ1. What are the use of ontologies to enterprise modelling? With respect to ontologies and enterprise classification, we considered a number of issues: RQ1.1. In which business segments were ontologies used for enterprise modelling? RQ1.2. In which organizational functions were ontologies used in enterprise modelling? RQ1.3. What are the preferred languages to build enterprise modelling ontologies? RQ1.4. What are the preferred tools to build enterprise modelling ontologies? RQ1.5. What are the preferred methodologies to build enterprise modelling ontologies?

Research Strategy. Following guidelines proposed by [12], in this stage, we defined the strategy used to search for primary studies, including search terms and resources to be searched. We conducted searches for primary studies in the following electronic databases: Association for Computing Machinery (ACM), Elsevier peer-reviewed full-text articles (ScienceDirect) and Institute of Electrical and Electronics Engineers (IEEE). The search string used in this procedure is composed of two parts: Enterprise Modelling AND Ontology. In order to improve this initial structure, we determined synonyms, related terms and alternative spellings. We incorporate these additional keywords using boolean operators "AND" and "OR", providing a conceptual and complete query which was used as a basis to construct the final search strings. We then used the advanced search tool to adapt the conceptual string to each electronic database

syntax and searched for these terms in the title and in the abstract of the paper. The conceptual query had the following structure:

{[(ENTERPRISE AND ONTOLOGY) OR (ENTERPRISE ARCHITECTURE AND ONTOLOGY) OR (ENTERPRISE ENGINEERING AND ONTOLOGY) OR (ENTERPRISE MODELLING AND ONTOLOGY) OR (ENTERPRISE MODELING AND ONTOLOGY)] OR [(ENTERPRISE AND ONTOLOGIES) OR (ENTERPRISE ARCHITECTURE AND ONTOLOGIES) OR (ENTERPRISE ENGINEERING AND ONTOLOGIES) OR (ENTERPRISE MODELLING AND ONTOLOGIES) OR (ENTERPRISE MODELING AND ONTOLOGIES)]}

Data Extraction Strategy. in this stage we defined the strategy to extract data from selected papers, including the selection criteria and the forms to extract the data from papers. We considered a paper as relevant based upon three selection criteria: (1) the paper presents the use of ontologies to enterprise modelling; (2) the paper answers the research question; (3) the paper is published in the last ten years. As exclusion criteria, we decided not to select those papers written in other languages than English neither those belonging to out of scope venues (e.g: BPM as "beat per minute" - health). In order to address the research questions and issues, we decided to group the selected papers in six main categories: Business Area, Organizational Function, Ontology Language, Ontology Methodology, Ontology Environment and Ontology Hierarchy

3.2 Execution

The main purpose of this phase is to perform activities which extract and synthesize data from papers. There are three stages associated with the execution phase: (1) Select Primary Studies, (2) Execute Data Extraction and (3) Synthesize Extracted Data.

Select Primary Studies. The automatic search resulted in 1079 papers potentially being relevant for our survey. IEEE delivered 82% of the results, followed by ScienceDirect (11%) and the ACM (7%). An initial manual filtering was then executed to refine the results, according to the defined data extraction strategy. We applied inclusion and exclusion criteria based on the abstract, introduction and conclusion of each paper. From the 1079 papers, 240 (about 22% of the total) were retained for further analysis. In order to retain only studies exploring the use of ontologies to enterprise modelling, we analysed the details of the 240 papers. After this detailed analysis, we obtained 105 primary studies (9.7% from total). The complete list of accepted papers is described in Appendix A.

Execute Data Extraction. In this stage, we aimed to collect the information needed to address the questions of this review. After the search and selection procedures, the primary studies were examined through the extraction forms, created in the START tool [16]. The papers were analysed considering the information required by each research question. The extraction forms were filled with text excerpts from the primary studies to answer each question.

Synthesize Extracted Data. In this stage, we collated and summarized the results of the included primary studies. The data extracted and synthesized in this stage is presented in the results section which can be read next.

4 Results

4.1 Overview of Studies

The final list of paper was limited to the past decade, with studies from 2000 to 2013. The investigation of use of ontologies to enterprise modelling was in continuous rise from 2008 to 2012, as presented in Figure 1.

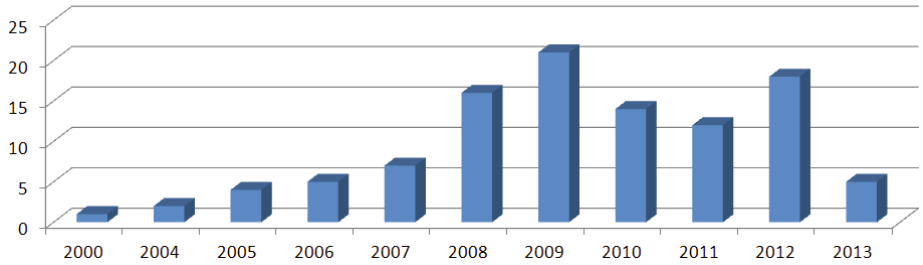

Fig. 1. Year Distribution

Most part of studies analyzed (61%) reported the use of ontologies intending to contribute to knowledge management. Second (21%), studies indicated use of ontologies to support the systems interoperability. Another portion of the studies (18%) used ontologies aiming to enable information retrieval.

The same distribution can be observed when different business segments are compared, except for services and virtual enterprises. According to studies, services enterprises used ontologies mainly for information retrieval while virtual enterprises used ontologies mainly aiming at systems interoperability, as presented in Figure 2.

Studies also indicated that knowledge management can be carried out with both formal and informal ontologies. However, studies indicated that companies prefer more formal ontologies when the concern is systems interoperability or information retrieval, as presented in Figure 3.

4.2 Evaluation of Research Questions

RQ1. What are the use of ontologies to enterprise modelling? This research question aimed to explore how ontologies could be used in enterprise modelling. As there are several types of enterprises, we consider relevant indicating the business areas (or segments) which are already using ontologies to improve their modelling. Looking inside the organizations, we consider interesting to point out

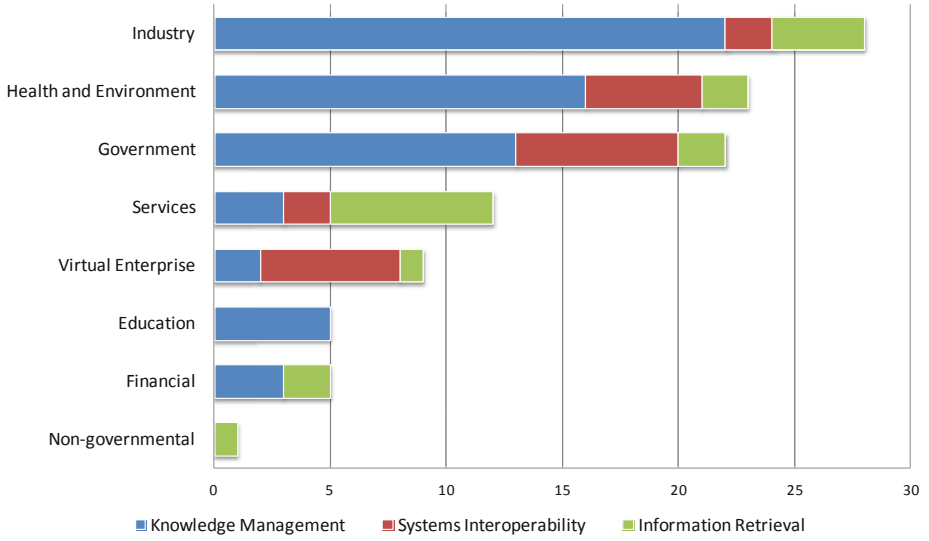

Fig. 2. Purpose of Ontologies by Business Segment

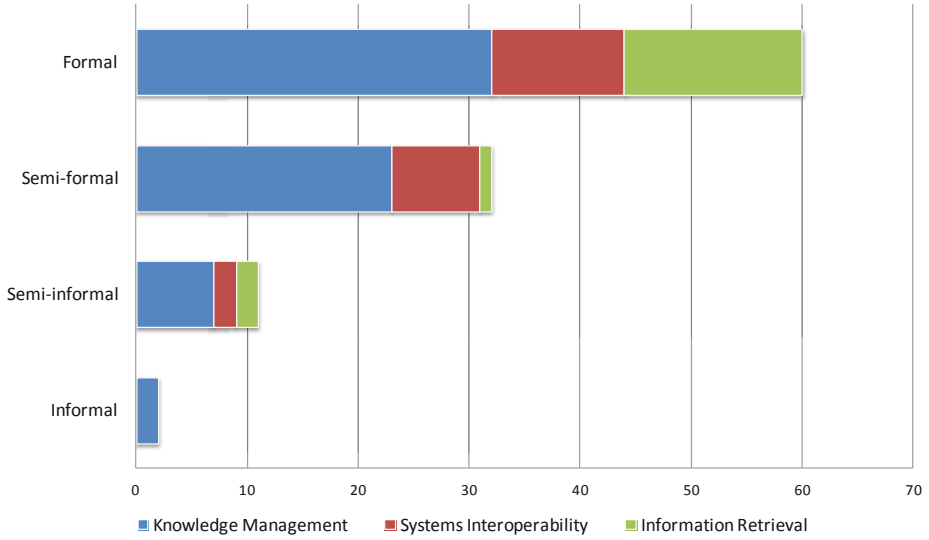

Fig. 3. Ontologies Purpose and Formalism

the organizational functions which use ontologies to support their modelling. On the other hand, we consider relevant indicating how the ontologies have been created, that is, the methodologies, languages and tools used for this purpose. Drawing on these conclusions, we may direct efforts of both ontology and enterprise modelling researchers towards a more conscious and coordinated use of conceptual knowledge.

RQ1.1. In which business segments were ontologies used to enterprise modelling? Most of the analysed studies is focused on Industry(27%), Health and Environment(22%) and Government(21%). Services(11%), virtual enterprise(8%), education(5%), financial(5%) and non-governmental organizations(1%) are the remaining business areas.

RQ1.2. In which organizational functions were ontologies used in enterprise modelling? Sixty-six percent of the analysed studies are related to Operations and to Research and Development (R&D) functions. A low percentage of analysed studies are related to Human Resources (HR) or Marketing.

RQ1.3. What are the preferred languages to build enterprise modelling ontologies? Most of analysed studies (48%) used the language OWL (Ontology Web Language) to represent ontologies. But it is important to mention that thirty-six percent of the studies did not mention the language used.

RQ1.4. What are the preferred tools to build enterprise modelling ontologies? 50 analysed studies (48%) did not mention the environment used to support ontology building. Most of the 55 remaining studies (69%) used the PROTEGE tool, which is a free and open source platform developed by Stanford Center for Biomedical Informatics Research.

RQ1.5. What are the preferred methodologies to build enterprise modelling ontologies? Less than 15% of the analysed studies mentioned the methodology used to build ontologies. There seems to exist an opportunity for researching the perception of engineers regarding the value of methodologies used to build ontologies. Figure 4 shows that most of the analyzed papers did not mention the methodology used to model organizations. Analyzing this figure, we can visualize that great part of analyzed papers used OWL with PROTEGE as a tool to enable enterprise modelling.

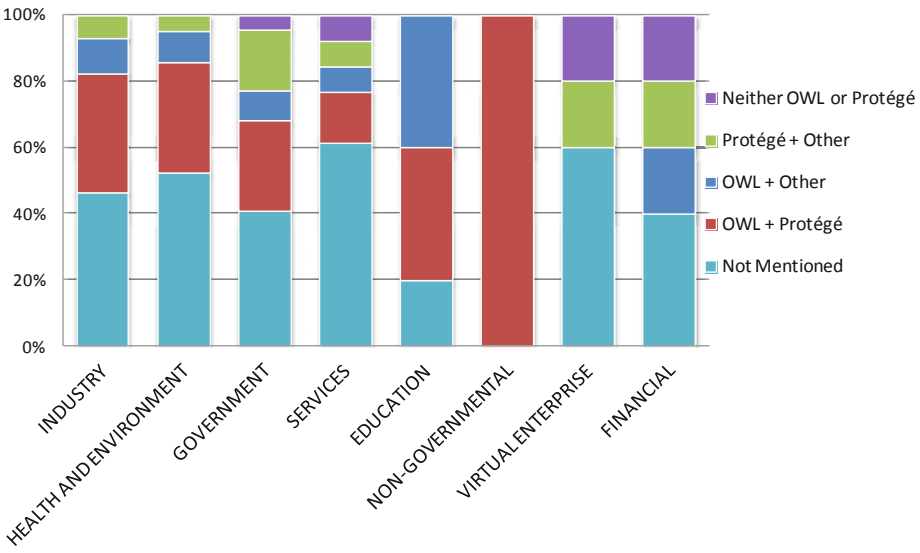

Fig. 4. General Distribution of Papers

5 Threats to Validity

In this Section, we address the limitations of this mapping study. First, only papers written in English were considered. Additionally, during data extraction, it was necessary to interpret the subjective information provided by studies. This happened because many studies did not present objective details regarding the topics investigated. Another potential threat to validity is the natural limitation of search engines, which may have caused the loss of relevant papers.

6 Conclusion

A state of the art survey on the applications of Ontologies in Enterprise Modelling has been given in this paper. The analysis presented shows that ontologies are used to assist in organizational modelling. Most of analyzed papers did not mention the methodology used to model enterprises. Thus, we believe that studies focusing on perception of relevance of methodology use for enterprise modelling is interesting in this context. OWL seems to be frequently combined with the PROTEGE environment. Therefore, studies to improve the link between language and environment must be performed. The results also highlight the need of further studies on enterprise modelling in organizations such as non-governmental, financial and educational. There seems to exist an opportunity for researching the use of ontologies to model HR and Marketing organizational functions.

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Appendix: List of Papers

#	Title	#	Title
1	SEMPATH Ontology: Modeling Multidisciplinary Treatment Schemes Utilizing Semantics	33	Research of Plant Domain Knowledge Model Based on Ontology
2	An Enterprise Ontology-Based Approach to Service Specification	34	Conceptual Modeling of Spatial Database Based on Geographic Ontology
3	A Negotiation Protocol to Support Agent Argumentation and Ontology Interoperability in MAS-Based Virtual Enterprises	35	An Application Model of SKOS-Based Ontology of Water Resources
4	An Ontology-Based Distributed Case-Based Reasoning for Virtual Enterprises	36	An Ontology-Based Framework to Model a GlobalPlatform Secure Element
5	Domain Modeling for Enterprise Information Systems - Formalizing and Extending Zachman Framework Using BWW Ontology	37	Emergency Response Organization Ontology Model and its Application
6	Ontology-centric, Service-Oriented Enterprise Campaign Management System	38	Towards an ontology of help to the modeling of accident scenarii: Application on railroad transport
7	WSMO-PA: Formal Specification of Public Administration Service Model on Semantic Web Service Ontology	39	Modeling and management of ontology-based credit evaluation meta-model
8	Advanced enterprise process modelling utilizing ontology semantics	40	Aligning medical ontologies by axiomatic models, corpus linguistic syntactic rules and context information
9	Enterprise Ontologies for Planning and Integration of Business: A Pragmatic Approach	41	An integrated spatial DSS design in Hydroinformatics based on ontology and domain modeling
10	Integrating Process and Ontology for Supply Chain Modelling	42	Research on emergency case ontology model based on ABC ontology
11	Ontology based knowledge modeling and reuse approach in product redesign	43	Ontology for Heart Rate Turbulence Domain From The Conceptual Model of SNOMED-CT
12	Ontology Model-Based Static Analysis on Java Programs	44	Ontology based data warehouse modelling - a methodology for managing petroleum field ecosystems
13	Ontologies and Rules for Rapid Enterprise Integration and Event Aggregation	45	Ontology and automatic code generation on modeling and simulation
14	A Multi-Dimensional Ontology Model for Product Lifecycle Knowledge Management	46	Open-Environmental Ontology Modeling
15	Research on manufacturing resource organization model based on ontology	47	A knowledge model for Mechatronic Product Development Based on ontology
16	Research and Application on OWL Ontology-Based Product Design Knowledge Model	48	Modeling the military role of computer generated force based on ontology
17	Using ontologies for representation of individual and enterprise competence models	49	Modeling and Building an Ontology for Neuropediatric Physiotherapy Domain
18	Ontology-based modeling of manufacturing information and its semantic retrieval	50	Project Approval Ontology Model and Its Application
19	The srBPA ontology: A formal representation of the Riva-based business process architecture	51	An ontology-based model for personalized financial planning product design
20	Ontology-based service-oriented architecture for emergency management in mass gatherings	52	Supporting Value Chain Integration through Ontology-Based Modeling
21	A Use Case Diagrams ontology that can be used as common reference for Software Engineering education	53	Ontology based data warehouse modeling and managing ecology of human body for disease and drug prescription management
22	An ontology-based environment for effective collaborative and concurrent process engineering	54	Wind turbines' condition monitoring: an ontology model
23	A Process-Driven and Ontology Based Software Product Line Variability Modeling Approach	55	Ontology-based technology model for the use in the early stage of product development

24	An ontology-based architecture for distributed digital museums	56	A Study on Marine Information Sharing and Integration Model Based on Ontology
25	Extensive overview of an ontology-based architecture for accessing multi-format information for disaster management	57	Ontology Modeling of Emergency Plan Systems
26	Virtual Laboratory ontology for engineering education	58	EDVO: A "One-Station" Emergency Response Service Model Based on Ontology and Virtual Organization
27	An Ontology-Based #x00026; Distributed Service Model for EG	59	Ontology meta-model for building a situational picture of catastrophic events
28	An Ontology-Based Architecture for Service Discovery	60	Modelling Energy and Transport Infrastructures as a Multi-Agent System using a Generic Ontology
29	The Smart Architect: Scalable Ontology-Based Modeling of Ancient Chinese Architectures	61	Ontology for Heart Rate Turbulence domain applying the conceptual model of SNOMED-CT
30	Using Ontologies to Aid the Teaching of Software Engineering	62	Research of Land E-Government Decision Support System Based on Ontology and Workflow Model
31	Semantic Information Integration for Electronic Patient Records Using Ontology and Web Services Model	63	SimPHO: An ontology for simulation modeling of population health
32	Home-based telemonitoring architecture to manage health information based on ontology solutions	64	POWER: programme for an ontology based working environment for modeling and use of regulations and legislation
65	An Approach of Domain Ontology Construction Based on Resource Model and Jena	88	Ontology Modeling for Goal Driven E-Government
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68	OntoMobiLe: A Generic Ontology-Centric Service-Oriented Architecture for Mobile Learning	91	Enterprise ontology based splitting and contracting of organizations
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70	Ontology-Based Modeling of Breast Cancer Follow-up Clinical Practice Guideline for Providing Clinical Decision Support	93	The pragmatics of event-driven business processes
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72	Reference Architecture for Medical Imaging Annotated in a GRID: Ontology-Based Services	95	Analysis of shipbuilding fabrication process with enterprise ontology
73	A model of intelligent distributed medical diagnosis and therapy system based on mobile agent and ontology	96	Design of product ontology architecture for collaborative enterprises
74	Service Management Model Based on Ontology	97	Knowledge sharing in virtual enterprises via an ontology-based access control approach
75	Designing a Conceptual Model for Herbal Research Domain Using Ontology Technique	98	Constructing an enterprise ontology for an automotive supplier
76	Knowledge Exploitation through Modeling, Navigation and Querying, an Ontology-Based Integrated Architecture	99	Business concepts ontology for an enterprise performance and competences monitoring
77	An architecture based SKOS ontology for scalable, efficient and fault tolerant grid resource discovery	100	The development of an ontology-based expert system for corporate financial rating
78	Geospatial semantic Web: architecture of ontologies	101	4 - An ontology for e-business models
79	Delineation and interpretation of gene networks towards their effect in cellular physiology- A reverse engineering approach for the identification of critical molecular players, through the use of ontologies	102	An ontology-based business intelligence application in a financial knowledge management system
80	Ontology-centered integration of project management, cost and resource modeling with analysis, simulation and visualization: a case study of space port operations	103	Considering environmental assessment in an ontological framework for enterprise sustainability
81	Shale-gas ontology, a robust data modeling methodology for integrating and connecting fractured reservoir petroleum ecosystems that affect production complexities	104	Rule-based ontological knowledge base for monitoring partners across supply networks
82	Re-use of an ontology for modelling urban energy systems	105	A Web-based Product Service System for aerospace maintenance, repair and overhaul services
83	Application of Emergency Case Ontology Model in Earthquake		
84	An Ontology-based Service Model for Smart Infrastructure Design		
85	Geo-ontology model based on description logic		
86	Hierarchical Ontology on Multi-scale Road Model for Cartographical Application		
87	Integration of product models by ontology development		