Towards Reusable Ontology Alignment for Manufacturing Maintenance

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Abstract. With advancements in technology and big data availability, industries are struggling with data interoperability and knowledge representation. Ontologies have a great potential to solve such problems. However, the lack of standardisation prevents the widespread adoption of ontologies in different manufacturing domains. We investigate the possibility of preparing ontology alignment for manufacturing maintenance. This paper provides an overview of the available ontologies in this domain. We also provide an openly available alignment between IMAMO (maintenance ontology) and CDM-Core (process ontology): `https://github.com/DominikFilipiak/IMAMO-to-CDM-Core`.

Keywords: Manufacturing maintenance · Ontology alignment

1 Introduction

Ontologies provide the ability to model and represent knowledge in a reusable manner. For example, Chang et al. [5] use an ontology to define a knowledge model providing definitions of common concepts and domain knowledge for a service robot. Further, ontologies enable interoperability [11] and therefore have a high potential to improve processes and save costs in various industries [9,4,14]. However, most of the ontologies are developed independently, which makes them incompatible, non-shareable, and severely limits their potential applications [8]. These issues can be addressed either directly by developing a shared ontology (or standardised development process) or through an ontology alignment. The ontology alignment process results in combined knowledge originally represented in multiple ontologies. In contrast, shared ontology development serves the same purpose but is more time consuming and tedious [6]. Therefore, we benefit from the existing body of knowledge to focus on the former.

Our work on the alignment focuses on ontologies in the manufacturing domain. The primary motivation for such a focus stems from the fact that maintenance in manufacturing industries accounts for 15 to 60% of total manufacturing operating costs [20]. Furthermore, to the best of our knowledge, no maintenance ontology alignment has been performed. The alignment of manufacturing maintenance ontology helps to combine scattered knowledge, which can then be used to improve maintenance, such as by performing predictive maintenance tasks like Cao et al. [3]. Combining different ontologies improves, for example, data and process integration for manufacturing maintenance and provides a solution to the industry's data heterogeneity challenge [17]. Paired with other systems, such an alignment can broaden semantic contexts in the production process, for example enhancing quality evaluation or failure analysis. While an ontology alignment can also be performed automatically, we focus on the manual approach due to the user acceptance and accuracy limitations of available tools [13]. We concentrate our efforts on answering the following research questions: *What ontologies for the manufacturing domain are available* (RQ1)? *To what extent can selected ontologies in the manufacturing maintenance domain be combined* (RQ2)?

The remainder of this paper is organised as follows. Section 2 provides an overview of the existing ontologies and answers RQ1. Section 3 explains the details of the ontology alignment process, which is related to RQ2. In Section 4, we discuss possible use cases for our work. The paper is also concluded there.

2 Ontologies for manufacturing

To provide the alignment, one has to identify ontologies suitable for this process. This section gives an overview of ontologies relevant to the manufacturing domain. There are several ontologies dedicated to general manufacturing. For example, *Process Specification Language* (PSL) [7] has been built to "facilitate correct and complete exchange of process information among manufacturing system" [7]. It is a standard that is openly available online. PSL has been formalised in OWL. It consists of the core component and a set of its extensions. Grüninger and Menzel argue that since different terminology is used by separate departments (such as logistics and resource managers), the business can benefit from establishing semantic relationships between used concepts. The *CDM-Core* ontology [15] was developed as a common base ontology for the manufacturing domain. It is used for process models, services and sensor data. Its authors describe CDM-Core as "the first publicly available applied manufacturing ontology" [15]. The authors demonstrate the usage of their ontology with cases of automotive exhaust production and metallic press maintenance. CDM-Core is also formalised in OWL and it is generally available.

More recently, *Additive Manufacturing Ontology* (AMU) was developed to address the lack of ontologies that are suited for modern manufacturing processes such as additive manufacturing [18]. It is developed as part of the Industrial

Ontologies Foundry (IOF) initiative, and is formalised using OWL and DOLCE. AMU focuses on modelling machines, products, features, types, and processes occurring in additive manufacturing. A use case of ontology-based validation of additive manufacturing data is presented in the paper. The authors also provide a short survey of ontologies for additive manufacturing. Other manufacturing-related ontologies are *MASON* [12], *Machine Tool Model* (MTM) [10], *Machine of a process ontology* (MOP) [19], *Manufacturing Service Description Language* (MSDL) [1], and *Part-Focused Manufacturing Process Ontology* (PMPO) [16]. Most of these are upper ontologies or are designed for general manufacturing.

There are, more specialised ontologies, for instance, explicitly developed for manufacturing maintenance. IMAMO (*Industrial Maintenance Management Ontology*) [9] is designed to cover all aspects related to manufacturing maintenance. This ontology includes various concepts related to the structure of equipment to be maintained – spare parts, failure detection, events, material resources, maintenance actors, technical documents, equipment states, and equipment life cycle. Another manufacturing maintenance ontology, *ROMAIN* [8] is similar in scope to IMAMO. It is built basing on the common Basic Formal Ontology (BFO) [2]. The authors present ROMAIN in a maintenance strategy effectiveness scenario.

3 Alignment

In this section, we explain our choice of ontologies and detail the process of aligning them. We have chosen IMAMO (maintenance ontology) and CDM-Core (process ontology), as these two ontologies were the best candidates for alignment. Both of these ontologies cover the subject of general manufacturing. Most of the other ontologies we examined are either upper ontologies or focused on more narrow disciplines within manufacturing. The scopes of IMAMO and CDM-Core are not equivalent, though – they are rather complementing each other. IMAMO concentrates on the maintenance process and defines some basic concepts for sensor data, whereas CDM-Core allows user to annotate process models, services and sensor data. Moreover, both of the ontologies are openly available online in OWL (many other that we identified were not).

The IMAMO ontology has 434 classes and 36 individuals, whereas the CDM-Core contains 240 classes representing 18 individuals. To perform the mapping, we analysed each concept of CDM-Core and searched for corresponding semantic concepts in IMAMO. A manual alignment was performed, in which only the superclasses of CDM-Core were considered. The alignment was conducted by the authors of this paper. Since the overall number of classes was relatively small, no specialised tool for the alignment was needed. If we found an equivalent class (mostly based on label and ontology structure), we created a `equivalentClass` element in our alignment. We were able to align 77% of the superclasses of CDM-Core. Some classes could not be matched. IMAMO defines more granular monitoring systems (in computational resource), such as Computerized Maintenance Management Software, Data Acquisition System, Diagnostics System, or Document Management System. In contrast, CDM-Core focuses more on the process modelling part. Additionally, IMAMO defines "external resource", which is used for representing subcontractors (no such concept in CDM-Core). The alignment is available publicly – the link is provided in the abstract.

4 Possible Use Cases and Conclusion

There are several possible use cases for the presented alignment, for example, they may consider sensor data. The IMAMO ontology and the CDM-Core ontology have both sensor data defined (`IMAMO#Sensor` and `CDM-Core#Sensor` respectively). The IMAMO sensor is defined as a device that detects and responds to some input from the environment. In a manufacturing case, this would be the physical environment where the sensor is attached. With this definition, one can now use the CDM sensors (e.g. `Electric power sensor`, `Pressure sensor`) in the IMAMO ontology without redefining it.

Another possible use case considers event-oriented systems. A key concept in maintenance is a triggering system that starts particular actions. IMAMO contains different classes facilitating this task: `Alarm`, `Event Observed by User`, `Improvement Request`, or `Notification (RUL, Warning)`. CDM-Core defines the `Component Fault` class, which defines multiple faults (`Gas Leakage`, `Cooler Efficiency Degradation`). In IMAMO, one would model these cases with a `Triggering Event – Alarm`. With the provided alignment, one can react on CDM-Faults and trigger a `Maintenance` with IMAMO.

This paper has given an overview of ontologies in the manufacturing domain. We analysed them in terms of the possibility of alignment. In conclusion, we decided to align the two publicly available ontologies CDM-Core and IMAMO first. We were able to match 77% root classes of CDM-Core with IMAMO. It can act as a starting point for other researchers to publish more alignments, thereby facilitating knowledge sharing in manufacturing. A certain limitation of this study is the lack of evaluation and validation. Therefore, future work might encapsulate comparing our alignment to automatically generated ones, as well as validating it with industrial domain experts. Future work could build on our mapping and expand it by both adding more ontologies and more sub-concepts.

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