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Index Terms—cyber-physical systems, mbse, sysml, modeling guidelines

I. INTRODUCTION

Modern Cyber-Physical Systems (CPS) are technical systems that combine mechanical, electronic, and software subsystems with physical elements embedded in the real world. The development of CPSs is becoming increasingly complex and challenging, due to their interdisciplinary nature and the need to ensure seamless integration between their physical and computational components [2], [3].

Model-Based Systems Engineering (MBSE) is a methodology for the development and management such complex systems, that addresses issues arising from the complexity and interdisciplinary nature of CPS, and provides the agility required to adapt to changing requirements and technologies. MBSE incorporates a centralized system model as the primary source of information, throughout the system lifecycle [2]–[6], [10], [11], [13]–[15].

SysML v1 has been widely adopted as the standard for modelling CPS and served as a key enabler MBSE. SysML v1 is a graphical, general purpose modelling language that is defined as an extension of the Unified Modeling Language (UML). Because it was built on top of UML, SysML v1 inherited several limitations from UML, that limited its expressiveness and usability for CPS modelling. However, it still provided a solid foundation for specifying and analyzing a system's behaviour, structure and requirements [3], [4], [7], [9], [11].

The release of SysML v2 represents the next generation of the Systems Modeling Language, designed as a comprehensive overhaul of SysML v1 that address its limitations and enhance the efficacy of MBSE practices. Unlike its predecessor, SysML v2 is built upon the Kernel Modeling Language (KerML), this approach ensures that SysML v2 inherits a formal semantic foundation, that is crucial for enhanced precision and automation in MBSE workflows. [3], [4], [7], [9]–[11].

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While these advancements introduced by SysML v2 are promising, the abstract nature of the language still presents challenges for ensuring consistent modeling practices across diverse engineering teams. Model inconsistencies creates a high risk of redundant effort, potential modeling errors, and lack of reuse of system elements, preventing them from being aggregated into a coherent overall system model. Therefore, mechanisms for implementing and enforcing modeling guidelines must evolve to leverage the native formal capabilities of SysML v2, that enable effective model verification processes throughout the development lifecycle [2]–[4], [9], [10].

Within the context of model analysis, a distinct differentiation between model validation and model verification is necessary.

Model validation is a form of static analysis that ensures a model's structural and semantic correctness. By detecting inconsistencies ranging from syntactic errors to mismatched data types, validation guarantees the model's precision and coherence. This process as a critical quality control, ensuring the model is reliable before it undergoes transformation or dynamic verification [4], [14].

Model verification, conversely, is a dynamic analysis technique focused on ensuring that the system specified by the model behaves exactly as intended under various conditions, thereby confirming behavioral adherence to specifications [14].

This work investigates the difference between mechanisms for implementing modeling guidelines in SysML v1 and SysML v2. We analyze the implications these differences have on model verification processes, by looking into a couple of specific scenarios.

II. THEORETICAL BACKGROUND

A. Model-Based Systems Engineering (MBSE)

Model-Based Systems Engineering (MBSE) is defined by the International Council on Systems Engineering (INCOSE) as "The formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the concept stage and continuing throughout development and later life cycle stages." [16]. Unlike traditional document-based approaches, where system's information is scattered across various files, MBSE is a methodology that centralizes system's information within a

unified model, which serves as the primary source of information that is managed throughout the system lifecycle [11]. This approach enhances collaboration among multidisciplinary teams, reduces errors from manual synchronization, and enables system architects to respond more quickly and effectively to numerous changes in requirements that occur during the development process [1], [6], [13].

B. *SysML v1 Foundations*

SysML v1 is a graphical, general purpose modeling language that is widely recognized as the standard language for MBSE, serving as a foundational tool for specifying, analyzing, designing and verifying complex multidisciplinary systems [1], [4], [7]. SysML v1, adopted by the Object Management Group (OMG) in 2007, was essential in advancing MBSE practice by providing capabilities for formally capturing system requirements, structure, behaviour, and parametrics [11]. The language is defined as an extension of the Unified Modeling Language (UML), allowing it to adopt established modeling concepts [4]. SysML v1 organizes its modeling constructs into four main categories:

- **Structure:** This aspect is modeled using Block Definition Diagrams (BDDs) and Internal Block Diagrams (IBDs). BBDs are used to define components, interfaces, and relationships at black-box level, while IBDs offer a white-box perspective by outlining the internal structure of a single block [7].
- **Behaviour:** SysML v1 provides several behavioral diagrams, including State Machine Diagrams, Sequence Diagrams, and Activity Diagrams [7], [13]. These diagrams capture distinct uses for modeling system behaviour.
- **Requirements:** System requirements are specified in Requirement Diagrams, that largely rely on natural language representation, although they can be linked logically to other model elements [7], [9].
- **Parametrics:** Parametric Diagrams define mathematical constraints and equations between system elements. They support preliminary calculations and analysis within the model, though they often require external tools for complex evaluations [7].

SysML v1 allows the restriction of modeling practices through UML profiling mechanism, enabling the construction of specialized extensions. The central element for customization is the **stereotype**, which functions as a distinct metaclass within UML [1]. Stereotypes enable the customization of existing metaclasses by associating them with specific properties and constraints, thereby tailoring the modeling language to meet domain-specific requirements [1], [12].

The **Object Constraint Language (OCL)** function as a specialized textual specifications language that enables formally defining rules, constraints and queries on models especially those created using UML [10]. It was developed to overcome the limitations of graphical modeling by allowing precise specification of rules that cannot be easily represented visually [1].

C. *SysML v2 Foundations*

[4], [9], [10]

III. RESULTS

- A. *SysML v1 Implementation of Modeling Guidelines*
- B. *SysML v2 Implementation of Modeling Guidelines*
- C. *Comparative Analysis*

IV. DISCUSSION AND IMPLICATIONS

V. CONCLUSION AND OUTLOOK

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