Semantic Data Model for Operation and Maintenance of the Engineering Asset

Andreas Koukias, Dražen Nadoveza, Dimitris Kiritsis

Semantic Data Model for Operation and Maintenance of the Engineering Asset

Andreas Koukias, Dražen Nadoveza, Dimitris Kiritsis

École Polytechnique Fédérale de Lausanne,
Laboratory for Computer-Aided Design and Production,
STI-IGM-LICP, Station 9, CH-1015, Lausanne, Switzerland
andreas.koukias@epfl.ch, drazen.nadoveza@epfl.ch
dimitris.kiritsis@epfl.ch

Abstract. The management of engineering assets within an organization is a challenging task that aims to optimize their performance through efficient decision making. However, the current asset data management systems suffer from poor system interoperability, data integration issues as well as an enormous amount of stored data, thus preventing a seamless flow of information. The aim of this work is to propose a semantic data model for engineering asset management, focusing on the operation and maintenance phase of its life cycle. Ontologies are proposed because they can capture the semantics of data, create a shared vocabulary to describe the knowledge for sharing in the domain and provide reasoning capabilities. This model will gather all the knowledge necessary to assist in the decision making process in order to improve the asset's availability, longevity and quality of operations.

Keywords: asset, asset management, maintenance, ontology model, semantics

1 Introduction

Engineering assets within an organization can be the foundation for its success and future and are defined as "as any core, acquired elements of significant value to the organization, which provides and/or requires – according to a user or provider point of view – services for this organization" [1]. The management of physical assets, such as machining tools, can be a challenging task in order to optimize their performance through efficient decision making and reduce their maintenance costs, increase the revenue and guarantee their overall effectiveness [2]. Physical or engineering assets, such as machining tools and containers, are distinguished from intangible or virtual assets such as knowledge, software, or financial assets [3].

According to the definition of asset management proposed by the Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM) [4], and adopted for this work, asset management is "the process of organizing, planning and controlling the acquisition, use, care, refurbishment, and/or disposal of physical assets to optimize their service delivery potential and to minimize the related risks and costs over their entire life through the use of intangible assets such as knowledge based decision making applications and business processes." Asset management is a holistic and interdisciplinary approach that covers in the context of physical assets the whole life cycle of the asset, from the acquisition to the disposal of the asset. Its scope extends from the daily operations of assets trying to meet the targeted levels of service to supporting the organization's delivery strategies, satisfying the regulatory and legal requirements and minimizing related risks and costs [5-7]. Asset management is particularly important now with the ageing of the equipment, the fluctuating requirements in the strategy and operation levels and the emphasis on health and safety requirements [6].

We consider that the key concept to achieve optimization of asset management is the management of the asset's data. Information systems in asset management extend from collecting, storing and analyzing the asset information to supporting decision making and providing an integrated view [5]. Decision makers use a variety of tools on their day-to-day and long-term activities and their effectiveness depend greatly on the quality of data. The requirements for the asset data demand that it is always complete, accurate, timely, consistent and accessible [8]. It is important that organizations can efficiently track the current and historical information of the assets concerning their status and component configuration along their lifecycle [2]. However, asset data management systems currently suffer from system interoperability, data integration issues as well as the enormous amount of the stored data, thus preventing a seamless flow of information for monitoring and controlling the assets [8-10].

The vision of Semantic Web can be the key to the harmonization of the information models, since it suggests using software agents that are able to understand the meaning of data and create connections between data automatically, to gain new information. Based on this vision, ontologies can be used to capture the semantics of data, resolve semantic heterogeneities and optimize data quality and availability. Gruber [11] defines the ontologies as explicit formal specifications of the terms in a domain and relations among them whereas Noy and McGuiness [12] describes an ontology as a formal explicit description of concepts in a domain of discourse, with properties of each concept describing various features and attributes of the concepts and restrictions on slots. Ontologies offer a shared vocabulary to describe the knowledge for sharing in a certain domain or application area.

Among the main phases that consist the engineering asset lifecycle [2], the current work focuses on the operation and maintenance phase where the aim is to optimize the overall performance of the asset and guarantee its availability and longevity. The main obstacle is that available information concerning the asset's operation, configuration, maintenance and planning is currently disparate and thus not put to effective use in order to improve its quality of operations. The aim of this work is to propose a semantic data model that will integrate all this information for an engineering asset within an organization. Based on the Semantic Web vision, ontologies are proposed since they can capture the semantics of data, resolve semantic heterogeneities, create a shared domain vocabulary and optimize data quality and availability. We consider the various entities that are involved in the asset's usage and maintenance, as well as their relations, and try to develop a semantic data model that will assist in increasing the productivity of the asset and maintaining it, with minimum cost and high reliability.

2 Related Work

There are many research efforts using or recommending ontologies in the asset management domain, but to our knowledge none are focusing on the operation and maintenance phase of the asset's lifecycle. In [6] the authors develop an initial and fundamental asset management ontology and subsequent process architecture in order to support an organization's asset management initiatives, using a manual text mining approach. In [9], ontologies with Description Logic are used in a case study in asset lifecycle management in order to demonstrate the benefits of implementing ontology models in industry. An ontology-based implementation for exploiting the characteristics of time in asset lifecycle management systems is presented in [10], mainly in maintenance but also considering the entire lifecycle.

The development of a generic asset configuration ontology is recommended in [2], in combination with a prototype workflow management system, in order to provide a generic and active asset configuration management framework for a better visibility of through-life asset configurations. Furthermore, the authors in [13] propose a conceptual model for the adoption and implementation of ontologies in the area of Road Asset Management, in order to assist the automated information retrieval and exchange between heterogeneous asset management applications.

Moreover, in order to achieve an efficient asset management, the minimum functional requirements at the operational level are presented at [14], whereas in [8] the requirements are outlined and a model for improving the strategy by classifying the assets is proposed. Lastly, concerning the use of ontologies on the maintenance domain, an ontology to support semantic maintenance architecture is proposed in [15], a domain ontology for industrial maintenance is shown in [16] and an ontology in order to model the condition monitoring and maintenance domain knowledge is introduced in [17].

3 Asset Management Semantic Data Model

Based on the available literature in the defined scope of activities, we propose a semantic data model for the operation and maintenance of an engineering asset, which can be seen in Figure 1. The dotted line in the middle of the model separates the static asset data, e.g. asset function and specifications from the dynamic asset data e.g. operation data and maintenance schedule. The model consists of the main upper asset ontology and the related lower asset event domain ontology. In order to provide a better understanding, the top-level concepts of the proposed model are firstly defined below:

- Asset: the engineering asset, as previously defined. It may be possible to break down the asset in its technical components, which may be considered as assets themselves.
- Asset_Specification: static data originating from documentation and containing all asset specification data. This is developed during the design and building phases of the asset lifecycle and depicting the target asset operation and maintenance data in order to guarantee performance and availability.
- Asset_Function: the main functionality and possibly also secondary functionalities, performed by the asset.
- Actor: the person or group of persons in the plant who is responsible for operating and managing the asset and has a specific functional role
- Asset_State: the current physical state of the asset which can be either normal, degraded or in failure.
- Maintenance_Schedule: defines the sequence of asset maintenance activities, specifying the maintenance tasks and their frequency.
- Asset_Operation_Data: data stored during the operation of the asset, e.g. asset temperature. The instances over a period of time provide a historical view of the asset's operations. Depending on the values of the operation data, this can be separated into categories of operation status.
- Asset_Configuration_Data: record of the asset configuration status at any point of time. The instances can assist in tracking the current and historical changes of asset configurations.
- Asset_Maintenance_Data: data concerning the performed asset maintenance activities.

We consider that the events that take place during the asset's operation and maintenance phase can be modeled as a lower event domain ontology. Initially, we define an event as any transient occurrence of interest for the asset which can be distinguished between internal events as changes of state caused by an internal asset transformation and external events with direct effects on the asset. In this work the low-level events are considered, which declare every status update and are necessary for monitoring the state of the asset e.g. value update. The high-level events that exist on a higher abstraction level and concern the long term asset strategy are not in the scope. A special type of low-level event is the Alarm which represents an abnormal asset's state that requires the user's attention and has warning purposes.

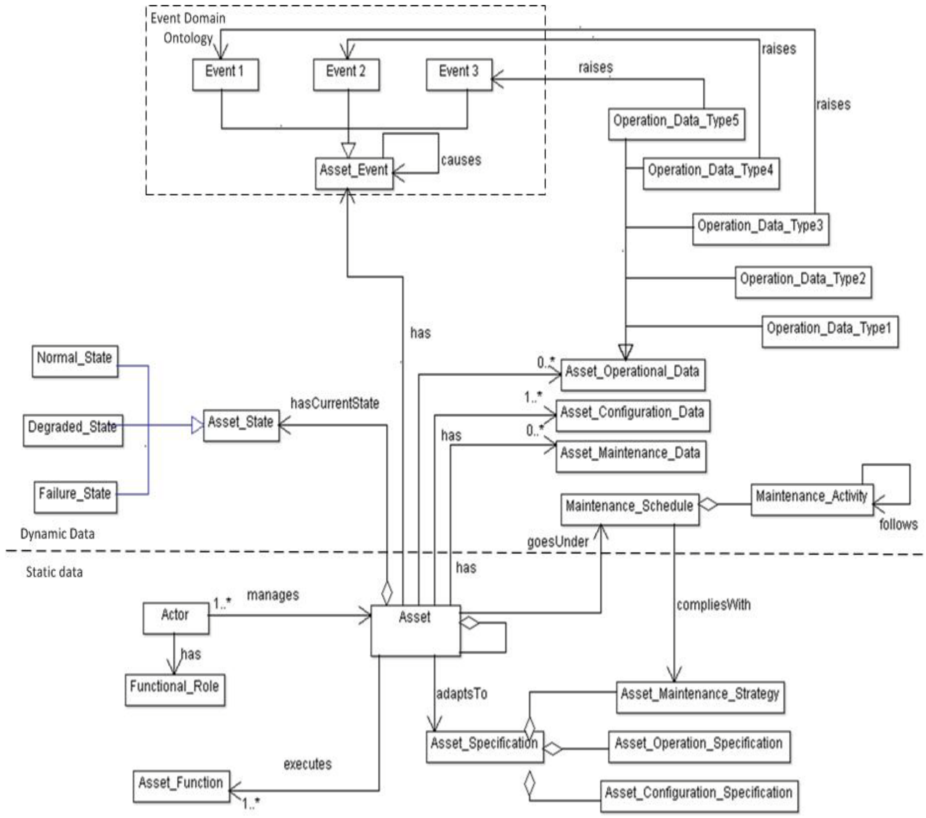

Fig. 1. Engineering asset management semantic data model

The current approach recommends the use of the ontology reasoning capabilities on the proposed model. Reasoning can be applied in many different scenarios in the ontology, based on predefined rules, in order to provide the capability of answering queries e.g. if the asset fulfills the operational requirements, and thus generate new knowledge.

In order to provide a better understanding, a typical scenario is described using the proposed semantic model. Firstly, we define the different Operation_Data_Types for the asset according to its operation values and corresponding to different operation phases. These phases can be either normal, e.g. operating, warming up or belong to different types of abnormal operation mode. If a value from the operation data e.g. the asset temperature, exceeds its predefined thresholds according to the Asset_Operation_Specification, the Asset_Operation_Data is classified to its respective operation mode and the relevant Asset_Event is raised accordingly from the lower event ontology. When the specific Asset_Event is raised, the historical Asset_Operation_Data, Asset_Configuration_Data and Asset_Maintenance_Data can be examined, as well as other Asset_Event instances, in order to evaluate whether there have been indications leading to this event e.g. temperature consistently rising towards and eventually surpassing the threshold or possibly skipping a maintenance action or adapting a wrong configuration. Based on predefined rules and using the reasoning capabilities, one possibility would be the classification of the asset in the Degraded_State and the subsequent adjustment of the adapted Maintenance_Schedule e.g. repair or replace a defective asset component before production begins. Another possibility would be the need to modify the Configuration_Data, e.g. reduce the rpm, in order to keep the Asset_Operation_Data within its specifications.

Overall, a set of rules and procedures can be defined to support the reasoning system to make knowledge which is implicit only to the experts, explicit, by using the available events, operational data, configuration data and maintenance data in order to adjust to an improved maintenance strategy as well as select an optimal operation configuration, thus managing the evolution of asset configuration. Overall, the proposed model can use the ontology knowledge to improve the asset performance, longevity and availability.

4 Conclusion and Future Work

This work proposed a semantic data model for an engineering asset, focusing on the operation and maintenance phase of its lifecycle, in order to model the domain, assist in the decision making process and improve the asset's performance and availability. In the next steps, we intend to implement the ontology model and evolve it on a description logic language to allow the ontology's reasoning, validate its consistency and demonstrate its benefits. We will also validate the model in a case study in order to evaluate its applicability and effectiveness on an asset's operation and maintenance phases. Furthermore, we intend to extend the model by including the asset high-level events in order to take into consideration the asset operation strategy, as well as the concept of asset service to cover the possible outsourcing of assets and the distinction between the different roles of asset owner and provider.

5 References

1. Ouertani M.Z., Parlikad A., McFarlane D. Through-life Management of Asset Information In: International Conference on Product Lifecycle Management, PLM' 08, PLM-SP4 - 2008 Proceedings, pp. 438 - 448, Seoul (2008).
2. Ouertani, M.Z. and Srinivasan, V and Parlikad, A.K.N. and Luyer, E and McFarlane, D.C. Through-life active asset configuration management In: International Conference on Product Lifecycle Management, PLM' 09, PLM-SP5 - 2009 Proceedings, pp.119-207, Bath, UK (2009).
3. Stapleberg, R.F. Risk Based Decision Making in Integrated Asset Management: From Development of Asset Management Frameworks to the Development of Asset Risk Management Plan. Professional Skills Training Courses: CIEAM - Cooperative Research Centre for Integrated Engineering Asset Management (2006).
4. Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM), http://www.cieam.com/

5. Koronios A., Steenstrup C., Haider A. Information and Operational Technologies Nexus for Asset Lifecycle Management In: 4th World Congress on Engineering Asset Management, Athens, Greece (2009).
6. Frolov V., Megel D., Bandara W., Sun Y., Ma L. Building An Ontology And Process Architecture For Engineering Asset Management, 4th World Congress On Engineering Asset, Athens, Greece (2009)
7. Frolov, V., Ma, L., Sun, Y. & Bandara, W. Identifying core function of asset management. In: Amadi-Echendu, J. (eds.), Engineering asset management review, Vol. 1. Springer-Verlag, London (2010)
8. de Leeuw V., Snitkin S., ARC Advisory Group. Asset Information Management: From Strategy to Benefit In: 7th International Conference on Product Lifecycle Management, PLM'10, Bremen, Germany (2010).
9. Matsokis A., Zamofing S., and Kiritsis D. Ontology-based Modeling for Complex Industrial Asset Lifecycle Management: a Case Study In: 7th International Conference on Product Lifecycle Management, PLM'10, Bremen, Germany (2010).
10. Matsokis A. and Kiritsis D. Ontology-Based Implementation of an Advanced Method for Time Treatment in Asset Lifecycle Management In: 5th World Congress in Engineering Asset Management, WCEAM 2010, Brisbane, Australia (2010)
11. Gruber T. R., Towards principles for the design of ontologies used for knowledge sharing In: International Journal of Human Computer Studies, vol. 43, pp. 907-928, (1993)
12. Noy N. F. and McGuiness D. L., Ontology development 101: a guide to creating your first ontology, Stanford KSL Technical Report KSL, (2009).
13. Nastasie, D.L. and A. Koronios. The Role of Standard Information Models In Road Asset Management In: 4th World Congress on Engineering Asset Management, WCEAM 2009, Springer-Verlag London Ltd, Athens, Greece (2009)
14. Haider, A. Information technologies implementation and organizational behavior: An asset management perspective In: Technology Management in the Energy Smart World (PICMET), 2011 Proceedings of PICMET '11: , vol., no., pp.1-11 (2011)
15. Karray M H, Morello-Chebel B, Zerhouni N. Towards a maintenance semantic architecture In:4th World Congress on Engineering Asset Management, WCEAM 2009, Athens, Greece (2009).
16. Karray M H, Morello-Chebel B, Zerhouni N. A Formal Ontology for Industrial Maintenance In: Terminology & Ontology: Theories and applications, TOTh Conference 2011, Annecy, France (2011)
17. G. Jin, Z. Xiang, and F. Lv, Semantic integrated condition monitoring and maintenance of complex system In: 16th International Conference on Industrial Engineering and Engineering Management, IE&EM '09, pp. 670 –674 (2009)