

Finding the Gap: A Systematic Review on the Integration of Problem Structuring Methods in Systems Engineering Models

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ABSTRACT

There are numerous studies on Model-Based Systems Engineering (MBSE) and Problem Structuring Methods (PSM) but little discussion on the integration of these two areas. This article undertakes a systematic literature review to explore the integration of PSM in MBSE models, an area that remains largely unexplored. Addressing the research problem of whether PSM is effectively used in structuring Systems Engineering (SE) models, the study aims to verify the existence and applicability of such models that incorporate PSM in their design. Using the PRISMA methodology, searches were conducted in six academic databases, identifying over 120 articles, of which only seven met the selection criteria. The findings highlight a significant gap in the literature: an almost complete absence of SE models that explicitly integrate PSM, with only one study showing significant integration. This underscores the need for future research, encouraging innovation and the development of new approaches that combine PSM and SE.

KEYWORDS. Systems Engineering Integration; Problem Structuring Methods (PSM). Systematic Literature Review (PRISMA).

Paper topics (indicate in order of PRIORITY the paper topic(s))

POI – OR in Industry

AD&GP – OR in Administration and Production Management

TEL&SI – OR in Telecommunications and Information Systems

1. Introduction

The historical trajectory of Systems Engineering reveals a significant evolution from document-centric approaches to Model-Based Systems Engineering (MBSE) [Crawley et al. 2016; Dori, 2016]. This shift addressed the need for a holistic and pragmatic understanding of systems, enhancing situational awareness and facilitating more efficient model revision and system cohesion (Voirin, 2017).

The rise of MBSE marked a refinement in representing and analyzing complex systems. The Systems Modeling Language (SysML), derived from the Unified Modeling Language (UML), became an important standard for representing software systems [Friedenthal et al. 2015]. SysML adapted UML's capabilities to meet the specific needs of systems engineering, enabling broader and more heterogeneous system modeling [Holt and Perry 2018]. This need for comprehensive expression of system requirements and functionalities drove this advancement [OMG SysML 2021].

Methodologies such as OPM (Object-Process Methodology), Arcadia, and OOSEM (Object-Oriented Systems Engineering Method) have emerged within MBSE to address engineering system complexity. However, implementing MBSE methodologies like OOSEM and Arcadia faces challenges. The complexity of systems often leads to uncertainties and ambiguities, especially in initial modeling phases. These challenges intensify when systems span multiple engineering disciplines or face evolving requirements and operational constraints [Crawley et al. 2016]. Thus, MBSE's effectiveness relies on a clear understanding of system requirements and continuous adaptation to changing environments, essential for OOSEM [Kosiakoff, et al. 2019].

In parallel, operational research has benefited from Problem Structuring Methods (PSMs). Methods such as SSM, SODA, VFT, and System Dynamics navigate multifaceted scenarios with conflicting interests and intangible variables [Keeney, 1996]. The adaptability and insight of PSMs in uncertain situations are significant strengths. Although primarily qualitative, PSMs also integrate quantitative analyses [Mingers and Brocklesby 1997]. A persistent challenge is their heterogeneity and lack of rigorous standardization, making them dependent on the practitioner and the specific situation [Edson et al. 2005].

This article, structured as a literature review, seeks to establish a dialogue between Systems Engineering and PSMs. The research aims to investigate the existence of systems engineering models incorporating PSMs for precise definitions of traditionally ambiguous concepts. The article contextualizes, analyzes, and reviews the relevant literature on the subject. It is organized in a logical sequence, beginning with the chosen methodology (Section 2), followed by a section dedicated to the search parameters and preliminary results (Section 3). The selection of studies is detailed (Section 4), clarifying the inclusion and exclusion criteria. The selected studies (Section 5) are followed by an assessment of their quality (Section 6), providing a solid basis for the results and discussion (Section 7), where the main findings are presented and contextualized within the broader landscape of Systems Engineering and PSMs, concluding with insights and future research directions (Section 8).

2. Methodology

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol has established itself as a fundamental guideline in the academic field for conducting and reporting systematic reviews and meta-analyses, and is widely recognized for its capacity to promote clarity, completeness, and transparency in review processes [Moher et al. 2009]. This meticulously developed structure not only assists researchers in managing the vast amount of literature but also ensures the integrity and quality of research findings, which is essential for scientific validation and informed decision-making in academia and professional practice [Page et al. 2021].

The relevance of the PRISMA protocol is evidenced by its widespread adoption, facilitating a uniform and methodologically solid approach that is essential for comparability and synthesis of evidence across various knowledge areas. Its strength lies in its detailed checklist and inclusive flowchart, guiding authors in preparing consistent reports, contributing to a more reliable and less biased body of literature. In addressing Systems Engineering models that employ Problem Structuring Methods (PSM), the use of the PRISMA protocol was crucial. It offered the necessary

tools for a comprehensive and thorough review, considering the complexity and multidisciplinary nature inherent in this field of study.

2.1 Objective and Research Questions

The primary objective of this review was to identify specific models within Systems Engineering that employ PSM, addressing the following research questions:

- a) Are there Systems Engineering models that incorporate PSM?
- b) What are these models?

2.2 Search Strategy Development

The search strategy was structured to initially explore four renowned scientific repositories: IEEE Xplore, ACM Digital Library, Web of Science, and Scopus. In each platform, search strings were crafted, considering the characteristics of each database to maximize the breadth and precision of search results. This process was imperative, especially considering terminological and indexing nuances in each system. IEEE Xplore and ACM Digital Library focused on literature discussing Systems Engineering models employing PSM, while Web of Science and Scopus aimed to identify works addressing any PSM applied in Model-Based Systems Engineering (MBSE).

However, despite this approach, the initial search yielded an unexpectedly limited amount of relevant literature. This scarcity led to the strategic decision to expand the search to include two additional significant databases: Science Direct and Google Scholar. This inclusion aimed to broaden the research horizon, seeking any study intersecting PSM and MBSE, regardless of the article's scope. Although this expansion partially mitigated the limitations inherent in the initial databases, it only modestly increased the results.

2.3 Study Selection

The selection of studies adopted a three-stage approach to progressively deepen the analysis of the collected material. The first stage involved a preliminary screening based on titles and abstracts, excluding publications clearly out of scope. The second stage required a full-text reading of the remaining works, essential for fully understanding the studies' relevance and context, ensuring only the most pertinent to the review theme were considered.

The third and final phase employed the "Snowball" methodology [Wohlin, 2014], which proved valuable in broadening the research scope. This technique involved analyzing the bibliographic references of significant studies, identifying earlier or subsequent works that could also contribute to the body of knowledge. Throughout these stages, inclusion and exclusion criteria were rigorously applied to ensure the selected studies were highly relevant and strictly aligned with the review's central theme.

2.4 Data Extraction

Data extraction from relevant studies employed a crafted form essential for the uniform and structured collection of information from each selected work pertinent to this research in PSM and MBSE. This process was required, given that only a fraction of the initially identified publications met the specific criteria of involving both PSM and MBSE in the context of interest, with many results presenting coinciding acronyms but distinct contexts. The extraction form focused on critical details such as authors, year of publication, specific types of PSM employed, the MBSE model used, and the context of each study.

2.5 Quality Assessment of Studies

Quality assessment of selected studies emphasized objectivity, even amidst qualitative analysis. To ensure an impartial and comprehensive appreciation of each work, fundamental criteria were clearly delineated, guiding the evaluation process. The criteria included relevance to the research, integration of MBSE with PSM, clarity of the proposed model, appropriate use of PSM, evidence of model validation, temporal relevance, and evidence-based conclusions. Each study was evaluated based on these criteria using a scale from 1 to 5, with detailed documentation maintained to ensure transparency.

2.6 Data Synthesis

The collected data were synthesized and presented in the "Results and Discussion" section, resulting from a detailed thematic analysis. This analysis categorized relevant information, covering aspects such as the types of PSM employed, their application contexts, and identified advantages and challenges. Although the evaluation was rigorous, it is important to highlight its qualitative nature, implying possible varied interpretations and inviting future reviews by other domain experts.

3. Search Parameters and Results

The objective of this systematic review was to explore relevant and current literature by conducting strategic searches in six renowned academic databases. Each database was chosen for its relevance and literature coverage in the context of Systems Engineering and Problem Structuring Methods (PSM). To ensure the comprehensiveness and quality of the retrieved studies, searches were defined by specific parameters such as publication periods, scope, and keywords related to PSM in Systems Engineering.

Table 1 summarizes the search strategies used, highlighting the databases, applied parameters, and obtained results.

Table 1: Search Results Overview.

Database	Search Strategy	Period	Scope	Results
IEEE Xplore Digital Library	("Systems Engineering" OR "System Engineering") AND ("Problem Structuring Methods" OR "PSM")	1997 - 2023	Conferences; Journals; Early Access	31
ACM Digital Library	[[Title: "systems engineering"] OR [Title: "system engineering"]] AND [[Full Text: "problem structuring methods"] OR [Full Text: "psm"]]	2012 - 2023	ACM Guide to Computing Literature	8
Web of Science	TS=("Model Based Systems Engineering" OR "MBSE") AND TS=("Problem Structuring Methods" OR "PSM")	2020	All databases; All collections	3
Scopus	TITLE-ABS-KEY("Model Based Systems Engineering" OR "MBSE") AND TITLE-ABS-KEY("Problem Structuring Methods" OR "PSM")	1970 - 2023	Documents; Research Data	Docs 5; Res. Data 6
ScienceDirect	("Model Based Systems Engineering" OR "MBSE") AND ("Problem Structuring Methods" OR "PSM")	1997 - 2023	Journals & Books	31
Google Scholar	("Model Based Systems Engineering" OR "MBSE") AND ("Problem Structuring Methods")	1970 - 2023	All Citations and patents	44

At this stage, the preliminary universe of works identified through systematic searches in six academic databases was presented, emphasizing different aspects of Systems Engineering and Problem Structuring Methods (PSM). IEEE Xplore and ACM Digital Library were chosen for their prominence in Computer Engineering, essential for exploring works related to system design in UML, closely linked to MBSE due to their common origin with SysML. Web of Science and Scopus were selected for their significant coverage of journals in Operational Research, the field most directly addressing PSM. This approach ensured valuable insights and a panorama of PSM applications in MBSE.

In contrast, the strategies in ScienceDirect and Google Scholar aimed to capture a broader spectrum of literature, ensuring interdisciplinary works were not overlooked. This research methodology involved systematic searches, with each search strategy rigorously applied. To ensure up-to-date literature, a new round of searches was conducted, comparing previous results and

including new findings. The last update, on the first semester 2024, serves as an accurate record of the existing literature and emphasizes the need for future periodic reviews, given the dynamic nature of this field.

4. Study Selection

To identify studies relevant to this review, was employed a tripartite and meticulous approach to select the results. This process, structured in three phases, aimed to deepen the evaluation of the collected articles, with customized criteria to identify works genuinely addressing the defined scope. Among the 122 results from the search strategies, only seven studies were selected, reflecting the rigor of the process. This careful approach ensured the relevance of the studies and demonstrated the commitment to transparency and replicability in research.

4.1 Inclusion and Exclusion Criteria

In outlining the method for selecting studies, it is essential to establish clear and directed criteria to ensure the pertinence and relevance of each work in the context of this review. The intention was to balance an inclusive approach, considering a broad spectrum of literature, with a focused one, limiting it to studies genuinely applicable to the research objective.

Table 2: Inclusion Criteria.

Criteria	Description
Focus Topic	Works on Problem Structuring Methods (PSM), Systems Engineering (SE), or Model-Based Systems Engineering (MBSE).
Language	Articles written in English.
Accessibility	Studies with full access.

Table 3: Exclusion Criteria.

Criteria	Description
Focus Deviation	Works that deviated from the central scope.
Superficiality	Content that mentioned key terms without in-depth analysis.
Incomplete Access	Articles that were not fully accessible.
Duplicates	Works already selected in other databases.

4.2 Selection Process: Detailed Analysis Steps

The selection process was planned to ensure that the chosen works aligned with the review's objectives. Each phase was structured to ensure precise and reliable selection of studies.

- **1st Phase: Preliminary Screening**

Evaluations were based on the titles and abstracts of articles to promptly eliminate those not fitting the inclusion criteria, particularly criteria 1. Many articles, despite having relevant acronyms, deviated from the central research context.

- **2nd Phase: Scope Screening**

Remaining works were thoroughly evaluated. Duplicates from different databases were removed, and the rest were fully read. It was crucial to determine if the keywords found were genuinely discussed in the article or merely cited tangentially.

- **3rd Phase: Snowball Method**

Studies meeting the 2nd phase criteria were analyzed for references and citations to assess their relevance. Seminal portfolios were screened again to evaluate references and citations, ensuring additional relevant literature was included.

4.3 Process Documentation

The meticulous documentation of the selection process for each consulted database highlights the commitment to a rigorous, transparent, and consistent approach throughout the review. Table 4 presents the results obtained at each stage for each database, ensuring clarity about the origin and selection of articles used in the review.

Table 4: Selected Studies:

Database	1 st Phase	After 2 nd Phase	Added in 3 rd Phase	After 3 rd Phase	Total Works
IEEE Xplore Digital Library	3	1	0	0	1
ACM Digital Library	1	0	0	0	0
Web of Science	0	0	0	0	0
Scopus	0	0	0	0	0
ScienceDirect	5	2	1	1	3
Google Scholar	8	3	2	0	3

5. Data Extraction

A structured form was used for analyzing selected studies, capturing essential data like database origin, article details, methodologies, and integration levels. This was necessary due to the varied initial publications, ensuring relevance to the integration of PSM and Systems Engineering methodologies for qualitative evaluation.

Table 5: Standard Data Extraction Form:

Question	Data Extraction
1	Database (<i>Options: IEEE Xplore Digital Library, ACM Digital Library, Web of Science, Scopus, ScienceDirect, Google Scholar</i>)
2	Article Title
3	Authors
4	Year
5	Systems Engineering Model or Methodology
6	Problem Structuring Method
7	Integration between model and method (<i>Scale: 1 to 5</i>)
8	Integration Description (<i>Scale: 1 to 5</i>)
9	Complete model presentation (<i>Scale: 1 to 5</i>)
10	Interaction with other areas of Operational Research (<i>Options: N, PSM, MCDA, Optimization, OR</i>)
11	Suitable for Snowballing (<i>Options: S - Yes DOWN, S - Yes UP, S - Yes ALL, N - No</i>)

Some questions require special attention due to the nature of their measurement scales and response options. For question 7, "Integration between the model and method," was used a scale ranging from 1 (not used in any part of the Systems Engineering model) to 5 (PSM integrated into the method in a specific phase). Questions 8 and 9 employ a Measurement Scale from 1 (insufficient) to 5 (excellent), allowing a qualitative evaluation of the description and presentation of the model. Question 10 seeks indications of interaction with other areas of Operational Research, with options like "N" for no relation and "OR" for interactions with multiple areas. Finally, question 11 evaluates the relevance of executing the Snowball method in the articles, possibly indicating execution from references ("Y - Yes UP"), citations ("Y - Yes DOWN"), both ("Y - Yes ALL"), or none ("N").

Table 6: Data Extraction Tables from Selected Studies:

Article 1	
Question	Response
1	IEEE Xplore Digital Library
2	Engineering the Organization: Providing New Insights Into Organizational Design Using Systems Principles
3	P Tully, E Goddard, A Hale, E Parsons
4	2014

5	Organizational design process (author's proposal)
6	Does not present any PSM, only suggests its use
7	2 - Used only to understand the system context, not as an integral part of the model
8	2 - Deficient
9	4 - Good
10	N - No other relations with OR
11	Y - Yes DOWN (in citations)

Article 2	
Question	Response
1	ScienceDirect
2	Framing the Intractable: Comprehensive Success Factor Analysis for Grand Challenges
3	Joseph V. Sinfield, Ananya Sheth, Romika R. Kotian
4	2020
5	Comprehensive Success Factor Analysis - CSFA (author's proposal)
6	SSM, SODA e SCA
7	2 - Used only to understand the system context, not as an integral part of the model
8	1 - Insufficient
9	4 - Good
10	OR - More than one area of Operational Research
11	Y - Yes DOWN (in citations)

Article 3	
Question	Response
1	ScienceDirect
2	Systems Approach to the Development and Application of Technical Metrics to Systems Engineering Projects
3	Dawn Gilberta, Mike Yearworth, Les Oliver
4	2014
5	The article deals with Systems Engineering Project Evaluation, not restricted to any specific model.
6	Does not address any PSM, but points out its usefulness in the proposed evaluation
7	2 - Used only to understand the system context, not as an integral part of the model
8	1 - Insufficient
9	2 - Deficient
10	PSM - Other methods
11	Y - Yes ALL (references and citations)

Article 4	
Question	Response
1	ScienceDirect* (Snowball)
2	Industrial adoption of Model-Based Systems Engineering: an investigation within the defence industry
3	Bayramoğlu, Alitan (MASTER'S THESIS)
4	2022
5	The author proposes a model to understand the factors influencing the adoption of models (like MBSE) in the industry
6	SSM
7	1 - Not used in any part of the Systems Engineering model
8	1 - Insufficient

9	3 - Barely Satisfactory
10	N - No other relations with OR
11	N - No

Article 5	
Question	Response
1	Google Scholar
2	Exploration and early validation in Systems Engineering
3	Marianne Kjørstad (DOCTORAL THESIS)
4	2022
5	Framework de Engenharia de Sistemas Humanos H-SEIF (author's proposal)
6	SSM
7	3 - Presents the possibility of using PSM in the model but does not do so
8	2 - Deficient
9	4 - Good
10	N - No other relations with OR
11	Y - Yes ALL (references and citations)

Article 6	
Question	Response
1	Google Scholar
2	Complexity Decision Making and General Systems Theory: An Educational Perspective
3	M. Kudret Yurtseven, Walter W. Buchanan
4	2016
5	The author addresses only GST (General Systems Theory) and does not address any MBSE model
6	SSM, SODA, SCA e System Dynamics
7	3 - Presents the possibility of using PSM in the model but does not do so
8	3 - Barely Satisfactory
9	1 - Insufficient
10	OR - More than one area of Operational Research
11	S - Yes UP (in references)

Article 7	
Question	Response
1	Google Scholar
2	Transitioning Systems Thinking to Model-Based Systems Engineering: Systemigrams to SysML Models
3	Robert Cloutier, Brian Sauser, Mary Bone, and Andrew Taylor
4	2015
5	Presents a methodological cycle diagram for generating "Systemigrams"
6	BSSM, a variation of SSM
7	5 - PSM integrated into the method at a specific phase
8	4 - Good
9	3 - Barely Satisfactory
10	N - No other relations with OR
11	Y - Yes DOWN (in citations)

As described in the previous section, the Snowball method was employed to identify relevant literature through the references and citations of selected works. Specifically, Article 4,

"Master's Thesis: Industrial adoption of Model-Based Systems Engineering: an investigation within the defence industry," was identified and selected from the citations analysis of Article 3, "Systems Approach to the Development and Application of Technical Metrics to Systems Engineering Projects." Similarly, through applying the Snowball method to citations from Article 7, "Transitioning Systems Thinking to Model-Based Systems Engineering: Systemigrams to SysML Models," an eighth work emerged but was found to be duplicated with Article 5 and thus was discarded.

6. Quality Assessment of Studies

The selected studies underwent a meticulous quality assessment to ensure significant contributions to Systems Engineering. This evaluation was based on clear, objective criteria designed to provide an impartial and comprehensive analysis of each work. Specific criteria were established to maintain rigor and objectivity, and are summarized in the Table 7:

Table 7: Evaluation Criteria Table:

Evaluation Criteria	Description
Relevance to research	Verifies the study's contribution to the review's objective, especially its relation to PSM and the engineering model.
Integration of MBSE with PSM	Analyzes the integration and applicability of PSM to the proposed engineering model in the study.
Clarity of Proposed Model	Assesses the clarity and detail with which the Systems Engineering model is presented.
Appropriate Use of PSM	Examines the adoption and proper application of the Problem Structuring Methodology in the MBSE context.
Validation Evidence of the Model	Searches for empirical evidence of PSM's effectiveness within MBSE, such as case studies, simulations, or benchmarks.
Temporal Relevance	Prioritizes more recent studies due to the dynamic nature of Systems Engineering.
Substantiated Conclusions	Evaluates if conclusions are directly derived from the results, avoiding generic or opinion-based inferences.

Each study was rated using a scale previously employed in this analysis, with values defined as follows: 1 - Insufficient, 2 - Deficient, 3 - Barely Satisfactory, 4 - Good, and 5 - Excellent. The results of this evaluation are presented in the Table 8:

Table 8: Articles Evaluation Table:

Evaluation Criteria	Article 1	Article 2	Article 3	Article 4	Article 5	Article 6	Article 7
Relevance to research	1	2	2	1	3	2	4
Integration of MBSE with PSM	2	1	1	1	2	1	5
Clarity of Proposed Model	3	4	1	4	4	1	3
Appropriate Use of PSM	2	1	1	1	1	2	3
Validation Evidence of the Model	1	2	4	4	3	3	5
Temporal Relevance	3	4	3	5	5	3	3
Substantiated Conclusions	2	4	4	3	3	3	4

Among the evaluated studies, "Transitioning Systems Thinking to Model-Based Systems Engineering: Systemigrams to SysML Models" by Robert Cloutier, Brian Sauser, Mary Bone, and

Andrew Taylor, stood out for its significant quality and alignment with the research objectives. This qualitative evaluation was strictly aimed at assessing the studies' alignment with the specific objective of this article, not as an overall judgment of the articles' quality. All selected works demonstrated high academic rigor, contributing innovative insights and being solidly grounded in recognized scientific methods.

7. Results and Discussion

The research identified 122 initial works across six academic databases, with only seven meeting the criteria. This highlights the specificity of the subject and the precision of the selection process. The scarcity of Systems Engineering models incorporating PSM is surprising, given their potential synergy. PSMs could significantly enhance system definition and modeling. The absence of clear integration in established models suggests an opportunity for future research.

There was considerable variation in how PSMs are described and applied, complicating data extraction. Additionally, PSMs' interdisciplinary nature might hinder their identification within Systems Engineering. Among the selected studies, only one, "Transitioning Systems Thinking to Model-Based Systems Engineering: Systemigrams to SysML Models," demonstrated substantial integration between PSM and MBSE. This finding suggests that while PSM integration is nascent, it is feasible and valuable.

8. Conclusion

This systematic literature review, following the PRISMA protocol, reveals a significant gap in Systems Engineering literature, particularly in integrating Problem Structuring Methods (PSM). The objective was to identify and analyze Systems Engineering models incorporating PSM to achieve a more precise definition of ambiguous concepts within multidisciplinary systems.

The guiding questions—whether Systems Engineering models incorporate PSM and which models—were addressed, illustrating the scarcity of studies in this intersection and the potential for future advancements. The research found that out of over 120 initial works, only seven met the criteria, with only one showing significant PSM integration in a Systems Engineering model. This underscores the unexplored potential of PSMs in Systems Engineering and signals the need for deeper investigation. PSM methodologies offer robust tools for structuring complex problems and can enhance understanding and management of complex systems, facilitating decision-making and project optimization.

The absence of consolidated models employing PSMs in Systems Engineering highlights a fertile field for innovation. Researchers and professionals are encouraged to explore this promising intersection, aiming to create and validate models that integrate PSM benefits into Systems Engineering. Future research should also aim to understand and overcome obstacles to PSM integration, fostering a stronger synergy between these two areas.

In summary, this article answers the research questions and opens new research directions. The conclusion is not an endpoint but an invitation to continue exploring this vast, unmapped territory where Systems Engineering and Problem Structuring Methods can coexist and thrive. This work aims to serve as a catalyst for future investigations, encouraging studies that translate theory into innovative and effective practices, positively influencing Systems Engineering.

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