A Well-founded Domain Ontology For Offshore Petroleum Production Plants

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Abstract

This article outlines the approach used to create a domain ontology for characterizing the facilities in offshore petroleum production plants. The ontology is being built using a comprehensive set of requirements gathered from industry and defined using a series of competency questions. The ultimate objective is to provide a standard, officially defined reference vocabulary to assist engineers and information technology professionals in categorizing and connecting facilities and measures used in production plant monitoring and simulation. The ontology uses GeoCore and a continuing version of the core ontology created by the Industry Ontology Foundry (IOF) as middle-level ontologies and BFO as a top-level ontology. This study is a component of the Petwin project, which investigates the best methods for creating a digital twin for the industry's use in monitoring and modeling petroleum output.

Keywords

petroleum, ontology, production plants, offshore, digital twins

1. Introduction

Our project has the challenge of providing the framework for the semantic interoperability of data operated by a digital twin of a petroleum production plant. The data that supports production operation planning and control in petroleum plants are usually spread across many systems from several service companies that perform specific tasks during operations. These systems exchange data using proprietary or partially standardized formats. The integrated operation center receives these data labeled with their source and meaning and analyzes them to support short-term decisions. Petroleum engineers produce simulations to define the medium to long-term operations plan and evaluate economic viability with this data.

A digital twin (DT) implements a virtual mirror of a production plant to support monitoring, simulation, prediction, and data analytics on the production and facility maintenance data[1]. This real-time integrated view of a petroleum plant requires a uniform view of the data to help operators supervise the behavior of oil flow and facilities in actual time. However, the data transformation to a common platform or format would be an extraordinarily complex and

Proceedings of the 15th Seminar on Ontology Research in Brazil (ONTOBRAS) and 6th Doctoral and Masters Consortium on Ontologies (WTDO), December 22-25, 2022.

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effort-demand task in such a diverse data volume. Then, a semantic tool to identify and describe the data under a common descriptive vocabulary with an associated explicit description of each term's meaning and logical restrictions emerges as a valuable contribution to the data integration problem. Many researchers have focused on using ontologies for this problem due to their great potential in improving communication in digital twin environments [2].

This paper presents the current development of the Offshore Petroleum Production Plant Ontology (O3PO), a well-founded domain ontology of production plant physical assets and associated properties.

2. Related Work

When it comes to data management, the petroleum sector has several obstacles. The large number of businesses that provide specialized services and utilize proprietary software creates a complicated environment for handling field data across the whole supply chain. As a result, a substantial effort has been undertaken to create industry standards in response to the digitalization requirements of Industry 4.0. Some efforts in this way are the industry glossaries like the Professional Petroleum Data Management (PPDM) "What is a Well?"[1] and "What is a Completion?"[2]. Also, there are initiatives to provide a semantic framework, such as the ontology and reference library of ISO 15926 [3], and a syntactic framework, such as the integrated data platform from the Open Subsurface Data Universe Forum (OSDU)[3], data standards of Energistics Consortium, such as PRODML and RESQML standards, and the equipment specifications from CFIHOS. The previous projects have centralized data accessibility in two approaches: (1) defining a typical software architecture for data storage and access and (2) defining a standard data model that supports an integrated view. Both approaches are complementary but leave behind one of the complex aspects of data integration and interoperability: providing the users and software applications an explicit representation of the meaning of the entities to support the automatic alignment of data. Then, despite the referred efforts, accessing integrated data and reasoning over it remains an issue in the offshore environment, in which service companies, operators, and platform leasing companies work together, but each with their distinct system. In this way, we aim to develop an approach to deal with this issue in a better way.

3. Material and Methods

We followed NeOn methodology [4]for the construction of our ontology. Following the steps outlined in the process, the requirements specification was realized through a series of interviews with subject matter experts from the sector, mostly petroleum engineers involved in the daily operations of the petroleum facility. The professionals were questioned about their daily work, information needs, and general activities during each one to two hour session. One ontology expert and two domain experts conducted each interview over the phone while it was being recorded. Following the transcription of the interviews, competency questions (CQs) were

[1] https://ppdm.org/ppdm/PPDM/Standards/What_is_a_Well/PPDM/What_is_a_Well.aspx
[2] https://ppdm.org/ppdm/PPDM/IPDS/What_is_a_Completion/PPDM/What_is_a_Completion.aspx
[3] https://osduforum.org

defined and used as specified requirements to create our ontology. Some examples of competency questions we identified in this phase are provided in Table 1.

Table 1
Examples of competency questions used to specify the requirements of the ontology.

Nr.	Competency Question
1	What is the well connected to?
2	What are the components of the well?
3	What is the temperature in the wellhead of a well in time X?
4	How many injector wells are connected to a platform?
5	What is the type of fluid that is being injected through the well?

The O3PO ontology uses BFO [5] as a top-level ontology. It is a straightforward, condensed, and thoroughly documented fundamental ontology with a realist philosophical underpinning that demonstrates its suitability for a material domain like the structure of a production plant. Furthermore, because BFO is widely used across many areas, it can serve as a unifying framework for other relevant ontologies created in the domain. The adopted version of BFO is 2.0, made available in 2015. Besides BFO, O3PO derives some concepts from the GeoCore [6] and the Industrial Ontology Foundry (IOF) ontologies [7] middle-level ontologies. GeoCore, in particular, provides GeoCore:rock and GeoCore:earth_fluid which were later specialized for the terms reservoir and petroleum present in O3PO. IOF-Core provides a set of middle-level terms that facilitate the definition of domain entities such as equipment in petroleum production.

Prior to the conceptualization phase of ontology development, standards that provide definitions were used as non-ontological resources to be later merged, producing a consensual formal definition of entities. ISO 15926-4, and glossaries from PPDM were considered non-ontological resources since they deliver such definitions. Table 2 shows some of the chosen terms along with their semi-formal definitions.

Table 2: Examples of semi-formal definitions of some entities included in O3PO.

Entity	Definition
well	**def.** an `IOF:engineered_system` that is contained in a `O3PO:wellbore` for producing or injecting fluid from or to a `O3PO:reservoir`.
pipeline	**def.** an `IOF:engineered_system` that is composed of one or more `O3PO:pipe`, that may also be composed of pipe joints, `O3PO:pump`, `O3PO:valve`, and control devices, that has all its components connected in a single line, and that can convey liquids, gases or finely divided solids.
tubing	**def.** an `O3PO:pipeline` that is installed in a `O3PO:well`, located inside all casing strings, that extends from the `O3PO:wellhead` to the production or injection `O3PO:zone`, to conduct fluids between the `O3PO:reservoir` and the `O3PO:christmas_tree`.

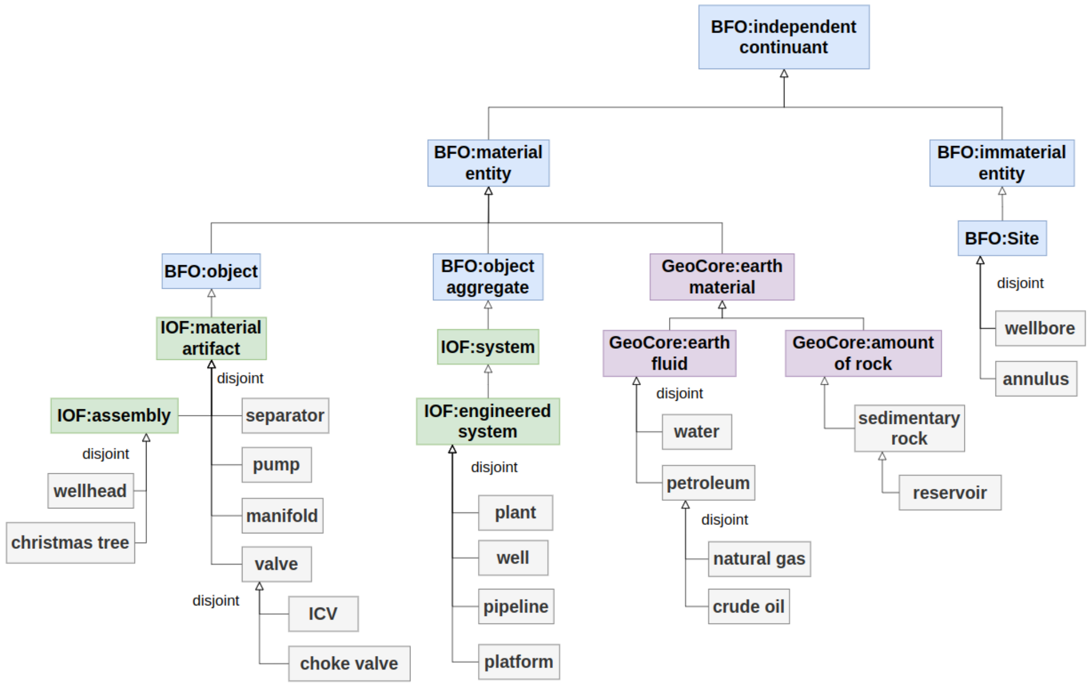

Figure 1: O3PO's is_a hierarchy.

4. The ontology

The taxonomy is shown in Figure 1 along with the primary categories of independent continuants taken into account in the ontology. The main components of the oil path from a `O3PO:reservoir` to a `O3PO:platform` are covered, passing through a `O3PO:well`, a `O3PO:christmas_tree`, possibly a `O3PO:manifold` gathering the flow from several wells, and the various `O3PO:pipeline` connecting these items.

It also provides means to further detail the description of the oil path by including specific instances of `O3PO:tube` and `O3PO:valve` that compose a pipeline or other pieces of equipment, e.g., a christmas tree (related to the oil and gas domain). For instance, a pipeline is a system that is composed of a combination of connected pipes, valves and other pieces of equipment and that has the ability of conveying fluids, regardless the context in which it is present.

Besides those, our ontology also includes categories for entities that are defined in terms of their contingent aspect, notably, regarding the way in which an asset is being employed. Among those, we have the `O3PO:producer_well` and `O3PO:injector_well` types, i.e., wells involved in the flow of oil from the reservoir to the platform or from the platform to the reservoir, respectively. We also have different subtypes of `O3PO:pipeline`, namely, `O3PO:tubing` (i.e., pipeline installed inside a well), `O3PO:flowline` (i.e., pipeline connecting the well to a manifold or to a platform) and `O3PO:riser` (i.e., pipeline connecting a well or a manifold to a platform). Those are entities defined as bearing certain `BFO:roles`.

The ontology includes certain types of properties of importance for monitoring the state of the plant. They are defined as specializations of `BFO:quality` and include both natural, physical quantities (e.g., `O3PO:temperature`, `O3PO:pressure`) as well as properties that artifacts have in virtue of their design (e.g., `O3PO:valve_position`, which corresponds to the degree to which a valve is open/closed).

5. Current State of Research

The research is currently focused on modeling ocurrents for the realization of BFO:roles. Also specializations of the relation "connected to" based on Flow Systems Ontology (FSO) are being added[8]. The ontology is been applied to a dataset from Mero Field, in order to provide the semantic requirements for a time-series visualization application generated as a product of Petwin Project.

5.1. Publications

We submitted a full paper in Formal Ontologies Meet Industry (FOMI) conference held in Tarbes, France, in October 2022. The paper was accepted and is currently published in the conference proceedings [9]. Also, we are currently rewriting a journal paper to be submitted later this year.

The ontology is available in a public repository at this link. Please feel free to point any issues and problems.

6. Next Steps

- Validate the ontology by comparing results obtained from the ontology to expected answers of competency questions and applying to real data.
- Finish writing documentation for the ontology and master's thesis.

7. Acknowledgements

Research partially supported by CAPES (Funding Code 001), CNPq, and Project Petwin (financed by FINEP and LIBRA Consortium).

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