A Visual Analysis of Hazardous Events in Contract Risk Management

Georgios Stathis[1,2][a], Giulia Biagioni[2][b], Athanasios Trantas[2][c], Jaap van den Herik[1][d] and Bart Custers [1][e]

[1] *eLaw - Centre for Law and Digital Technologies, Leiden University, Kamerlingh Onnes Building, Steenschuur 25, Leiden, the Netherlands*

[2] *Unit ISP, TNO, New Babylon, Anna van Buerenplein 41a, Den Haag, the Netherlands*

{*g.stathis, h.j.van.den.herik, b.h.m.custers*}@*law.leidenuniv.nl*, {*georgios.stathis, giulia.biagioni, thanasis.trantas*}@*tno.nl*

Keywords: Intelligent Contracts, Contract Risk Management, Bow-Tie Method, Legal Visualisation, Preventive/Proactive Law, Ontology Engineering, Ontology Visualisation.

Abstract: This article proposes a new visual analysis method of hazardous events to be used in contract risk management. We present our research work for the creation of an ontological extension of the Onassis Ontology to manage, analyse and visualise risk data. Onassis is an openly accessible ontology that we earlier designed to structure contract automation data. Onassis and its extension for risk management contribute to the development of trustworthy Intelligent Contracts (*iContracts*). They allow for the creation of explicit data out of usually implicit contractual information and legal processes on which it is possible to perform cross-referencing analysis with other collections of data. The ontological model that resulted from our study additionally contributes to the disambiguation of the bow-tie method structure, the primary method for analysing and visualising hazardous events. To achieve this, we use the following methodology. We visualise the bow-tie method in an ontology and then investigate the presence of taxonomic ambiguities or even errors in its structure. The results present an enriched version of bow-tie conceptualisation, in which entities and relationships are translated into openly-accessible and *ready-to-use* ontological terms, whereas risk analysis becomes visible.

1 INTRODUCTION

The world of LegalTech is facing the dawn of Intelligent Contracts (*iContracts*). *iContracts* aim to support end users with drafting legal documents via the adoption of automation techniques [Mason, 2017]. Thus far, *iContracts* have not been designed to include the editing and visualisation of risk data [Stathis et al., 2023]. Nevertheless, risk data play a fundamental role in contract risk management.

- Definition 1: **Risk Data** denotes a defined set of information (data), in any format (but increasingly in digital form), that is used by an organisation for diverse Risk Management and other business processes [1].

Nowadays, legal experts act as legal risk managers who examine legal risk data in order to safeguard the interests and rights of the parties that are involved in a given agreement. Cross-investigation between different sources (such as databases) may help users quickly identify the risks associated with the (legal) documents that they are drafting [Haapio and Siedel, 2013]. In analytical processes, both visualisation methods and ontologies (i.e., formal representations of knowledge) can be truly beneficial to carry out a conjoint analysis of diverse data sets [Hogan, 2020] and [Dudáš et al., 2018]. They can be used to (1) reach a deeper understanding of the risks involved in a certain arrangement, (2) design an efficient strategy to visualise the manifestation of a potential hazardous event, and (3) develop remedies and repair mechanisms prohibiting disastrous events. Although these methods may lead towards remarkable analytical results, their potential has yet to be completely unlocked. This is mostly owing to two reasons. First, there is no unambiguous visual structure that is unanimously used to observe and analyse the core entities

[a] https://orcid.org/0000-0002-4680-9089
[b] https://orcid.org/0000-0002-9005-7945
[c] https://orcid.org/0000-0001-7109-9210
[d] https://orcid.org/0000-0001-9751-761X
[e] https://orcid.org/0000-0002-3355-8380

[1] https://www.openriskmanual.org/wiki/Risk_Data

of the risk management framework as well as their relationships [de Ruijter and Guldenmund, 2016]. Second, there is no ready-to-use and openly accessible ontology that has been developed to disambiguate any given reference system [Agrawal, 2016]. Therefore, to offer a contribution to the resolution of the problem areas mentioned in (1), (2), and (3), our research will focus on the creation of an ontological model to analyse, visualise, and manage risk data in *iContracts*. In so doing, it will particularly examine and discuss the limitations of the bow-tie visualisation medium to manage and visualise risk data.

In 1979, a diagram to analyse hazards was first presented at the Imperial Chemistry Industry course of the University of Queensland in Australia [Kluwer, 2017]. The shape of the figure sent back took the form of a bow tie, from which it consequently took the name. Today, the bow-tie diagram is de facto standard used to perform visual legal risk management analysis. The method mirrors the conceptualisation framed in ISO 31000:2018 that has been developed by the International Standardization Organisation (ISO)[2] [Kishchuk et al., 2018] and [de Ruijter and Guldenmund, 2016]. ISO 31000:2018 is a guideline that provides a generic framework for the management of all types of risks, including legal risks [3]. The bow-tie visualisation system makes the relationships between the entities designated by ISO discernible and explicit. Although attempts have been made, the theoretical structure of both ISO 31000:2018 and the bow-tie method has not yet been translated into the expressivity of a ready-to-use ontology [Agrawal, 2016].

Ontologies enable, *inter alia*, model-based meta-analysis [Becker and Alow, 2019]. Meta-analysis can be applied to conduct different risk management analyses either to infer new pieces of information or to draft more solid clauses related to risks in contracts. Ontologies are designed to reduce ambiguity between the entities and clarify the relationships between them [Nirenburg and Raskin, 2001].

According to Ruijter and Guldenmund, there is no consensus on the specific definition of the bow-tie visualisation system except its shape and core concepts [de Ruijter and Guldenmund, 2016]. The main diverging points may originate from the ambiguity of the relationships among the entities in the bow-tie structure. This may result in subjectivity, in terms of both interpretation and intended use.

To clarify the bow-tie and ISO 31000:2018 structures, and derive new insights into the method and standard, we will therefore design an ontology mirroring the relationships portrayed in the bow-tie diagram. We will then test it against taxonomic constraints that lead to the creation phases of ontologies. The resulting ontological vocabulary will be linked to the Onassis ontology that we previously designed [Stathis et al., 2023] [4].

Designing a set of machine-understandable vocabulary terms allowing to monitor and manage risk in relation to the violation of specific contractual clauses means taking the expressiveness of *iContracts* a step further. Moreover, having openly accessible ontological vocabularies for risk management data further allows smaller entities with limited economic availability to implement monitoring strategies to reduce the occurrence of hazardous events in relation to contractual clauses. By including risk data and risk management strategies, *iContracts* will not only serve the purpose of formally describing an agreement between different parties, but will also even monitor and prevent the occurrence of hazardous events connected to legal risk. Thus, the avoidance of dispute consequences becomes possible.

The contribution of this research is therefore twofolded. First, it explores the limitations of the bow-tie visualisation method to perform large scale analysis. This will similarly bring new insights into its structure. Second, it proposes a set of openly-accessible vocabulary terms to structure and manage legal risk data.

As a result of the aforementioned information the RQ guiding our investigation is: To what extent is it possible to translate the bow-tie method into a visualisation of an ontology for contract risk management without altering the bow-tie structure?

We structured the paper as follows. Section 1 provided the introduction. In Section 2, a brief literature review is provided. Section 3 presents the method of research. Section 4 states the results of our research and Section 5 discusses those results. Finally, Section 6 answers the RQ and provides our conclusion.

2 LITERATURE

In this section, the state-of-the-art literature is presented. Section 2.1 introduces sources on contract risk management. Section 2.2 presents the latest re-

[2]ISO is an independent, non-governmental international organisation with a membership of 164 national standard bodies, founded in 1947 and headquartered in Geneva, Switzerland. In this concern cf.https://www.iso.org/about-us.html

[3]ISO, (2018), 31000:2018: Risk management – Guidelines, iso.org, abstract

[4]Onassis is accessible at https://github.com/onassisontology/onassisontology

search regarding ontologies developed to structure risk management data.

2.1 Contract Risk Management

The most exhaustive academic source on contract risk management, which is targeted to practitioners, is Haapio and Siedel's book, Guide to Contract Risk [Haapio and Siedel, 2013]. Contract risk can be identified in multiple sources. Ideally a database of contract risks should exist to help legal experts identify instances more quickly and efficiently, as it happens in other domains [Patterson and Neailey, 2002] and [Kuwahara et al., 2015].

In the industrial, energy and environmental areas, visualisation methods, such as the bow-tie, are often used to manage risk and prevent the occurrence of hazardous events within domain-specific projects [for Chemical Process Safety, 2018]. A bow-tie method is used for visualising risk in a holistic manner by taking into consideration proactive and reactive risk measures [Kluwer, 2019].

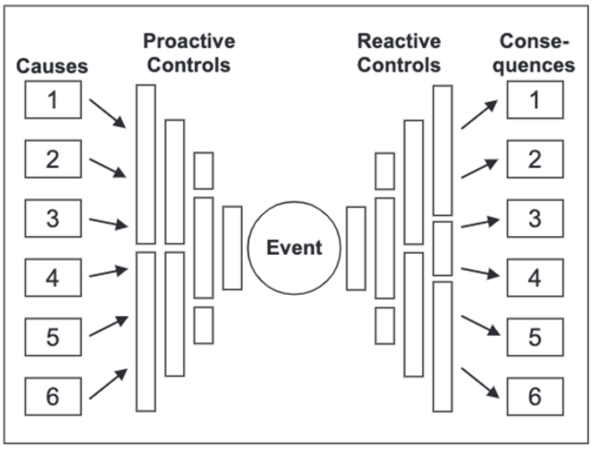

Figure 1: Bow-tie method

A bow-tie diagram helps to visualise and control contract risk [Haapio and Siedel, 2013]. It has been used in a variety of risk analysis environments and for various risk management purposes [Khakzad et al., 2012].The usefulness of the bow-tie method stems from its ability to visualise the complexity of legal risk [Dauer, 2006]. Figure 1 shows a representation of the bow-tie method.

The bow-tie method mirrors, at the level of the entities, the conceptualisation framed in the ISO 31000:2018 standard [5]. The standard defines eight concepts that are considered to be essential to manage risk: Risk, Risk Management, Stakeholder, Risk Source, Event, Consequence, Likelihood and Control. In multiple industries, including the legal industry, it is also possible to develop a risk matrix or risk register after visualising the risk management process via the bow-tie diagram [Leva et al., 2017]. In the risk matrix/register, beyond the Risk, Cause, Consequence, Likelihood, Impact, one may also add a Priority Ranking, Response plan, the entity Responsible for the plan, a Deadline, and a Validation section [Lu et al., 2015]. Consequently, risk ranking becomes possible for a clearer visualisation of the immediate risks requiring management as well as a contract risk response. In relation to contract risk, the response mostly relates with contract drafting and procedural aspects [Espenschied, 2010, Fox, 2008].

2.2 Ontologies for Contract Risk Management

Although ontologies may be a powerful instrument to perform contract risk management analysis, they are not very common in the field. This is mostly due to the scientific immaturity of the domain. However, efforts have been made to build a framework enabling both the analysis of the risk assessment process, and the codification of the relationships (i.e., roles and responsibilities) between the various entities involved in a risk management organisation. Examples are provided by the Description of a Model Ontology (DOAM) [6], and the Risk Function Ontology (RFO), respectively [7]. Although DOAM and RFO offer great contributions to the field, they still lack the needed level of expressiveness that can allow users to structure risk management data at a processing level while framing information within the *modus operandi* of the bow-tie method. Regarding ontologies aiming to mirror the implementation phases of the bow-tie process, we could not find any vocabularies designed for this specific purpose either on the Linked Open Vocabularies (LOV) catalogue [8] or the Open Risk Management (ORM) Foundation website [9]. Ultimately, we did observe an attempt to develop an ontology for the ISO risk management standards which did not result in a ready-to-use model [Agrawal, 2016].

[5]ISO, 2018, ISO 31000:2018 Risk management — Guidelines, iso.org)

[6]https://www.openriskmanual.org/ns/doam/index-en.html

[7]https://www.openriskmanual.org/ns/rfo/index-en.html

[8]https://lov.linkeddata.es/dataset/lov

[9]https://www.openriskmanagement.com/

3 METHOD

Our methodology aims to identify (1) the possible presence of violations of taxonomic constraints, and (2) ambiguous constructs in the conceptualisation of the bow-tie visualisation medium. In 3.1, we translated the bow-tie design into the expressiveness of an ontology by mirroring the bow-tie relationships and entities. In 3.2 we introduce three types of taxonomic errors. We subsequently, in 4.1, check the presence of taxonomic ambiguities and errors by following the best practices for the development of ontologies and the detection of fallacies in the models. The outcomes of our analysis are presented under results.

3.1 Ontology Visualisation of the Bow-Tie Method

As presented in the previous section and discussed by [de Ruijter and Guldenmund, 2016], the entities pictured in the bow-tie method relate to one another as follows.

1. The causes of a hazardous event are protected by proactive controls.
2. The proactive controls relate to a hazardous event. They result from the causes and are designed based on the nature of the hazardous event.
3. The hazardous event is contained by both the proactive and reactive controls (barriers).
4. The reactive controls are conceptualised based upon the nature of the hazardous event to marginalise its consequences. They relate to both a hazardous event and its consequences.
5. The consequences are limited by the reactive controls to which they relate.
6. The risk which is not represented in the bow-tie diagram can be intuitively associated with the hazardous event itself. This is mostly based upon the guidelines of the ISO 31000:2018 standard.
7. The stakeholder, who is not represented in the bow-tie diagram, can be intuitively associated with the hazardous event. This can be derived from the guidelines of the ISO 31000:2018 standard.
8. The likelihood, which is not represented in the bow-tie diagram, measures the probability of the occurrence of a hazardous event as described in the guidelines of the ISO 31000:2018 standard.

When translating the entities and relationships of the bow-tie diagram into the expressiveness of an ontology, we will firstly attain the structure presented in Figure 2.

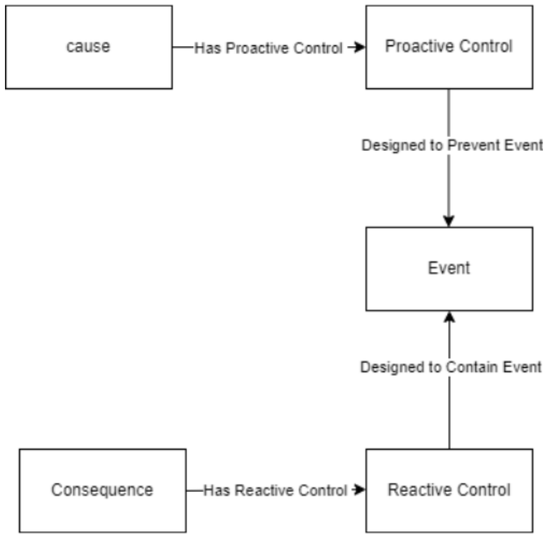

Figure 2: Bow-tie Centred Ontology

The validity, efficiency, and consistency of the ontological structure presented in Figure 2 can be tested against the presence of taxonomic errors.

3.2 Three Types of Taxonomic Errors

According to [Gomez-Perez, 1995], [Gómez-Pérez et al., 2004], [Gómez-Pérez, 2001], [Fahad et al., 2008] and [Fahad and Qadir, 2008], there are three main types of taxonomic errors. They are inconsistency errors, incompleteness errors, and redundancy errors.

Inconsistency errors may be caused by circulatory errors (i.e., entities defined as sub-entities or super-entities of itself), partition errors (i.e., instances belonging to various disjointed classes), or semantic inconsistency errors (i.e., when ontologists define concepts as sub-classes of concepts to which they do not pertain).

Incompleteness errors may be of three types, namely, (a) incomplete concept errors (they occur when concepts and relationships of the domain are overlooked and not defined in the structure), (b) incomplete axiom errors (they occur when ontologists omit important axioms and information about the classification of a concept), or (c) sufficient knowledge emission errors (they take place when concepts have only necessary descriptions). Incompleteness errors lead to ambiguity and create a lack of proper reasoning mechanisms.

Redundancy errors happen when pieces of information are inferred more than once from the relationships, classes, and instances of the ontology. They can be: redundancies of sub-class/sub-property errors (they may occur when classes or relationships directly or indirectly have more than one sub-class/sub-property relationship); identical formal definition of classes, properties and instances (i.e., proprieties, classes and instances have different names but provide the same formal definition); or redundancy of disjoint relationships (i.e., concepts explicitly defined as disjointed from other concepts more than once).

In order to derive more insights into the bow-tie method and to test the actual taxonomic validity of the bow-tie centred ontology displayed in Figure 2, we tested this ontology against the three types of taxonomic errors discussed in the preceding paragraphs. Our results are presented in the subsequent section.

4 RESULTS

This section presents the results of our research. The results concern the taxonomic errors in the ontology visualisation of (4.1) the bow-tie centred ontology and (4.2) the enriched bow-tie ontology.

4.1 Taxonomic Errors in the Bow-tie Centred Ontology

The bow-tie centred ontology (Figure 2) presented in the previous section mirrors the exact relationships that are framed by the bow-tie method (Figure 1) and a few of the concepts of ISO 31000:2018. As discussed above, the risk, stakeholder, and measure of likelihood are not addressed by the bow-tie analytical medium. This resulted in the absence of their concepts from the bow-tie centred ontology. The same can be said for the measure of likelihood regarding the occurrence of a hazardous event. The lack of these concepts in the diagram and ontology causes several knowledge emission errors. Other incompleteness errors that can be found in the bow-tie centred ontology are incomplete concept errors.

In the bow-tie diagram (Figure 1), only the relationships between (1) the causes and proactive controls, (2) the proactive controls and hazardous event, (3) the hazardous event and reactive controls, and (4) the reactive controls and consequences are described. However, these four relationships may lead to ambiguity when performing cross-referencing analysis with a bow-tie centred ontology and/or diagram.

Below we discuss two types of ambiguities. First, the problems identified in the bow-tie centred ontology originate from the ambiguity in the relationships between the entities that are framed by the bow-tie visualisation method. Second, the taxonomic errors that we individualised, namely incomplete concept errors and sufficient knowledge emission errors, do not only concern the relationships between causes, proactive controls, and the hazardous event (i.e., the left side of the bow-tie visualisation method) but even the relationships between the hazardous event, reactive controls, and consequences. Ultimately, no other type of taxonomic errors have been detected in the bow-tie centred ontology.

4.2 The Enriched Bow-tie Ontology

To resolve the taxonomic errors identified in the bow-tie centred ontology (Figure 2), we shifted the relationships in the previously presented ontological model from a cause-sequential order of connected entities to a node-centred one. In the resulting version of the model, the cause, proactive control, reactive control, and consequence are directly connected to the hazardous event. We identified the hazardous event as the most core component. The hazardous event is here conceived as a physical occurrence possibly associated with a point in time. Furthermore, we considered the cause, reactive control, proactive control, and consequence as human-derived observations rather than actual physical situations. This makes it so that every time a hazardous event is identified by a legal expert, a unique identifier shall be created for it, regardless of whether its nature is similar or identical to another event. Unlike the case of the hazardous event, the identifiers of identical causes, reactive controls, proactive controls, and consequences can be reused across use cases.

As previously discussed, the bow-tie visualisation method (Figure 1) does not include (1) the relationship between the hazardous event and the risk, (2) the relationship between the hazardous event and stakeholders, and (3) the relationship between the measured probability of a hazardous event and the hazardous event itself.

The new vocabulary terms of the Onassis ontology demonstrate the relationships presented above as follows. The risk is connected to a hazardous event that is, in turn, linked to a measure of probability. Based on the structure of the risk matrix analysis, we connected the stakeholder directly to the impact of a hazardous event. The probability and impact measures are then associated with a level of risk which is subsequently linked to the risk itself. Both probability and impact measures are connected to a source. Figure 3 displays the new vocabulary terms that we added to the Onassis ontology.

To conclude, the rationale behind the new classes and properties of the Onassis Ontology can be described as follows.

1. The Risk *involves* a Hazardous Event and a Risk

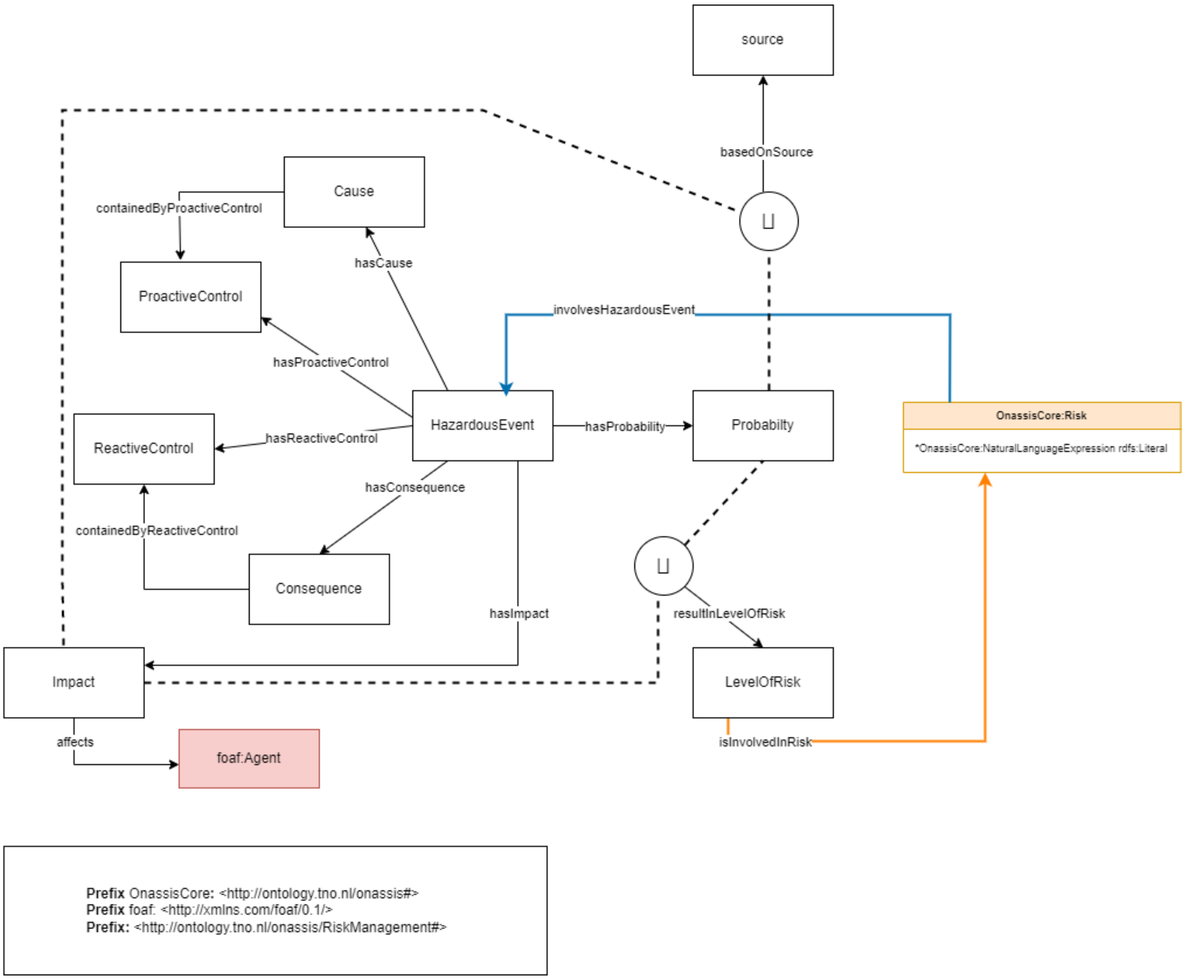

Figure 3: New vocabulary terms of the Onassis Ontology.

Measure.

2. The Hazardous Event *has* a Cause, Proactive Control, Reactive Control, Impact, and Consequence.
3. The Cause *is contained by* the Proactive Control.
4. The Consequence *is contained by* the Reactive Control.
5. The Impact of a Hazardous Event *affects* an Agent.
6. The Hazardous Event *has* a Probability number.
7. The numbers of the Probability and Impact *result* in a Level of Risk.
8. They are *based on* a Source.
9. The Level of Risk *is* ultimately *involved* in a Risk.

To design the new vocabulary terms for Onassis, we used the Resource Description Framework Schema (RDF/S) and Ontology Web Language (OWL).

The logical consistency of the new vocabulary terms has been tested via an ontology reasoner [10]. The coherency of the model with domain knowledge has been validated by running competency questions on sample data which are accessible via GitHub [11].

5 DISCUSSION

The discussion concentrates on examining the research consequences for (5.1) ontology visualisation, (5.2) contract risk management, and (5.3) iContracts.

[10] Specifically by launching reasoner Hermit 1.4.3.456 on sample data in the Protégé editor: https://mvnrepository.com/artifact/net.sourceforge.owlapi/org.semanticweb.hermit/1.4.3.456

[11] https://github.com/onassisontology/onassisontology/blob/main/img/Visualisation.png

5.1 Ontology Visualisation

Visualisation analysis allows users to examine and compare large amount of data [Dudáš et al., 2018]. However, if some details are omitted, they can mislead analysts by leading them to erroneous analytical results. As it is possible to observe from the application of ontological taxonomic constraints on the bow-tie structure, the bow-tie visualisation system suffers from some limitations. In a large-scale comparative analysis, the bow-tie method can possibly lead to data ambiguity due to the lack of direct relationships between the core component (i.e., hazardous event) and related entities (i.e., cause, consequence, proactive and reactive controls). Furthermore, we recognised that the system does not represent all concepts theorised in the ISO 31000:2018 standard to manage risk. To overcome the above discussed problems, we created an ontological model that embraces the full expressiveness of the ISO 31000:2018 standard. Ultimately, we ensured the presence of connections between all entities described by ISO in order to prevent the occurrence of ambiguity in ontological knowledge representations.

The new vocabulary terms that we designed extend the Onassis core ontology that we previously created. They do not aim to replace the conceptualisation of the entities of the bow-tie method. They focus on enriching it while providing a ready-to-use ontological model to manage and describe risk data in *iContracts*. When visualised, the enriched bow-tie model takes the shape of a more complex and amorphous Figure 3 rather than the classical *papillon* Figure 1. This is due to the granularity of the ontolology.

5.2 Contract Risk Management

Having openly-accessible vocabulary terms to describe risk data is vital for improved analysis and management of contract risk. A legal expert is able to (1) better define contract risk, (2) improve contract clauses, and (3) better understand the level of risk per contract. An additional benefit is that the open-source nature of our work can help companies exchange risk data to refine the measuring of impact probabilities for improved risk ranking.

Although we identified some limitations in the conceptualisation of the risk management visualisation framework provided by the bow-tie method, we equally deem that such a structure can play a fundamental role in cross-referencing analysis with different collections of data to manage risk if the potential cause of ambiguity is resolved. Based on this consideration, we decided to enrich the bow-tie by (1) adding more relationships in its structure and (2) translating the "enriched bow-tie" into the expressiveness of an ontology. This will allow interoperability between data sets while hopefully leading to the attainment of new insights for the evaluation of risk in contractual clauses.

5.3 Intelligent Contracts

Our research shows that risk data are able to contribute into making *iContracts* more responsible. The responsibility mainly derives from the fact that risk data can be explicitly examined thanks to the creation of a set of interlinked metadata (i.e., the extension of the Onassis ontology that we designed) that can be used to structure information regarding risk. The new vocabulary terms can, in fact, make the usually implicit information about contact risk evident and clear while fostering the possibility to compare different data collections coming from diverse data sets. As a result, risk management can improve due to the large scale comparative analysis of diverse data records [Haapio and Siedel, 2013].

6 CONCLUSION

The present section provides (a) the answer to the RQ, (b) further research suggestions, and (c) the research novelty.

Regarding our RQ (viz. *To what extent is it possible to translate the bow-tie method into a visualisation of an ontology for contract risk management without altering the bow-tie structure?*), we provide the following answer.

The conversion process of the bow-tie conceptualisation into ontological terms highlighted the presence of missing relationships between entities in the bow-tie method as well missing ISO-specified concepts. To reduce the possibility of introducing ambiguity into the analytical and management processes of risk data, we searched for and found further relationships between entities in the ontology compared to those that are represented in the bow-tie system. Ultimately, we added the missing ISO-specified concepts that were not present in the bow-tie method. This resulted into a new version of the bow-tie visualisation medium as well as an openly-accessible ontological model to manage and describe risk data.

In relation to further research, the key question at this point is how to best move forward from here. An essential step in conducting further research is to validate the successful integration of the developed contract risk management ontological framework in iContracts. Our following research will focus on validating the integration experimentally.

The research novelty is that we have demonstrated how it is possible to make explicit a traditionally implicit process, in such a way that data processing becomes possible. So far, legal experts have not reached consensus on how to manage contract risk. Our paper shows how it is possible. Moreover, in relation to the bow-tie method, we presented a new theoretical version for it which builds upon the old one, disambiguate some of the bow-tie constructs, and enrich its conceptualisation.

ACKNOWLEDGEMENTS

Georgios is the main author. Giulia provided a scientific framework for the research. Athanasios contributed in the literature. Jaap and Bart are the main supervisors.

REFERENCES

Agrawal, V. (2016). Towards the ontology of iso/iec 27005: 2011 risk management standard. In *HAISA*, pages 101–111.

Becker, B. J. and Alow, A. M. (2019). *Model-based Meta-Analysis and Related Approaches*, pages 339–364. Russell Sage Foundation.

Dauer, E. A. (2006). The role of culture in legal risk management. *Scandinavian Studies in Law*, 49:49–6.

de Ruijter, A. and Guldenmund, F. (2016). The bowtie method: A review. *Safety Science*, 88:211–218.

de Ruijter, A. and Guldenmund, F. (2016). The bowtie method: A review. *Safety science*, 88:211–218.

Dudáš, M., Lohmann, S., Svátek, V., and Pavlov, D. (2018). Ontology visualization methods and tools: a survey of the state of the art. *The Knowledge Engineering Review*, 33.

Espenschied, L. E. (2010). Contract drafting: Powerful prose in transactional practice. American Bar Association.

Fahad, M. and Qadir, M. A. (2008). A framework for ontology evaluation. pages 149–158.

Fahad, M., Qadir, M. A., and Shah, S. A. H. (2008). Evaluation of ontologies and dl reasoners. In Shi, Z., Mercier-Laurent, E., and Leake, D., editors, *Intelligent Information Processing IV*, pages 17–27, Boston, MA. Springer US.

for Chemical Process Safety, C. (2018). *Bow Ties in Risk Management: A Concept Book for Process Safety*. Wiley-AIChE.

Fox, C. M. (2008). Working with contracts. *What Law doesnt teach you. Second Edition. New York: Practising Law Institute*.

Gomez-Perez, A. (1995). Some ideas and examples to evaluate ontologies. pages 299–305.

Gómez-Pérez, A., Fernández-López, M., and Corcho, Ó. (2004). Ontological engineering: With examples from the areas of knowledge management, e-commerce and the semantic web. In *Advanced Information and Knowledge Processing*.

Gómez-Pérez, A. (2001). Evaluation of ontologies. *International Journal of Intelligent Systems*, 16(3):391–409.

Haapio, H. and Siedel, G. J. (2013). A short guide to contract risk.

Hogan, A. (2020). *Linked Data*, pages 515–625. Springer International Publishing, Cham.

Khakzad, N., Khan, F., and Amyotte, P. (2012). Dynamic risk analysis using bow-tie approach. *Reliability Engineering & System Safety*, 104:36–44.

Kishchuk, B., Creed, I., Laurent, K., Nebel, S., Kreutzweiser, D., Venier, L., and Webster, K. (2018). Assessing the ecological sustainability of a forest management system using the iso bowtie risk management assessment tool. *The Forestry Chronicle*, 94(1):25–34.

Kluwer, W. (2017). The history of bowtie. http://www.cgerisk.com.

Kluwer, W. (2019). The bowtie method. http://www.cgerisk.com.

Kuwahara, S., Yoshino, N., Sagara, M., and Taghizadeh Hesary, F. (2015). Role of the credit risk database in developing smes in japan: Lessons for the rest of asia.

Leva, M. C., Balfe, N., McAleer, B., and Rocke, M. (2017). Risk registers: Structuring data collection to develop risk intelligence. *Safety science*, 100:143–156.

Lu, L., Liang, W., Zhang, L., Zhang, H., Lu, Z., and Shan, J. (2015). A comprehensive risk evaluation method for natural gas pipelines by combining a risk matrix with a bow-tie model. *Journal of Natural Gas Science and Engineering*, 25:124–133.

Mason, J. (2017). Intelligent contracts and the construction industry. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 9(3):04517012.

Nirenburg, S. and Raskin, V. (2001). Ontological semantics, formal ontology, and ambiguity. In *Proceedings of the International Conference on Formal Ontology in Information Systems - Volume 2001*, FOIS '01, page 151–161, New York, NY, USA. Association for Computing Machinery.

Patterson, F. D. and Neailey, K. (2002). A risk register database system to aid the management of project risk. *International Journal of Project Management*, 20(5):365–374.

Stathis, G., Trantas, A., Biagioni, G., van den Herik, J., Custers, B., Daniele, L., and Katsigiannis, T. (2023). Towards a foundation for intelligent contracts. In *Proceedings of the 15th International Conference on Agents and Artificial Intelligence - Volume 2: ICAART,*, pages 87–98. INSTICC, SciTePress.