Petrol, Gaz ve Madencilik Endüstrisinde Bilgi Gösterimi için Ontoloji Temelli bir Yaklaşım

Araştırma Makalesi/Research Article

Övünç ÖZTÜRK

Bilgisayar Mühendisliği Bölümü, Manisa Celal Bayar Üniversitesi, Manisa, Türkiye
ovunc.ozturk@cbu.edu.tr
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Özet— Petrol, gaz ve madencilik endüstrisinde semantik web teknolojilerini kullanan bazı çalışmalar olsa da bunların çoğu, sondaj, keşif ve üretim gibi çeşitli faaliyetlere ait verilerin toplanması ve analizi ile ilgilidir. Öte yandan, döngü sürelerini ve dolaylı maliyetleri önemli ölçüde azaltabilen semantik web uygulamaları geliştirmek de mümkündür. Bu çalışma, semantik web teknolojileri ile petrol, gaz ve madencilik endüstrisi arasındaki boşluğu dolduran bir uygulamadır. Bu çalışma kapsamında bir sondaj araçları ontolojisi prototipi önerilmektedir. Önerilen ontolojinin popülasyonu için başlangıç olarak matkap ucu örnekleri seçilmiştir. Ontoloji popülasyonu sürecinde mevcut e-tablo dokümanları, ürün katalogları ve ürün verilerini içeren web sayfaları kullanılmıştır. Bu makalede, çalışma sürecinde edinilen ontoloji geliştirme deneyimi ve bu deneyimin diğer çalışmalarda nasıl kullanılabileceği açıkça anlatılmaktadır. Seçilen ontoloji popülasyonu yöntemleri, matkap uçlarının yanısıra değişik alanlardaki birçok ürün için de uygulanabilir. Bu nedenle, önerdiğimiz yöntemin uygulanabilirliği, bu çalışmada ele alınan ürünlerin ötesine uzanmaktadır. Bu çalışmada ayrıca, önerilen ontolojiyi kullanarak, farklı satıcılara ait matkap uçlarını aramayı ve karşılaştırmayı destekleyen bir matkap ucu portalı da sunulmaktadır.

Anahtar Kelimeler— ontoloji geliştirme, sondaj araçları, GoodRelations

An Ontology Based Approach for Knowledge Representation in Oil, Gas and Mining Industry

Abstract— Although there are some works applying semantic web technologies in oil, gas, and mining industry, most of them involve finding and analyzing the data from a variety of activities such as drilling, exploration and production. On the other hand, it is also possible to develop semantic web applications that may dramatically reduce cycle times and indirect costs. This work is a practice that bridges the gap between semantic web technologies and oil, gas, and mining industry. We propose a prototype drilling tools ontology. We populate the ontology focusing on drill bit concept as a starting point. In the population phase, we used existing spreadsheet documents, product catalogs and web pages containing product data. We document clearly what has been learned from the experience of building the ontology and how the experience can inform the work of other investigators. The same ontology population methods apply also to other products; therefore, the applicability of our work extends well beyond the specific products we are considering in our project. This ontology is also used in a prototype drill bit marketplace portal, which supports searching and comparing drill bits of different vendors.

Keywords— ontology development, drill tools ontology, GoodRelations

1. INTRODUCTION

The problems of information redundancy and sharing are common in mining industry [1]. Especially, drilling is a key technology in exploration for and extraction of oil, gas, geothermal, and mineral resources. Data integration and knowledge representation in the oil, gas, and mining industry domain are two challenges much work is focused upon [2]. As a solution, there are some works on using semantic technology in this domain. The Semantic Web, in which data on the web pages of structured and labeled in a manner that can be read directly by computers, is the new form of Web [3]. This new form of Web brings many new possibilities. The Semantic Web vision suggests to model information on the web using ontologies. An ontology is an explicit specification of a conceptualization [4]. This representation involves modeling classes, relations between classes, class and property relations in a domain of discourse using a standard web-based ontology language (e.g. OWL [5])).

Ontologies are used and developed for Semantic Web-enabled applications in a wide range of different domains. In [6], an ontology is proposed for representing and sharing knowledge in the manufacturing domain. An ontology for food additives is used in the mobile application named FoodWiki, in order to help patients to take control of their food consumption [7]. VetiVoc is an ontology for Fashion, Textile and Clothing domains [8]. In [9], an ontology for policy management is proposed in order to provide access control. An earthquake and disaster management terms ontology is developed in [10]. [11] used ontologies for multi-agent systems in the tourism domain, and developed a travel ontology.

Most of the efforts on Semantic Web in oil and gas industry involves finding and analyzing the staggering amount of data from a variety of activities such as drilling, exploration and production, reservoir management, major capital projects, facility and downstream operations. Some of the works, which are related to the standards and sources of knowledge for this domain, are listed below:

• WITSML (Wellsite Information Transfer Standards Markup Language): WITSML is a standard for transferring drilling data from well sites to centers where the data can be stored and processed. WITSML also defines a way of querying the data stored in WITSML servers. The standard is on an XML format.

• DDR - Daily Drilling Report: The daily drilling report is a standardized format for transferring data about daily drilling to the Norwegian oil authorities. By Norwegian law, all operators drilling in Norwegian areas must hand in such a report every day to keep track of the drilling activity at the Norwegian continental shelf. The DDR standard itself is by large based on WITSML.

• ISO 15926: ISO 15926 is a large ontology and information repository created by the POSC organization. Its main purpose is to be used as a reference library that in part has ontology structure. For the most part it contains information relevant to oil and gas, process and chemical industries. But it can also be used for other industries and businesses. As the people working on ISO 15926 has recognized the value in being able to connect the ontology to OWL, more and more have been done in this direction.

• Schlumberger Oilfield Glossary: The Schlumberger Oilfield Glossary is an online repository of domain knowledge in the oil and gas domain. This includes drilling as well as production, and other subdomains. The focus will lie on the drilling part of the repository. It is quite extensive with over 3000 entries in total, of which a substantial part is on drilling. Many of these entries describe various kinds of equipment, and how they are fitted together. But there is also information on processes and tasks performed on the drilling rig. Much of this, and the most interesting for this thesis, is what happens downhole while drilling. There are many entries which link to each other and describe the tools and equipment used while drilling.

• AKSIO: The AKSIO project is a completed project that had the goal of making information retrieval from documents concerning drilling easier. The idea was to use an ontology to annotate documents with names from the ontology to reflect the actual content in the documents. This way, one could use the ontology to search for matches to the annotations as well as annotations that are related in some way through the ontology. This way of expanding the search would mean that more documents that might be relevant could be found as well.

• The MinExOnt ontology [12]: an ontology for the mineral exploration domain. This ontology is built using Web Ontology Language (OWL) and Protégé [13] ontology editor. The MinExOnt ontology includes terms describing real objects, activities, and processes in mineral exploration.

On the other hand, it is also possible to use semantic web technologies to model the drilling tools and equipment themselves. Using an ontology-based product atlas for drilling tools may dramatically reduce cycle times and indirect costs by improving the using efficiency of domain knowledge. For example, with today's search engines, it is very difficult to answer complex questions like "Which type of drill bit is the most used in Europe?", or "Which brands produce the most durable drill bits?". The reason for this is that today's search engines use keyword scanning and show documents that contain keywords in the results [14]. It is the user's responsibility to eliminate the responses that are irrelevant and to find out the desired results from the thousands of results listed [15]. Since Semantic Web technologies has a direct effect on the web search activity, Semantic Web technologies and ontologies are also supported by today's popular search engines.

Schema.org [16] is a suggested vocabulary for creating a common set of schemas for structured data formatting on web pages. It is an initiative supported by today's search engines. Accordingly, the website content is marked up with meta data about this content. Microdata, RDFa, or JSON-LD formatting languages are used at this stage. Thus, search engines can access the meaning of a web site through the mark up. In 2012 GoodRelations [17] ontology was integrated into Schema.org. GoodRelations is the most powerful vocabulary that contains all the details of your products and services. It is currently supported by Google and Yahoo and is used by more than 10,000 shops. This paper presents an ontology that may be expanded to form a semantic web based online forum of drilling tools for linking customers and vendors. The proposed ontology is also compatible with GoodRelations ontology.

The paper structured as follows: next section presents the review of existing related ontologies and the classes and properties of these ontologies that we re-used. Section 3 describes the ontology. Section 4 presents the ontology population process. Section 5 describes the web application that we developed based on our ontology. Section 6 presents some well-known metrics concerning our ontology. Finally, Section 7 concludes the article with a brief talk about possible future work

2. REUSED ONTOLOGIES

Today anyone can publish anything on the web. Likewise, anybody should be able to publish structured data about anything on the semantic web. Therefore, we need ontologies, covering all the common things published by users. Schema.org is the common thing vocabulary, which is supported by Google and Yahoo for the idea of semantic web. schema.org grows by integration of other ontologies [14]. In 2012, the GoodRelations ontology was integrated into schema.org, which means all GoodRelations classes and properties can be used directly from the schema.org namespace. GoodRelations is the most powerful vocabulary proposed for publishing product and service definitions in an understandable way by search engines and computers. The proposed ontology is compliant with schema.org and GoodRelations product atlas project [17]. Figure 1 shows the reused terms from schema.org and GoodRelations ontology.

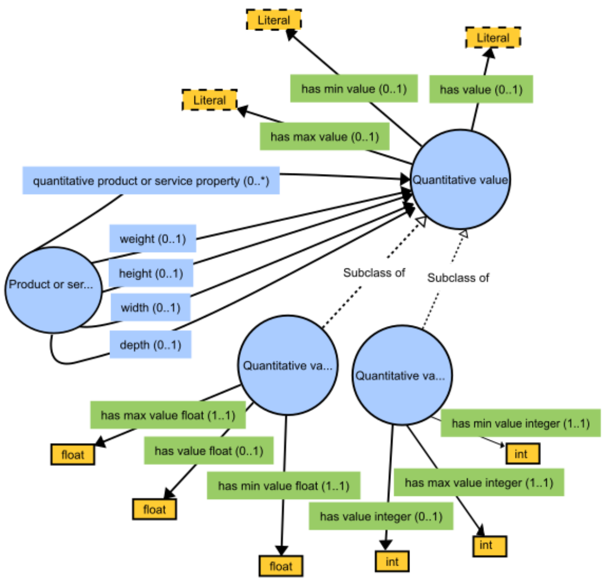

Figure 1. Reused terms of GoodRelations Ontology

The reused classes and properties are described as follows:

• gr:ProductOrService: The superclass of all classes describing products or services types, either by nature or purpose. This class is equivalent to "http://schema.org/Product". "DrillingTools" class is specified as a subclass of "ProductOrService" class in our ontology.

• gr:QuantitativeProductOrServiceProperty: Each property specifying a quantitative value or interval, with the corresponding unit of measure, is defined as a subproperty of "quantitativeProductOrServiceProperty".

Schema.org and GoodRelations are higher level ontologies that capture generic concepts in the domain. We could not find an overlapping ontology that captures the drilling tools and their properties. The closest study to ours is "the coal mining equipment ontology" [1]. The coal mining equipment ontology and our ontology can be used in collaboration. Our ontology is a specialized ontology about the drilling tools. The coal mining equipment ontology is a more general ontology. Figure 2 shows the properties in the coal mining ontology. Figure 3 shows the taxonomy of the coal mining equipment ontology partially. The most important difference between two ontologies is the property richness. In our ontology, we define the specific properties of each class in the ontology. On the other hand, coal mining equipment ontology defines the general properties of the mining equipment (Figure 2). In our approach, the more specific properties are defined in the ontology instantiation process by the ontology developer. Therefore, our ontology has a higher property richness value. The "DrillingTools" class in our ontology has common individuals with "Coal_mining_equipment" class and its subclasses in the coal mining equipment ontology.

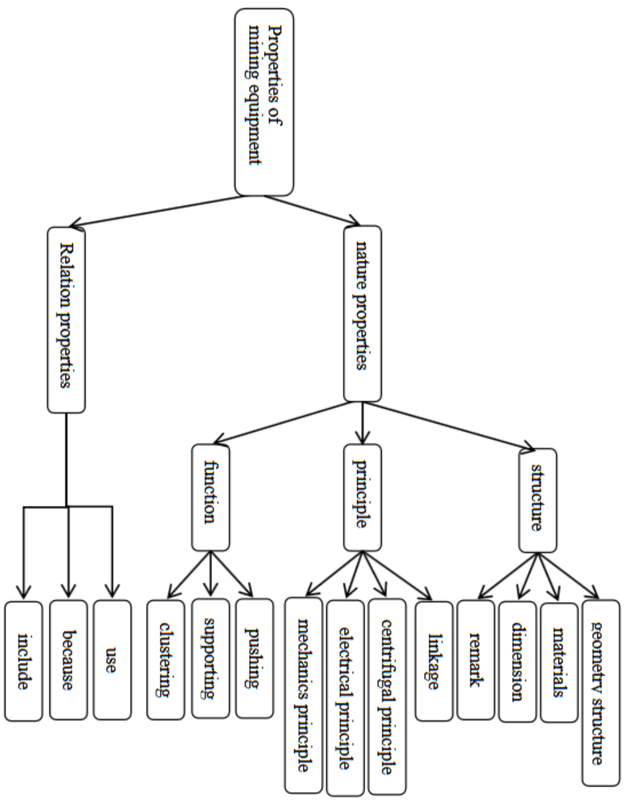

Figure 2. Properties in Coal Mining Equipment Ontology

3. ONTOLOGY

In a typical drilling engineering application, holes are drilled toward the underground using a shaft-like tool with a cutting edge, and in particular through rotation. A drilling rig is a complex structure where large weight is fixed to a mechanical structure. The function of the equipment is to rotate a string of drill pipe to drill a hole in the ground.

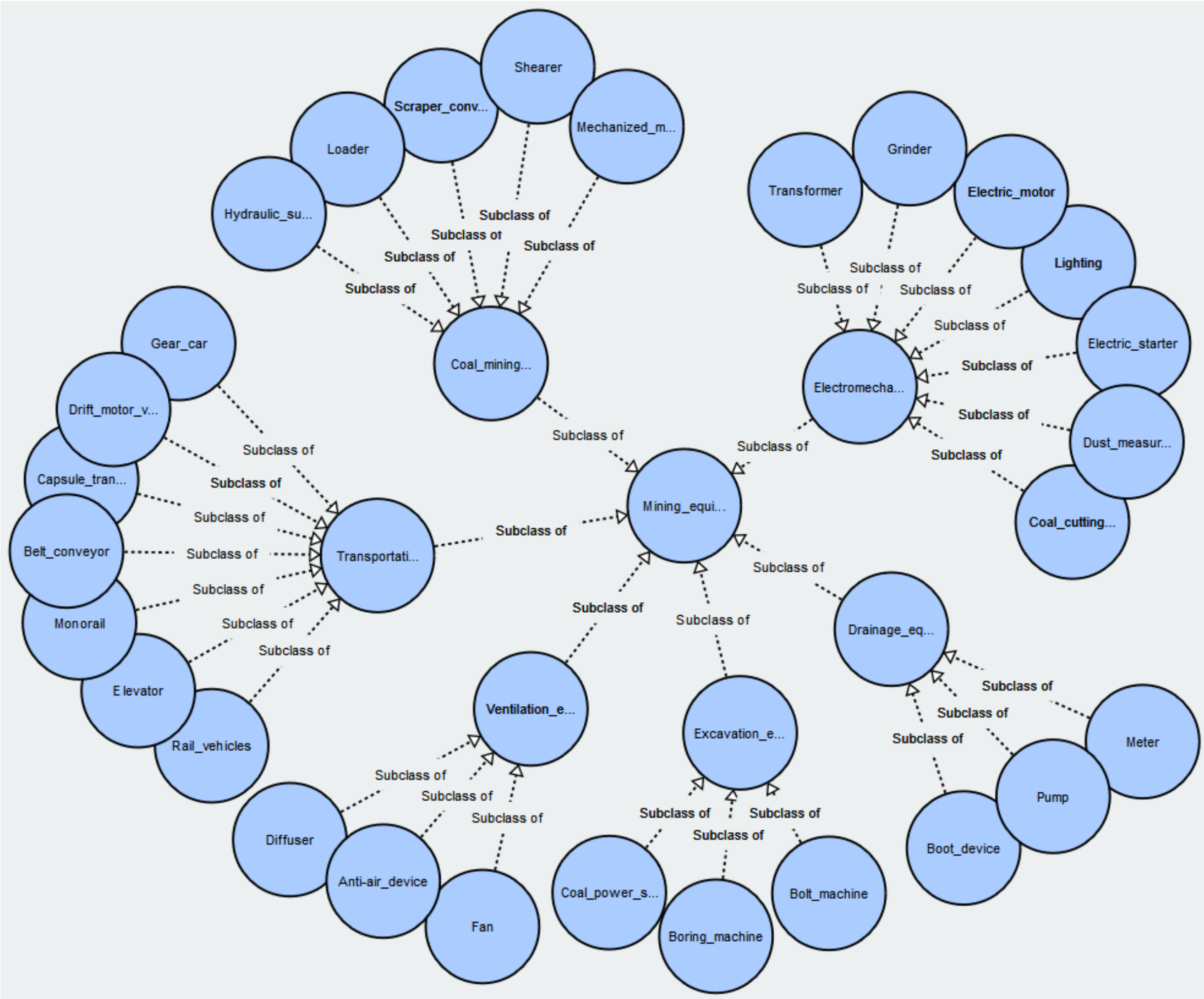

Figure 3. Terms in the Coal Mining Equipment Ontology (partially).

In the rotary drilling method, a downward force is applied by attaching a large and heavy drill bit to the tip of the bottomhole assembly. The drill bit is rotated by a drill string made up of high-quality drill pipe and drill collar.

In this work we build the drilling tools ontology (https://figshare.com/articles/Drilling_Tools_Ontology/5688127) to model the components of a drill rig, especially the parts that are replaced frequently. For example, drill bits do not last that long and one of most frequently replaced parts in mining and similar boring operations. Therefore, in our ontology we try to model such frequently changed parts in more detail. We defined these parts by analyzing the web pages which sell drilling tools and by interviewing the domain experts from academy and industry to gain a broader view. We used Protégé Ontology Editor 3.5 [13] for building the ontology. Figure 11 in Appendix shows the classes and the properties in our ontology. We define the main classes in the ontology as follows (Definitions are taken from [18], [19] and [20]):

• Casing: After drilling a hole in a certain length, the well should be covered with a steel pipe called the casing. Casing is defined as a heavy, large diameter steel pipe that can be lowered into the well for some specific functions.

• CoreBarrel: a heavy, usually a steel pipe that applies weight on bit for drilling hard, compact and rocky grounds.

• CrossOverSub: Cross-over sub is used to join bottom hole assembly components with dissimilar threads. There are different types of cross over subs such as box to box, pin to box, and pin to pin.

• DrillBit: A drilling bit is defined as the cutting or boring tool, which is used to drill a cylindrical hole in rotary or impact drilling. It is made from very hard material, located at the end of the drill string and used to drill cylindrical holes. The bit consists of a cutting element (cutters) and a fluid circulation element(nozzles).

• DrillCollar: It is a part of drill string that provides weight on bit. It is a heavy tubular usually made up from steel.

• DrillJar: They are designed to deliver an impact either upwards or downwards. They are used to increase the pulling capacity in case of tight hole or stuck pipe in the deviated wells.

• DrillPipe: heavy seamless steel or aluminum tubing used on drilling rigs. It is designed as a hollow in which drilling fluid is circulated. It has various sizes, strengths and wall thicknesses.

• DrillRig: A drilling rig is a steel structure with other equipment and rig components.

• DrillRod: It is the largest part of the drill string. It is designed to provide rotary motion and flushing medium to the drill bit.

• DrillString: Drill string transmits drilling fluid and rotational power to the drill bit. It is composed of drill pipe, drill collars and drill bit.

• Hammer: Pneumatic or hydraulically designed tool for transmitting impact energy at a certain frequency to the drill bit via drill rod.

• KeySeatWiper: If the drill pipe makes continued contact with the side of the hole, the hole is enlarged to form a key seat. In this case, a stabilizer or key seat wiper is used to free the pipe.

• Pump: A pump is used for conveying waste water, thickened sludge, tailing, explosives etc. in mining.

• RollerReamer: Roller reamers are used to enlarge the borehole in case of drill bit is under gauge and to keep the drill string at the center of the well.

• Shank: Short steel rod that connects the drill string to a rock drilling machine.

• Stabilizer: They are used to control the quality and deviation of the hole during drilling operation. They mechanically balance the bottom hole assembly in the borehole.

• WhipStock: It is a steel ramp which is specially designed to reduce deviation and doglegs in the well.

Figure 12 in Appendix shows the class hierarchy of the ontology. All of the classes in the ontology are documented using the “rdfs:comment” property. If the class has a synonym then it is specified using the “rdfs:label” property. Figure 4 shows the documentation of “FixedCutterBit” class.

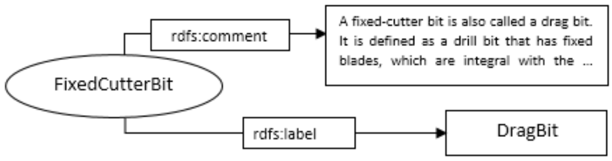

Figure 4. Documentation of the “FixedCutterBit” class.

4. ONTOLOGY POPULATION

Drill bits are important tools for any drilling operation and drill bit selection is one of the key economic factors in an overall well-budget. According to a report by [21], roller-cone bit was the largest product segment accounted for over 70% of total market volume in 2014. Therefore, we have chosen the concept “DrillBit” and definitions and axioms that are tightly related to drill bits as a starting point for populating the ontology.

The assertional model of an ontology includes formulas that describe the instantiation of concepts and roles with individuals. The assertional part of our ontology contains 2002 drill bit individuals from 5 different brands with their 18363 relations. The assertional model is mainly constituted of “DrillBit” individuals, with auxiliary “Hammer” and “Shank” individuals. Table 1 summarizes some statistics about the individuals of “DrillBit” class. We also defined 129 individuals for “Hammer” class and 55 individuals for “Shank” class. Therefore, we have 2186 individuals in total.

Table 1. Some statistics about the individuals of “DrillBit” class.

Brand	Individual	Individual Relations
Atlas Copco	458	2748
Bulroc	917	894
Halco	157	1092
Mincon	150	10065
Sandvik	325	3564
Total	2002	18363

Since populating an ontology manually is extremely labor-intensive and time-consuming work, we also describe the tools and methodologies that we used to speed up and rationalize the population process. In this work, data is gathered using two different approaches: (a) by producing structured interoperable data from product features on the web (b) by extracting data out of tables in PDF product catalogs.

The first approach is more adaptable to dynamically changing data and it is easier and faster to apply. Unfortunately, an important part of the vendors does not publish their product data on the web sites or the data on the web is inaccurate or inadequate. Instead, they publish their useful data in product catalogs (usually in PDF format). In the latter case, it is appropriate to use the second approach.

The first approach [22], [23] proposes a tool, namely IRIS, that requires the user to manually create a web page-specific template. Then, with the help of this template, the tool automatically creates an ontology containing the product data on the web page. In this step, the template file is converted to XPath queries and the HTML page is parsed into a DOM tree using HtmlUnit [24]. Then the DOM tree is queried using XPath queries for the required product properties. The list of product individuals with corresponding property values is the final output of the tool.

In this work, we used IRIS to extract the drill bits designed by Atlas Copco Secoroc (http://www.atlascopco.us/usus /products/drilling- tools/1460331/). The 458 drill bits with 6 attributes are collected by IRIS tool using our template in Figure 5.

```
SELECT=(div), ATTR=(class), VALUE=(columns clearfix fixed)
<
SELECT=(div), ATTR=(class), VALUE=(column column01)
<
SELECT=(p[1]), GETMETHOD=(asText),  AS=(product.productID)
>
SELECT=(div), ATTR=(class), VALUE=(column column02)
<
SELECT=(p[1]), GETMETHOD=(asText),  AS=(product.title)
>
SELECT=(div), ATTR=(class), VALUE=(productTable)
<
SELECT=(td), ATTR=(style), VALUE=(width:70%),
GETMETHOD=(asText),  AS=(product.propertyName);
SELECT=(td), ATTR=(style), VALUE=(width:30%),
GETMETHOD=(asText),  AS=(product.propertyValue)
>
>
```

Figure 5. The template file for extracting drill bits by AtlasCopco.

The second approach involves extracting data out of tables in PDF product catalogs and importing it into spreadsheets with the aim of building product ontologies automatically from spreadsheets in a fast and effective way [25]. We extracted 1544 DTH drill bits designed by Bulroc (http://www.bulroc.com/Brochures/buttonBits.pdf), Halco (www.halco.uk), Mincon (http://www.mincon.com/) and Sandvik (http://tebyc.com/wordpress/wp-content /uploads/ 2012/09/sandvik_dth_tools_product_catalogue.pdf). Figure 6 shows the following steps of this method:

• Defining the main classes of the KB: In our case, the main class is “DrillBit”.

• Processing Catalogs: In this step, tables in PDF product catalogs are converted to spreadsheets using a program called Tabula [26] or HTML tables in the web pages are copied into spreadsheets manually.

• Editing the data in spreadsheets: Before transforming spreadsheet files into ontologies, a data normalization procedure is carried out on them. Some important syntactic normalizations carried out in this step are: applying small capitalization to text; replacing several symbols (€, % and °) with text; deleting the end of line character; replacing non-alphanumeric characters by underscore character. All these operations are handled programmatically using a simple Java code.

• Automatic Mapping of Spreadsheets to Ontology: In this step, all spreadsheet files created in the previous steps are converted to the “DrillBit” ontology file automatically by our Java application. This application binds each row in the spreadsheet to an individual of “DrillBit” class. The application defines the properties in the first row as attributes of the “DrillBit” class, and binds values in the remaining cells as attribute values of related individuals. At the end of this process, the system returns a list of “DrillBit” individuals in an OWL ontology.

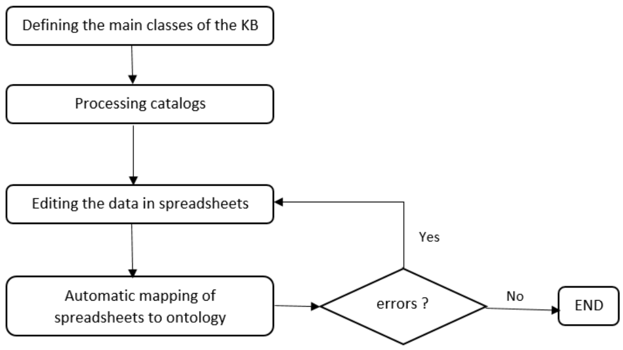

Figure 6. Scraping product catalogs in PDF.

Figure 7 shows an example “DrillBit” individual in the ontology. In this representation, class individuals are shown in ovals, object properties are shown in white rectangles, quantitativeProductOrServiceProperties are shown in dark grey rectangles, datatype properties are shown in light grey rectangles, literals are shown in ovals with dashed lines.

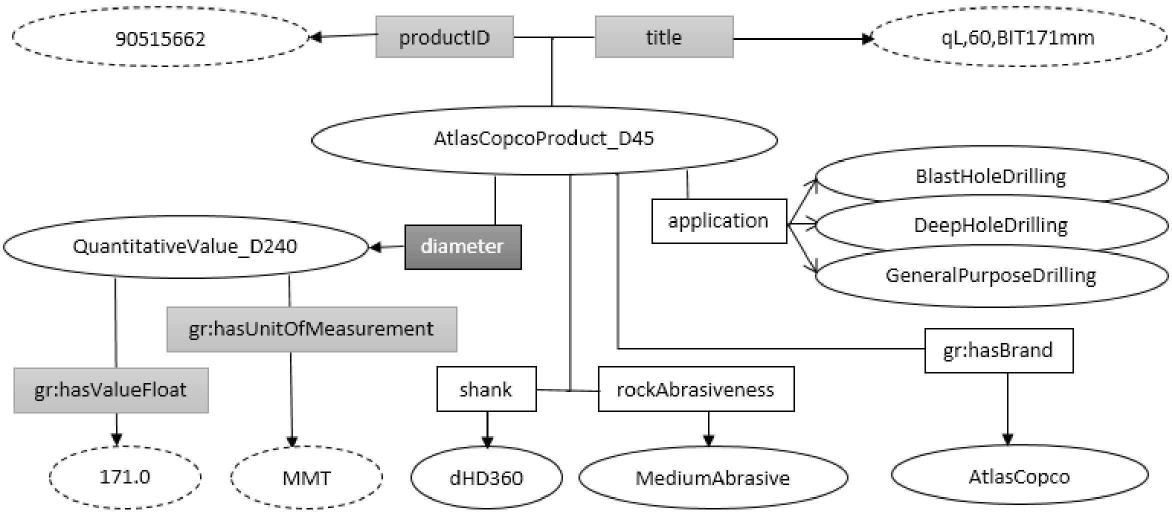

Figure 7. Instantiation example of the "DrillBit" class

5. DRILL BIT MARKETPLACE PORTAL

We developed the drill bit marketplace to provide users run complex queries on the structured data published by vendors. The portal consists of a browser and server application (Figure 8). The server side consists of a Cayley Graph Database and a Meteor application. The interactive user interface of the browser is created by using ReactJS JavaScript Library.

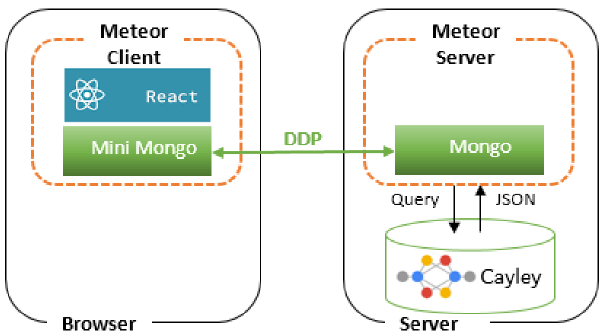

Figure 8. The drill bit marketplace portal architecture

Each property on the leftmost panel in Figure 9 is a ReactJs component. Whenever "Add" button is pressed, a new condition is appended to the "Query Conditions" panel. "Execute Query" button runs the Gremlin query in the "Query Conditions" panel on the Cayley REST API. Each query result is a JSON object which is listed as a React component in the "Results" panel (Figure 10). Every chip on the "Query Conditions" panel corresponds to a query condition. If more than one chip for a property is added to the query conditions, then "OR" operator is applied on them. The conditions with different properties are added to the query with "AND" operator. All the query results are listed on the "Results" panel.

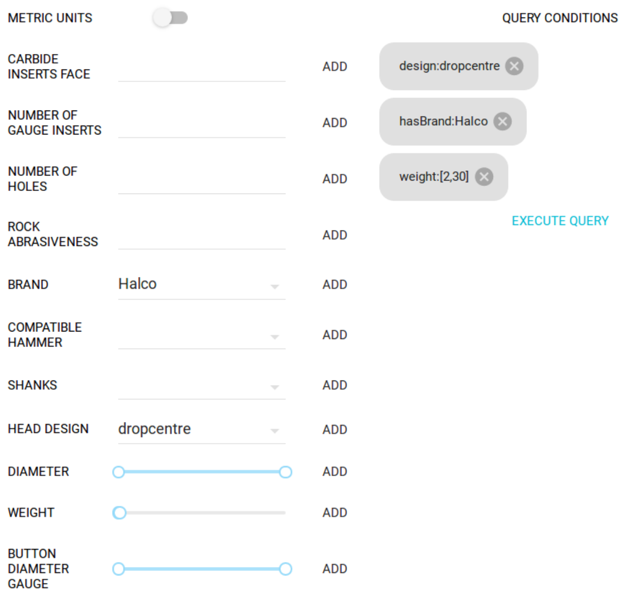

Figure 9. The drill bit marketplace portal (left panel)

Figure 10. The drill bit marketplace portal (right panel)

6. EMPIRICAL ANALYSIS OF THE ONTOLOGY

Ontology evaluation is assessing an ontology with specific criterions to choose the most appropriate ontology for a given case [27]. Many studies on the evaluation of ontologies have been presented in the literature [28, 29]. For example [27, 30] compare an ontology against a "gold-standard", which is suitably designed for the domain of discourse. However, in our case there is not a suitable gold standard to use.

Another approach involves evaluating the ontology through user's experiences, but it is also hard to determine the right experts and objective standards for the domain of discourse.

Yet another approach involves evaluating how effective an ontology is in the context of an application [31]. In this manner, we developed a prototype drill bit marketplace portal, but it is a long running work to make observations for the effects of the ontology on the performance of the system.

Other approaches are based on evaluating ontologies using metrics and metric frameworks. In [32], the authors collect the following metrics from OntoMetrics [33], OntoQA [34], [35]:

No. of classes (noc): specifies how many classes are in the ontology.

No. of instances (noi): specifies how many instances are in the ontology.

No. of properties (nop): specifies how many properties are in the ontology.

No. of root classes (norc): specifies how many root classes are in the ontology.

No. of leaf classes (nolc): specifies how many leaf classes are in the ontology.

Average Population (ap): average number of instances per class.

Class richness (cr): the number of instantiated classes divided by the total number of classes in the ontology.

Explicit depth of subsumption hierarchy (dosh): specifies the maximum depth of the ontology taxonomy.

Relationship richness (rr): the number of relationships other than subclasses divided by the total number of relationships.

Inheritance richness (ir): average number of subclasses per class.

Table 2 shows the metric values for our ontology. In [32], authors download many ontologies (around 1500) from Swoogle and extract the metrics that we also used. The authors collect 1413 metrics using their ontology set. Table 3 compares the metric values of the ontology set with the values of our ontology.

Table 2. Metric values for the Drilling Tools Ontology

noc	noi	nop	norc	nolc	ap	cr	dosh	rr	ir
78	2186	40	18	63	28.02	0.47	7	0.38	2.72

Table 3. Comparison for metric values

	Avg	StdDev	Min	Max	DTO
noc	36.11	78.53	1	945	78
noi	28.13	97.59	0	991	2186
nop	24	54.75	0	952	40
norc	6.69	11.29	0	194	18
nolc	27.46	61.77	0	823	63
ap	1.34	2.97	0	67	28.02
cr	0.54	0.44	0	1	0.47
dosh	2.54	2.4	1	30	7
rr	2.78	3.68	0	71	0.38
ir	0.34	0.42	0	1.83	2.72

Number of classes and properties in the ontology are close to the mean values of the ontology set. Number of individuals and average population are even higher than the maximum values of the sample ontology set. Despite the high number of individuals, the value of class richness is below average. The main reason is the instances in the ontology are not evenly distributed among the classes in the ontology. Considering we started to populate ontology with "DrillBit" class and the classes having relations with that class, many of the classes in the ontology are not populated. As other classes in the ontology are instantiated, this value will be also increased.

Considering the norc, nolc, dosh and ir values, it is concluded that the ontology taxonomy is closer to the vertical nature. An ontology with a vertical nature may reflect a very detailed type of knowledge, while an ontology with a horizontal nature represents a wide nature of general knowledge. This is an indication that the drilling tools ontology represents a detailed and rich knowledge and covers the specific area of the domain of concern in detail.

Finally, the low rr value indicates that the number of properties other than the subclass relations are relatively low. This value will be increased by further modeling the properties of the classes other than "DrillBit" class.

7. CONCLUSION AND FUTURE WORK

This work is an attempt to build an ontology to bridge the gap between Semantic Web technologies and oil, gas and mining industry. In this work, we focus on drill bit concept as a starting point. This ontology is also used in a prototype drill bit marketplace portal, which supports searching and comparing drill bits of different vendors. The ongoing work is populating the ontology with individuals of drilling tools other that drill bits. Yet another possible work is to develop methodologies for speeding up the validation and organization of product data uploaded by vendors.

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APPENDIX

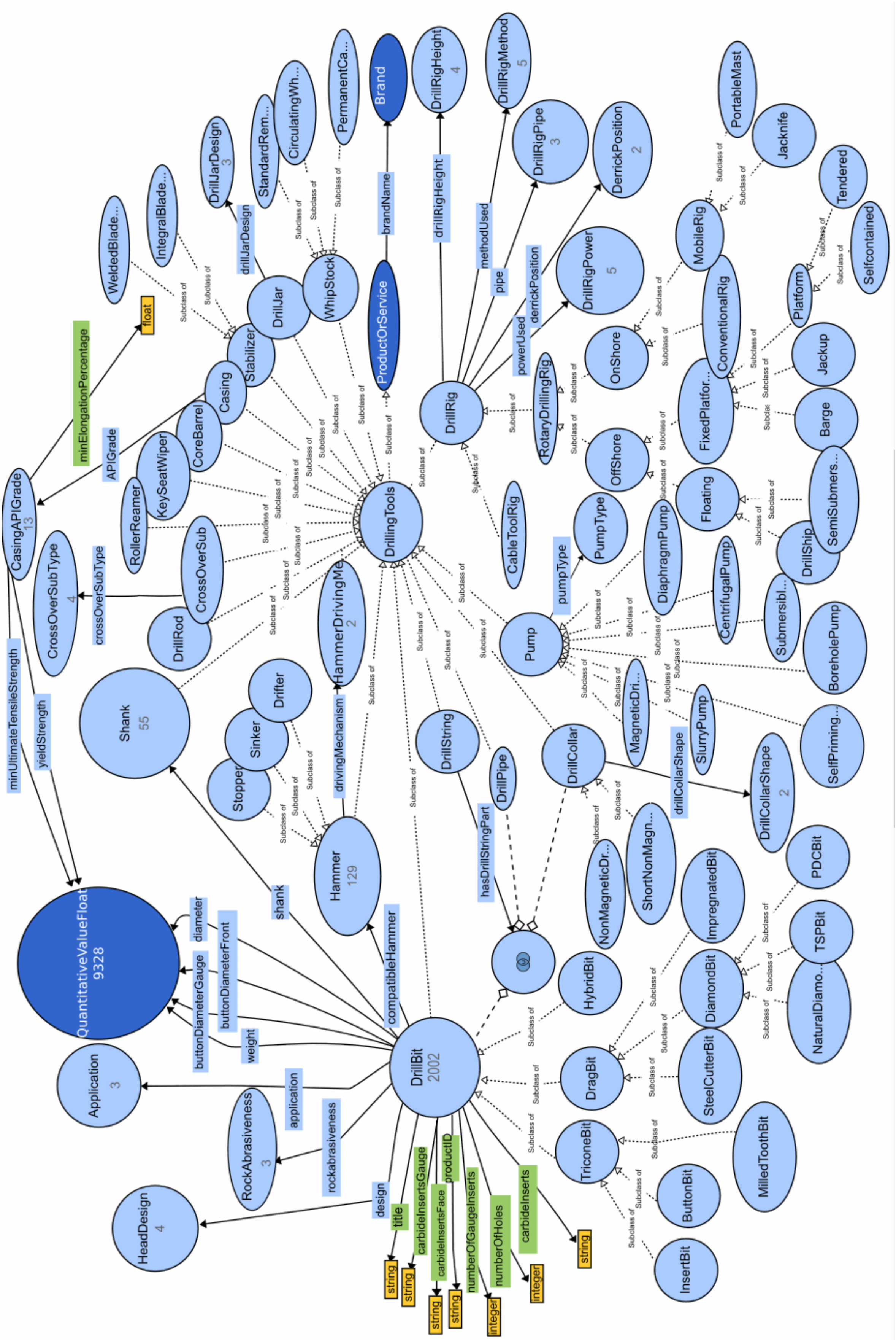

Figure 11. The drill bit marketplace portal architecture

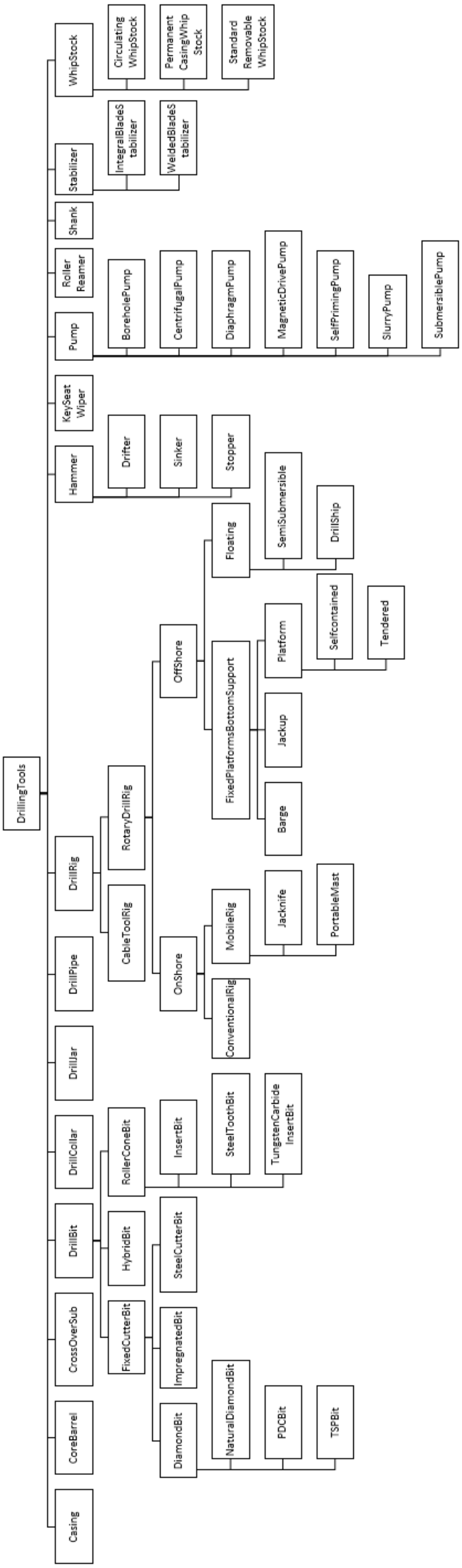

Figure 12. The drill bit marketplace portal architecture