Framework for the Selection of Systems Engineering Modelling Languages and Methods for Special Purpose Machinery

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Abstract: This paper addresses the importance of how a model-based approach can optimise the management of Special Purpose Machinery (SPM) projects during the offer phase. It identifies a number of Systems Engineering languages and methods and creates a comprehensive comparative framework. This framework will help SPM users to apply sound criteria, compare them with their own needs and select an appropriate language and method to take the first steps towards implementing SE. Thereby it contributes to the success of complex SPM projects by ensuring comprehensive system modelling.

Keywords: Model-Based Systems Engineering (MBSE), Complex Systems, Modelling, Offer Management, Special Purpose Machinery

1 Introduction

For the economic stability and prosperity of the region, the competitiveness of European businesses is of paramount importance. In a globalised world characterised by technological change, stringent sustainability requirements and shifting market dynamics, businesses face a wide range of challenges and opportunities (Dumitrescu et al., 2021). They must continually improve their innovation, efficiency and adaptability to succeed in this dynamic environment (Albers et al., 2022).

The increasing complexity of product development requires a comprehensive, system-oriented approach and efficient coordination of interdisciplinary development teams. Systems Engineering (SE) is emerging as a suitable approach to address these challenges (Haberfellner et al., 2019; Wilke et al., 2021). According to the International Council on Systems Engineering (INCOSE, 2023), SE is defined as "a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles (Mundt et al., 2023) and concepts, and scientific, technological, and management methods" (INCOSE, 2023). SE seeks holistic solutions to complex problems. It considers all relevant design aspects, including resilience, safety, sustainability, usability, manufacturability and business models.

Studies show that many companies have recognised the need to implement Systems Engineering (Dumitrescu et al., 2021; Gausemeier et al., 2013). However, small and medium-sized enterprises face particular challenges, mainly due to their limited resources and expertise, which makes a transition difficult (Wilke et al., 2024b; Wilke et al., 2023b; Wilke et al., 2023c; Wilke et al., 2021). Nevertheless, the mechanical and plant engineering sector is of paramount importance for European competitiveness. “Germany contributes almost half of the European Union’s mechanical engineering value added. German engineering companies have an exceptionally high degree of vertical integration, reflecting their predominant role in providing tailored solutions to individual customer challenges” (VDMA, 2021). This trend towards product individualisation can also be observed in other industries, but especially mechanical and plant engineering. However, in order to improve performance and maintain or gain a competitive edge on the global stage, it is imperative to introduce interdisciplinary approaches within this engineering sector. Targeted support in the selection and implementation of SE methodologies is therefore crucial. To illustrate this need, this paper focuses on the Special Purpose Machinery (SPM) sector. SPM involves the development of highly specialised systems tailored to specific industrial needs. The offer phase (a similar term in this context is bid management) plays a key role in the success of SPM projects, enabling the customisation of solutions, the acquisition of competitive advantage and the overall success of the project (Kleinaltenkamp, 1999). Achieving competitive advantage in this industry requires the use of high quality system models that effectively capture the intricacies of these systems and facilitate an efficient development process (Philbin, 2008). However, choosing the appropriate modelling language and method for Systems Engineering activities can be a difficult task given the numerous options available, each with their own strengths and weaknesses (Tschirner et al., 2015). Therefore, an approach is proposed to investigate and analyse the existing languages and methods suitable for representing the offer phase in SPM. This paper presents a review of current state-of-the-art languages and methods, and formulates a catalogue of criteria for modelling languages and methods relevant to the offer phase in SPM (Wilke et al., 2024b). Furthermore, recommendations for the most appropriate approach are provided. The focus of this paper is on the approach and the identified criteria for SPM. The resulting framework can be used by companies to select languages and methods for their needs. The framework is for companies aiming to implement Model-Based Systems Engineering (MBSE) in order to achieve digital continuity. A tool selection is not included at this point.

1.1 Contribution and Methodology

Over time, a variety of modelling languages and methods have been developed. In the 1990s, modelling with the Unified Modelling Language (UML) became popular, particularly in software development. In 2007, the Systems Modelling Language (SysML) was created as part of an initiative by the International Council on Systems Engineering (INCOSE) and the Object Management Group (OMG). SysML is currently considered by INCOSE to be the standard for modelling complex systems. It can be used to represent and link requirements, system behaviour and system structures. The language is currently undergoing a revision based on feedback from the last few years. The final version of SysML v2 was approved by the OMG earlier this year. But is this formal language suitable for every company, such as SPMs? This paper aims to answer that question. An overview of methods and languages as well as the development of criteria shall support the selection of suitable modelling languages and methods.

In a first step, the concrete research questions are defined (chapter 1.2). These are used as the basis for the evaluation of the state of the art (chapter 2). The third chapter describes the procedure for establishing a framework for language and method selection. This includes the presentation of evaluation criteria (section 3.2), the presentation of a comparison framework (section 3.3), and an exemplary recommendation of a language and method for the offer phase in special purpose machinery (section 3.4). As an example, 11 languages and 19 methods are evaluated. Chapter 4 summarises the findings and provides a brief outlook. The research reported is part of the prescriptive phase of the Design Research Methodology (Blessing and Chakrabarti, 2009) and therefore no evaluation takes place, only an exemplary application.

1.2 Research Question

As mentioned in the introduction, the main objective in conceptual design during the early specification phase is the need to standardise the machine while taking into account the stakeholder requirements. For these reasons, the aim of this paper is to support the selection process of a modelling language and method in SE for the creation of a system architecture, using the example of the offer phase of special purpose machinery. This leads to the following research questions:

- Which methods and languages are suitable for the offer phase in special mechanical engineering?
- How could a company proceed with the selection of methods and languages?

In order to answer these research questions and to evaluate the state of the art, requirements for the solution have been developed and are specified in Table 1. The requirements are based on the literature and were derived from the problem analysis. They have been formulated in accordance with the INCOSE Guide to Writing Requirements (INCOSE Requirements Working Group, 2022). For example, the area of SPM should be considered in the context of this work (R1). An evaluation support should also be provided (R4) according to the specific criteria, all information relevant to the offer should be taken into account (R2) and so on.

Table 1. Requirements for developing a selection framework for SPMs

R1 – Consideration of the area of SPM	The approach shall consider the specific characteristics and requirements of the SPM domain. It ensures that the assessment process aligns with the unique needs of SPM for a thorough evaluation.
R2 – Mapping of all offer-relevant information	The approach shall provide relevant information and data required during the SPM offer phase. The information shall include cost and time estimates, feasibility studies, and other background information necessary to prepare an accurate offer.
R3 – Rapid design creation or adaptation should be taken into account	The approach shall enable the design creation or adaptation to be performed with optimized efficiency and responsiveness, ensuring that processes are streamlined and outcome-focused within the operational constraints of the SPM industry. The SPM industry is very dynamic, where companies not only need to develop new systems from scratch but also need to modify and adapt their product based on stakeholder requirements.
R4 – Provide evaluation support according to the specific criteria	The approach shall include a guideline for the development of specific evaluation criteria for the SPM offer phase, enabling the effectiveness of different languages & methods to be assessed in terms of performance, efficiency and other factors.
R5 – Enable identification and selection of appropriate languages and methods	The approach shall include a defined process to systematically identify and select the most appropriate languages and methods for the SPM offer phase, detailing steps for exploration, comparison, and selection based on predefined criteria.

R6 – Provide a guiding method for the user	The approach shall provide a methodology that guides users to make informed choices based on their needs and objectives, highlighting the strengths and weaknesses of existing languages and methods and assisting in the selection of the most appropriate option.
R7 – Ease of usability	The approach shall provide a clear and structured framework to guide the user through the decision-making process and help them quickly identify the best choice given their goals and needs.
R8 – Ensure universal applicability to all SPM	The approach shall be universally applicable across the SPM industry, suitable for various types of SPM companies regardless of size or project scope.

2 State of the art

The main objective of this chapter is to examine the current state of the art for evaluating MBSE languages and methods for the offer phase in SPM. An open access literature search was conducted to identify and analyse relevant scientific literature. The research has shown that there are only a few studies that focus on this specific topic. Figure 1 shows an overview of the considered approaches from areas of manufacturing, mechatronics, SPM, offer phase, different MBSE languages and methods and their comparison, as well as the criteria to be considered for the comparison. The authors reviewed and quality controlled each other's evaluations.

Evaluation Scale:

● Fulfilled

◐ Partially fulfilled

○ Not fulfilled

		Requirements							
		Consideration of the area of SPM	Mapping pf all offer-relevant information	Rapid design creation or adaption	Evaluation support	Identification and selection of language and methods	Provide a guiding method for the user	Ease of usability	Ensure universal applicability to all SPM companies
	Approaches	R1	R2	R3	R4	R5	R6	R7	R8
MBSE in the manufacturing domain	A Review on Application of MBSE to Manufacturing and Production Engineering Systems AKUNDI, A.; LOPEZ, V.	◐	○	○	○	◐	◐	◐	◐
	MBSE for Machine Tools and Production Systems (Model-Based Production Engineering) KÜBLER, K.; SCHEIFELE, S.; SCHEIFELE, C.; RIEDEL, O.	◐	○	○	○	○	○	○	◐
MBSE in the mechatronic systems	A SysML-based methodology for mechatronic systems architectural design MHENNI, F.; CHOLEY, J.-Y.; PENAS, O.; PLATEAUX, R.; HAMMADI, M.	◐	○	○	◐	○	◐	◐	◐
	Customer-centric and function-oriented development of mechatronic systems ZERWAS, T.; JACOBS, G.; BRAND, L.; DEHN, S.; SPÜTZ, K.; HÖPFNER, G.; MATZ, C.; GUIST, C.; BERROTH, J.; KONRAD, C.; KOHL, J.	○	◐	○	○	○	○	○	○
	Interdisciplinary structural modeling of mechatronic production systems using SysML4Mechatronics KERNSCHMIDT, K.	◐	○	◐	○	○	○	○	◐
	Mechatronic System Design using MBSE and Set-Based Concurrent Engineering Principles BORCHANI, M. F.; AMMAR, R.; HAMMADI, M.; CHOLEY, J.-Y.; YAHIA, N. B.; BARKALLAH, M.; LOUATI, J.	◐	○	◐	○	○	◐	○	◐
Special Purpose Machinery	Durchgängiges mechatronisches Engineering für Sondermaschinenbau FRANK, G.	●	○	◐	○	○	○	○	◐
	General Engineering data model in Special Purpose Machine engineering QI, Z.; SCHAFER, C.; KLEMM, P.	◐	○	○	○	○	○	○	◐
	Modeling Dependencies to Improve Cross-domain Collaboration in the Engineering Process of SPM HELBIG, T.; ERLER, S.; WESTKÄMPER, E.; HOOS, J.	◐	◐	○	○	○	○	○	◐
Offer Phase	A critical overview of the RFQ process of a Global Company AHMED, M.; TOSTE, E.	○	◐	○	○	○	○	○	○
	Effort estimation in quotation phase of complex project development TIUC, D.; DRAGHICI, G.	◐	◐	○	○	○	○	○	○
	Using lean principles to streamline the quotation process: a case study BUZBY, C. M.; GERSTENFELD, A.; VOSS, L. E.; ZENG, A. Z.	○	◐	◐	○	○	○	○	○
Modelling language and methods	Business Process Modelling Language: A Comparative Framework PEREIRA, J. L.; SILVA, D.	○	○	○	◐	◐	◐	◐	○
	Selecting a Process ML für Process Based Unification of Multiple Standards and Models BALLA, K.; TRIENEKENS, J. J.; KELEMEN, Z. D.; KUSTERS, R. R.	○	○	○	◐	◐	◐	◐	○
	Survey of Model-Based Systems Engineering (MBSE) Methodologies ESTEFAN, J.	○	○	○	◐	◐	◐	◐	○
	New MBSE Methodology Based on transdisciplinary Quality System Development Lifecycle Model ABDELRAZEK, M.; ARAFA, A.	○	○	○	◐	◐	◐	◐	○
Criteria identification	A decision-making framework for selecting an MBSE language – A case study to ship pilotage BASNET, S.; BAHOOTOROODY, A.; CHAAL, M.; VALDEZ BANDA, O. A.; LAHTINEN, J.; KUJALA, P.	○	○	○	◐	○	◐	◐	○
	Key properties for comparing modeling languages and tools: Usability, completeness and scalability LETHBRIDGE, T.	○	○	○	◐	○	◐	◐	○
	A Taxonomy of MBSE Approach by Languages, Tools and Methods SAQUI-SANNES, P. DE; VINGERHOEDS, R. A.; GARION, C.; THIRIOUX, X.	○	○	○	◐	○	◐	◐	○

Figure 1. State of the art for developing a selection framework

From the state of the art, it is evident that the analysis of existing MBSE languages and methods shows a gap in the literature, especially with respect to the offer phase of SPM. Therefore, there is a need to explore languages and methods that address the unique aspects of the SPM domain and the offer phase. Although there is literature that compares languages and methods in general (c.f. Figure 1) e.g. (Abdelrazik et al., 2019; Di Maio et al., 2021; Dori et al., 2014; Mostafa Aboushama, 2020; Pereira and Silva, 2016; Zingel, 2013), there is a noticeable lack of comparison that encompasses the necessary aspects of system modelling in the context of the offer phase and SPM. Furthermore, although some papers discuss the use of model-based approaches and its advantages for SPM e.g. (Helbig et al., 2016), they do not provide a comprehensive comparison and evaluation that can guide the user in selecting the appropriate languages and methods. Also, some of the literature examines the criteria that need to be considered when comparing languages and methods, but they do not necessarily consider the aspects of the bidding phase and SPM (cf. Figure 1). There are approaches to selecting modelling languages for mechatronic systems in manufacturing and production as a whole e.g. (Akundi and Lopez, 2021; Kübler et al., 2018), but no literature does this specifically for SPM. Therefore, further research is needed to identify and define the specific requirements for modelling an SPM system, focusing on the offer phase. The uniqueness of the offer phase within the SPM domain requires special study. It differs significantly from other project phases in terms of objectives, constraints, and decision-making processes. This makes the gap in the literature particularly apparent. This research will fill the existing gap and enable practitioners to effectively model and analyse complex systems within the offer phase. A comparison of the state of the art with the requirements from Table 1 leads to the following assessment, as shown in Figure 1. A close examination of Table 1 reveals that no existing work fully addresses the requirements set forth in this research. This observation clearly highlights the critical need for this study to address the specific challenges and requirements of the SPM offer phase. The lack of a comprehensive and tailored comparison of MBSE languages and methods for the SPM offer phase demonstrates the importance in guiding practitioners and researchers to effectively model and analyze complex systems during this critical project phase, ultimately leading to improved project outcomes.

3 Development of a language and method selection framework

In this section, the framework to select suitable languages and methods for the offer phase of SPMs is presented. Based on the defined requirements and the state of the art, a procedure for the development was defined (section 3.1). In chapter 3.2 the criteria determination for the framework is presented. The final section provides a recommendation of a selection for the offer phase of SPMs. It also explains how companies can apply the framework to their own needs.

3.1 Procedure for the development

Figure 2 shows the defined milestones for the development of the framework. The procedure consisted of five parts. First, a literature review was conducted to identify all languages and methods. Criteria were then identified and defined to evaluate the languages and methods in general, for special purpose machinery and explicitly for the offer phase. This is described in more detail in chapter 3.2. An exploration followed. The identified languages and methods were filtered and those not related to SE were excluded. In the literature search, the advantages and disadvantages of the languages and methods were collected in detail. In the process, 350 literature sources were analyzed. The languages and methods were then ranked according to the defined criteria. This and the recommendation are described in detail in chapter 3.3.

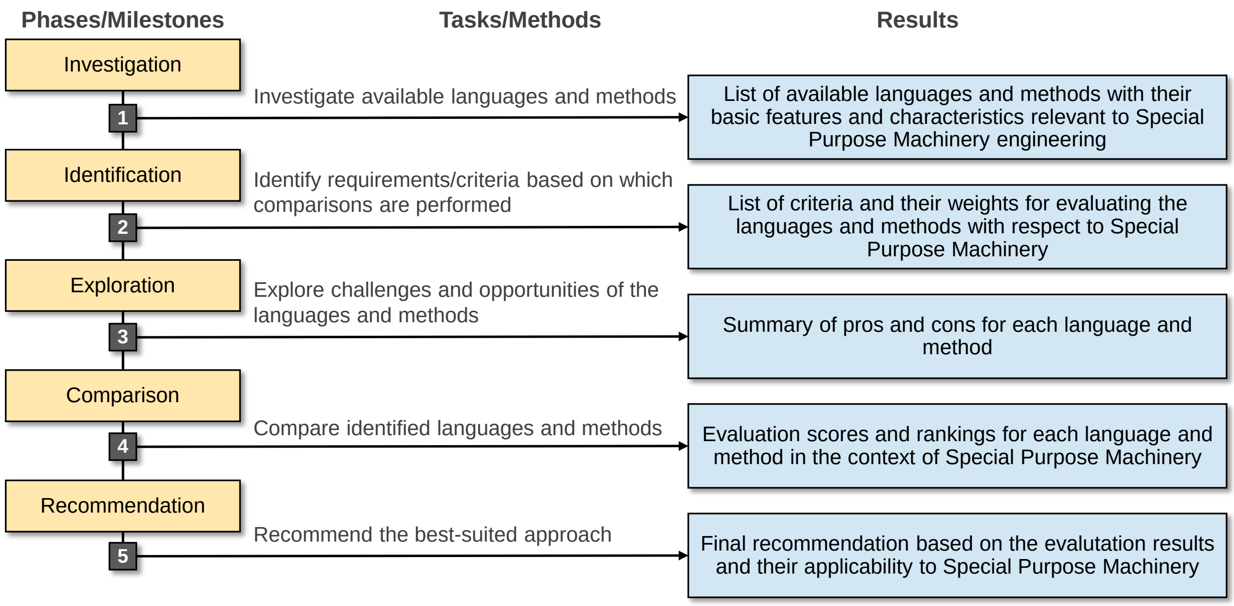

Figure 2. Procedure for developing a selection framework

3.2 Criteria determination for the evaluation of languages and methods

Based on the solution plan shown in Figure 2, this section describes the second step, the identification of criteria for evaluating languages and methods. This section presents the guidelines for modelling the system by identifying the modelling capabilities of languages and methods based on an offer phase and SPM requirements. The development of the list of criteria is based on the literature and the requirements of the offer phase in SPM. These criteria give direction to the investigation and allow for a structured and systematic evaluation process. The criteria can be categorised into several dimensions, each addressing different aspects of relevance. In the case of this paper, the catalogue of criteria is divided into three categories: Category 1 identifies the criteria related to the SPM domain. Category 2 identifies the criteria of languages and methods required to model all information needed in the offer phase of SPM. Category 3 identifies the general criteria that can be useful in selecting the most appropriate modelling language and method. The Framework for the Evaluation of MBSE Methodologies for Practitioners (FEMMP) was also considered in the selection of criteria. The FEMMP defines a set of criteria against which methodologies are evaluated (Weilkiens et al., 2016). Table 2 shows the result of the criteria from category 2. By way of example, the criteria that are important for the offer phase in special purpose machinery are explained. All identified criteria are shown in Figure 4.

Table 2. Exemplary explanation of the criteria for the offer phase of special purpose machinery

Requirement elicitation	Accurately capturing and understanding customer requirements is critical to the success of any project. Since the offer phase is created for the customer based on their requirements, it is critical to understand them properly. The language or method chosen should facilitate clear communication between those involved in the project and the customer, and enable comprehensive requirements to be established. It should be able to handle different types of requirements, including functional, non-functional, and user requirements.
Cost estimation	Cost estimation is one of the most important factors during the offer phase. An accurate cost estimate helps to create a competitive and compelling offer(Hooshmand et al., 2016). Effective cost estimation helps project managers set realistic budgets, make informed decisions, and present a reliable offer to the client, and also helps the offer stand out from the competition. Therefore, the language/method should be able to provide an effective cost estimate.
Risk assessment	Similar to cost estimation, risk assessment plays an important role during the offer phase. It provides project managers with early information about potential risks and ultimately helps them make an informed decision. A robust language/methodology should have a mechanism to identify different types of technical, financial, or organizational risks.
Documentation	Any language/method should provide effective documentation and track offer-relevant content. Clear and well-documentation helps understand the project and facilitates the team members with the necessary information.
Collaboration	Effective communication and collaboration are crucial to the success of any project. They enable stakeholders to communicate, share knowledge, and work as a team. The chosen language or method should provide collaborative features (Wilke et al., 2024a) that allow team members to work together efficiently, synchronously, or asynchronously, regardless of their geographic location. Collaboration also increases productivity, reduces errors, and improves decision-making processes by facilitating the exchange of ideas and feedback.
Time constraints	Time is another important factor during the offer phase. The customer always wants the product as quickly as possible and without delay on the agreed delivery date. Therefore, the language/method under consideration should be able to provide time constraints that help project managers define clear milestones, set realistic timelines, and make an informed decision to the customer that will increase customer satisfaction.
Modification management	Many projects start with requirements provided by the customer. Nevertheless, over time, updates and changes to the requirements are inevitable, and the language/ method should be able to handle this. Effective modification management ensures that the teams can adapt to evolving customer needs with minimal interruption, improving project agility and customer satisfaction.
Extensible	Any language/method should be capable of covering the project’s entire life cycle and its subsequent stages. Anyone who wants to implement the language/method wants long-term usability and to incorporate knowledge throughout the project. Therefore, the chosen language/method should not be limited to the initial phase of the project but should have the ability to be extended throughout the entire lifecycle.

3.3 Language and method recommendation for the offer phase in special mechanical engineering

In this paper, the comparative framework represents a central stage in the analysis of modelling languages and methods. The comparative framework evaluates a filtered list of modelling languages and methods against the list of criteria presented in section 3.2. The evaluation was carried out through a thorough literature review using the 7-point Likert scale. A 7-point Likert scale provides seven different response options related to a level of agreement that is clear enough for the respondent without confusing them. The 7-point Likert scale was chosen because it is known to be the most accurate of the Likert scales and has other advantages (Formplus, 2023): It is easy to use. It provides a better reflection of the respondent's true rating. And it is the best solution for questionnaires such as those that are used in usability evaluations. The 7-point Likert scale rating is depicted in Figure 3 (Taherdoost, 2019).

Rating	Corresponding detail
1	Strongly Disagree
2	Disagree
3	Somewhat Disagree
4	Neither Agree nor Disagree
5	Somewhat Agree
6	Agree
7	Strongly Agree

Figure 3. 7-point Likert scale for the assessment of methods and languages

Figure 4 shows an extract from the final evaluation of the languages and methods based on the defined criteria. Some of the information not available in literature is rated 4 on the 7-point Likert scale, meaning that the requirements are neither met nor unsatisfied. Two additional reviewers confirmed this assessment. At this point, the authors emphasize that Figure 4 represents a subjective evaluation based on the literature. By acknowledging the subjective nature of the evaluation, the authors demonstrate transparency and highlight the need for further investigation. It is critical to ensure that the chosen language and method are compatible. This compatibility check will help ensure that the chosen approach effectively addresses the challenges and meets the criteria of a specific company.

Criteria list		Modelling Languages											Modelling Methods																		
		SysML	UML	MARTE	SysML4CONSENS	ModelicaML	LML	AADL	EAST-ADL	SysML4Mechatronics	SoaML	…	OOSEM	SYSMOD	Arcadia	RUP-SE	STRATA	RePoSyD	OPM	ASAP	Grid	UAF	LITHE	Motego	SPES	SA	ViTech	Harmony SE	CONSENS	SpecIF	…
General criteria	Reusability	7	7	6	7	7	4	7	7	7	7	…	7	7	7	6	6	7	1	7	7	6	7	7	3	4	7	7	7	6	…
	Learnability	3	5	3	3	5	7	3	5	3	5	…	3	3	5	3	7	4	6	6	2	3	6	4	6	4	3	7	6	4	…
	User-friendly	3	2	3	3	7	7	7	5	6	6	…	3	6	6	5	6	7	6	6	6	5	7	6	3	4	4	3	6	4	…
	Redundancy											…	5	4	7	4	7	3	6	4	5	5	4	4	4	4	3	3	7	7	…
	Consistency	7	3	1	7	3	2	3	7	7	7	…	6	6	7	7	7	7	7	7	7	6	6	6	7	7	7	7	7	4	…
	Tool support	7	7	6	7	6	7	2	3	3	6	…																			…
	Tool independence											…	7	7	1	1	1	7	1	7	7	4	4	4	7	1	6	7	5	7	…
	Systematic approach	7	7	3	7	5	3	7	6	6	6	…	7	1	7	7	7	7	7	4	1	7	7	4	7	6	1	6	5	7	…
	Requirement	7	3	6	7	7	7	5	5	3	6	…	6	7	7	7	6	7	3	5	6	7	6	7	7	1	7	6	7	7	…
	Functional	7	6	7	7	7	7	7	7	6	7	…	3	7	5	6	6	7	5	7	6	7	7	7	7	6	6	7	7	7	…
	Logical structure	7	7	7	7	6	7	7	5	7	7	…	7	6	7	7	7	7	7	1	6	7	7	7	7	4	6	7	7	7	…
	Physical structure	7	7	7	7	6	7	7	7	7	6	…	7	6	7	7	7	7	7	6	6	7	7	7	6	4	7	1	7	4	…
SPM criteria	Complexity	7	7	7	7	7	7	6	5	7	7	…	6	5	7	6	5	6	5	7	7	7	7	7	6	6	5	4	7	7	…
	Compatibility	3	7	5	6	6	4	5	3	7	7	…	7	7	6	3	6	7	7	5	7	3	7	7	6	4	4	4	7	7	…
	Performance analysis	7	5	7	3	7	7	7	5	4	4	…	6	4	7	5	4	4	1	1	7	7	7	4	7	7	3	7	6	4	…
	Scalability	7	6	3	4	4	4	7	7	4	7	…	7	7	7	7	6	7	6	7	7	5	4	4	7	4	4	4	7	7	…
	Adaptability/customization	5	5	5	7	4	6	6	7	6	6	…	7	7	6	7	7	3	6	5	7	7	7	4	7	4	4	4	4	6	…
	Variants	3	3	4	4	7	4	3	7	7	7	…	3	6	5	1	7	6	6	3	6	3	3	1	4	4	1	5	6	7	…
	Integration	7	7	4	5	6	4	7	7	7	7	…	2	1	2	1	6	6	6	3	6	3	3	1	4	4	1	5	6	7	…
Offer phase criteria	Requirement elicitation	7	3	7	7	7	7	6	7	7	7	…	7	7	7	7	7	7	7	7	6	6	7	7	7	7	7	7	7	7	…
	Cost estimation	2	3	1	4	1	7	6	3	4	1	…	1	1	7	6	5	4	1	7	1	6	7	3	1	4	5	6	7	6	…
	Risk assessment	6	6	7	7	1	7	7	7	5	6	…	5	1	7	7	5	7	1	1	7	7	7	1	6	1	7	6	4	4	…
	Documentation	7	7	7	7	3	7	4	7	4	6	…	6	7	6	7	5	6	6	6	7	7	7	6	7	7	5	7	7	7	…
	Collaboration	5	6	5	4	7	7	4	7	4	7	…	7	7	7	7	7	7	7	6	6	6	7	4	7	4	7	6	7	7	…
	Time constraints	2	1	7	4	4	7	7	7	1	4	…	1	4	4	7	4	7	1	1	4	3	4	1	1	4	5	4	6	4	…
	Modification management	7	5	4	7	4	4	4	4	7	4	…	7	6	7	7	7	4	7	7	6	4	7	4	7	4	6	6	4	7	…
	Extensible	3	7	7	7	5	7	6	7	7	6	…	3	7	7	7	4	4	3	7	3	7	5	4	6	6	4	4	6	7	…
	Sum	140	132	129	145	132	147	140	147	136	149	…	136	137	158	145	152	155	126	132	143	148	159	126	150	116	130	136	162	157	…

Figure 4. Extract from the languages and methods evaluation matrix

The highest overall score of 162 was reached by the language and method CONSENS. This means that it meets the most criteria. The system design of intelligent technical systems can be supported with the help of the CONSENS modelling language and method (Gausemeier et al., 2019). It is a consistent approach to the holistic and interdisciplinary description of mechatronic systems for creating the system model in the concept phase. The abbreviation stands for CONceptual design Specification technique for the ENgineering of complex Systems (Gausemeier et al., 2019).

It is closely followed by LITHE and Arcadia; also strong contenders with scores of 159 and 158 respectively. On the other hand, OPM, with a score of 126, appears to be one of the lowest, lacking factors such as cost estimation, risk assessment and performance analysis, which are essential for modelling SPM projects.

Interestingly, different languages and methods emerge as the best choices when focusing solely on SPM or offer phase criteria. When considering specific criteria, it's worth noting that if only SPM criteria are selected as the primary focus, then the best option would be SoaML, as it performs well in this regard. However, if only the offer phase is considered, RUP-SE emerges as the top choice. This provides users with valuable alternative perspectives when choosing a language or method for their modelling needs.

In summary, the choice of the best language and method should be based on a careful assessment of project-specific needs and criteria. CONSENS, LITHE and Arcadia currently lead the field in overall performance, but others may excel in specific contexts. It's important to tailor the choice to those needs, and the criteria above provide a starting point for making an informed decision.

3.4 Example application of the framework

The following application example clearly illustrates the ability to tailor the comparison framework to specific criteria, thereby enabling strategic decision making that is closely aligned with the unique requirements of the offer phase in SPM. It provides an insight into how the comparative framework can be tailored to the user's needs and how the choice of modelling language and method can change depending on the criteria selected for evaluation. It is emphasised that the choice of modelling language and method should not be seen as a 'one size fits all' decision, but rather as a customised approach that responds to each user's priorities and objectives. This flexibility allows users to make strategic choices that best suit their modelling needs in different contexts and scenarios.

Suppose a user wants to create a system model for the offer phase in SPM. They want to identify the most appropriate modelling language and method. Their main priorities are ease of learning and use for their team members. They also want to be able to use the language and method to estimate costs and risks during the offer phase. Furthermore, the chosen language and method must be compatible with SPM projects and be able to analyse the performance of the system. Based on the information provided by the user, the comparison framework can be tailored to evaluate the description provided by the user and would be as follows.

Criteria list		Modelling Languages											Modelling Methods																		
		SysML	UML	MARTE	SysML4CONSENS	ModelicaML	LML	AADL	EAST-ADL	SysML4Mechatronics	IDEF	…	OOSEM	SYSMOD	Arcadia	RUP-SE	STRATA	RePoSyD	OPM	ASAP	Grid	UAF	LITHE	Motego	SPES	SA	ViTech	Harmony SE	CONSENS	SpecIF	…
	Learnability	3	5	3	3	5	7	3	5	3	5	…	3	3	5	3	7	4	6	6	2	3	6	4	6	4	3	7	6	4	…
	User-friendly	3	2	3	3	7	7	7	5	6	5	…	3	6	6	5	6	7	6	6	6	5	7	6	3	4	4	3	6	4	…
SPM criteria	Compatibility	3	7	5	6	6	4	5	3	7	7	…	7	7	6	3	6	7	7	5	7	3	7	7	6	4	4	4	7	7	…
	Performance analysis	7	5	7	3	7	7	7	5	4	7	…	6	4	7	5	4	4	1	1	7	7	7	4	7	7	3	7	6	4	…
Offer phase criteria	Cost estimation	2	3	1	4	1	7	6	3	4	7	…	1	1	7	6	5	4	1	7	1	6	7	3	1	4	5	6	7	6	…
	Risk assessment	6	6	7	7	1	7	7	7	5	4	…	5	1	7	7	5	7	1	1	7	7	7	1	6	1	7	6	4	4	…
	Sum	24	28	26	26	27	39	35	28	29	35	…	25	22	38	29	33	33	22	26	30	31	41	25	29	24	26	33	36	29	…

Figure 5. Custom application of the framework based on selected criteria

Figures 5 is the result of translating the user requirement to the potential list of modelling languages and methods to provide a comparative framework. From Figure 5 it can be concluded that the most suitable method is LITHE with 41 points. Besides LITHE, Arcadia is also a viable option for the criteria considered. This result also differs from what was observed in Figure 4, where the CONSENS method received the highest score. A good language is LML, taking into account the criteria specified by the user. LML seems to satisfy most of the user requirements.

From the above observations and recommendations, it is clear that there is no universally ideal language or method for modelling the SPM offer phase. Instead, the choice should be tailored to the user's needs, bearing in mind that not all languages and methods can satisfy every criterion. Therefore, the proposed comparative framework serves as a valuable resource, providing the user with a guide to learn more about the languages and methods and make an informed decision based on their individual needs and priorities. A company can use this framework to create a ranking to determine the language and method best suited to its needs. However, it is important to check that the language and method are compatible. The result is only a basis for decision making and it may be necessary for the company to further adapt the language and method (Wilke et al., 2023a). In practice, it is important to evaluate the method, the language and the MBSE tool and to ensure their compatibility. It is emphasized that the tool must fit the chosen language and method, and only one specific example is given here to illustrate this. It should also be considered whether MBSE has already been implemented in parts of the company. This may also affect the choice of language and method.

4 Summary and Outlook

As industries become increasingly complex, SPM must integrate multiple disciplines and manage processes effectively. Systems Engineering has emerged as a comprehensive approach to this challenge, providing a structured methodology for designing, analyzing, and managing complex systems throughout their lifecycle. This paper examines the field of SE and explores its application in the context of the offer phase for SPM. The offer phase plays a key role in developing the SPM, where the needs and requirements of the potential customer are assessed and defined, and preliminary system architectures are conceptualized. This phase lays the foundation for the entire project lifecycle and underlines the importance of accurate and comprehensive system modelling. Hence, the thesis explores the different languages and methods within SE, recognizing their importance in this endeavor.

The research objectives were achieved within the scope of this research paper. The main objective was to identify the different languages and methods available and to investigate the scope and benefits each provides for creating a system model. In addition, the secondary objective was to guide the user in selecting the most appropriate language/method based on their specific requirements. In order to achieve this, the paper first examined the state of the art languages and methods that support the creation of a system model. Based on thorough research, a list of languages and methods was generated, further refined and filtered to match the SPM offer phase. At the same time, a list of criteria was created, taking into account the different stakeholder requirements in the area of the SPM offer phase. The criteria and languages/methods were then used to create a comparative framework that explored the different aspects of the languages and methods. In order to help the user make an informed decision during the selection process, a 7-point Likert scale rating was provided using this comparative framework.

As the paper relates to the prescriptive phase of DRM, there are currently no results on the actual applicability and support of the proposed selection framework in practice. It has only been carried out as an example. The current criteria for system modelling in SPM are based on a thorough literature review. However, they should be cross-checked with real company feedback as they are likely to evolve. Case studies with real examples of custom-built systems can validate the effectiveness of the modelling languages and methods being investigated. Collaboration with industrial partners can apply the research results in practical scenarios. Interdisciplinary perspectives of system modelling for SPM can be explored by collaborating with experts from other fields. The integration and impact of a company's existing IT tool landscape, such as the use of specific CAD and PDM/PLM tools, could also significantly influence the choice of modelling languages and methods. This consideration could be further explored in future research.

Acknowledgement

This research and development project is/was funded by the Ministry of Economy, industry, climate action and energy of the State of North Rhine-Westphalia (MWIKE) in the context of the Leading-Edge Cluster ‚Intelligent Technical Systems OstWestfalenLippe (it‘s OWL)‘ and super-vised by Project Management Jülich (PtJ). The responsibility for the content of this publication lies with the author.

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