The ARK Platform: Enabling Risk Management through Semantic Web technologies

Ademar CROTTI JUNIOR [b], Maryam BASEREH [a], Yalemisew ABGAZ [a], Junli LIANG [c], Natalia DUDA [c], Nick MCDONALD [c], and Rob BRENNAN [a,1]

[a] *ADAPT Centre, School of Computing, Dublin City University, Dublin, Ireland*
[b] *ADAPT Centre, School of Computer Science and Statistics, Trinity College Dublin, Dublin, Ireland*
[c] *School of Psychology, Trinity College Dublin, Dublin, Ireland*

Abstract. This paper describes the Access Risk Knowledge (ARK) platform and ontologies for socio-technical risk analysis using the Cube methodology. Linked Data is used in ARK to integrate qualitative clinical risk management data with quantitative operational data and analytics. This required the development of a novel clinical safety management taxonomy to annotate qualitative risk data and make it more amenable to automated analysis. The platform is complemented by other two ontologies that support structured data capture for the Cube socio-technical analysis methodology developed by organisational psychologists at Trinity College Dublin. The ARK platform development and trials have shown the benefits of a Semantic Web approach to flexibly support data integration, making qualitative data machine readable and building dynamic, high-usability web applications applied to clinical risk management. The main results so far are a self-annotated, standards-based taxonomy for risk and safety management expressed in the W3C's standard Simple Knowledge Organisation System (SKOS) and a Cube data capture, curation and analysis platform for clinical risk management domain experts. The paper describes the ontologies and their development process, our initial clinical safety management use case and lessons learned from the application of ARK to real-world use cases. This work has shown the potential for using Linked Data to integrate operational and safety data into a unified information space supporting more continuous, adaptive and predictive clinical risk management.

Keywords. ARK Platform, Organisational Change, Risk Management.

1. Introduction

Managing clinical risk is an integral part of any organisation providing clinical services. The Cube is an established methodology for analysing socio-technical systems which offers a framework for managing such risks [1, 2, 3]. It is used to identify, assess, and classify risks, and to plan, execute, and evaluate risk mitigation actions (projects). The

[1] Corresponding Author: Rob Brennan; E-mail: rob.brennan@adaptcentre.ie.

Cube methodology helps domain experts building case studies which lead to an evidence base that supports better practice and governance.

Organisations already collect and study (human-oriented) risk information in the form of risk registers, annual safety reports and incident reports. They are also increasingly overloaded with digital operational data that could be used to inform risk management as well as operational management. Typically these two management cycles operate independently, upon siloed data, and focus on qualitative analysis (risk) or quantitative analysis (operations in digitally transformed organisations like modern clinical practice) respectively. These differences mean that it is hard to find machine-readable rather than human-focused risk data and even harder to fuse it with structured operational data or predictive analytics from data science projects, despite the utility that these sources may have for implementing a more dynamic and effective risk management system. These disconnected activities also make it difficult to efficiently analyze and build a machine readable evidence base that is suitable for modern automated or semi-automated analytical approaches. Even though the Cube methodology supports such activities, its deployment has been hampered by the lack of an integrated platform facilitating its use.

This paper describes the Access Risk Knowledge (ARK) platform for Cube-based risk analysis and evidence base collection. ARK uses Semantic Web technologies to model, integrate, and classify risk and socio-technical system analysis information from both qualitative and quantitative data sources into a unified risk graph. This graph is based on three new ontologies: a risk terminology expressed as a SKOS model, a Cube analysis vocabulary, and an ARK project vocabulary. The ARK platform and ontologies have been built to study this research question: "to what extent can a Linked Data approach support semantic interlinking and interoperability between quantitative and qualitative risk data, extraction and representation of risk domain knowledge, and enhance dynamic and integrated analysis of risk by supporting the Cube methodology?".

ARK is built as a native web application in Node.js with a React user interface driven from an Apache Jena triplestore based on our developed ontologies. The ontologies are based on two years of iterative development between mixed teams of organisational psychologists and knowledge engineers. By using these technologies, the ARK platform provides a way to standardize social-technical analysis outputs into a self-describing semantic graph that can include Cube structured questionnaire-based analysis, multi-dimensional synthesis, or risk mitigation project-oriented views of the organisation under study. It also allows for semantic interlinking and interoperability of diverse data sources such as operational data or analytics. It facilitates making qualitative data machine readable by richly representing it in the Cube ontology along with metadata, and it enables human-oriented textual responses to be annotated with terms from the risk terminology. This paper describes the following contributions:

- The Cube Ontology, ARK projects vocabulary, and ARK risk terminology. They enable formal and structured socio-technical analysis of systems and SKOS representation of the background knowledge on risk management (including provenance of term definitions).
- The ARK application. This provides a user interface for curation of structured Cube responses (including interlinking supporting evidence) and navigation around the multi-dimensional Cube system analysis or risk mitigation project analysis.

- Case study-based evaluation. We present preliminary results of a case study where the ARK Platform has been used for Cube socio-technical analysis in a real-world problem.

The remainder of this paper is organised as follows. A motivating use case is presented in Section 2. Section 3 describes the development of the ARK Platform. Section 4 presents a case study and preliminary results. Section 5 discusses related work. Section 6 concludes the paper.

2. Use Case

This section describes background on the Cube methodology and the high level use case and requirements for risk management tools.

2.1. Background on the Cube methodology

The Cube methodology has been developed over twenty years by organisational psychologists working on safety systems for the health, aviation and finance domains. It supports progressively building a multi-dimensional analysis of complex systems [1]. It provides a framework for initiating and analysing organizational change through interlinked, dimension-specific questionnaires. The general Cube questionnaire has 96 major questions systematically organised into six project stages (Problem, Solution, Develop, Implement, Plan and Prepare, and Verify and Embed), four aspects (Activity, Culture, Functional System and Sensemaking), and four dimensions (Goal, Process/Sequence, Social, and Information and Knowledge). The methodology guides an expert probing an organisation using questions and then analysing it by systematic combination of sets of related three-dimensional answers to identify risks, mitigations, and sources of value. Applying the Cube methodology is a continuous process of improvement of an organizational system. Risks and mitigations are identified and this initiates a new improvement project which is evaluated and verified. At each stage, the experts will fill out questions and complete analyses.

2.2. Early Cube Tool Support

Prior to our research, the Cube methodology was manually deployed by a risk management domain expert using a cumbersome spreadsheet as an aid. Limitations of this approach included insufficient navigation flexibility as analysis often requires non-linear completion of questionnaires, a lack of embedded rules or relations between question answers, inability to easily generate different interactive views of the data for analysis, no ability to support for semi-automated analysis or validation of answers, no interlinking to existing datasets, analytics or evidence, limited ability to reuse analysis results from project to project, no sharing or team working support and no embedded reference glossary of terms for safety analysts. A fair characterisation of this system would be to say it was only suitable for highly trained domain experts and provided no automation or data synthesis supports.

2.3. Clinical Risk Management

Risk management is one of the most important procedures performed within clinical environments, with strong impacts on the quality of service [4]. Due to the high volume of available risk data from different sources (e.g. incident reports, electronic healthcare records, best practice guidelines), it is often impractical in terms of time and effort for humans to reliably extract the most relevant risk information from the data and use it for effective decision-making and process improvement recommendations. Accordingly, it is urgent that we develop innovative semi-automated but fair, accountable, and transparent solutions to fuse, summarize, and categorise the risk data and evidence into patterns and knowledge that will help safety experts to more effectively address safety improvement in an evidence-driven way.

3. The ARK Platform

In this section, we present the Access Risk Knowledge (ARK) platform and ontologies that support socio-technical analysis of clinical risk management using the Cube methodology. The ARK Platform relies on Semantic Web technologies and W3C standards to integrate interoperable qualitative clinical risk management data with quantitative operational data and analytics. The platform is composed of the Cube ontology[2] and the Project vocabulary[3] which is used to support data capture and analysis through the Cube methodology, a safety management taxonomy[4] described using W3C's standard Simple Knowledge Organisation System (SKOS)[5], and a prototype web-based application, which allows domain experts to apply social-technical analysis through the Cube methodology. Figure 1 presents an overview of the the ARK platform.

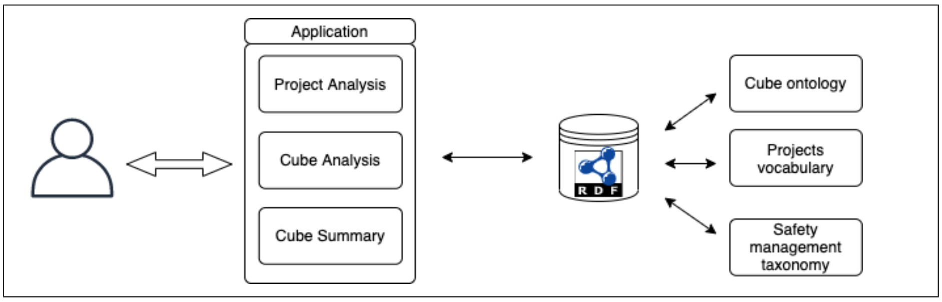

Figure 1. The ARK Platform overview

[2]Available at `https://w3id.org/ARK/Cube`.
[3]Available at `https://w3id.org/ARK/Projects`.
[4]Available at `https://w3id.org/ARK/Terminology`.
[5]`https://www.w3.org/2004/02/skos/`.

3.1. The Cube Ontology and Project vocabulary

The Cube ontology and the Project vocabulary were developed to enable data capture and analysis through the Cube methodology. The ontologies are based on two years of iterative development between mixed teams of organisational psychologists and knowledge engineers. The ontologies were implemented using the Web Ontology Language (OWL) specification[6] in protégé[7]. Moreover, the ontologies were designed following Gruber's [5] principles and guidelines for ontology development. The purpose of such principles is to assure knowledge sharing, reusability and interoperability. Thus, the ontologies contain human-readable metadata as well as documentation, are free of inconsistencies, are extensible and customizable allowing for different Cube questionnaires to be instantiated while still following concisely the multidimensionality of the Cube methodology. The Cube ontology and Project vocabulary include major concepts, structures and relationships together with a concise definition of the terminologies described in the Cube methodology. The ontologies have also been validated using the Ontology Pitfall Scanner [6], documented with machine and human readable metadata, which is used to automatically generate documentation through WIDOCO [7], and are served following Linked Data principles. Figure 2 presents the core components of the Cube ontology, which are discussed in the following subsections.

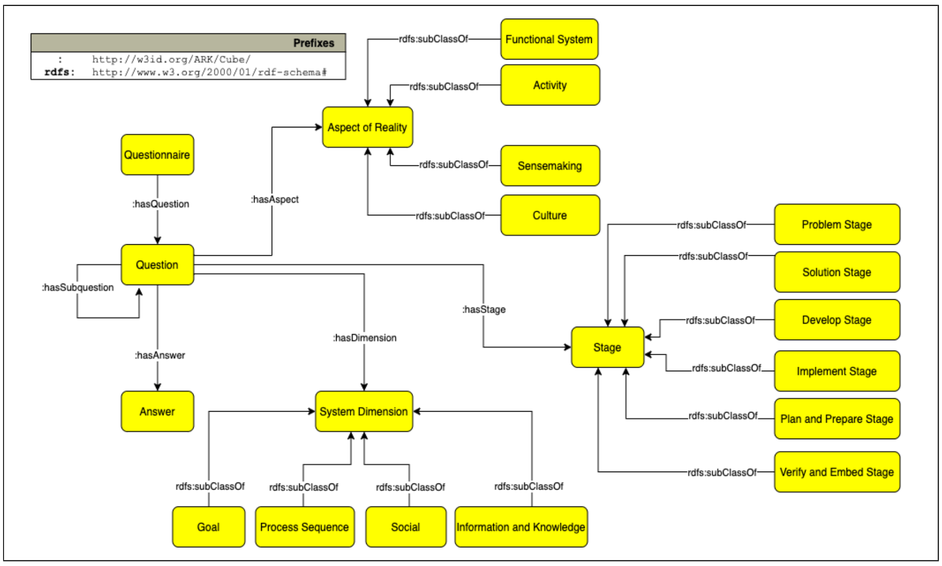

Figure 2. Core components of the Cube ontology

The Cube ontology is used in the overall architecture of the ARK Platform in two ways. First, it serves as a repository of the standard Cube questionnaire. Moreover, when there is need for customization, depending on the domain or organization where the Cube methodology is being applied, different Cube questionnaires can be instantiated. Second,

[6]https://www.w3.org/TR/owl2-primer/
[7]https://protege.stanford.edu/

the Cube ontology is used to represent responses to the Cube questionnaire, enabling an evidence base that supports governance within the organization. On the other hand, the Project vocabulary allows organizations to structure risk analysis through the Cube methodology by way of projects and sub-projects.

3.2. Safety Management Taxonomy

The safety management taxonomy was defined using SKOS, a W3C Recommendation designed to support the use of knowledge organization systems. In the ARK Platform, the developed taxonomy allows users to annotate risk management data described using the Cube ontology with qualitative operational risk data. Concepts in the taxonomy have been defined by domain experts and have at least a description and, when available, their source. Since these domain experts do not have expertise in Semantic Web technologies, the taxonomy was defined in a collaborative environment which is later transformed. This transformation was performed using R2RML[8] mappings created with the aid of an editor [8]. Finally, the taxonomy was documented using WIDOCO and, like the Cube ontology and Projects vocabulary, is served following Linked Data principles.

3.3. ARK application

The ARK application was built using Node.js and React, and offers three main interfaces where users can interact with the Cube methodology. The first component allows organizations to define projects. The second component (Figure 3) guides users into using the Cube methodology by allowing questionnaires to be answered. In order to provide experts with a more comprehensive and granular analysis, this component allows users to interlink answers with supporting evidence. Finally, this component also provides the functionality to classify answers with risk-related concepts using the developed safety management taxonomy.

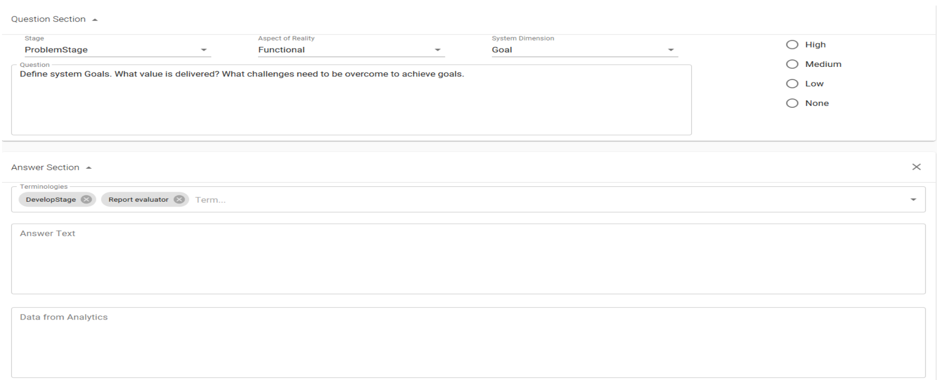

Figure 3. Cube analysis interface: answering Cube questions.

The third component, called Cube summary, focuses on the summarization and visualisation of answers at the end of each stage. The Cube summary component provides

[8]A a W3C Recommendation allowing one to define customized mappings to convert non-RDF resources to RDF. `https://www.w3.org/TR/r2rml/`

functionality that enables viewing answers similarly to a Rubik's Cube, where the visualisation of any stage, aspect and dimension can be configured by the user. Figure 4 presents the Cube summary component.

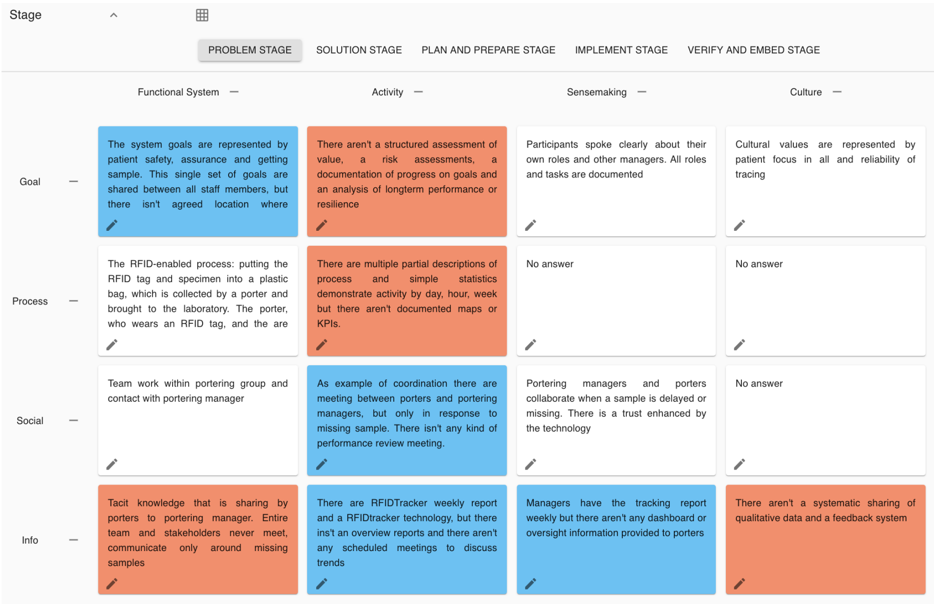

Figure 4. Cube summarization: dynamic summary of the cube analysis

4. Case Study

The ARK platform has been developed with the aim of facilitating risk analysis of complex systems through the Cube methodology. To evaluate the platform, a preliminary case study has been conducted, in which, two participants were asked to use the platform to address a clinical risk management problem and report their experiences through separate interviews.

Participants were recruited and introduced to the case study by one of the research team members. To assess the different levels of expertise, one of the participants was an expert in risk management, while the other was a non-expert user.

4.1. Experiment Task: The Clinical Risk Management Case

The task participants were asked to perform was related to a clinical risk management case which had previously been described in an MSc thesis [9]. The thesis analysed the impact of collective leadership approaches on the integration of electronic health record systems. Participants were asked to study the aforementioned thesis, and analyse its risk in change using the ARK Platform. It is important to note that this is the first time participants had access to this material. Participants worked on this task for 4 days.

4.2. Discussion

After task completion, participants were interviewed in relation to their reflection over its use, integrity/consistency of functions in the platform, and efficacy. Other features evaluated include:

- Descriptions of concepts defined in the safety management taxonomy concepts within the project analysis interface.
- The ability to navigate questions and answers in the ARK platform using different dimensions and aspects.
- The ability to hide features/aspects.
- The ability to summarize user's answers.
- The ability to provide evidences to qualitative answers.

Participants found training to be necessary when being introduced to the platform. Nonetheless, participants evaluated its learning curve as fairly easy. Participants described the platform as complex in relation to the amount of information needed in each question, and the number of questions to be answered. Participants also described that the large number of questions within the Cube questionnaire contributed to a comprehensive understanding of the complex system presented in the experiment task. In this context, even though the summary component was found useful, participants described having to switch back and forth through different dimensions and aspects continuously. Furthermore, participants also described the use of platform as time-consuming (estimated at 3 to 4 hours to complete). In terms of integrity, the platform was verified as consistent, in which, the relation between different functionalities is clear and easy to navigate. Other features, such as the possibility of interlinking data sources as evidences, taxonomy definitions being available through the interface, the ability to hide features/aspects, have also been considered helpful.

Generally, in terms of efficacy, participants found the platform useful and they confirmed that it gives a comprehensive overview of the analysed use case. The reaction over Semantic Web technologies-driven features to support the Cube methodology has had a positive outcome. Even though our preliminary results are promising, a comprehensive evaluation using other instruments, such as standard usability tests and a larger number of participants, is required to validate our findings.

5. Related Work

The use of ontologies for the analysis of organisational change and risk management has been proposed in different domains. For instance, the authors in [10] used ontology-based risk management framework to enhance the management of organisational risk. Ontology-based feed-forward risk management is also proposed in [11] to create a multi-level approach for feed-forward risk management. Other ontology applications are used to support risk assessment in supply networks [12]. A more specific application of ontology-based risk management is proposed in [13] which focuses on the development of a risk knowledge management integrated into the Business Information Modelling environment for construction risk knowledge management. The risk knowledge is represented using an ontology to annotate documents and produce a map which is used to infer paths. In contrast, our work is focused on supporting change risk analysis processes using ontologies, Semantic Web and Linked Data technologies by leveraging the Cube methodology.

There are also ontology development efforts towards the semantic modelling of systematic data collection and analysis tools such as questionnaires. The semantic modelling of traditional questionnaires [14, 15] allows the semantic representation of questionnaires and their answers. Even if their work focuses on a traditional data collection of linguistic importance and on the semantic enrichment and interlinking of manually collected data, the structure used in these ontologies overlap with the structure of the Cube questionnaire. These ontologies, however, are not expressive enough to represent the Cube methodology..

6. Conclusion and Future Work

In this paper, we introduce the ARK platform and ontologies for socio-technical analysis applied to clinical risk management. The proposed platform provides an extensible interface, that is customizable in terms of its representation, and interoperable through its ontology-driven back-end for representing social-technical analysis through the Cube methodology. Our preliminary evaluation of the system shows that our proposed platform is capable of representing core concepts, relationships, customisation, and visualisation of the Cube methodology. A limitation of our evaluation is the number of participants which will be targeted in future experiments.

Future work includes enhancing the platform with additional functionalities including rich domain knowledge related to organisational risk, knowledge extraction from the supporting documents, and improvements described by participants of our preliminary study. Finally, future work will also be focused on evaluating the platform with a wide community of users through standard tests.

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