Integrating Legal Considerations into Model-Based Cyber-Physical-Systems Development

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Abstract: Developing complex cyber-physical systems (CPS) demands a variety of disciplines like engineering, software development, economics and legislation to effectively communicate with each other. Enabling this interdisciplinary communication is a challenge that can be tackled with the use of a model-based systems engineering approach in combination with domain-specific modeling languages. In domain-specific modeling frameworks that implement these approaches, however, research reveals an oversight: an insufficient consideration of legislation disciplines. Since regulations have a significant impact on CPS, omitting their incorporation early on during development can significantly delay deployment and lead to exponentially rising development costs. This position paper advocates for a compliance-by-design approach through the early integration of legal requirements into domain-specific architecture frameworks. By bridging the gap between technical and legislative disciplines, the interdisciplinary development of CPS is enhanced, not only ensuring the technical robustness of the systems but also regulatory compliance. This results in mitigating development risks, especially avoiding pitfalls of costly adaptions to the system due to late-stage integration of legal considerations.

1 INTRODUCTION

Dependability in the landscape of complex cyber-physical systems (CPS), has emerged as a challenge. Dependable systems, by definition, must be reliable, available, maintainable, safe, and secure (Laprie, 1995). When developing these systems, multiple disciplines such as engineering, software development, design, legislation, and management are involved. For the successful realization of CPS not only effective communication among these fields but also managing the system's complexity is crucial. A methodology that proved valuable for this purpose is model-based systems engineering (MBSE) (INCOSE Technical Operations, 2007). Using models as key artifacts, not only the complexity of systems can be mastered; by storing the models in repositories accessible to everyone involved, also a consistent source of truth is enabled. For effective communication between stakeholders from different fields so-called domain-specific languages (DSLs) are used as modeling languages for MBSE-based approaches. These languages are tailored to a specific domain so that they can be understood intuitively by all involved parties, leading to effective interdisciplinary collaborations (Fowler, 2010).

A well-known example of such dependable, complex CPS are power grids intertwined with information and communications technology, better known as smart grids (Steinbrink et al., 2018). Within the smart grid domain, the Smart Grid Architecture Model (SGAM) framework (Smart Grid Coordination Group, 2012) alongside an SGAM-specific DSL (Neureiter, 2017) was designed to facilitate a structured development approach for smart grids, that also effectively involves relevant stakeholders. However, the smart grid not only faces challenges due to its complexity and its necessity for dependability. This domain also has to deal with national and international legislation. Especially due to concerns regarding privacy and security, it faces numerous policies aiming at protecting consumers' privacy and security (Brown and Zhou, 2019). A tangible example of the importance of legislation is the smart metering rollout in Europe. (Zhou and Brown, 2017) found that

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national policy measures have a significant influence on the smart-metering deployment in Europe.

Developments centered around the SGAM framework, as well as similar manifestations in domains like the automotive claim to incorporate all relevant stakeholders. However, policymakers, regulations and legislation are frequently omitted. Legislative interventions can help drive smart grid advancements forward by utilizing regulatory mandates and enhancing social acceptance. Nevertheless, without effective communication between policymakers and engineers innovations like the smart meter rollout can also be significantly delayed (Faber et al., 2023). Moreover, if regulations influencing the development of systems are not considered from an early development stage, but need to be integrated during late phases, the development costs can increase exponentially. Therefore, the goal of this position paper is to raise awareness within the CPS development community, that the early integration of legal consideration is not just a compliance exercise but a strategic approach to ease communication between engineers and policymakers as well as avoid exorbitant expenses due to late changes of the system's architecture.

2 RELATED WORK

To underpin the position of this paper, the following section outlines research that has been conducted in the field of MBSE as well as the interdisciplinary development of complex systems. Moreover, to frame the context of this work, this section outlines architecture frameworks tailored to domains dealing with such complex systems as the Industry 4.0, automotive or smart grid domain.

2.1 Domain-Specific Architecture Frameworks

CPS are a challenge to master during development due to their high complexity. To tackle this challenge, systems engineering was extended by means of models, resulting in MBSE (INCOSE Technical Operations, 2007). However, without a well-structured approach, models alone are not sufficient for the development of complex systems. For that reason, in the smart grid domain for instance, the SGAM, as depicted in Figure 1, was developed during an initiative of standardizing smart-grid-related processes (Smart Grid Coordination Group, 2012). SGAM is a domain-specific framework that aids with a well-structured development approach tailored to the specific needs, perspectives, and viewpoints of

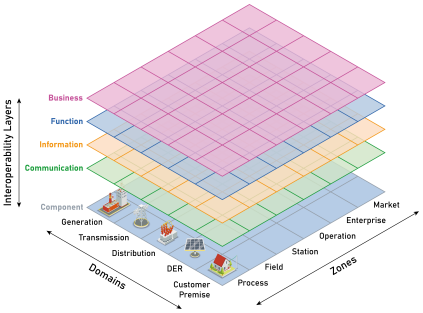

Figure 1: Smart Grid Architecture Model (figure based on (Smart Grid Coordination Group, 2012)).

the smart grid domain. Hence, this framework incorporates every stakeholder that is involved in smart-grid-related development processes, no matter which professional discipline they come from. To combine the theoretical approach of the SGAM framework with a model-based approach, (Neureiter, 2017) introduced a model-based DSL. Opposed to so-called general-purpose languages, which are typically used in MBSE, DSLs are tailored to a specific domain, being intuitively understandable for domain experts (Fowler, 2010). Hence, DSLs form a suitable model-based tool for the purpose of domain-specific frameworks. This advancement of utilizing DSLs for MBSE approaches results in so-called domain-specific systems engineering (DSSE) (Neureiter and Binder, 2022).

Inspired by the achievements of SGAM in the smart grid domain, similar initiatives have been undertaken in other domains such as Industry 4.0 and the automotive sector. These efforts led to the two frameworks Reference Architecture Model Industrie 4.0 (RAMI 4.0) in the Industry 4.0 domain (Deutsches Institut für Normung, 2016) and the Automotive Reference Architecture Model (ARAM) in the automotive domain (Polanec et al., 2022). Like the smart grid framework, both RAMI 4.0 and ARAM utilize DSLs to enable a model-based development approach.

These domain-specific architecture frameworks provide a suitable basis for effective interdisciplinary development of highly complex systems. In the following, this necessity for effective communication across different fields within the same domain is outlined in detail.

2.2 Interdisciplinary Development

When it comes to the development of highly complex CPS, typically numerous distinctive disciplines are involved in the process. The more complex the systems are, the more disciplines are involved and the more difficult it becomes to efficiently communicate

across the different involved fields. To overcome this challenge, well-structured interdisciplinary development approaches are needed as outlined by (Neureiter and Binder, 2022). The authors suggest the use of models to enable a holistic understanding of CPS. In engineering, models centered around clarity and understanding rather than detail and accuracy should be used according to (Lee, 2016). The DSL tailored to the SGAM framework was developed following this principle, utilizing a DSSE approach. (Neureiter and Binder, 2022) also highlight the importance of anticipating all stakeholder's perspectives. However, taking a closer look at the description of the business layer in the SGAM user manual (Smart Grid Coordination Group, 2014) the following content is defined: the business layer can be used to represent business capabilities, use cases, business processes, and business models; but also regulatory structures as well as policies. Hence, stakeholders from all of these fields should be taken into account when developing a model-based approach. In the past, research tried to address the issue of incorporating non-engineering fields.

(Pavlovic et al., 2016) considered the business layer of SGAM in detail, particularly focusing on the integration of business aspects in the context of local energy markets. While mentioning that this layer should host policies, the authors primarily concentrated on modeling elements like business actors and roles alongside their responsibilities.

To mention another example, the SGAM-based DSL implemented by (Neureiter, 2017) provides a practical application of the framework's theoretical concepts whilst advancing MBSE for smart grids. However, while enhancing the modeling and communication capabilities within the smart grid domain, this DSL on the business layer primarily focuses on the business aspects, omitting regulatory and legal considerations.

A similar focus on business aspects can be observed in the automotive domain and the development of the ARAM framework (Polanec et al., 2022). Hence, the importance of regulatory and policy considerations is recognized in the DSSE community, however, these aspects are not adequately incorporated into the system's architecture models.

3 POSITION STATEMENT

This position paper advocates for integrating regulation, interdisciplinary collaboration between policymakers and engineers as well as requirements engineering into early development stages—*by design*—of complex CPS. Following these principles leads to a paradigm shift towards a model-based *compliance-by-design* approach. This not only ensures that legal requirements are foundational elements of a system architecture. By enhancing interdisciplinary communication between policymakers and engineers utilizing domain-specific modeling frameworks, system development can be aligned with regulatory landscapes. Moreover, policymakers gain a well-structured and clear insight into the system architecture of complex CPS, facilitating comprehension of how regulations can be tailored to support the realization and deployment of CPS. Enabling this understanding, regulations can become enablers enhancing efficient deployment of CPS by eliminating potential obstacles through informed regulatory adaption. In the following, this position statement is outlined in detail.

3.1 Interdisciplinary Communication

The rollout of smart meters serves as an example to highlight the necessity of cooperation between policymakers and engineers regarding complex systems. To successfully facilitate not only the development of such systems in compliance with relevant regulations but also their public acceptance, engineers and policymakers need to share their respective expertise. However, effective communication between different disciplines introduces challenges. Different disciplines often use different professional terminology, which is not necessarily familiar to another discipline. At this point, the domain-specific frameworks come into play. To provide a holistic view of the system under development, these frameworks alongside their DSLs aim at incorporating all relevant stakeholders from different disciplines with a significant impact on the system's design. Regarding the integration of various technical and economic disciplines, there has been considerable research. However, the inclusion of legal disciplines has been minimal up to now.

3.2 Requirements Engineering as Enabler

In the context of domain-specific modeling frameworks, engineers are not familiar with the integration of legal texts. However, engineers are well-versed when it comes to the incorporation of technical standards, which form the basis for the identification of technical requirements. Since legal texts also serve as a source for requirements, the commonality between standards and legal texts lies within requirements engineering. Requirements engineering is the process

of evaluating, documenting and verifying stakeholder needs to identify key requirements of the system under development. Stakeholders can be natural persons, other systems, standards, or regulations that affect the requirements of the system directly or indirectly (Sommerville and Sawyer, 1997).

Frameworks like SGAM or ARAM, however, do not directly incorporate requirements within their structure or associated DSLs. Therefore, this gap should be closed by utilizing a focused approach to requirements engineering. Legal texts and regulatory guidelines could be incorporated within domain-specific frameworks by translating them into specific requirements. Hence, we recommend conducting research on how to directly or indirectly incorporate requirements with frameworks like SGAM or ARAM.

3.3 Compliance by Design

Research shows that regulations and legal considerations are not simply an obligation for the development of complex systems but can also have a significant influence on the design, operation and public acceptance of these systems. If not considered early on in the development phase, however, the deployment of systems can not only be delayed drastically; changes that are introduced at late stages of development can lead to exponentially increasing costs and might compromise the system's operational efficiency.

Drawing parallels from established approaches like security-by-design, (Vereno et al., 2024) recently discussed the concept of *compliance by design*. The authors emphasized the importance and benefit of MBSE in this approach, which highlights that compliance by design could prove valuable for the model-based development of complex systems. This approach ensures the seamless integration of legal considerations into the system's architecture from early development stages throughout the whole life cycle, facilitating the development of dependable systems that is compliant with regulations.

4 CONCLUSIONS

Developing CPS especially in domains like the smart grid or automotive presents challenges, like effective interdisciplinary communication due to the involvement of numerous stakeholders from diverse disciplines. Domain-specific architecture frameworks in combination with an MBSE approach, claim to address this challenge by providing a structured and comprehensive methodology for the interdisciplinary development of dependable CPS. Nevertheless, research presents a gap in the integration of regulations and legal considerations which have a great influence on CPS: regulations can positively influence their advancements by enhancing social acceptance. However, if integrated at late stages of development not only deployment is delayed but the costs of development can escalate exponentially. To properly prevent this risk, this paper outlined the following suggestions:

1. **Interdisciplinary Communication.** It is important for domain-specific architecture frameworks to not only integrate stakeholders like diverse engineers, developers and economists but to consider legislative disciplines as well, resulting in true interdisciplinary communication.
2. **Requirements Engineering as Enabler.** Regulations are a source for requirements. Hence, research should be conducted on how to effectively translate legal texts into specific requirements as well as how to combine this requirements-engineering approach with model-based domain-specific architecture frameworks.
3. **Compliance by Design.** Based on concepts like security by design, the presented suggestions need to be incorporated at early stages of CPS development, resulting in *compliance by design*.

By following a compliance-by-design approach, not only can expensive late-stage modifications be avoided, but it can also be assured that the development of dependable CPS complies with national and international legislation. Moreover, incorporating the language of policymakers into engineering frameworks can improve effective communication between those two parties, facilitating both, the alignment of CPS development with regulatory landscapes and comprehension of how regulations can support the acceptance, realization and deployment of CPS.

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