The Challenging Landscape of Model-based Initiatives

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Abstract

It is common throughout industry to see digital transformation through model-based initiatives (MBIs). The prevalence of models can now be seen across systems engineering (SE) activities, throughout the life-cycle. So why is it challenging to understand the landscape of SE and Architecture in the context of MBIs?

The authors analysed key concepts and relationships of systems life-cycle activities (ISO/IEC/IEEE 15288) and architecture descriptions (ISO/IEC/IEEE 42010). Although base level activities and approaches could be generalised, there were issues with common understanding.

A conceptual model has been produced, describing aspects of the landscape for SE life-cycle processes and MBIs. The importance of architecture description languages and their associated metamodels is also discussed in terms of how these contribute as enablers towards model-based transformations.

This paper shows how an increased use of robust ontologies and metamodels, and their integration with underlying SE life-cycle processes and models, can contribute to improved common understanding when transitioning to a model-based organisation.

Introduction

An INCOSE UK joint workstream was formed to understand the relationship between Architecture and Model-based Systems Engineering (MBSE) and explore areas of common interest. One of the themes is the Landscape of Architecture and MBSE, which this paper has been produced from. The purposes of the theme are to: identify key relationships and dependencies between architecture and MBSE, provide a map of the landscape, understand where architecture and MBSE converge and diverge, and to support the other themes. To establish common ground, the authors represented key terminology and relationships for systems life-cycle activities and architecture descriptions (ADs) as conceptual models. These conceptual models were elaborated on to capture key aspects of the Systems Engineering (SE) and Architecture landscape (the Landscape) and the relationship with model-based initiatives (MBIs). This paper discusses the team's challenges with modelling the architecture of the Landscape and reflects on the need for integrating MBI-related systems life-cycle processes (SLCPs) into the organisation when transitioning to a model-based organisation.

Landscape

This section identifies a number of key themes that group concepts relevant to the Landscape. These represent one possible way of partitioning the Landscape and serve only to aid the discussion. The concepts and relationships considered are not comprehensive and their selection represents work done to date, which centres on ISO 15288 [ISO 2015a] and ISO 42010 [ISO 2011]. Understanding how these relate to one another and the SE lifecycle has been tackled as an SE problem using a modelling approach. The System of Interest (SoI) in this case is the SE organisation. The focus is on using an MBI to transition to a model-based-organisation. This transition requires addressing all aspects of organisational change, including people, processes and tools, and understanding of the current and future architecture and SE landscape.

Figures 1 and 2 show aspects of the Landscape, which are discussed in subsequent sections.

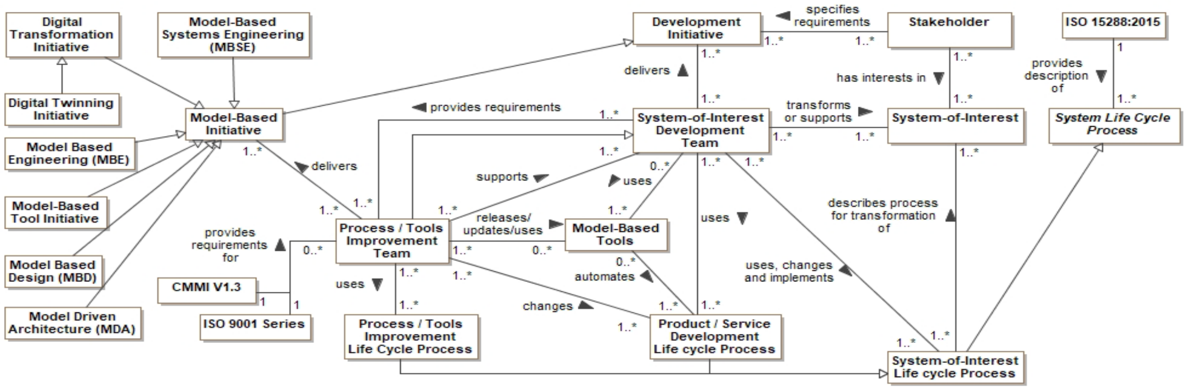

Figure 1: Model-based Initiative Landscape – Initiatives and the SoI Life Cycle

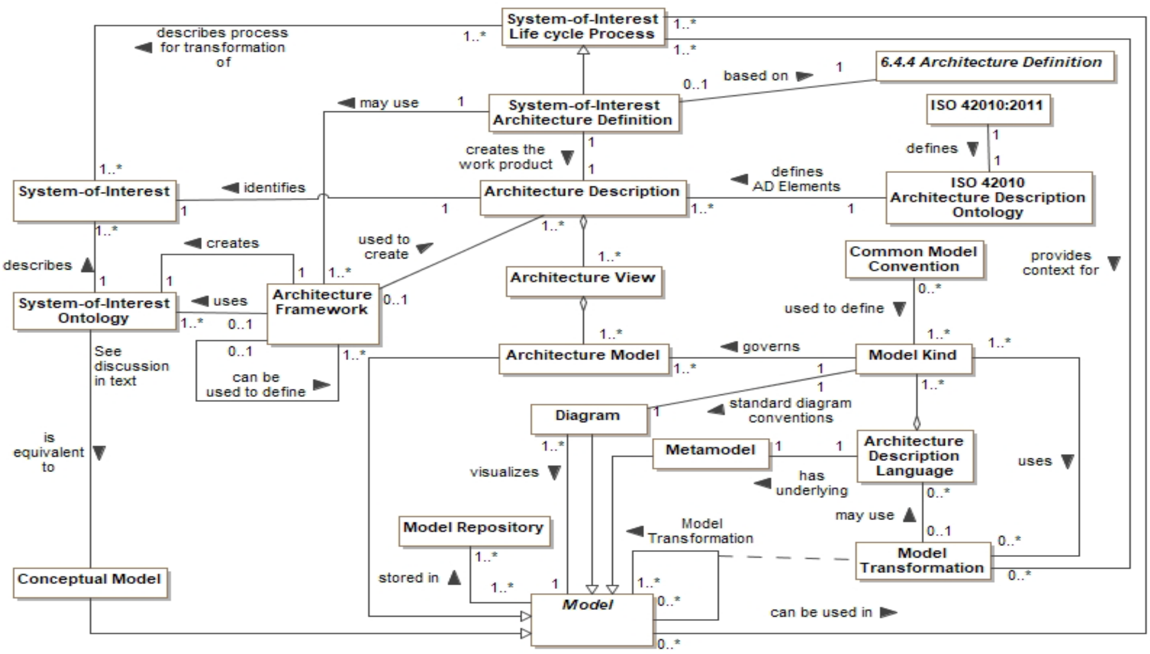

Figure 2: Architecture Landscape: SoI Life cycle and Architectural Elements

Model-based Initiatives (MBIs)

MBIs aim to transform organisations by making models the basis of the way that they do business. MBIs cover a variety of approaches adopted by engineering organisations that make use of model(s) throughout the system lifecycle. These models capture aspects of the SoI, including the architecture, using different conventions, or model kinds [ISO 2011]. Approaches used include Model-Based Systems Engineering (MBSE), Model-Based Design (MBD), Model-Driven Architecture (MDA), Model-Based Engineering (MBE) and digital twinning. Model-based refers to the application of technologies to represent artefacts through models. Model-driven refers to the application of technologies that transform one model kind to another.

System Life-cycle Processes (SLCPs)

An SoI Development Team (people) transforms an SoI from its initial concept phase to its retirement or replacement phase using a set of System Life Cycle Processes (SLCP). Each SLCP is described in the INCOSE SE Handbook [INCOSE 2015], which is derived from ISO 15288 [ISO 2015a]. Each SLCP may need to be tailored (terminology, tools, wider process) to both the SoI and the organisation where they are used. The teams using these SLCPs need the appropriate skills, knowledge and experience (competence) to carry out their role. The Architecture Definition process brings stakeholder needs, requirements and concepts of operation into a coherent system Architecture Description (AD). This AD is used as the foundation for the remaining design and analysis processes. Models are used to support and integrate established System Life Cycle Processes (SLCPs), not to replace them.

Models

A Model is a representation of something. This might be expressed in clay, in a document or digitally. MBIs will make use of various Model Kinds - conventions for a type of modelling [ISO 2011] - which govern architecture Models. Other important Model Kinds discussed here include Metamodels (loosely: a model that describes models) and Conceptual Models. The purpose of the Models and the use of Model Kinds will differ according to the lifecycle stage and the type of MBI. Diagrams are one way to visualise a Model or parts of the Model.

Ontologies

The term Ontology, as used in SE, can broadly be understood as a description of concepts and the relationships between them. The exact definition of the term varies between reputable sources according to the way they see the world and is beyond the scope of this paper. See Guizzardi [2006] and Smith [2004] as examples of detailed treatments with contrasting stances. Ontology is important in the context of the Landscape because it is central to both Architecture and MBSE and provides the basis for building conceptual models of the Landscape itself. The Landscape is vast, so early focus on developing an Ontology helps with managing, visualising and navigating its complexity.

Architecture Frameworks and Architecture Description Languages

The purpose of an Architecture Framework (AF) is to establish common practices related to ADs for a particular domain or group of stakeholders [ISO 2011]. In other words, an AF constrains the work products associated with producing ADs. Typically, an AF contains viewpoints, and identifies a set of Stakeholders and their associated concerns (Figure 5 [ISO 2011]). AFs can be used for creating ADs or developing architecture modelling tools and methods. Many AFs exist, about 80 are listed on the ISO

42010 website [WG42 2020], and they are often focused on a particular domain or industry. Well-known examples listed by WG42 [2020] include The Open Group Architecture Framework (TOGAF), Zachman Framework (ICT-focussed), and Ministry of Defence Architecture Framework (MODAF).

An Architecture Description Language (ADL) is described as "any form of expression for use in ADs" [ISO 2011]. ADLs are similar to AFs, except an ADL has at least one Model Kind and optional Architecture Viewpoints. Both provide reusable elements for an AD. ADLs include a wide variety of "modelling languages" and notations ranging from UML [OMG 2017] to notations such as fault tree [IEC 2006] and may be combined to allow a modelling tool to produce SE artefacts.

Discussion

Describing the Model-based Initiative Landscape through models

An organisation implementing an MBI must understand the applicability of different engineering modelling approaches to the different stages of the systems engineering lifecycle. Organisational transition to model-based working is complex and complicated, so modelling the architecture of the MBI landscape is proposed as a means to manage the transition. The approach documented here is intended to reflect one suitable for an organisation implementing an MBI, where the organisation itself is treated as the SoI. Here the authors acted in the role of the SoI Development Team (Figure 1). The goal is to produce an AD describing the Landscape of an imagined SE organisation.

The authors brought different experiences to modelling the MBI Landscape. This was useful as it brought breadth to the discussion, but also challenging because it highlighted significant differences in their understanding of common SE concepts that were assumed to be 'universal knowledge'. The challenges mimicked those faced by SE organisations transitioning to model-based ways of working.

An AF and/or ADL can be useful for creating an AD of an MBI by constraining the AD work product, with the aim of communicating a common way of conceiving the Landscape. This is important for improving the way that people, processes and tools interact and work together, because the "mismatch of underlying models is the greatest impediment to integration and interoperability" [Martin et al. 2004].

Organisations may have AFs/ADLs mandated by their customers, but otherwise must decide between developing a custom AF, adopting an off-the-shelf AF, or modifying an existing AF. Challenges arise if an AF/ADL does not align with the architecture being described. This means that decision makers and modellers involved in MBIs must understand how an AF/ADL addresses the concerns of all stakeholders.

Ontologies, metamodels and conceptual models

ADLs almost always have an underlying model, formed from sets of node-connector-node groups (called triples) and rules for their use. The terms Ontology, Metamodel and Conceptual model are all used in relation to these underpinnings of an ADL. The team found that the terms are frequently used interchangeably and there is little agreement on the distinction between them. ISO 42010 [ISO 2011] does not clearly define the terms, but the following relationships have been inferred:

- ontology = concepts + relationships + multiplicity constraints
- metamodel = ontology + attributes + constraints (other than multiplicity)

[ISO 2011] conflates Conceptual Model with Ontology, but does not define either. To understand the term 'conceptual model', the authors refer to Guarino et. al [2019] who argue that "conceptual models are models of conceptual mental representations that cognitive agents build, use and manipulate during cognition" and emphasise that they are "not models of a given domain, but rather models of how we conceive of that domain".

Agreeing a conceptual model of the Landscape was problematic due to the authors' differing experiences, as well as disagreement between and ambiguity in the key architecture and SE reference works considered [ISO 2011][ISO 2015a][INCOSE 2015]. The conceptual models underpinning those works are rarely modelled explicitly, with a reliance instead on text-based glossaries that omit important concepts and inadequately define relationships. ISO 42010 does include diagrams to communicate parts of its conceptual model/ontology, but these are disconnected and are partly inconsistent with the written text. The authors are therefore guided by the key works mentioned while recognising their limitations and the need for further work.

SE ontologies are usually classified as domain ontologies, characterised by a bottom-up approach. Foundation(al) ontologies by contrast take a top-down, abstract approach founded on axioms. Ideally, domain ontologies specialize foundation ontologies, but in practice are usually developed independently. Core ontologies address the middle ground by linking a foundation ontology to one or more domain ontologies to harmonise them. Garcia et al [2020] provide an accessible example of this in the field of geology. Mapping domain concepts and relationships to a suitable foundation and/or core ontology is a sound approach to improving shared understanding and supporting model exchange and integration. The authors hope to develop a core ontology for MBIs in future.

Integrating

Integration and exchange of models is affected by several factors: the quality of the AF/ADL specifications; the implementation of any AF that uses an ADL; and/or the tool vendor's implementation of the ADL specification in a modelling tool. The modeller may independently introduce errors by picking the wrong AD element. It may be impossible to exchange model elements because their meanings are too different or because the constraints do not allow elements to be combined. Foundation ontologies can help but many of the typical SE notations/products have existed for years and have not yet been underpinned by integrating a foundation ontology. All of these effects impact the ability to correctly exchange or transform the model.

There is little consensus between organisations and in literature on the definition of individual terms. Standards establish requirements for a wide range of organisations, but often use abstract terminology that does not reflect common usage. Some common names for ADLs include the terms 'modelling language' or 'modelling', but many do not, meaning the name alone is not a useful selector or predictor of its potential use for AD. This is probably because many of the names existed before current standards were published and some of the terms are deliberately defined broadly.

Model Repository Integration and Model Transformations

Engineering models may be held in different repositories depending on their kind. Tool integrations can be defined as part of the activity of modelling the tool infrastructure, however often in-house solutions need to be developed. Another practical issue is integration of models with repositories that are outside the scope of the MBI whilst maintaining traceability. This is evident when legacy data is held separately, for example historical, intellectual property protection or security reasons. A mechanism to transform models is therefore required. As a system transitions through the life-cycle, there is also a need to transform models to change their model kind. This could be to transform between different types of models, or to auto generate code.

Model transformation takes a model, in part or whole, as an input to transform into a pre-defined output. This utilises automated approaches, therefore the model transformation must have a mapping between the source and target metamodels. When considering the Landscape, this increases the importance of having metamodels that accurately describe each ADL and associated tool implementations that have been validated. These relationships are tightly coupled, driving the need to understand constraints imposed on model transformations by the selection of a tool and/or ADL.

System Life Cycle Processes

Tailoring the SLCPs for a specific organisation needs to take into account the requirements from other process initiatives such as the ISO 9001 series [ISO 2015b] [ISO 2015c] and the CMMI [SEI 2010]. An MBI aims to better integrate multiple requirements into a single tailored SLCP along with any models and supporting tools, which requires cross team integration and collaboration. This integration for a specific SLCP including models and tools needs to be reflected in training and support for the people in the various teams. Good examples of both using the SLCP and the models to deliver the outcomes are important to ensure consistency across multiple teams.

Conclusion

The purpose of an MBI is not to change underlying SLCPs, but to better integrate them. Modelling the Landscape in a given context provides a way to map concerns from all parts of the organisations involved. This can help with obtaining buy-in from all stakeholders, which is essential for a successful transition. Treating the organisation (including people, processes and tools) as a system and modelling the MBI is valuable as it helps the Improvement Team identify and address the integration challenges highlighted in Discussion, as well as other challenges specific to each organisation.

The Discussion section offers organisations several ideas for facilitating a smooth transition through modelling the architecture of the MBI landscape. These share a theme of improving common understanding between stakeholders, which can be communicated through an AD. AFs and ADLs can offer useful constraints, provided they are aligned to what is described. Identifying and describing the ontologies used by stakeholders facilitates this alignment, especially if they can be mapped to shared foundational axioms. With these aspects in place, model transformation is feasible. This facilitates exchange of information between model repositories and thus increases the level of integration that is possible. Tighter integration enables better SE in many ways, including improving understanding between people, interoperability of tools and consistency across SLCPs.

Modelling the Landscape was a challenging, but effective, means to describing common understanding. The benefits of building strong conceptual foundations were clearly demonstrated and SE organisations stand to benefit significantly by adopting a similar approach to MBIs.

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