Towards an Ontology of Offshore Petroleum Production Equipment*

Nicolau O. Santos[1,*,†], Mara Abel[1,†], Fabrício H. Rodrigues[1,†] and Daniela Schmidt[1,†]

[1]Informatics Institute, Federal University of Rio Grande do Sul (UFRGS), Av. Bento Gonçalves, 9500, Agronomia, Porto Alegre, RS, 91509-900, Porto Alegre, Brazil

Abstract

This document shows the current research progress and methodology applied to build a domain ontology for describing facilities in offshore petroleum production plants, based on an extensive requirement collection developed in industry and formalized through a set of competency questions. The final goal is to create a uniform and formally defined reference vocabulary to help engineers and information technology people label and relate measures and facilities in the production plant monitoring and simulation. The ontology uses BFO as a top-level ontology and employs GeoCore and an ongoing version of the core ontology produced by the Industry Ontology Foundry (IOF) as middle-level ontologies. This research is part of the Petwin project that studies the best practices for developing a digital twin for monitoring and simulating petroleum production in the industry.

Keywords

ontology, petroleum production, equipment

1. Introduction

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) [1, 2], semantic frameworks, such as the reference library of ISO 15926 [3], data standards such as PRODML [1] and RESQML [2], and the equipment specifications from CFIHOS [4]. 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

FOMI 2022: 12th International Workshop on Formal Ontologies meet Industry, September 12-15, 2022, Tarbes, France

*Corresponding author.

†These authors contributed equally.

nicolau.santos@inf.ufrgs.br (N. O. Santos); marabel@inf.ufrgs.br (M. Abel); fhrodrigues@inf.ufrgs.br (F. H. Rodrigues); dschmidt@inf.ufrgs.br (D. Schmidt)

0000-0003-0901-2465 (N. O. Santos); 0000-0002-9589-2616 (M. Abel); 0000-0002-0615-8306 (F. H. Rodrigues); 0000-0002-0076-1462 (D. Schmidt)

[1]www.energistics.org/prodml-data-standards/

[2]www.energistics.org/resqml-data-standards/

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 based on well-founded ontologies to better deal with the data interoperability problem.

In our work, we adopt the definition of ontology as established by Guarino [5]: "An ontology is a logical theory accounting for the intended meaning of a formal vocabulary, i.e. its ontological commitment to a particular conceptualization of the world.". In practical terms, a computational ontology comprises a set of categories, relations, attributes, instances, and axioms in machine-readable language that define the properties of entities that exist in a particular portion of the world, being able to deliver explicit knowledge to a computational system[6]. Ontologies are known for being a great alternative when it comes to conceptual modeling. They can be used as a reference for terminology when users from different backgrounds work together. Also, ontologies can be used for data integration since entries in relational tables can be mapped to other instances of terms, defined classes, or relations in the ontology, thus aligning different databases. Given that, ontologies could help in retrieving the meaning, provenance, and restrictions regarding the entities modeled in data applications.

In addition, this work is part of a larger project that has the challenge of providing the framework for the semantic interoperability of data operated by a digital twin of a petroleum production plant. 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[7]. This 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 real-time. With that, besides the issue of data interoperability, the ontology is also intended to provide semantics to the description of an offshore petroleum production plant with respect to field development.

Thus, 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. The analysis of the domain and the definition of the considered terms were based on the main standards of the petroleum industry as well as interviews with domain experts. The ontology builds upon the Basic Formal Ontology (BFO)[6] and reuses some parts of the GeoCore[8] and IOF-Core[9] middle-level ontologies.

The rest of the paper is organised as follows. §2 presents the domain context with current data interoperability and associated problems. §3 presents the ontology, the methodology used, and the possible uses of the ontology. §4 discusses our results and research limitations, and finally, §5 concludes the paper and presents future work.

2. Domain Context

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. This is an issue for the integrated operation center, which has to integrate data from such distinct sources in order to analyze it to support short-term decisions.

Also, the entire chain of events from exploration to production produces data that supports the decisions of petroleum engineers about well flow or water and gas injection and equipment maintenance. These engineers produce simulations to define the medium to long-term operations plan and evaluate economic viability with this data. But to do that, the engineer has to look for the data scattered in different places hindering the simulation and decision-making process. It would be ideal if the data was automatically integrated so that there would be less delay in decision-making.

However, the data transformation to a common platform or format would be an extraordinarily complex and effort-demanding 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 [10]. With an ontology-based semantic tool, petroleum operating companies could retrieve the meaning, provenance, and restrictions regarding the entities modeled in data applications in real-time. Also, data integration between siloed systems would be accomplished by mapping the terms on the companies' systems to the concepts provided in the ontology.

3. O3POntology

The goal of O3PO is providing a uniform, formal vocabulary referring to entities that pertain to an offshore petroleum production plant. This goal was motivated by the amount of data inherent in modern offshore enterprises and the high number of companies that work together during field production. The scope of the ontology comprises a set of assets that are part of the oil path between the reservoir and the platform, including wells and subsea equipment.

Among other possible uses, O3PO provides three main benefits:

- Listing the properties that characterize a given asset (e.g., a well) directly (e.g., properties that inhere in the well) or indirectly (e.g., properties that inhere in some component of the well).
- Listing the components of an asset, knowing that a piece of equipment is part of an asset without the need to directly state that, by following a suitable chain of relations.
- Following the sequence of equipment that enables hydrocarbon flow from the zone to the platform, through the "connected_to" relations.

For the ontology development, we adopted the NeOn methodology [11] as a reference guide to the development of our ontology. Following the activities prescribed in the methodology, the requirements specification was realized through a set of interviews with domain specialists from the industry, mostly petroleum engineers in the petroleum plant's daily operation. Each interview lasted 1 to 2 hours and questioned the professionals about their daily tasks, information requirements, and overall activities. Each interview was conducted by one ontology expert and two domain experts, remotely and recorded. After, the interviews were transcribed to identify competency questions (CQs), adopted as requirements specification to develop our ontology. In this phase, we identified 35 competency questions, a summary of them is presented in Table 1. Notice that the competency questions relate to instances of classes such as well and pump.

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 are the components of the tubing of a well?
4	Does a well have a pump installed in it?
5	How many inflow control valves (ICVs) compose the tubing of a well?
6	What is the temperature in the wellhead of a well?
7	How many wells are producing from a reservoir?
8	How many injector wells are connected to a platform?
9	What is the type of the well?
10	What is the type of fluid that is being injected through the well?

Prior to the conceptualization phase of ontology development, standards that provide definitions were used as a non-ontological resource to be later merged, producing a consensual formal definition of entities. Among them, RDS-O&G, DEXPI, CFIHOS, OSDU, and Energistics PRODML were not used since they do not offer definitions for the entities in the domain. ISO 15926-4, and PPDM were considered non-ontological resources since they deliver such definitions.

ISO 15926, named "Industrial Automation Systems and Integration of Life-cycle Data for Process Plants", including Oil and Gas Production Facilities, is an International Standard to regulate the flow of information in a process plant life cycle. In particular, the Reference Data Library provided in Part 4 was used as a non-ontological resource for developing O3PO.

Besides that, there are many well-established standards and consensual resources to specify aspects from the industry that were considered as a starting point to model our proposed ontology. In this step, for each CQ that we intend to answer with the ontology, we look for the standards in order to identify a related term. For each term, we gather a set of natural language definitions from the referred non-ontological resources. Based on those definitions, we elaborated semi-formal Aristotelian definitions using the genus-differentia form. Table 2 shows some of the chosen terms along with their semi-formal definitions.

The O3PO ontology uses BFO as a top-level ontology. The adopted version of BFO is 2.0, made available in 2015. It is a simple, small and well-documented foundational ontology with a philosophical basis on realism that shows to be adequate for a material domain such as the facilities of a production plant. On top of that, BFO is widely adopted in the different domains, and its last version, ISO/IEC 21838-2 or BFO-2020, is published in ISO[3], which makes it suitable to work as a common umbrella for other related ontologies developed in the industry.

Besides BFO, O3PO derives some concepts from the GeoCore [8] and the Industrial Ontology Foundry (IOF) ontologies [9] middle-level ontologies. GeoCore, in particular, provides Geo-

[3]www.iso.org/standard/74572.html

Core: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. Figure 1 shows the relations of reuse between the mentioned ontologies.

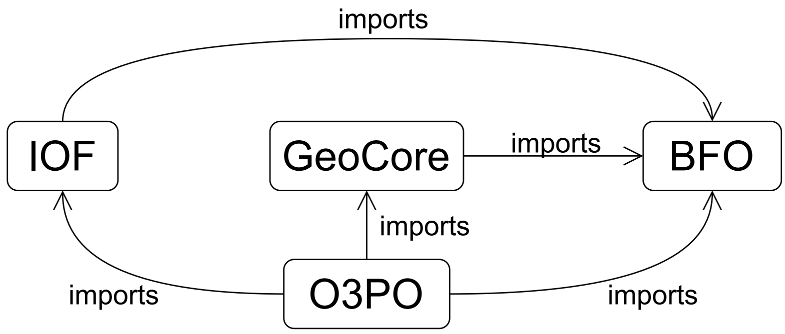

Figure 1: Imported Ontologies.

For each term, we gather a set of natural language definitions from the referred non-ontological resources. Based on those definitions we elaborated semi-formal Aristotelian definitions using the genus-differentia form. 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.
valve	**def.** a `IOF:material_artifact` that controls the flow of fluids.
pipe	**def.** an `IOF:material_artifact` that is enclosed and hollow and that acts as a passageway to carry different sorts of things (e.g., fluids, cables, other ducts).
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`.
temperature	**def.** a `BFO:quality` that corresponds to the intensity of the thermal energy of a `BFO:material_entity`.

3.1. The Ontology

Figure 2 presents the taxonomy with the main types of independent continuants considered in the ontology. It covers the main entities that compose the oil path from `O3PO:reservoir` to a `O3PO:platform`, 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 [4]. Such types of entities categorize individual objects for what they essentially are, independently of their surrounding circumstances. For instance, a pipeline is a system that is composed of a combination of pipes, valves and other pieces of equipment and that has the ability of conveying fluids, regardless the context in which it is present. |

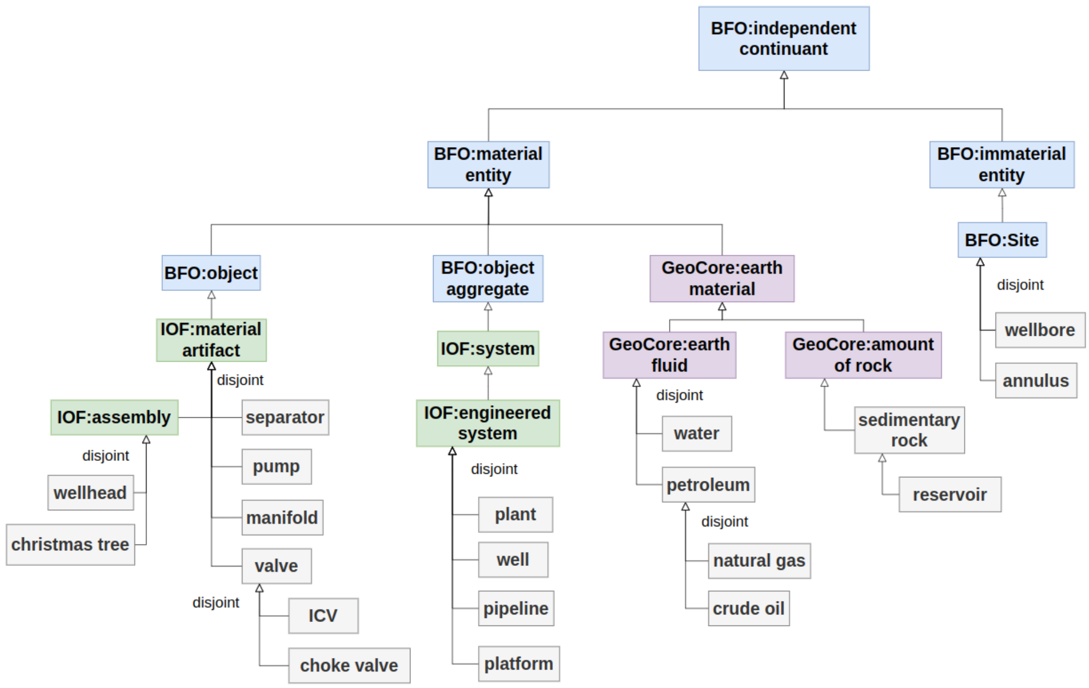

Figure 2: O3PO's is_a hierarchy.

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.,

[4] As in many specialized domains, common terms can assume a technical meaning that only makes sense if considering in the context of application. Disambiguation in this case is guaranteed by the subsumption relation with the upper class. For example, "christmas tree" is subclass of equipment not subclass of "decoration object".

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`, which are shown in figure 3. These are the roles that the pipes play when they serve as a conduit for the oil: the tubing is responsible for transporting the oil from the reservoir to the wellhead, while the riser is responsible for transporting the oil from the seafloor to the platform. These are processes with certain characteristics; consequently, it makes sense to have the corresponding roles (for example, it is more difficult to make the oil rise than to move it sideways, so pipes are subject to different effects). The exact processes in which these roles are realized will be defined in future works. By detaching the essential nature of entities from their contingent aspects our ontology allows keeping track of an entity throughout changes it may endure. E.g., distinguishing the notions of well that is initially used to produce oil and that is later employed to inject fluids into the reservoir).

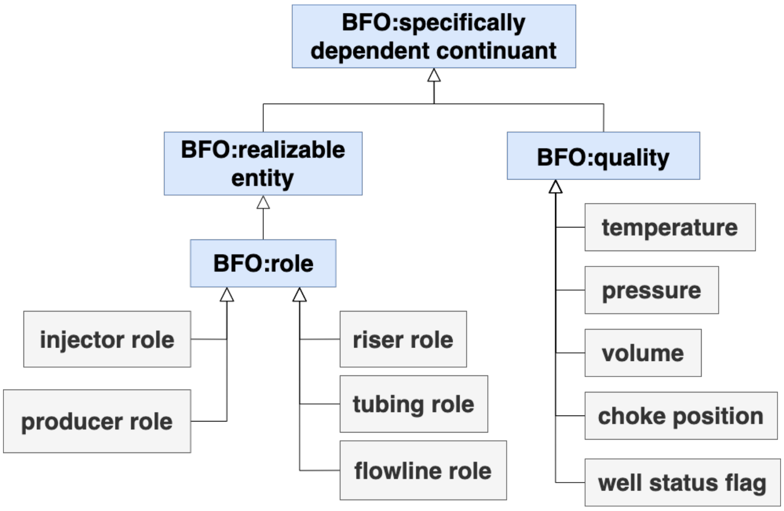

Figure 3: BFO:specifically dependent continuants in O3PO.

Our ontology also includes certain types of properties of importance for monitoring the state of the plant. Figure 3 presents some of those properties. 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). Similarly to the contingent types that were previously described, these properties can also be used to describe changes in the state of equipment (e.g., the closing/opening of valves can change the status of a well).

Finally, the ontology includes two main types of relations that can hold among the considered assets. One of them is the `O3PO:component_of` relation, which is a binary, transitive mereological relation that holds between instances of `BFO:material_entity`. It is used to denote the functional decomposition of plant assets. The other is the `O3PO:connected_to` binary symmetric relation. It is used to denote the oil path through the diverse assets in the plant. On top of that, if we have 3 objects X, Y, and Z such that X is O3PO:connected_to Y that is O3PO:component_of Z, X is considered to be O3PO:connected_to Z. Likewise, if Y is O3PO:component_of X and Y is O3PO:connected_to Z, X is also considered to be O3PO:connected_to Z. Currently, the ontology is adapting the Flow Systems Ontology (FSO) [12] to conceptualize different types of connection. We created counterparts of the FSO:exchanges fluid with relation and its specializations such as FSO:feeds fluid to and FSO:supplies fluid to as subclasses of the relation O3PO:connected to. These relations were not considered transitive. The adaptation of FSO will enable reasoning about fluid exchange across different systems in the plant.

Figure 4 shows an example of the use of the entities of our ontology to describe the oil path in a production plant. It depicts the path of the oil from a O3PO:reservoir to a O3PO:platform through a chain of O3PO:suppliesFluidTo and O3PO:component_of relations. Besides that, it shows a partial decomposition of a well into some of its components as well as their characterization with qualities presented in Figure 3. The relations depicted in Figure 4 are between instances and different configurations can exist depending on the oil production environment conditions.

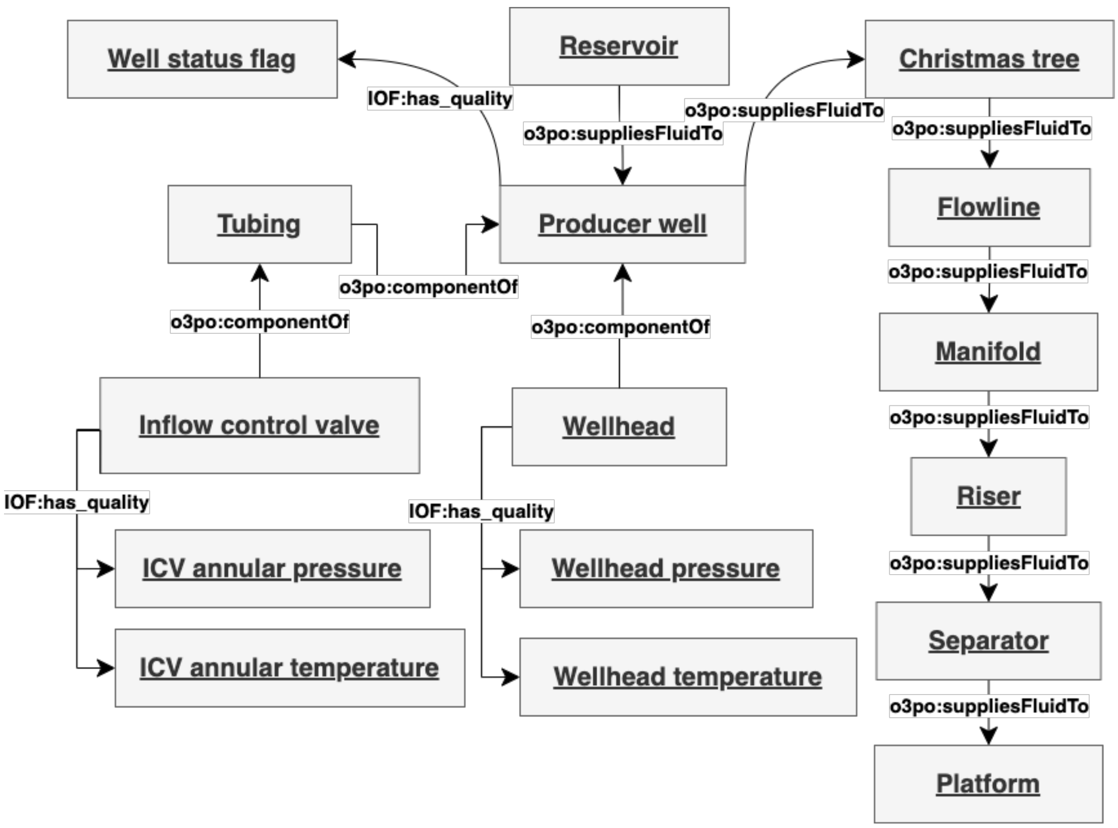

Figure 4: Example of use of relations in O3PO

Figure 5 shows an example of the relations between occurrents currently covered in the ontology with material entities and their qualities. Currently, O3PO:flow rate is considered an

`IOF:process characteristic` of a `O3PO:flow` process. Important to note that the treatment of ocurrents in the domain is in early stages.

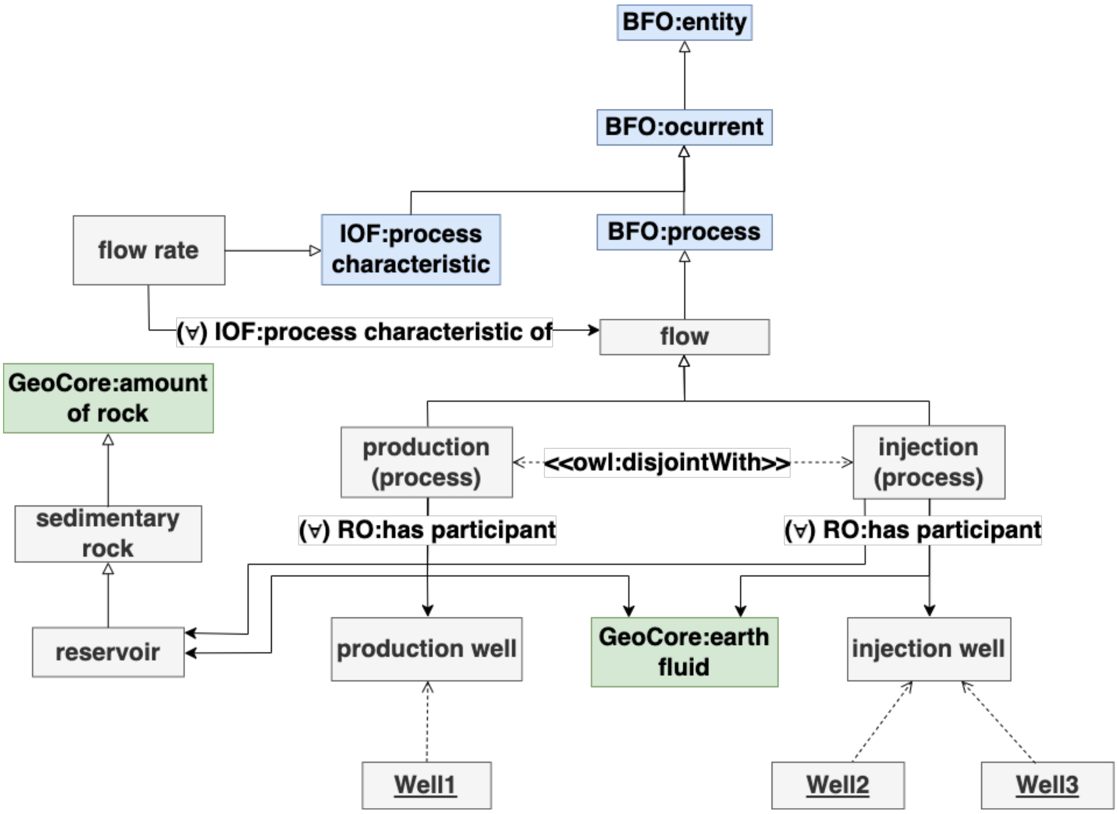

Figure 5: Diagram showing relations between ocurrents and continuants in O3PO

3.2. Uses of the Ontology

As usual for a deepwater offshore field, many data sources are distributed in the production plant due to the number of sensors in the wells and equipment. The data acquired in each measurement performed by a sensor is usually stored in a CSV file next to its timestamp, forming a time-series reflect the historical values for the measured property.

A difficulty that engineers have is tying such data to the corresponding physical assets in the plant. For example, if an engineer wants to gather all pressure time series from a given well, s/he has to inspect the label of each CSV file to check whether it corresponds to a property of interest of the desired well. It would be desirable to have means to obtain all the time-series from the well without looking for each data file spread on the company's data stores.

To handle this, one could use the ontology to annotate the files with reference to the type of property that was measured, the instance of the entity that has the property, and the unit of measurement. Moreover, given the representation of relations between assets, it would be possible to perform more elaborated semantic searches on the data, regarding information that would probably not be present in the label of the data file. For instance, it would allow searching files referring to the position of all valves that are part of the producer wells connected to a give manifold.

4. Discussion

O3PO intends to define entities present in offshore petroleum production plants formally. Through the vocabulary uniformization, it will be capable of constraining the meaning of terms, defined classes, and relations that will later inspire the data interoperability and efficient reasoning in field operator databases. The choice of resources to be used in the ontology development was limited to the available literature that helps in reaching this goal.

It is important to differentiate the O3PO from other ontologies produced in the past. One aspect that makes O3PO different is the fact that it uses BFO's guidelines and philosophical view of the world to define the entities in petroleum production. This characteristic contrasts with other initiatives such as OntoCAPE, which considers a systems view of the world something not considered in BFO. Also, ISO 15926-2 has a 4D view of the world in opposition to the three-dimensional view of BFO. In addition, O3PO was built to meet the specific requirements that are not covered by existing BFO-compliant ontologies (e.g., GeoCore [8], ENVO [13]). Even so, it is noteworthy that multiple ontological and non-ontological resources were considered and reused during the development of our ontology.

Another aspect that differentiates O3PO from other initiatives is that it has the goal of delivering formal constraints to entities in the domain through logical axioms. ISO 15926-4 and PPDM provide natural-language definitions for entities in the petroleum industry, but the definitions do not constrain the meaning of entities' meaning formally. O3PO intends to provide that for a specific section of the oil industry, offshore petroleum production plants. ISO 15926-14 does provide formal definitions, but for higher-level concepts such as Object and Aspect, already covered in BFO. This part defines lower-level terms such as Person, but not lower-level terms in the domain such as Choke Valve or Production Well. O3PO intends to fill that gap using the available resources such as the above-mentioned ISO 15926-4 as references for later formalizing definitions.

4.1. Limitations

O3PO provides many benefits to information management in offshore petroleum production plants. However, there are some limitations to the capabilities of the ontology.

- Even though O3PO provides the means to tie values of properties (e.g., pressure and temperature) to material entities, the ontology is unable to handle missing data, erroneous data, and other problems related to the observation of properties and not just to the properties themselves - which is not part of the original scope of the ontology.
- The ontology, as of yet, does not handle actuators which are fundamental to production monitoring and safety maintenance. Due to the substantial number of such devices in offshore petroleum production facilities this particular subject is in the scope of the ontology and will be addressed in future work.

- Currently, the treatment of connections between the components of a subsea production system is still not ready to accommodate the effect of closed valves, obstructions, and other issues on the fluid path. Since such events are part of the daily operation in a petroleum facility it is within the scope of the ontology and will also be treated in future work.

5. Concluding Remarks

This paper presented a well-founded domain ontology in the domain of offshore petroleum production. The research has focused on defining what entities are present in an offshore plant, properties of interest for monitoring its behavior, and relations that allow conveying the compositional structure of the plant and the connections between its components regarding fluid flow.

Our intention in this research project is to create a semantic layer between data and the petroleum production information systems to help in integrating diverse data in an oil production enterprise, to allow reasoning over such data, and to support the operations of a digital twin.

To some extent, the ontology provides means to mirror the assets in a production plant, which can contribute to a digital twin application. It covers properties that are continuously measured in petroleum production (e.g., `O3PO:pressure`, `O3PO:temperature`, and `O3PO:choke position`) as well as is supports the representation of the functional composition of assets and their connections. With that, the ontology allows a semantic account for snapshots of the plant at any instant, which could compose a historical view revealing the behavior of the plant.

Future work will be focused in addressing the limitations listed in Section 4.1. In particular, we plan to extend the ontology to deal with the issue of the measuring of properties (e.g., by incorporating the stimulus-sensor-observation ontology design pattern [14] and elements of the Information Artifact Ontology - IAO [15]). Current and future progress in ontology development can be seen in a public repository in Github[5].

Acknowledgments

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

References

[1] Professional Petroleum Data Management Association (PPDM), What is a Well?, 2014. URL: https://ppdm.org/ppdm/PPDM/Standards/What_is_a_Well/PPDM/What_is_a_Well.aspx.

[2] Professional Petroleum Data Management Association (PPDM), What is A Completion?, 2018. URL: https://ppdm.org/PPDM/PPDM/Member/What_is_a_Completion.aspx.

[3] International Organization for Standardization, Industrial automation systems and integration — Integration of life-cycle data for process plants including oil and gas produc-

[5] github.com/BDI-UFRGS/O3POntology

tion facilities — Part 4: Initial reference data (ISO/TS Standard No. 15926-4), 2019. URL: https://www.iso.org/standard/73830.html.

[4] International Association of Oil & Gas Producers (IOGP), Capital Facilities Information Handover Specification (CFIHOS) - Specification Document, Technical Report, International Association of Oil & Gas Producers (IOGP), 2020. URL: https://www.jip36-cfihos.org/cfihos-standards/.

[5] N. Guarino, Formal ontology in information systems: Proceedings of the first international conference (FOIS'98), June 6-8, Trento, Italy, volume 46, IOS press, 1998.

[6] R. Arp, B. Smith, A. D. Spear, Building Ontologies with Basic Formal Ontology, MIT Press, 2015. doi:10.7551/mitpress/9780262527811.001.0001.

[7] R. Minerva, G. M. Lee, N. Crespi, Digital Twin in the IoT Context: A Survey on Technical Features, Scenarios, and Architectural Models, Proceedings of the IEEE 108 (2020). doi:10.1109/JPROC.2020.2998530.

[8] L. F. Garcia, M. Abel, M. Perrin, R. dos Santos Alvarenga, The GeoCore ontology: A core ontology for general use in Geology, Computers & Geosciences 135 (2020) 104387. doi:10.1016/J.CAGEO.2019.104387.

[9] B. Smith, F. Ameri, H. Cheong, D. Kiritsis, D. Sormaz, C. Will, J. N. Otte, A First-Order Logic Formalization of the Industrial Ontology Foundry Signature Using Basic Formal Ontology, in: Proceedings of the Joint Ontology Workshops (JOWO), Graz, 2019.

[10] E. Kharlamov, M. Skjaveland, D. Hovland, T. Mailis, E. Jimenez-Ruiz, G. Xiao, A. Soylu, I. Horrocks, A. Waaler, Finding Data Should be Easier than Finding Oil, in: Proceedings - 2018 IEEE International Conference on Big Data, Big Data 2018, 2019. doi:10.1109/BigData.2018.8622035.

[11] M. C. Suárez-Figueroa, NeOn Methodology for Building Ontology Networks: Specification, Scheduling and Reuse (2010).

[12] V. Kukkonen, A. Kücükavci, M. Seidenschnur, M. H. Rasmussen, K. M. Smith, C. A. Hviid, An ontology to support flow system descriptions from design to operation of buildings, Automation in Construction 134 (2022). doi:10.1016/J.AUTCON.2021.104067.

[13] P. L. Buttigieg, E. Pafilis, S. E. Lewis, M. P. Schildhauer, R. L. Walls, C. J. Mungall, The environment ontology in 2016: Bridging domains with increased scope, semantic density, and interoperation, Journal of Biomedical Semantics 7 (2016). doi:10.1186/s13326-016-0097-6.

[14] K. Janowicz, M. Compton, The stimulus-sensor-observation ontology design pattern and its integration into the semantic sensor network ontology, in: CEUR Workshop Proceedings, volume 668, 2010.

[15] B. Smith, W. Ceusters, Aboutness: Towards foundations for the information artifact ontology, in: CEUR Workshop Proceedings, volume 1515, 2015.