How do specialists express risks: an applied ontology for the oil & gas domain

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Abstract. *Risk constitutes a polysemous idea, referencing concepts such as a triggering event to an undesired consequence, the probabilities of the event and the dimension of the consequence. Combined with the lack of standardization, the idea of risk in a given domain can be documented in a multitude of ways, often carrying implicit knowledge. For this reason, a proper conceptual model can enhance natural language processing algorithms applied to risk documentation. This work proposes a framework for the development of the conceptualization of risks in oil and gas projects documented by specialists of the Petroleum Reservoir domain. It offers domain experts a predefined set of concepts that resonate with their area of expertise. We expect that the result, an applied risk ontology composed of the words dominated by reservoir professionals, can be easily adopted in future risk documentation.*

1. Introduction

In the last fifty years, efforts have been directed towards developing best practices of risk management [Renn 1998] in a multitude of areas [CALÔBA 2018], including the oil & gas industry [Aven and Vinnem 2007] [Hastings and McManus 2004].

Intertwined with processes of industrial project management [ISO 31000:2018(E) 2018], practices of risk management include: the standardization of risk concepts [ISO 73:2009(E) 2009]; the design of workflows for risk assessment; the execution of risk mitigation actions; and definitions on how to measure risks [Aven and Renn 2010].

Such practices, however, can end up by producing many documents and reports elaborated by technical specialists, who may not necessarily have been provided with adequate qualification on the *risk* domain. These documents are often composed by texts in natural language containing risk descriptions.

Because risk is a polysemous and somewhat unclear concept [Patt and Schrag 2003], the description of risks in natural language may carry implicit knowledge on the causes and uncertainties that lead to the hazards posed by a specific risk experience. For that reason, the documents that result from risk management practices often express a project's risks in an incomplete fashion.

Among some proposed definitions of risk, a common ground relies on the notion of damage or impact caused by uncertain events (or chain of events) [Aven 2010]. In some cases the definition extends to the triggering cause to the occurrence of the risk, and to metrics of probability of events and severity of the impact [Kaplan and Garrick 1981]. Sharing a common knowledge of risk and agreeing on a taxonomy for its expression could provide an ideal description of risk, one that clarifies all taxonomy elements (*uncertainty*, *cause*, *impact*, etc.).

Specifically for the oil and gas industry, the activity of oil production forecasting constitutes an inherently risky activity. Usually conducted by petroleum reservoir professionals, production forecasts have as input uncertain parameters of the geological conditions that generated the reservoir, with the ultimate goal of subsidizing investment and operational decisions.

Petroleum reservoirs were generated under unknown geological circumstances, and lay buried kilometers underground. Samples and data on reservoirs are expensive, and thus scarcely accessible. Our knowledge about their size and productivity is incomplete and uncertain. This makes oil production forecasting a very risky task.

Recently, the outcomes of conceptual models and domain ontologies led to successful applications of applied risk ontologies in data processing tasks. The results comprise knowledge inference [Esteban et al. 2018], semantic reasoning [Ding et al. 2016], optimization of supply networks [Palmer et al. 2018] and real-time monitoring of cybersecurity risks [Vega-Barbas et al. 2019].

This work shows how using a text-based framework [Garcia et al. 2020b] led to a first attempt into proposing an applied ontology of the risk domain to the case of the oil & gas industry - more specifically those risks associated with the petroleum reservoir domain. We founded our ontology in the Common Ontology of Value and Risk [Prince Sales et al. 2018] and the GeoCore [Garcia et al. 2020a] Ontology, which provide the necessary definitions to a better understanding of geology and risk domains, respectively.

To the best of our knowledge, there are no public relevant available conceptual models targeting risk documentation in natural language, which usually remain as corporate intellectual property.

The main goal of our work is to clarify and model concepts through a common understanding of reservoir risks in projects of the oil & gas industry, allowing the development of algorithms to risk processing, including semantic reasoning.

The remaining of this work is organized as follows: in Section 2, we introduce a brief description of the UFO Ontology, the top-level ontology in which our work is ultimately founded. In Section 3 we present the GeoCore Ontology and the Common Ontology of Value and Risk, as well as the Frequency-based Ontological Analysis of

Petroleum Domain Terms. Section 4 contains the methodology conducted in order to build our applied ontology, and its results are presented in Section 5. Finally, in Section 6 we present our conclusions.

2. A Brief Introduction to UFO and OntoUML

OntoUML is a language whose meta-model has been designed to comply with the ontological distinctions and axiomatization of a theoretically well-grounded foundational ontology named UFO (Unified Foundational Ontology) [Guizzardi 2005, Guizzardi et al. 2015]. UFO is an axiomatic formal theory based on contributions from Formal Ontology in Philosophy, Philosophical Logics, Cognitive Psychology, and Linguistics. In the remainder of this section, we briefly explain a selected subset of the ontological distinctions put forth by the Unified Foundational Ontology (UFO). For an in-depth discussion, philosophical justifications, formal characterization and empirical support for these categories one should refer to [Guizzardi 2005, Guarino and Guizzardi 2015].

Take a domain in reality restricted to endurants [Guizzardi 2005] (as opposed to events or occurrents). Central to this domain we will have a number of object *Kinds*, i.e., the genuine fundamental types of objects that exist in this domain. By a kind, we mean a type capturing essential properties of the things it classifies. In other words, the objects classified by that kind could not possibly exist without being of that specific kind.

Kinds tessellate the possible space of objects in that domain, i.e., all objects belong necessarily to exactly one kind. However, we can have other static subdivisions (or subtypes) of a kind - naturally termed *Subkinds*. As an example, the kind 'Person' can be specialized in the subkinds 'Man' and 'Woman'.

Phases but also typically subkinds appear in OntoUML models forming (disjoint and complete, i.e., exhaustive) *partitions* following a *Dividing Principle* [Wieringa et al. 1995]. For example, we can have the following *phase partitions*: the one including 'Living Person' and 'Deceased Person' (as phases of 'Person' and according to a 'life status' dividing principle).

Relators (or *relationships* in a particular technical sense [Guarino and Guizzardi 2015]) represent clusters of relational properties that "hang together" by a nexus. Moreover, relators are full-fledged *Endurants*. Objects participate in relationships (relators) playing certain *Roles*. For instance, people play the role of spouse in a marriage relationship; 'Spouse' (but also typically 'Student', 'Teacher', 'Pet', 'Rented Car') are examples of what we technically term a *role* in UFO, i.e., a relational contingent sortal (since these roles can only be played by entities of a unique given kind). There are, however, relational and contingent role-like types that can be played by entities of multiple kinds. An example is the role 'Customer' (which can be played by both people and organizations). We call these role-like types that classify entities of multiple kinds *RoleMixins*.

Finally, types that represent properties shared by entities of multiple kinds are termed *Non-Sortals*. In UFO, besides rolemixins, we have two other types of non-sortals, namely *Categories* and *Mixins*. Categories represent necessary properties that are shared by entities of multiple kinds. In contrast, mixins represent shared properties that are necessary to some of its instances but accidental to others.

3. Related work

3.1. GeoCore Ontology [Garcia et al. 2020a]

GeoCore Ontology is a core ontology for the description of geological knowledge. It was developed using the BFO top-level ontology [Arp et al. 2015] with the purpose of facilitating the development and integration of domain ontologies in the geological domain. In the following, we describe the entities from GeoCore that we used in this work.

The central idea in the GeoCore Ontology is that geoscientits have to deal with two distinct kinds of material entities, earth materials and geological objects. The relation between earth materials and geological objects is one of *constitution* - the relation between something and what it is made of-, which, in the view adopted by GeoCore, isn't a parthood relation. *Earth materials* are natural amounts of matter. They come into existence by nature, without any artificial aid. Since they are amounts, they don't hold unity criteria and aren't necessarily maximally connected, but they are ontologically rigid and provide an identity criteria. On the other hand, a *geological object* is a naturally occurring entity constituted by some earth material that is maximally connected, thus, provides an unifying criteria. The external surface delimiting a geological object is named a *geological boundary*. Geological objects may be the bearer of some *geological structure*, which is the pattern of the internal arrangement of the object. Finally, when two distinct geological objects are in physical contact (i.e., they are physically adjacent), they are in a special relation of *geological contact*.

3.2. Common Ontology of Value and Risk [Sales et al. 2018]

Conducted under the principles of the Unified Foundational Ontology (UFO) [Guizzardi 2005], the Common Ontology of Value and Risk provides a well-founded ontology which describes value and risk in terms of events and their causes.

This ontological analysis proposes a relationship between *risk* and *value* notions, and concludes that the process of assessing risk is a particular case of that of ascribing value. By formalizing those two concepts, the authors seek to disentangle three perspectives: (i) an experiential perspective (value and risk in terms of events and their causes), (ii) a relational perspective (the subjective nature of value and risk), and (iii) a quantitative perspective.

The work presents the similarities between value and risk as both having goal dependency, context dependency, uncertainty and impact - thus, Value and Risk are commonly decomposed into "smaller" events.

The experiential perspective ascribes risk to objects and events, and was the main guide to instantiate an applied ontology to the petroleum reservoir risk scenario - since our work will be centered in defining such *objects* and *events*.

3.3. Frequency-based Ontological Analysis of Petroleum Domain Terms [Garcia et al. 2020b]

Applying statistical analysis of relevant terms in a corpus of the geology domain, this article defines a set of terms as the first step towards developing a domain ontology for Petroleum Geology.

The proposed framework ranks the relevant terms present in a domain thesaurus according to their frequency in a selected domain corpus, which are then examined by domain experts, in order to identify the continuant entities relevant within the geological domain (i.e., those that are exclusively related to Geology).

An ontological definition for each of the 15 top-ranked selected is then proposed, in alignment with Basic Formal Ontology and the GeoCore Ontology.

In addition to the proposed domain ontology for Petroleum Geology itself, another important contribution of this work is providing a helpful framework to evaluate thesauri, which contain a considerable number of terms, and extract relevant terms from the thesauri that will compose the ontology. This framework optimizes the time of domain experts, whose examination is crucial to provide and disambiguate term definitions, and to identify and disambiguate the relations that connect those terms.

4. Methodology

4.1. Document selection

Over the last decade, Petrobras adopted the *Front-End-Loading* (FEL) methodology [10. 2013] in the deployment of capital investment projects of the Exploration & Development (*upstream*) segment [Motta et al. 2014]. Project approval is conducted in phases with defined objectives, and each phase contains workflows and processes in which requirements are fulfilled, providing elements to measure the project maturity and to deliver the necessary information for decision support.

Entangled with project management rituals are the assurance procedures, including workshops for project risk identification. In the last ten years, petroleum reservoir specialists in Petrobras have conducted hundreds of workshops of project-phase risk identification, documenting over 2500 risks in *upstream* projects associated with their domain of knowledge.

Each risk is described in a sentence, and a set of approximately 2500 sentences constitute the corpus originally selected to subject to a frequency-based ontological analysis. With the aid of one expert in the reservoir assurance procedures, a subset of the original corpus was selected through keyword search (Table 1) within the sentences.

The final set of documents used in this study is composed of 340 target sentences describing those risks associated with geomechanical aspects of the petroleum reservoir. Because of its reduced size, the terms selected to compose the ontological seed of our applied ontology were those with higher frequency within the target sentences.

4.2. Selecting Ontological Seed

After applying the basic raw text processing tasks (tokenization, removal of punctuation, stopwords and special characters), the application of statistical analysis provided a rank of the words appearing in the target sentences. Those 345 words were then subject to two questions:

1. Is it a term from the Geomechanics of Petroleum Reservoir domain?
2. Does it refer to a continuant (i.e., an object or a quality to describe an object)?

Theme	Keywords (PT-BR)
Fouling	'incrustacao'
Fouling	'asfalteno'
Fouling	'hidrato'
Geomechanics	'reativacao'
Geomechanics	'compactacao'
Geomechanics	'colapso'
Geomechanics	'subsidencia'
Geomechanics	'exsudacao'
Geomechanics	'geomecanico'
Geomechanics	'caverna'

Tabela 1. Keyword search in sentence selection

The remaining 54 terms in Portuguese have their meanings documented by an expert, using definitions based on Petrobras' Glossary [PETROBRAS 2007], Schlumberger Oilfield Glossary [SHLUMBERGER 2019], the Open Wordnet [Tessarollo and Rademaker 2020] and Wikipedia. Those terms were used as ontological seed to build a conceptual model of the geomechanical phenomena in petroleum reservoir that lead to risk experiences in investment projects.

Section 4.3 contains the definitions of relevant terms as proposed by the domain specialist, used to conduct ontological analysis. The definitions are Aristotelian, in the form A =def is a B that C, where A is the term we are defining, B is a class of GeoCore or UFO, and C is the set of properties that makes A a specialization of B.

4.3. Term definitions

Reservoir =Def. is a GeoCore: Geological Object that is a geological configuration constituted by GeoCore:Amount of Rock with specific properties, storing hydrocarbons and/or water.
Water = Def is a GeoCore: Earth Fluid in the liquid state whose molecules are composed of two atoms of hydrogen and one atom of oxygen.
Petroleum =Def is a GeoCore: Earth Fluid that is a mixture of hydrocarbons in liquid, solid or gas state, which may also contain chemical compounds composed of nitrogen, sulfur, oxygen, etc.
Oil = Def is a GeoCore: Earth Fluid that is usually referred to as the Petroleum stripped from its gas phase.
Fracture =Def is a GeoCore:Geological Structure that is concretized by a discontinuity in the topology of one or more GeoCore: Geological Objects.
Fault =Def is a Fracture approximately plane and concretized by the displacement between two GeoCore: Geological Objects.
Porosity =Def is a Quality Universal that inheres in a GeoCore: Amount of Rock that is the fraction of the Rock's total volume represented by empty spaces.
Overlying Rock =Def if a Geocore: Geological Object constituted by a non-porous GeoCore:Amount of Rock that lays above the Reservoir and acts as a seal to fluid flow.
Seal =Def is a UFO: Role played by GeoCore:Geological Objects or GeoCore:Geological Structure with the capacity of containing or isolating fluid flow.

Well =Def is a UFO: Kind that is a cavity drilled in the ground, properly equipped to fulfill the purpose of (i) obtaining oil or natural gas; (ii) inserting fluids in a Reservoir;(iii) verifying the presence and dimensions of a Petroleum Reservoir; (iv) evaluating the depth of geological layers.
Production Well =Def is a UFO: Role played by a Well properly equipped to obtain oil or natural gas from a Reservoir.
Injection Well =Def is a UFO: Role played by a Well properly equipped to insert fluids in a Reservoir.
Project =Def is a UFO: Kind that is an effort deployed to create a product, service or exclusive result, requiring human, material an financial resources in order to be executed.
WOR (Water-Oil-Ratio) =Def is a UFO: Quality that inheres in a Production Well that is the instant ratio of water and oil rates (measured in standard conditions).
Pressure =Def is a UFO: Quality Dimension that inheres in a GeoCore:EarthMaterial, and defines the scalar measurement of the action of forces over a determined space, which can be in liquid, solid or gas state.
Injection Pressure = Def is the Pressure that inheres in a GeoCore: Earth Fluid that is inserted in the Reservoir through the Injection Well.

4.4. Building the ontology

Having in mind the definition of concepts and some previous efforts into modeling the petroleum reservoir domain [Guizzardi et al. 2010], we then modelled the relationships between terms of the ontological seed extracted from the texts. Since many of those elements correspond to geological entities, we then based their definitions and relationships among them on the concepts of the GeoCore Ontology, as can be observed in Figure 1, showing the petroleum reservoir and its constituents, and its relation with the sealing rock.

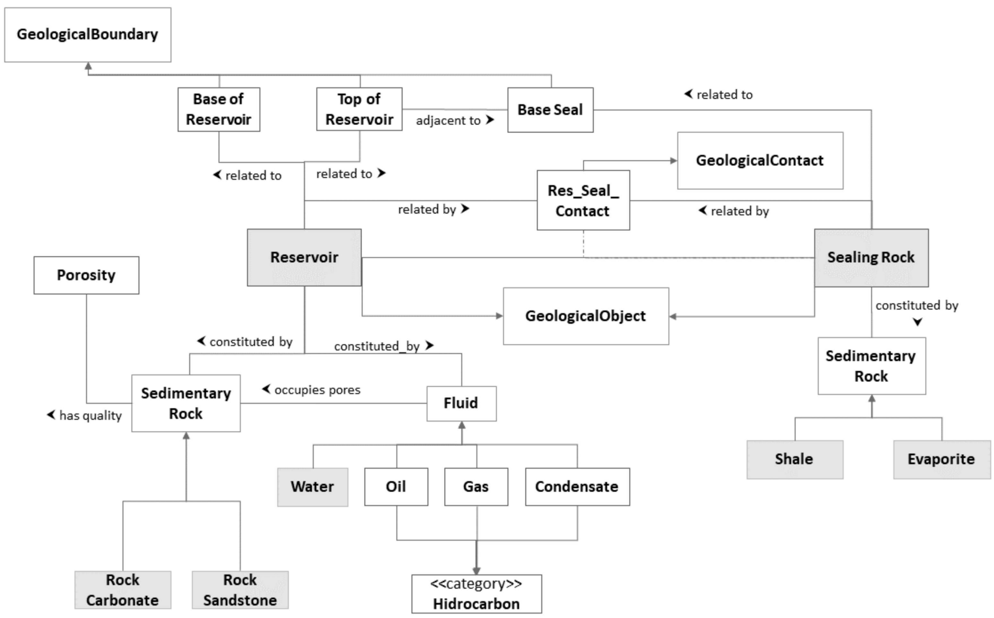

Figura 1. Oil Reservoir, Caprock and constituents

It is worth noticing that, since the GeoCore Ontology and the Value and Risk Ontologies are founded under the definitions of different top ontologies - respectively, the

Basic Formal Ontology (BFO) [Arp et al. 2015] and the Unified Foundational Ontology (UFO) [Guizzardi 2005], we faced the challenge of dealing with conceptual ”translation”. Since the goal here was to represent risk experiences, we followed the definitions adopted in the Common Ontology of Value and Risk, translating some concepts of the GeoCore Ontology to UFO-based definitions. This translation is partial and can be presented as future work.

5. Applied ontology to oil & gas risks related to reservoir geomechanics

From the experiential perspective of the Common Ontology Of Value and Risk, it is noticeable that Risk Experiences are composed by a series of Objects and Subjects (thus, the continuants) and their inherent properties - Vulnerability, Capability and Intentions -, or dispositions.

Combining this risk conceptualization with the built ontology for petroleum reservoir was a task conducted with the aid of domain experts, who pointed out the chain of events leading to a certain risk experience, as well as the continuants and dispositions that participate in a given Risk Experience. Corpora analysis was also crucial to interpret how specialists perceive and document the elements that compose risk experiences.

In a similar way we defined uncertainty parameters those given by nature and we do not have control over them (e.g. the reservoir porosity and permeability), and control parameters those ones we have any sort of influence over them (e.g. the separation pressure and temperature of the equipments in the surface). The disposition ”Vulnerability”of risk agents is then modelled considering those characteristics we are not able to control (likewise uncertainty parameters) and ”Capability”those characteristics we can have any sort of influence on (likewise control parameters).

For purposes of detailing how this process was conducted, take, as an example, the Subsidence Risk Experience (Figure 2). Evaluating sentences from corpora, the ontology and with the help of the expert, the adopted definition establishes that the Average Pressure (Threat Capability) that inheres in the Reservoir (*Threat Object*) participates in the (Reservoir) Depletion (*Threat Event*). Such depletion phenomena is in fact the reduction in the reservoir's average pressure due to the extraction of oil and gas. As a result, the Amount of Rock that constitutes the Reservoir (*Risk Enabler*) can have its Pore Collapse Potential (*Vulnerability*) affected, resulting in a Pore Compression (*Loss Event*). When occurs, such subsidence event hurts Environmental Safety Constraints (*Intention*) of a Petroleum Field Development Projects, or Project (*Risk Subject*).

The remainder of the modelled risk experiences for Reservoir Geomechanics sre detailed in Tables 2,3, and 4.

6. Conclusions and Final Remarks

One of the challenges of risk management is the proper standardization of concepts and terms. Despite the vast documentation with standards and procedures, risk standardization in a specific knowledge domain can be a rather difficult task, specially considering the lack of intimacy of domain experts with such standards and procedures covering the risk domain. When asked to express risks, experts can end up by referring to terms of their area of expertise rather then terms of the risk domain. This work is an initial effort into

Risk Experience	Subsidence	Oil Exudation
Risk Subject	O&G Project	
Intention	Environmental Safety	
Threat Event	Depletion	Overpressuring
Threat Object	Reservoir	Injection Well
Capability	Average Pressure	Injection Pressure
Loss Event	Pore Compression	Seal Rupture
Risk Enabler	Amount of Rock	Sealing Rock
Vulnerability	Pore Collapse Potential	Rupture Potential

Tabela 2. Elements of Subsidence and Exudation Risk Experiences in the proposed ontology for reservoir related risks in *upstream* projects

Risk Experience	Water-Oil-Ratio Increase	
Risk Subject	O&G Project	
Intention	Produced Oil Volume	
Threat Event	Depletion	Overpressuring
Threat Object	Reservoir	Injection Well
Capability	Pressure	Injection Pressure
Loss Event	(fault) Reactivation	
Risk Enabler	Fault	
Vulnerability	Reactivation Potential	

Tabela 3. Elements of Increase in WOR (for Geomechanical reasons) Risk Experience in the proposed ontology for reservoir related risks in *upstream* projects

Risk Experience	Well Collapse
Risk Subject	O&G Project
Intention	Cost
Threat Event	Depletion
Threat Object	Reservoir
Capability	Average Pressure
Loss Event	Pore Collapse
Threat Enabler	Well formation
Vulnerability	Porosity

Tabela 4. Elements of Well loss/damage (for geomechanical reasons) Risk Experience in the proposed ontology for reservoir related risks in *upstream* projects

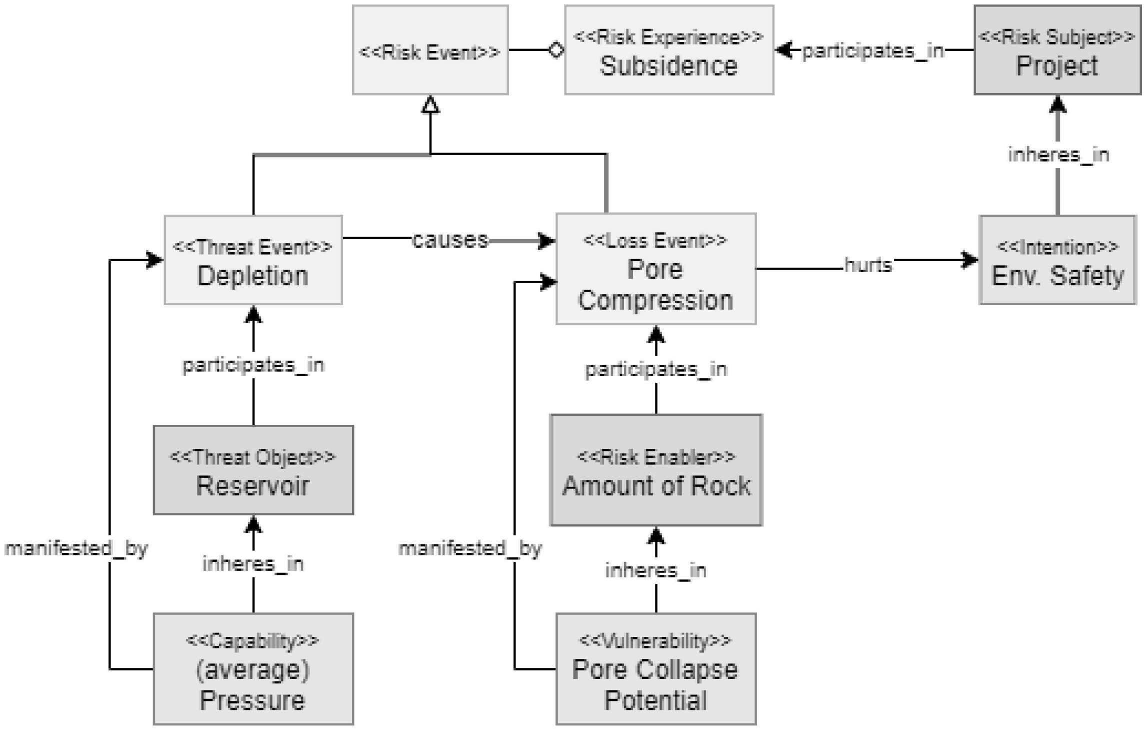

Figura 2. Subsidence Risk Experience

standardizing petroleum reservoir related risks, offering domain experts a predefined set of concepts that resonate with their area of expertise.

The key to clarify such concepts was to evaluate a small corpus elaborated by reservoir experts in risk assessment routines, and to use lexical properties of this corpus to determine which terms constitute each actor in the *Risk Experience*, as perceived by the expert. We expect that the result, an applied risk ontology composed of the words dominated by reservoir professionals, can facilitate the comprehension and adoption of this conceptual modeling in future risk assessment workshops.

Specially in the case of petroleum reservoir related risks in *upstream* projects, there is no available public corpora documenting such theme, and the material used in this work is of limited size. Despite the small quantity of sentences used to characterize the relevant terms of the domain, such information was valuable and offered a departure point, or ontological seed - then enriched by the definitions provided by a reservoir specialist.

The results brought by this work do not cover all possible *Risk Experiences* of reservoir domain in the oil & gas *upstream* projects. Enriching this conceptual model will be the subject of future work.

Another limitation of our applied ontology is the lack of feedback evaluating the robustness of its domain representation. Hopefully such evaluation can be conducted in the future, either through application of this ontology natural language processing tasks or by its adoption by the petroleum reservoir community as a tool for risk documentation.

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