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RESEARCH PAPER

OT Modeling: The Enterprise Beyond IT

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Abstract Enterprises are composed of an enormous number of elements (e.g., organizational units, human resources, production processes, and IT systems) typically classified in the business or the IT domain. However, some crucial elements do not belong in either group: they are directly responsible for producing and delivering the company's goods and services and include all the elements that support day to day operations. Collectively, these elements have been called operational technologies (OT) and have been conspicuously excluded from enterprise modeling (EM) approaches which traditionally have focused on the business and IT dimensions. Evidence of this is the absence of OT elements in languages and metamodels for EM. This is in line with the historical division between IT and OT in organizations that has led to information silos, independent teams, and disparate technologies that only recently have started to be reconciled. Considering that OT is critical to most productive organizations, and the benefits that EM brings to its understanding and improvement, it makes sense to expand EM to include OT. For that purpose, this paper proposes an extension to ArchiMate 3.0 which includes crucial OT elements. On top of that, this paper also proposes an approach to further expand ArchiMate to address specific industries where more specific OT elements are required. This is illustrated in the paper with an extension for the Oil and Gas case that was validated with experts belonging to five companies in the sector.

Keywords Enterprise modeling · Operational technologies · ArchiMate

1 Introduction

Enterprises are inherently complex social constructs that are composed of an enormous number of elements. To understand an enterprise, it is necessary to create models that capture, simplify, abstract, and organize key organizational elements such as areas and groups, available human resources, production processes, and IT systems. Models thus serve to represent a reality (mapping feature), presenting only some pertinent characteristics (reduction feature), in order to stand in for the observed reality with respect to some concern (pragmatic feature) (Stachowiak 1973). The practice of creating and using models to represent and reflect upon organizations is known as enterprise modeling (EM). Enterprise models provide integrated views of the organization that are helpful to analyze, from the perspective of business goals, components such as business units and processes, available resources, and IT elements (Sandkuhl et al. 2014; Clark et al. 2013).

While EM approaches have already gone a long way and are successfully used in several fields, they currently have some shortcomings that limit their applicability and the reach of its benefits. So far, EM mainly focuses on two

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domains of the enterprises: the business domain, which focuses on business models and processes, strategies, and organizational units, among others; and the IT domain, where the technological components related to information management and communication are studied, including hardware and software. Said focus casts aside other domains that some industries are interested in modeling in order to have a thorough view of the organizations. In particular, many companies have a large number of technology-related components, processes, and teams which are not typically considered part of IT. These are closer to the operation and production of the companies, and are critical to support day to day production of services and goods ultimately delivered to consumers. These include operational technologies (OT) to control and monitor equipment (devices, actuators, sensors and software) in industrial processes, processes and activities executed by personnel, and the production equipment itself. Nevertheless, the underlying enterprise modeling languages and tools, which play a key role in EM, typically target IT and business components and leave all these components aside. Though some languages offer extension mechanisms (Chiprianov et al. 2012; Kosar et al. 2010) to fit other enterprise requirements that are not considered, these could be ill-suited for OT modeling if they do not take into account the relations to the base elements.

Given this context, we have identified three main problems that we intend to address. The first one is the omnipresent disconnection between operational technology (OT) and IT, which may be found across asset intensive organizations. This has led to the existence of OT and IT teams with completely different skills that hardly communicate with each other, separate information silos that are never reconciled, and completely different technology stacks. Moreover, OT and IT alignment, convergence, and integration are highly sought after in today's industries. Future trends such as cloud manufacturing, which combine OT and IT, promise added value not only for a single enterprise but also for a collaborative supply chain (Li and Mehnen 2013). These phenomena has been studied both in academia (Hahn 2016) and by IT/OT software and service providers and vendors (Red Hat 2017; Harp 2016; Ascent 2012).

The second problem is the limitation of EM languages and tools, which principally target the business and IT domains. Given the widespread discussion about the 4th industrial revolution and the necessary convergence of automation and information technologies, it is surprising that the leading EM approaches lack the means to directly describe cyber physical systems, embedded devices, and other elements that are typically included among the internet of things context. The third problem is the inadequacy of generic EM approaches to address specific industry verticals. While generic solutions can certainly be useful to some degree, modeling OT for particular settings requires adapted elements and visual representations. Customized approaches are then needed, specialized to the needs of each business to include key technological and operational components. This approach is particularly useful in OT due to the great technological differences between industries, and because domain specific languages (DSL) have been empirically shown to be better than general purpose languages in the cognitive dimension (Kosar et al. 2010).

To solve the described problems, it is necessary to have modeling means (metamodels and languages) that allow the description of business, IT, and OT structures, as well as the way in which they intertwine. It is also necessary to have extension and configuration mechanisms that make it possible to address the concerns of specific industries and companies by adjusting models and notations. In this paper, we present an Enterprise Modeling language that extends ArchiMate 3.0 to (1) include OT concepts and notations, and (2) allow its specialization for specific industries with the addition of elements and relationships, and the modification of graphical notations. Even though we use ArchiMate 3.0 as a base language, our approach can be applied to other Enterprise Modeling languages. We demonstrate the ability to create industry specific extensions by means of an example in the oil and gas industry, which was validated with industry experts using two rounds of surveys.

The rest of the paper is structured as follows. Section 2 presents an overview of Enterprise Modeling languages. Then, Sect. 3 describes operational technologies, introduces its main concepts, and discusses the limitations currently found to model OT and relates them to the business and the IT domains. Section 4 presents the extended metamodel which forms the core of our proposal for modeling OT. It is followed by Sect. 5 which shows how this core can be adapted for specific industries and illustrates it with an example and its validation in the oil and gas vertical. Section 6 then explores related works and Sect. 7 concludes the paper by discussing its contributions and the practical concerns related to its usage.

2 A Brief Overview of Enterprise Modeling Languages

In order to build enterprise models, it is necessary to have enterprise modeling standards, languages and tools. Modeling languages are defined as "a graphical or textual language for visualizing, specifying, constructing, and documenting the artifacts of a software-intensive system (Chiprianov et al. 2012). As such, textual modeling languages express models in natural language through standardized and agreed keywords, while graphical modeling languages use visual notations. The latter are largely used in enterprise modeling.

The definition of a graphical modeling language has two parts. Firstly, it is necessary to describe its abstract syntax, typically through a metamodel (Cengarle et al. 2009) that defines the elements of the language and their relationships. Secondly, it is necessary to define the concrete syntax for the language. This includes the graphical notation for each of the elements and relationships, as well as other grammar rules typically based on layouts, color, size and other graphical qualities (Moody 2010).

ArchiMate, ARIS, and MEMO (The Open Group 2016; Frank 2011; Scheer 2000) are just three among the Enterprise Modeling languages available today. However, the high level of abstraction of these and similar languages usually has the consequence of generating non-standard, company-specific languages that extend and enhance existing languages (Bjekovi et al. 2014). Other more specialized languages and standards, such as BPMN, soaML, and sysML, are usually used together with general EM languages in order to provide the necessary details about certain domains.

Domain specific modeling languages (DSML) are "languages that offer, through appropriate notations and abstractions, expressive power focused on, and usually restricted to, a particular problem domain (van Deursen et al. 2000). Experts favor these domain languages as they allow them to communicate and validate assignments in their own domain (Frank 2013). DSMLs also promote the convenience and productivity of modeling, and contribute to model quality and integrity with their special graphical notations (Frank 2013). DSMLs can be created by using extension mechanisms of existing modeling languages in order to add new model elements and relations that are specific to some domain. For example, UML has three extension mechanisms (stereotype, tag, and profile) (Booch et al. 2005) which allow for the creation of domain specific languages based on UML.

As mentioned previously, ArchiMate is a graphical modeling language developed by the Open Group that can be used for Enterprise Modeling. ArchiMate offers an integrated architectural approach that describes and visualizes different architecture domains and their underlying relations and dependencies (The Open Group 2016). Furthermore, the language is aligned with the Architecture Content Framework of TOGAF and incorporates elements of the business, information, application, and technology architectures. One of the main advantages that the language offers is the ability to model a wide scope of architectures and elements using the same standard: it spans a broad spectrum of elements and domains that makes it possible to create wide-range models. However, the tradeoff behind this is the lack of detail offered. In order to cover this problem, it is necessary to use more specific languages such as BPMN, or sysML.

3 The World of Operational Technologies

Gartner, the research and consulting company in IT related topics, defines operational technologies (OT) as the hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the enterprise (Gartner 2016). These elements are especially important in asset intensive industries, such as oil and gas, energy production, manufacturing, mining, and commercial real estate. In these cases, the domain of OT embodies the genuinely critical resources and operations that help to carry out daily tasks and operations required for business success.

Nowadays, OT encompasses a number of elements that are fundamental for achieving industrial goals. For example, enhancing production throughput by reducing production process time can be achieved through operational equipment asset management (machinery, operators, etc.) or constraint analysis (bottlenecks in operation, equipment limits, etc.) The OT domain also includes elements to control and monitor equipment such as actuators, sensors and software and the equipment used in operational activities (production machines, pumps, refrigerators, etc.) Furthermore, modern technological achievements in fields such as Internet of Things (IoT) and especially IoT for manufacturing, cloud computing, big-data, miniaturization, GPS systems, and cyber physical systems have led to OT components that are capable of generating loads of information that business should take into account. This has resulted in a trend where the connections between manufacturing and information technologies are highly sought after. For instance, cloud manufacturing systems are distributed networks that consist of virtualized services for manufacturing enterprises that allow a cost-effective, flexible, value enhancement and scalable solution through which they share databases and software (Li and Mehnen 2013).

This disconnection between operational and information technologies is not evident just in the technical ambit: there are multiple differences between these two domains that first have to be understood in order to bridge the gap over them. For example, there is a clear difference in ownership and governance of the elements that belong to OT and IT that has led to creation of organizational silos (Haider 2012). Also, there is the idea that OT elements are exclusively responsible for the operation of the business, while IT is responsible for supporting business aspects such as accounting. Likewise, the employees in charge of OT and

IT have very different skills, knowledge, and concerns. This creates unnecessary tensions, leads to power struggles, and makes it harder for the two sides to collaborate and create sources of new value and efficiencies (Hunter and Westerman 2009). Nonetheless, enterprises are working on bridging the gap in between IT and OT through technologies and tools that blend both domains such as IoT. A critical requisite for a successful IoT solution is a Services Platform allowing the connection of multiple devices, sensors and applications, while managing and controlling different systems and processes.

Enterprise Modeling should be useful to help understand how OT may add and create value to the business, in particular given its relation with IT. However, there are few approaches that can be used to accurately include this domain into EM practices because most languages do not consider directly the implications of modeling OT elements and under-represent them. As mentioned before, ArchiMate is a very popular EM language but it focuses on the IT and business domains. This IT centric style inherently supports classic enterprise architecture approaches based on a business-data-application and technology decomposition. For example, a Product in ArchiMate is an aggregation of IT based services; thus, there is no clear way to describe a physical product in a manufacturing company (e.g. a shirt).

ArchiMate's latest 3.0 version now includes a physical layer. However, it is quite limited and includes only four new elements: Equipment, to model technological nodes; Facility, which models physical spaces where equipment is located and production occurs; Distribution Networks, which serve to move materials and products around; and Materials, which are consumed during the production processes. Although these elements are useful, they are insufficient to accurately model an entire OT architecture. Among others, ArchiMate lacks concepts to define operational controls in production processes, asset management, operational organization structure, and software components for monitoring and controlling equipment. Nonetheless, the new standard is a valid starting point to model the OT domain due to its leverage with the enterprise architecture community (The Open Group 2016).

Fortunately, the construction of a modeling language for OT does not need to start from scratch. The development of any domain language requires an in-depth analysis of the target domain (Frank 2013), and in the OT world there are already standards which identify key concepts and propose common terminology. These standards can be used as the base for a DSML for creating EM including also OT concepts. However, we found four shortcomings in the existing models that we analyzed. Firstly, they are extremely detailed, making them difficult to use and to learn, and thus restricting them to a very small set of users; secondly, some of them are industry specific and are not applicable to other industries even though there may be conceptually similar; thirdly, they use disparate terminology, often using the same terms for different concepts, and different terms for the same concept; finally, they are completely focused on their domain and might not offer or focus on connection points to other domains of interest for EM, and especially to IT and business. For example, the international standard ANSI/ISA 95 enterprise control system integration (Hawkins et al. 2010) is an example of the first shortcoming because of its detailed definitions of terms and object models to use in production process. On the other hand, and as stated in the second shortcoming, there is PPDM, an ontology and glossary uniquely for the oil and gas sector (PPDM 2016) which cannot be used in any other industry.

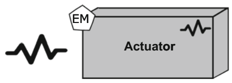
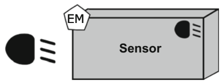
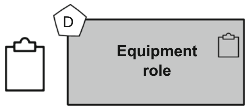
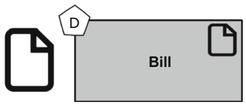
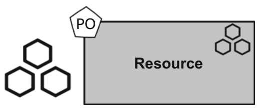
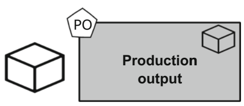
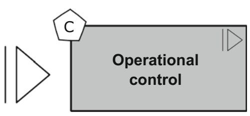
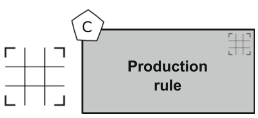
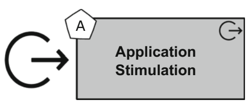
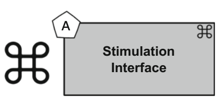
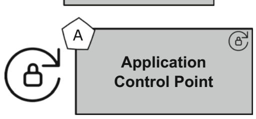
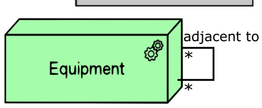
Finally, modeling production processes, transportation, equipments, products, and operational rules is substantially different in distinct industries. These differences are not only conceptual but also reach the graphical notations of languages, which should use icons that are as close as possible to the concepts of the industry. For example, transportation equipment in the manufacturing industry might be represented by vehicles while in an electricity company it is represented by power lines.

All of the aforementioned aspects, led us to the following conclusions that guide the work presented in the rest of the paper. Firstly, it is necessary to create Enterprise Modeling languages that are capable of modeling OT, IT, and business architectures in order to address crosscutting concerns. Secondly, an OT language should not be constructed from scratch but must be based on existing OT standards. Also, any proposed conceptual model should include a graphical notation instead of proposing just an abstract syntax. Finally, it should be possible to adapt the proposal to particular industries by specifying particular concepts that are exclusive to that industry, and specifying adequate graphical representations. In the following sections we present a language extension to ArchiMate 3.0 in which we introduce new elements to model the OT domain. We also show how it is possible to specify the language and the graphical notation for specific industries through an example in the oil and gas vertical.

4 An OT Modeling Extension

To address the described problems with respect to modeling operational technologies, in this paper we propose an approach based on three main ideas. Firstly, we propose a metamodel extension that introduces OT elements into enterprise models: on one hand, these elements serve to model the OT domain itself; on the other hand, the

Table 1 Description of the OT elements and their graphical notation

Element	Graphical modeling	Description
Actuator		An Actuator is an active structure component responsible for moving or controlling other mechanisms, systems or equipment
Sensor		A Sensor is an active structure that detects changes in operational equipment
Equipment role		An equipment role is defined as the responsibility for performing specific behavior, to which operational equipment can be assigned
Bill		A representation of the needed bills for production such as bill of lading, bill of materials, and bill of resources
Resource		A resource is defined as an enterprise asset that provides some or all of the capabilities required by the execution of operation activity and/or business process
Production output		A production output is a partial or finished product which has endured processing and production
Operation control		An Operational Control is the ability to perform control actions taking into account the available resources
Production rule		A rule is defined as a norm that directs an operational control
Application stimulation		An application stimulation triggers an occurrence in the operational infrastructure layer
Stimulation interface		The stimulation interface is defined as the intermediate between the operational data and the application control point that uses the data to take decisions
Application control point		An active structure that exercises direction over an application or software system
Proximity relationship		Indicates that an equipment is adjacent to another equipment

structure of the metamodel makes it possible to relate the new OT elements with those in the IT and business domains. The base for our metamodel is ArchiMate 3.0 but the same idea should be applicable to any other existing EM language. The second idea is a graphical notation for the OT extension intended to bring it closer to OT experts. Finally, we propose to extend and refine said OT metamodel (and its notation) in order to adapt it to the needs of specific industries and enterprises. Figure 1 shows a visualization of this idea: starting from an existing modeling language and the OT extension it is possible to create industry-specific extensions; then, different enterprises may further extend each one of those to create enterprise and industry specific models. The rest of this section presents the OT extension for ArchiMate while Sect. 5 discusses and illustrates industry-specific extensions.

As previously mentioned, the OT extension that we designed for ArchiMate 3.0 has the dual goal of modeling OT concepts and relating them to existing business, application, infrastructure, physical, and motivational

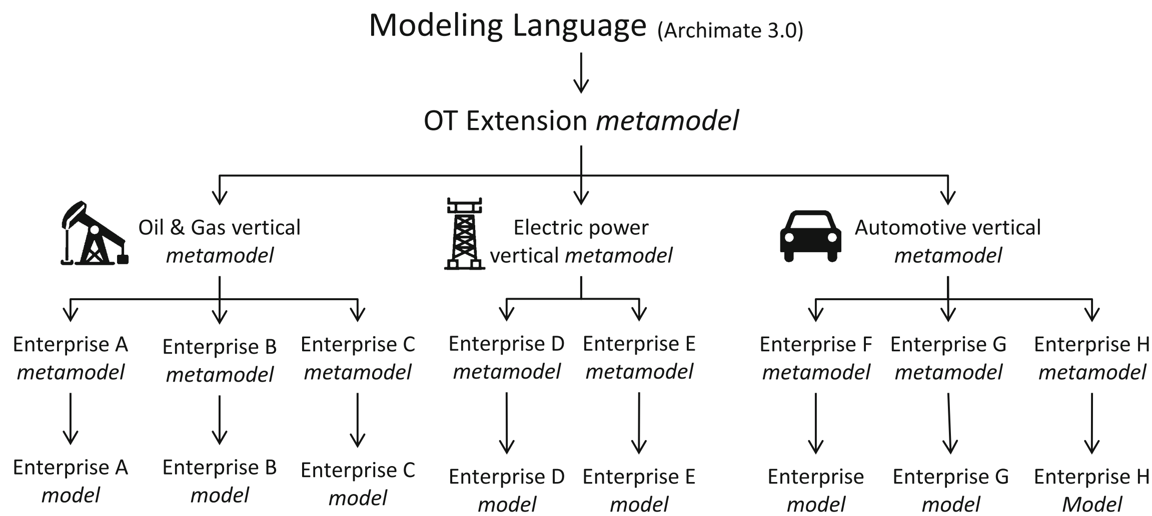


Fig. 1 Overview of the approach

concepts. The core of this extension was designed after studying existing standards and models, but it only contains elements from a level of abstraction high enough to meet the requirements of many industries. The proposed elements have relationships between them and relationships to existing ArchiMate elements. In particular, several of the proposed OT elements specialize concepts found in the physical layer added to ArchiMate in version 3.0. An earlier version of our core metamodel, that predated ArchiMate 3.0, was previously presented in (Blind et al. blind) and was completely re-constructed to build on top of the new elements.

Figure 2 shows the OT extension and its main relations to existing elements in the base metamodel. The metamodel presents significant ArchiMate elements from the technology, physical, application, and business layer (shaded elements), while the newly added elements of the OT core are white colored. Notably, not all ArchiMate elements are shown: only those with compelling significance for modeling OT are presented. Furthermore, some of the new elements are extensions to existing ArchiMate elements and thus they inherit the existing relationships to elements in the business, application and technology layers. Table 1 presents a description of each new element proposed as well as its graphical notation.

The new elements can be organized in five groups denoted in the figure with a pentagon and a letter in its corner: controls (C), equipment management (EM), descriptive artifacts (D), production objects (PO), and application controls (A). The controls' group defines restrictions that should be taken into consideration during the company's production, and includes two new elements: Operational Control, which can perform operational actions, and Production Rule which explains details of an Operation Control. Equipment management elements indicate, receive, and process control activities over production equipment. This group includes Sensors, which pick up events from equipment, and Actuators, which perform actions on the physical world. Descriptive artifacts, represented by Equipment Role and Bills (of materials), are used to portray other operative elements function, objective, or details. We have also included a production object (Resource) which represents tangible items involved in the production or the result of a production process. Finally, the main goal of elements in the application controls group is to control and ensure connectivity between software components and technological elements in automated production process where control systems can operate equipment (Blind et al. blind). The elements in this group include Application Stimulation, which is used to control equipment through Stimulation Interfaces exposed by Application Control Points.

Figure 3 presents an example where several of the proposed new elements are used. In this case, an IT Application Component (integrated management and gas accounting) generates stimuli for an OT Application (plant monitoring control application) that, using some Actuators (positioner), induces changes in some machine (gas compressor) located in a Facility (processing plant). Real-world performance information about the machine is then collected using Sensors (position sensors). These generate Data Objects which are finally consumed by the IT Application Component, thus closing the cycle.

5 Modeling OT in the Oil and Gas Industry

Each industry has its own set of characteristics defined by its business activities, their information requirements, and the technological components they use. The core OT

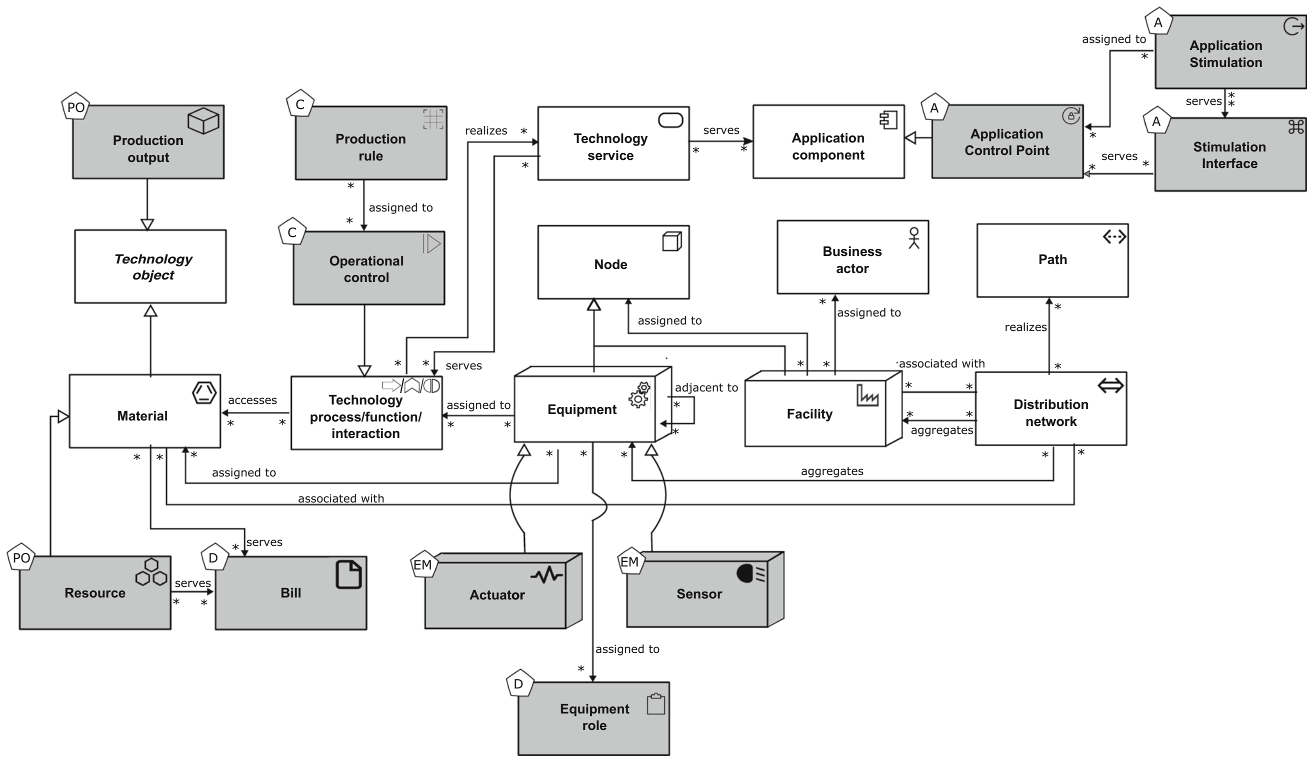


Fig. 2 OT metamodel extension

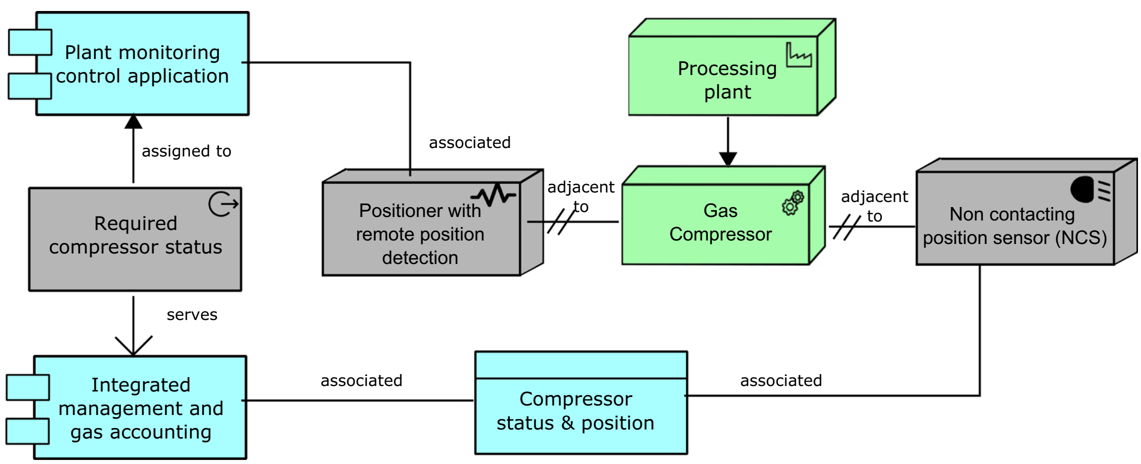


Fig. 3 An illustrative OT model

metamodel aims to fulfill the needs of industries no matter their core business activities. However, for each industry the ways in which OTs are used can drastically vary. Furthermore, companies in the same industry can have even greater variations depending on aspects such as their strategy, size, range of products, and market, among others (Rushton and Croucher 2017). Because of these differences, it is important to enable the core OT language to be extended and create specializations for different industries, including graphical notations adapted to the common concepts of said industries.

Extensions to the core OT metamodel may add new elements by specialization of existing ones, or by adding completely new ones. Each one of those elements should have its own graphical representation in order to facilitate the comprehension and communication of the models. Extensions may also remove unnecessary concepts and modify the original graphical notations. This allows the creation of models with the necessary granularity and specificity level for an entire industry vertical or for individual companies.

Since each industry is fundamentally different with respect to critical operational process, actors and roles, and equipment, among others, building an industry-specific extension should begin with the identification of relevant concepts. The established concepts can derive from extending and specializing OT elements as to refine the concepts inherited from the OT core metamodel. They also can be identified by studying existing standards and reference models in the industry. In the rest of this section we present an OT language extension for the oil and gas sector and proceed to validate this extension through two rounds of surveys.

5.1 OT in the Oil and Gas Industry

The oil and gas industry is one of the most influential sectors worldwide. It is commonly divided in three aspects: upstream, midstream and downstream. Upstream is where exploration and production takes place. This includes activities such as prospecting, seismic analysis, and drilling, which occur before starting production and stabilization. Midstream involves transportation, storage, and marketing of the crude oil, natural gas and natural gas liquids. Lastly, the downstream sector comprises the processing of the crude outputs into specific products such as gasoline, asphalt, lubricant, plastic, and synthetic rubber, among others (Devold 2013).

OT is critical in this asset intensive industry as production and management of the produced goods are the critical activities: even though information-centric tasks are important, they are secondary to all the production related aspects. In particular, in this industry a large variety of equipment is connected to sensors and actuators to allow their monitoring and automation through control elements like SCADA (Supervisory control and data acquisition) and PLC (programmable logic controller). Sensors in this industry are used to measure different production elements such as wellheads (speed, production), pipeline (integrity, flow), valves (pressure, temperature), and many others.

The oil and gas industry is rapidly developing and incorporating modern operational technologies to accomplish goals such as: production optimization, controlling operation cost and improving efficiency through automation and analysis of operational processes to generate new insights (Hilyard 2012). These new OT technologies are becoming the new normal for oil and gas companies which are now considering the adoption of robust products for Industrial IoT (Internet of Things) allowing the integration of production sensing, communication and analytics. However, according to the experts that we surveyed, current documentation of installed OT systems ranges from very detailed blueprints left by vendors to no documentation at all. Also, some of these documents are digitalized and can be electronically queried, while others are still in paper are geographically scattered. Finally, most of the documentation is available as engineering drawings without much information about communication protocols.

Current developments show an increasing need to integrate OT with the business and IT. However, the organizational structures and the organizational cultures have separated these two worlds to the point where there is distrust for one another and communication is difficult to achieve. On top of that, the current heterogeneity of protocols, brands, and technologies used in sensors, actuators and controls, as well as the low quality of existing documentation, makes the required integration very difficult.

In the rest of the section we present an OT metamodel tailored for oil and gas that incorporates the aforementioned core elements of the industry and relates them to IT and business elements.

5.2 Oil and Gas Metamodel Extension

In order to create an OT metamodel for the oil and gas industry, we identified a number of key elements that may be generically used in any company in the sector. Some of these were identified during interviews with industry experts; others were extracted from models such as PPDM (PPDM 2016) and the catalogs of suppliers of OT technologies. The selected concepts extend some of the elements in the OT core and serve to illustrate the construction of an industry specific metamodel. The resulting metamodel is presented in Fig. 4.

The OT language extension for oil and gas contains 26 new elements. Three of the original ArchiMate physical layer elements (facility, equipment, technology process) were extended to create specialized concepts. The other extended elements were production object elements and equipment management elements. The new elements can be seen with a grey background and surrounding the original OT extension in Fig. 4. For the technology process, we extended the element to create six broad process groups that take place in the oil and gas industry (exploration, production, transportation, distribution, storage, and refining and gas processing). Likewise, the newly introduced facility elements represent production sites (such as on-shore, off-shore facility or a plant). Because of their complexity, equipment elements are not very detailed but are just represented in groups according to their functionality. For example, exploration and drilling equipment might be used to represent objects such as a drill strings and mud pumps. This also occurs in the production outputs which are grouped in categories exclusive to this industry (gas products, crude oil product, petrochemicals). Finally,

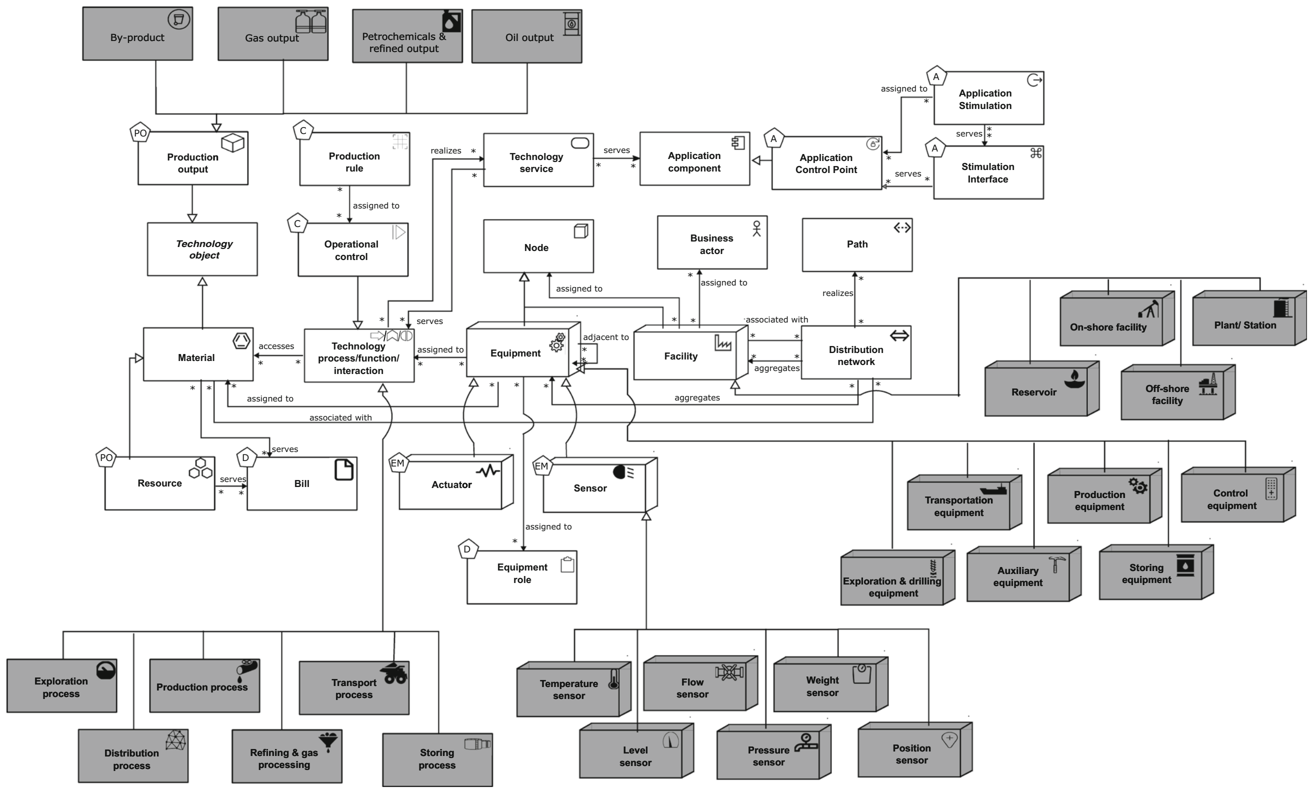


Fig. 4 OT metamodel for the oil and gas industry

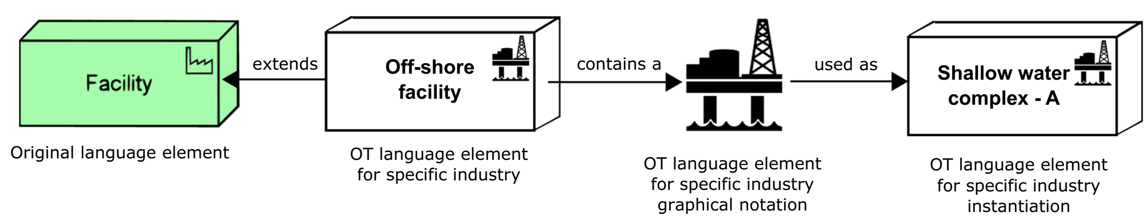


Fig. 5 A modeling scenario in the oil and gas industry

extended sensors (equipment management) are categorized according to their monitoring function such as temperature, level or flow tracking.

All of the proposed new elements have specific graphical representations tailor-made for the oil and gas industry and for its specific OT elements (see Fig. 5). These elements also have established relationship to elements in all of the other ArchiMate layers.

5.3 Validation of the Metamodel for the Oil and Gas Industry

To validate our proposal, we used two rounds of surveys in which we systematically solicited the judgement of a group of experts. The overall objective of the process was to assess the needs of the OT domain in the oil and gas industry and to corroborate our proposal for OT modeling.

The expert panel of respondents was composed by ten individuals from five different companies: three oil and gas companies that perform upstream, midstream and downstream activities, together producing (officially) over three million oil barrels per day; one of the largest field service companies; and an engineering and electronics company that offers products for the oil and gas sector. The diversity among the pool of experts provided meaningful contrasting and complementary points of view.

There were two rounds of surveys. The first one asked the individuals open and broad questions about their experience with OT components in their companies, the necessity for modeling OT, and the current state of OT and OT modeling in their enterprises. This was used to validate the main premises for this work and the answers obtained in this first survey were used to prepare the second survey.

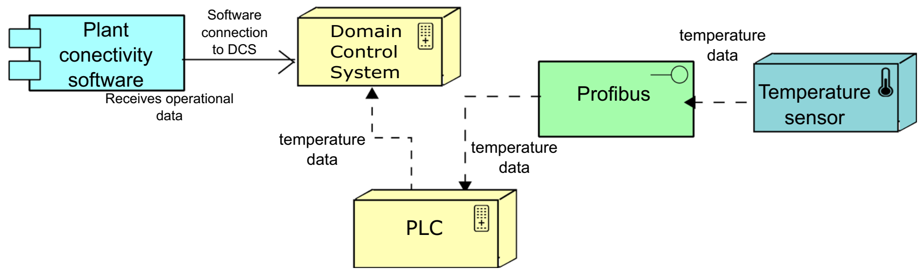


Fig. 6 A modeling scenario used for validation

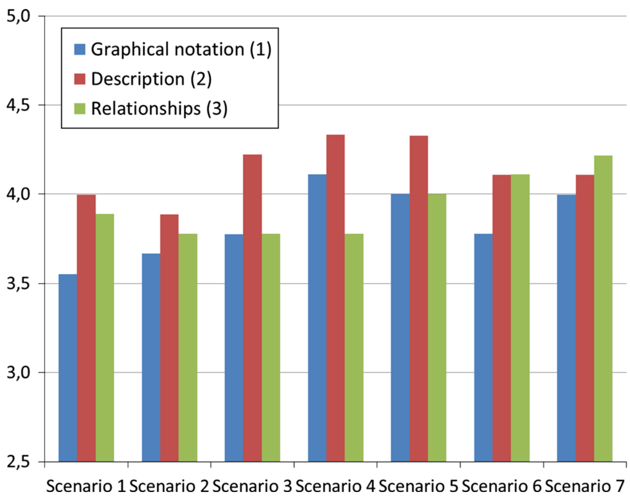


Fig. 7 Evaluation results (second section)

The second survey focused on validating our proposal. It was composed by thirty-five questions grouped into three sections. In this survey a Likert scale was used were the experts were asked to scale responses from one to five (1 = strongly disagree, 5 = strongly agree). The first section was closed general questions regarding the OT modeling languages and the need to model OT in relation to IT. In the second section of the survey, respondents were given seven short case scenarios in which different structures were modeled using our extended metamodel for OT in the oil and gas sector. As part of the survey, we also gave the respondents the descriptions of the elements included in the scenarios. An example of a scenario is shown in Fig. 6 where the respondents where shown different elements in different colors. Respondents were requested to score (likewise, from one to five) the graphical notation, the elements description, and the relations between elements. A section of additional commentaries was also enabled to allow respondents to write down more detailed opinion about each case scenario. The final section of the survey was closing questions in which the respondents were asked about facility to understand the models, the completeness of the elements and the obstacles they encountered.

Results in section one of the survey shows that the average score for the need to model OT in the oil and gas industry was high, marking a 94% score. On the other hand, the respondents were divided when asked if the languages and tools for modeling OT were enough, as 45% of the respondents mentioned that they were not enough and the remaining 55% considered the tools and languages appropriate. When asked if the enterprises knew the relationships between IT and OT, 81.8% of the respondents answered three or less on a scale from one to five.

The result of the questions about the scenarios presented in section 2 can be found in Fig. 7. The average ratings of the graphical notation were 3.8 ± 0.2 and a mode score of 4 (on a scale from one to five). Likewise, the description of the elements scored an average of 4.1 ± 0.17 and the mode remained the same (on a scale from one to five). Finally, the relations aspect of the cases was scored 3.9 ± 0.18 with the same mode of 4 (on a scale from one to five).

The last section of the survey results indicated that participants found the models easy to understand and most participants also agreed that the elements presented where relevant and could model OT in the oil and gas industry.

6 Related Work

In this section we explore works with relationships to our study. On one hand, there are approaches which extend ArchiMate to model domains which are not covered by this modeling language. On the other hand, we also review some studies that target the alignment of OT and IT. Relevant related work has thus been categorized in two groups: research on operational and information technologies alignment, and ArchiMate extensions for specific domains.

Research in operational technology is especially geared towards OT and IT integration, and asset management. Consulting and research companies in the market are currently starting to offer commercial tools and services to align OT and IT. For example, the IT services company Gartner proposes a strategic roadmap for IT/OT alignment (Gartner 2015). On the other hand, a taxonomy was proposed by Govan et al. to describe how organizations should converge, align, and integrate these two worlds. This taxonomy specifies when, why and how a company should align OT and IT and criteria to measure the success of convergence, alignment and integration (Kusk and Gao 2014). Haiders' paper on asset management illustrates joint governance frameworks for information and operational technologies as to imply a joint management of these two domains (Haider 2012). Likewise, another study proposes an outlook on information asset management for OT and IT and establishes the need to have combined data administration (Koronios et al. 2010). These works focus on the differences between the two domains and how to bridge the gap caused by said differences in order to avoid OT and IT silos through different mechanisms. However, none of these mechanisms focus on modeling the OT architecture and its relationship with IT.

Regarding the creation of extensions to the Archimate standard language, there have been numerous proposals. The first added extension to the standard was the motivation extension used to describe what drives the design and operation of an organization using elements like stakeholders, assessment, goal and requirements (Azevedo et al. 2011). Secondly, the implementation and migration extension was added in order to support TOGAFs Architecture Development Method by adding concepts such as work package, plateau, deliverable, gap, and implementation event (Jonkers et al. 2010). Modeling and extending ArchiMate is also considered in other domains that are not entirely covered by the standard. The Open Group proposes an approach to modeling enterprise risk management and security through either the use of unmodified ArchiMate concepts, the use of extension mechanisms defined by the standard, or the addition of new concepts that are not included in the language (Band et al. 2015). A separate research proposes ArchiMate improvements to model value through the language standard (Aldea et al. 2015). In this same domain another study models value connecting the technique e3value to ArchiMate through transaction patterns of the DEMO methodology (De Kinderen et al. 2012). Likewise, a separate work includes the use of ArchiMate, business model canvas, and e3value as a scenario in order to "specify, integrate and analyze multiple, heterogeneous enterprise models" (Caetano et al. 2017). Other researched domains include an ontological analysis of the concepts in modeling resources and capabilities with the ArchiMate standard (Azevedo et al. 2015) and an ArchiMate extension that studies a domain specific modeling language made for telecommunication services in order to capture design decisions and rationale (Chiprianov et al. 2012). Even though we also propose an ArchiMate extension, the domain language and construction technique differs from these studies target field.

7 Conclusion

This paper explored a number of problems related to operational technologies in the context of Enterprise Modeling. There is a historical disconnection between IT and OT that has led over the years to the formation of separate teams and the development of different technologies and best practices. However, the pressure for efficiency and the opportunities created by modern production-related technologies make it necessary to close the OT/IT gap. Nowadays, OT components are very much capable of doing data generation, process, storage, and communications that previously where exclusive activities of IT systems.

This paper presented an ArchiMate extension for OT that attempts to close the gap: on the one hand, it allows the creation of models of OT, thus expanding EM capabilities into this world. On the other hand, it allows creating relations between OT and IT/business elements. We consider this the most important aspect of the proposal because it integrates OT information and concerns into decision making processes; in particular, it facilitates making IT-related decisions taking into account OT elements, and vice-versa.

The OT extension proposed is intended to be a core extension that should be specialized. We found it impossible to create a generic OT extension applicable to every case because operational elements are extremely different depending on the context or particular industry. Thus, we decided to abstract only common concepts from standards and reference models, and to organize the core metamodel based on those abstractions. We also analyzed and proposed the necessary relations between those elements and the ArchiMate elements from the business, applications, technology, and physical layers. The end result was a base metamodel that can be used by itself to create relatively simple OT models, but that can be extended to address the needs of particular industries. We also created an OT metamodel for the oil and gas industry which we validated with industry experts through two rounds of surveys with industry experts. This showed that there is indeed a need to model OT and to relate it with IT elements in their industry. It also validated the approach, the graphical notation, the elements' description, and the proposed relationships.

A further point to consider and discuss which is relevant not only for our OT extension but also for ArchiMate in general, is the level of detail supported. Arguably, our OT extension is simple and is not capable of representing scenarios with a significant level of detail. However, the same can be said about almost every aspect of ArchiMate and similar languages. Where the language shine is when it is used to tie elements belonging in different domains. That is why it is perfectly reasonable for an EM approach to use BPMN for business processes and to use ArchiMate to relate processes to elements in other domains, such as applications or motivation. Similarly, the proposed OT extension is not intended to replace existing standards in that world and in specific industries. Instead, it aims to complement them by introducing the necessary elements to connect OT with IT and the business.

The final discussion point is the necessity of graphical notations to complement the conceptualizations: without a compelling notation, a meta-model will be seldom used by domain experts. Moreover, the graphical notation should include icons and abstractions that are familiar to the modeler and are thus semantically transparent (Moody 2010). This is particularly important in the OT world, where the physical existence of many elements makes it important to use icons that resemble their real world counterparts. On top of that, just defining graphical notations is not enough: tools (editors, repositories, publishers, etc.) are required to support the notations. In this respect, graphical language workbenches such as Eugenia, Sirius, GME, and GMF have an extreme importance for supporting the accelerated development and adoption of tools and languages (Kolovos et al. 2015; Eclipse 2017; Boldt 2016).

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