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Towards a Comprehensive Understanding of Stakeholder Frameworks in Systems Engineering: A Systematic Literature Review

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Abstract

Stakeholder engagement is critical in developing complex socio-technical systems. While Systems Engineering (SE) acknowledges their role, existing frameworks for identifying, communicating, applying, and integrating stakeholders remain fragmented and inadequate. This systematic literature review investigates existing frameworks for stakeholder engagement, contributes to a structured understanding of current practices and identifies critical gaps. A search across four databases yielded 1,149 results, from which 34 approaches were selected. Each was evaluated by three dimensions: the goals of the approach (e.g., supporting traceability of needs or enabling effective communication), its methodological foundations, and its application context. Findings show that no framework offers a satisfying solution across all dimensions; most are narrow in scope or lack validation. Only few approaches cover all phases of stakeholder engagement, from early identification to structured traceability and requirement elicitation. This review reveals a clear gap: the lack of validated, MBSE-compatible stakeholder frameworks that unify identification, interaction, traceability and requirement definition. Future research should develop and empirically test integrative, MBSE-ready approaches that are both rigorous and usable in practice.

Keywords: Stakeholder, Framework, Systems Engineering, Systematic literature review, Engagement

1. Introduction

Stakeholder needs are central to product development, especially as systems and their requirements become more complex. Enhanced communication tools have increased stakeholder interactions, while ongoing trends in digitalization, sustainability, and cybersecurity are contributing to more interdisciplinary requirements in the product development process [1].

Stakeholder frameworks help manage stakeholders and their evolving needs, which are essential to product development. Stakeholder needs reflect expectations for the system and fulfilling them adds real value, making their identification and integration crucial in the PDP [2]. These expectations transfer to specific product requirements. Effective frameworks must also maintain traceability and control of changing needs and requirements throughout all development phases, not just during initial elicitation [3].

Meeting end user needs is central to the PDP and closely linked to customer satisfaction and system success [4,5]. Early and ongoing stakeholder engagement not only improves project outcomes but also lowers costs in requirements engineering due to fewer needed resources [4]. Involving stakeholders early helps address changing demands throughout development [6].

Current research suggests that the engagement with all stakeholders, not only end users, to elicit requirements for the system under development is a valuable process but also raises challenges especially in complex systems and multidisciplinary scenarios. However, existing approaches often lack a structured foundation for operationalizing stakeholder involvement across the PDP, which hinders their consistent adoption in practice. A systematic investigation of available frameworks is therefore needed to understand their contributions and limitations.

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2. Stakeholders in Systems Engineering

Systems Engineering (SE) and Model-Based Systems Engineering (MBSE) are both interdisciplinary approaches that cover the whole PDP and aim to ensure that the needs and expectations of all stakeholders are satisfied [1,2]. A part of this is to encourage using frameworks for facilitating and coordinating stakeholder interaction. In this study, stakeholder engagement refers to all activities through which stakeholders contribute to and interact with the development process, including their identification, the elicitation and clarification of their expectations, continuous communication during development activities and the traceability of their needs into system artefacts across all phases of the PDP. SE integrates insights from complementary disciplines such as sociology and psychology and provides structured processes for translating stakeholder needs into actionable requirements. MBSE extends these principles by employing model-based representations in place of traditional document-centric approaches. While model-based representations enhance the traceability during the development process and enable the description of highly complex systems, it also becomes a barrier for stakeholders without knowledge of the modeling language [3].

Both approaches are particularly applicable to the development of complex systems. However, they primarily provide abstract, generalizable principles rather than prescriptive, directly implementable methods. Especially in the field of cooperation and communication specific frameworks are not available, slowing down the application of agile principles [3,4].

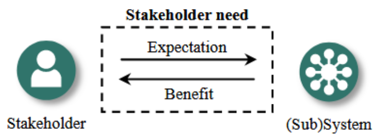

Figure 1 Stakeholder needs in SE according to Kubin et al. [2]

2.1. Stakeholder definition

The official definition of a stakeholder, as outlined in the INCOSE Systems Engineering Handbook [5], is as follows: *“A party having a right, share, or claim in a system or in its possession of characteristics that meet that party’s needs and expectations.”*

This broad definition potentially includes a wide range of individuals and groups as stakeholders. While such inclusivity ensures that no potential stakeholder is excluded, it also creates challenges in practical application, as stakeholders can differ widely across various systems and industries. Examples of stakeholders include users, customers, manufacturers, developers, project managers, and the general public, among others. In this context, "user" refers to the end user of a system, whereas "customer" denotes a commissioning body or prospective purchaser [2]. The large number and diversity of possible stakeholders significantly increase the complexity involved in identifying and engaging with them.

Stakeholders must be identified and their expectations elicited, as fulfilling these provides measurable benefits (see Figure 1). Their needs are then translated into structured, formalized requirements for developers to use in the PDP [1,2,5,6] . However, clear methods for identifying all relevant stakeholders and gathering their input are still needed.

2.2. Exemplary frameworks to involve stakeholders

To elucidate the current landscape of research on stakeholder frameworks within the PDP, three prominent models have been identified for analysis. Established reference approaches such as the SysML use case model and the stakeholder related viewpoints within the Industrial Internet Reference Architecture provide essential representations of stakeholder relations in system development, however they focus on structural and architectural viewpoints rather than on the practical engagement challenges targeted in this review. Therefore, this section concentrates on empirically investigated frameworks that propose concrete methods to support stakeholder interaction throughout development activities.

The Model-based System Architecting (MBSA) framework by Menshenin et al. [7] applies MBSE principles to the conceptual phase of system architecting. Its initial step consists of documenting stakeholder needs. Subsequent steps facilitate the development of multiple alternatives prior to selecting a final solution, enhancing and strengthening communication with stakeholders and improving traceability and transparency throughout the PDP. This allows stakeholders to follow how their requirements impact architectural decisions.

Madni [8] integrates SE modeling tools with game engines and VR interfaces, allowing stakeholders to interact with system prototypes in a virtual environment. A storyline immerses users further, making it easier to participate especially for non-engineers. System engineers continue using standard SE tools as they are used as foundation for the virtual model. The tool was applied to early-stage concepts, enabling stakeholders to give useful feedback to engineers upfront of any major design decisions.

A stakeholder identification method for new product development (NPD) described by Kain et al. [9] involves conducting interviews and using visual tools such as multiple domain matrices to identify stakeholders. This process takes place in the early stages of the NPD before any key design decisions. The visualizations help to recognize changing stakeholder requirements and address them, as well as illustrate how stakeholder influence shifts throughout the NPD.

All three frameworks primarily focus on early PDP stages and provide limited guidance for later development phases. Another key limitation is insufficient validation: Madni and Menshenin et al. used only self-designed exemplary applications, while Kain et al. conducted an industrial case study but did not develop an SE-compatible framework. All authors recommend conducting comprehensive studies to validate their concepts.

Existing frameworks tend to inadequately address the diverse challenges inherent in stakeholder engagement, frequently focusing on specific use cases or early-stage engagement rather than providing a comprehensive solution. The three examples underscore the lack of an integrated methodology that spans the entirety of stakeholder engagement throughout the PDP. Furthermore, the absence of a shared perspective concerning the timing, nature, and participants of engagement complicates both the assessment and selection of frameworks for practical implementation [10].

3. Research objective and design

The objective of this study is to provide a structured and comprehensive overview of existing stakeholder engagement frameworks within the product development process. This includes identifying their methodological foundations, analyzing how they support stakeholder interaction in practice and highlighting gaps that require further research to enable continuous and effective engagement across all development phases.

3.1. Research questions

The following research questions are designed to directly support the aim of mapping the current landscape, identifying classification criteria, and highlighting areas where further research is warranted.

RQ1: What approaches to the effective engagement of stakeholders within the product development process are discussed in scientific literature?

RQ2: How can these approaches be systematically classified and organized with suitable criteria?

RQ3: What research needs remain regarding the refinement, extension, and improvement of existing approaches?

To answer these research questions, a guideline for conducting a systematic literature review (SLR) is developed based on established SLR methods in the field of engineering and medicine. This guideline outlines procedures to comprehensively identify relevant research addressing the stated research questions and aims to provide an unbiased summary when consistently applied [15].

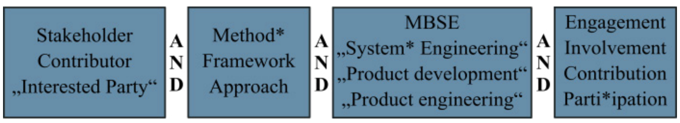

Figure 2 Search term

3.2. Research Design

A SLR reduces bias during study selection and data extraction, while providing a structured and objective overview of current research. [11]. The reasoning for the adaptation is to be as objective as possible and integrate the lessons learned in available systematic reviews. The general process consists of five phases relating to Ierardi et al. [12] among others:

3.2.1. Research phase

The first step in the research phase is to develop the research objective and consequently the research questions.

After defining the initial research questions, all steps were documented to support reproducibility. To ground the review in current terminology and industrial relevance, a focused literature scan was complemented by expert consultation. A professor, postdoctoral and doctoral researchers from TUHH as well as industry practitioners contributed to refining the research scope and search strategy prior to conducting the systematic review.

3.2.2. Planning Phase

Databases appropriate to the research field must be selected. For this study, four databases were used to reduce the likelihood of missing relevant literature. The Design Society database was included for its coverage of product development topics. Scopus was chosen for its broad range of publishers. INCOSE and IEEE Xplore were also incorporated due to their focus on systems engineering.

The next step involved establishing inclusion and exclusion criteria to eliminate obviously unrelated articles and low-quality research. The following quality criteria, encompassing the inclusion and exclusion criteria, were applied throughout the search process:

- Accessible via a TUHH account
- English and German language articles only
- (double-blind) Peer-reviewed papers exclusively
- Relevance to product development
- Novel or significantly modified frameworks

The final planning stage involved creating a Boolean search query, organized into four groups to minimize irrelevant results. Keywords were optimized with wildcards and paraphrasing. Figure 3 presents the English query; the same search was conducted in German.

3.2.3. Conduction phase

The conduction phase entails systematically searching relevant databases using the search query and initiating the screening process. Handling the extensive amount of literature, reference management software such as Zotero is utilised. In this review 1,149 records were initially identified. Subsequent steps include the removal of duplicate entries and the

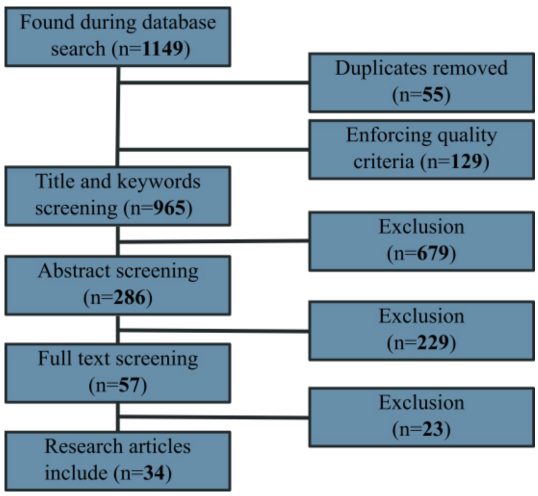

Figure 3 PRISMA diagram

application of quality criteria, followed by the evaluation of titles and abstracts for relevance. This screening is reiterated with both abstracts and full-text articles to determine the final set of studies for inclusion. Figure 2 visualizes the search and screening process according to the flow diagram of the PRISMA Statement [13].

3.2.4. Data extraction phase

After the literature search and screening, 34 papers remained. These have been reviewed and summarized in an overview table with key findings. Evaluation will begin by creating comparison criteria and identifying trends or gaps in current research, which will be discussed in Chapter 4.

3.2.5. Reporting phase

The reporting phase commences once all data has been gathered. This stage includes the preparation of the research paper, formulation of conclusions, and providing recommendations for future research on stakeholder engagement frameworks.

4. Results and discussion

A total of 34 frameworks will be evaluated to address the research questions. Given the number of studies, it is not feasible to provide a detailed evaluation of each framework. Nevertheless, we aim to present a holistic overview of the current research landscape, while acknowledging that an in-depth analysis of every framework cannot be guaranteed.

4.1. RQ1 – Overview and approaches to stakeholder engagement in the PDP

Several frameworks for stakeholder engagement focus on motivating stakeholders to participate in the PDP or on establishing systematic models for stakeholder engagement, as outlined by Morgan et al. and Madni [8,14]. Other studies highlight facilitation techniques, such as measures for high meeting participation introduced by Ankele et al. [15] or gamified stakeholder engagement strategies [16]. A smaller subset of articles explores the integration of AI and VR environments to enhance stakeholder participation especially during early development stages [8,14]. The review also identified a AI approach that aims to support the identification of expert stakeholders for future system generations [20].

A comprehensive review of all 34 research articles during data collection revealed that most developed frameworks address only specific use cases and frequently lack thorough validation (e.g., [17]). Furthermore, available frameworks often incorporate novel models that require extensive training or are designed for particular systems, limiting their general applicability (e.g., [7,9,18]).

4.2. RQ2 – Classification and comparison of approaches

Comparison criteria were developed during data collection due to notable differences observed during evaluation of RQ1. These criteria span three dimensions: goal, methodological foundation, and application context of each framework. These criteria serve for the distinction of the 34 papers and draw attention to frameworks which possibly fulfill more than one criterion. Table 1 displays the 5 goal-related criteria.

Figure 4 presents a selection of the results of evaluating the above-mentioned research articles on the criteria (full evaluation available at [19]). It becomes evident that barely any framework completely fulfills more than one goal. Most frameworks successfully accomplish one goal and partly fulfill other goals in doing that. Only two frameworks achieve two goals completely. Nonetheless, for every goal there are at least two frameworks mainly fulfilling it.

Table 1 Description of criteria regarding the goal of the framework

Goal of the framework	Key focus
C1: Consideration and Traceability of Stakeholder Needs in the PDP	Ensuring that stakeholder needs are consistently incorporated and traceable throughout the PDP
C2: Stakeholder Communication and Feedback	Outlining how, when and through which channel communication should be established
C3: Stakeholder Identification and Selection	Who should and shouldn't be involved to which level
C4: Requirements Identification in the Early Phase of Product Development	Focus on eliciting requirements and facilitating the engagement
C5: Coverage of whole PDP	Framework applicable to all phase of the PDP

Evaluating all 34 articles with our five criteria shows that C2 (facilitating communication and feedback with stakeholders) is the primary research focus, reflected in 16 frameworks. Ten frameworks address early requirements identification (C4), while only six concentrate on stakeholder needs' consideration and traceability (C1), and five target identification and selection (C3). Consequently, methods that support both the identification and traceability of stakeholders and their needs throughout the PDP remain insufficiently explored. Criterion 5 highlights the lack of frameworks covering all PDP phases, where no framework achieves a "fully accomplished".

The following five criteria concern the framework's methodological foundation, the second dimension of this evaluation. With many SE and MBSE methods available, ease of understanding and use is important. These criteria help users decide which framework suits their needs and highlight widely used research methods. Table 2 shows the criteria and corresponding number of research articles.

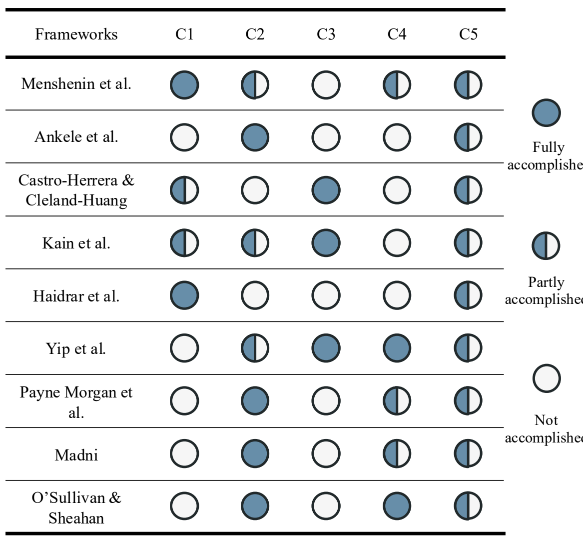

Figure 4 Selection: Overview accomplishment goal criteria

Table 2 Overview methodological foundation of frameworks

Methodological foundation	Number of research articles (n=34)
Agile principles	9
Formal MBSE	4
Using AI	1
Generally model-based	20

In this context, agile principles refer to frameworks that incorporate innovative approaches and communication methods for effective collaboration within multidisciplinary teams. These include techniques designed to enhance participation in meetings [15], human-centered design facilitated by gamified toolkits to support stakeholder knowledge development [16] and co-design methodologies implemented in open VR environments to generate and refine ideas during prototyping phases [20], among other strategies.

Of the 34 frameworks reviewed, only four are based on a formal MBSE. For example, some utilize SysML diagrams as the foundation for their frameworks or extend the application of MBSE methods [17].

The criterion “Using AI” is met by only one research article, which describes co-design guidelines augmented with AI to facilitate brainstorming for new product ideas. This tool converts basic sketches into refined visual representations, enabling stakeholders to engage with graphical content even without prior sketching skills [14].

Overall, model-based frameworks represent 20 out of the 34 examined (not including formal MBSE). As anticipated, many frameworks adapt established modeling techniques such as matrix visualization or the Delphi method [9,21].

Regarding the third dimension, one criterion has been established based on the application context. Due to the diversity of the research articles, comparing possible applications was essential. Another criterion specifically indicates if and how the framework is validated. Differentiating between the environment of a possible case study or a self-designed exemplary application.

Although numerous frameworks exist, more than half (18) have been developed for general applications rather than targeting a specific industry. Four are designed for the automotive domain, while three are intended for use in aircraft development (see Table 3 for an overview). Nonetheless, general frameworks are not universally applicable, as they originate from varied perspectives, including new product development (NPD) [9,16], MBSE environments [7,17], or system generation engineering [22]. Approaches following Co-design or Customer-centric guidelines as well as system of systems approaches have been identified.

Table 3 Overview application contexts of frameworks

Application context	Number of research articles (n=34)
General system development	18
Automotive/Mechatronics	4
Aircraft	3
Other	9

Table 4 indicates that out of 34 frameworks, nine have not been validated, 12 have only been applied in self-developed examples, and 13 have been evaluated through case studies in industrial or academic contexts. The limited extent of validation restricts the availability of measurable evidence for improvements in effectiveness. Consequently, organizations exhibit reluctance to adjust established processes without substantiated evidence of benefit.

Table 4 Overview types of validation for frameworks

Framework validation	Number of research articles (n=34)
Industry case study	6
University case study	7
Exemplary application	12
No validation	9

4.3. RQ3 –Research needs

The evaluation of RQ1 and RQ2 highlighted notable shortcomings in existing stakeholder frameworks. Comprehensive frameworks that span the entire PDP are lacking (see C5 in Figure 4) , leaving only fragmented methods applicable to individual phases, predominantly at the early stages of development. Available frameworks should be assessed for their applicability in later stages and if they prove unsuitable, adaptations should be pursued in subsequent steps.

Attention should also be directed to the MBSE readiness of these frameworks. As system complexity continues to increase, MBSE methodologies are expected to become increasingly prevalent. Therefore, frameworks designed to support efficient stakeholder engagement should be compatible with MBSE environments, and ideally, ease their implementation.

Both recommendations can be integrated with additional validation efforts to address the validation gap and provide results to quantify improvements in efficiency.

5. Conclusions and outlook

Starting with 1.149 search results, the SLR yielded 34 frameworks targeting stakeholder engagement during the PDP. While the number of frameworks is encouraging, critical gaps in current research became apparent during the evaluation.

Existing stakeholder frameworks remain fragmented, with a predominant focus on early PDP phases and limited applicability in MBSE environments.. While communication regarding stakeholders and requirement elicitation are well represented, critical aspects such as stakeholder needs traceability and stakeholder identification are insufficiently investigated. None of the identified frameworks provides comprehensive coverage across the entire PDP, leaving a gap for an integrated approach that enables continuous stakeholder engagement from identification and integration through to later use phases and even into subsequent product generations. Future frameworks should be extended to cover the entire PDP and better support stakeholder engagement across all development phases. Future research should focus on more than one goal according to our developed criteria (C1-C4) and undergo thorough validation in industry environments to measure effectiveness and better support comprehensive stakeholder engagement. Furthermore, guidelines for application of the frameworks should emerge from validation processes.

The limited use of formal MBSE based approaches can be linked to challenges frequently reported in the reviewed literature, including the need for specific modeling expertise and limited accessibility for stakeholders without engineering backgrounds. Recent industrial findings confirm that the high complexity of modeling languages, abstract representations and tool related barriers restrict the involvement of non-technical stakeholders in MBSE environments, which is why MBSE is often applied solely by technical experts in practice [23]. AI based mechanisms are increasingly discussed as a means to support interpretation of model-based information and to assist in navigating and maintaining stakeholder related data. Accessible, stakeholder specific visualizations integrated into easy to use tools are suggested as promising pathways to increase understanding, collaboration and participation of diverse stakeholder groups in MBSE contexts [23].

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