

Identifying the Thematic Trends of Model Based Systems Engineering in Manufacturing and Production Engineering Domains

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Abstract— Manufacturing and production systems have become increasingly complex in the past decade to meet the competitive demand in a growing industry. As these systems grow in complexity and flexibility, there is a need for efficient management and analysis of these systems. Model-based systems engineering (MBSE) addresses the complexity inherent with systems development with a model-centric approach that supported tailored modeling languages, methods and tools. This paper identifies the thematic evolution and trends and relationships found in the use and application of MBSE specifically in the manufacturing and production engineering domain. A collection of 471 published article from Institute of Electrical and Electronics Engineers (IEEE) and Science Direct over the past decade were used for the analysis using text mining techniques. Due to the limitation on the access to full text information of all the articles identified, only abstracts were considered for analysis. This effort helps the researchers across the domain to explore the reason behind and understand the change of the thematic perspectives of MBSE application over the last decade. In addition, the finding of the growing interest in addressing the aspects of complexity and systems requirements, and on the aspects of the use of MBSE for identifying and addressing the challenges related to Cyber Physical Systems help in paving a path for future research.

Keywords— MBSE, Manufacturing, Production, Text Mining, Model based Systems, Systems Engineering

I. INTRODUCTION

Today's increasing manufacturing and production systems complexity necessitates the application of innovative advancement approaches to preserve resources, money and time in order that organizations would stay competitive in current industry. [1] Traditional, document-centric methods have the potential to complicate present multi-disciplinary manufacturing and production industry systems. There is a great need for a transition from document-centric methods to methods that utilize a variety of procedures, approaches, and languages for the advancement, development, preservation, and optimization of systems for any manufacturing and production system. Model-based systems engineering (MBSE) addresses the inherent system complexities with a model-centric approach that supports and improves technical systems using multi-disciplinary methods, which include modeling languages and modeling tools, to increase quality production and optimize procedures [2].

As the current industry modernizes applications and procedures, systems become more technical and complex to achieve enhanced objectives. System optimization is achieved by integrating innovative structures that address system performance, flexibility, and consistency. [3] This allows the usage of state-of-the-art materials, manufacturing procedures, and software applications to give systems the foundation to increase complexity. The use of MBSE methodologies can increase an organization's competitiveness, as it increases production quality and quantity. It is because of these advancements that there is an increase in transition from document-centric to model-centric applications.

This increase in adoption of MBSE methodologies continue to modernize manufacturing systems and tools to increase performance and flexibility [4]. The implementation of MBSE allows the current industry to make a transition into Industry 4.0. In Industry 4.0, production and manufacturing systems are driven by interpretation of production plans curated by multiple disciplines [5]. This transition to Industry 4.0 allows for flexible production, however, complicates systems as there emerge more applications and procedures that must be designed and analyzed. "Since Industry 4.0 production systems are systems-of-systems, their structure and topology lead to a significant structural complexity that is difficult to be tackled" [5]. MBSE applications enables the shift towards Industry 4.0 increasing industrial productivity and promoting new technologies [6]. The shift towards Industry 4.0 can be streamlined with adoption of MBSE to develop applications and strategies that help culminate manufacturing and production systems that reach their technical abilities.

This paper identifies tools, languages, and thematic topics surrounding the adoption and use of MBSE in the manufacturing and production industry to highlight the reasoning for the transition from document-centric to model-centric applications. Text mining techniques of co-word analysis and topic mining are used to identify the aforementioned, using data (a collection of abstracts) gathered from Institute of Electrical and Electronics Engineers (IEEE) and Science Direct. The rest of the paper is structured as follows: Section II expands on the research method used where a brief background on the data used, Co-Word Analysis and Topic Mining techniques used. Section III illustrates the findings and discussion and Section IV on conclusion and future work.

II. RESEARCH METHOD

Text mining is defined as “an artificial intelligence (AI) technology that uses natural language processing (NLP) to transform the unstructured text in documents into organized data suitable for analysis” [7]. Text mining identifies relationships found between documents or a set of text data and organizes them into different categories. This data can then be transformed using a variety of techniques supported by various packages to glean information.

A. Data Used

A culmination of articles was identified, within the scope of application of MBSE in production and manufacturing engineering domains, from IEEE and Science Direct databases. Using a combination of keywords “MBSE”, “Manufacturing”, “Production”, and the phrase “Model-based Systems Engineering” a total of 471 unique articles were identified from the years 2000 to 2020. These articles were then exported into a CSV format and were categorized using article author, publisher, publication date, and abstract. Due to the limitation on the access to full text information of all the articles identified, only abstracts were considered for analysis. Next, the text mining framework developed by Niekler and Wiedmann [10] was used to do Co-Word Analysis and Topic Mining to explore the use of tools and languages referred to the use of MBSE in manufacturing and production engineering domain.

B. Co-Word Analysis

Co-word analysis is a technique that help to map the associations found within a specified set of text documents and maps the semantics [11], based on the premise that a given set of words enable to represent a significant amount of information associated to a given document. With the goal of identifying the commonly referred to tools and languages in the context of applying MBSE in manufacturing and production engineering applications, co-word analysis enabled in identifying the pair wise associations of words based on their frequencies [12]. Simply put, using co-word analysis the extent to which specific terms from the data used that appear alongside the terms of interest “language” and “tools” more often were identified.

C. Topic Mining

Topic modeling is a commonly used text-mining tool that identifies thematic trends within any type of text or collection of documents. The characterization of a specific topic from a set of text data/documents is based on the term distribution and the distribution of each topic contains in a given specific document [13]. In order to identify the thematic trends and elements in relation to the use of MBSE in manufacturing and production engineering domains, topic mining framework developed by Niekler and Wiedmann [10] was used to find re-occurring patterns of words. Latent Dirichlet Allocation (LDA) was used to identify the topics. It is a probabilistic unsupervised machine learning model that help to identify the composition of a given number of topics from a given text data having a similar semantic context [14].

Identified below are the steps followed to perform co-word analysis and topic mining on the data gathered for analysis using ‘Quanteda’ and ‘Topic Models’ packages in R.

Step 1: Abstract extraction of articles in relation to the use of MBSE in Manufacturing and Production engineering domains.

Step 2: Data conversion into CSV format with information on author names, title, abstracts, and year of publication.

Step 3: Data pre-processing in order to remove the stop words commonly used in English language, punctuation, and numbers.

Step 4: Creation of a document term matrix with a minimal frequency threshold of 5 to omit words that occur less frequently in the data set used.

Step 5: Determination of terms which co-occur with the terms of interest i.e. ‘tools’ and ‘languages’ to visualize graphically.

Step 6: Deleting empty rows of document term matrix to prepare the data for LDA.

Step 7: Topic identification and concatenating the five mostly observed terms of each topic.

Step 8: Ranking of the topics considering their distribution over the abstracts.

Step 9: Visualizing the topic proportions over each year of the data used.

III. DATA ANALYSIS AND FINDINGS

Following steps 1, 2, and 3 mentioned, resulted in a total of 471 unique documents and 1119 terms. For co-word analysis mutual information measures help to emphasize on the rare occurrences of terms to glean a specific context and a meaning that can be interpretable [10]. To a better interpretation the co-words of the terms of interest and of each co-word are identified. Illustrated in Figure 1 and Figure 2 are the network representation of the co-words of the terms of interest. This helped in identifying the frequently referred to tools and languages in light of the use of MBSE in manufacturing and production engineering domains.

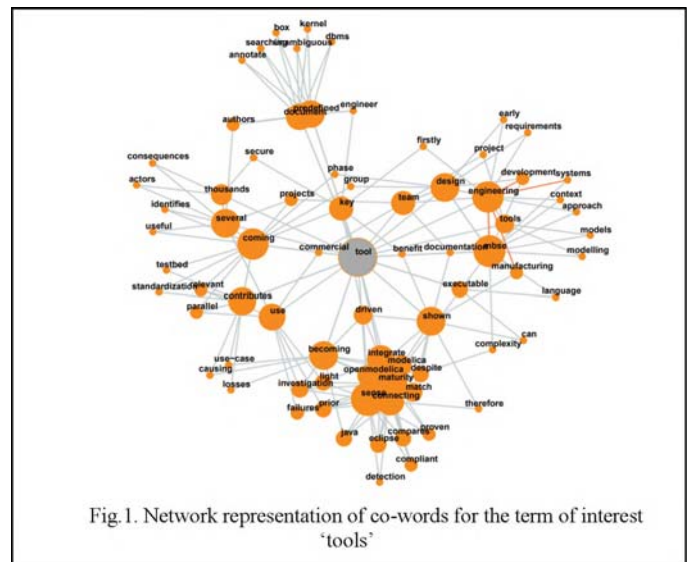
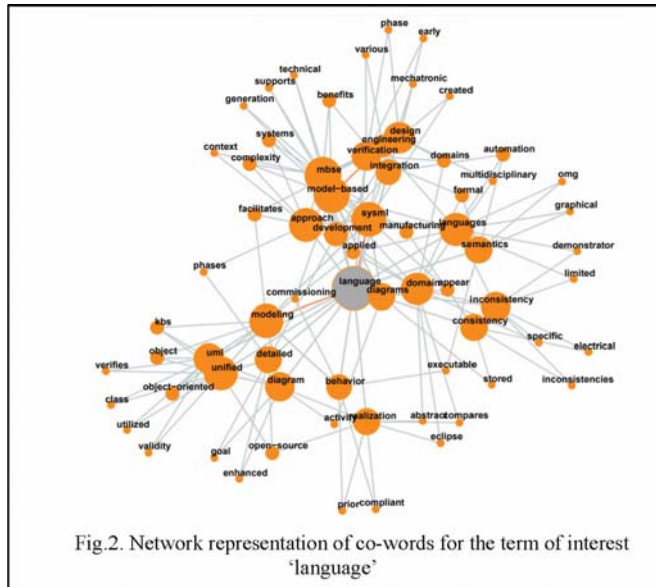


Fig.1. Network representation of co-words for the term of interest ‘tools’

Considering the most often referred to tools when referring to the use of MBSE in manufacturing and production engineering domains, as identified in Fig.1. Modelica and Eclipse were identified. Modelica and Eclipse tools are both related to the use and modeling of systems using the SysML (Systems Modeling Language) modeling language. Modelica is a non-proprietary, object-oriented, multi-domain modeling

language for component-oriented modeling of complex systems [8]. Many multi-disciplinary physical systems can be modeled using this software while using Modelica's language enabling customization. Eclipse (Software Development Kit) is a similar modeling software tool which can build integrated development environment (IDE) frameworks which utilize a variation of programming languages to develop a series of applications and open source MBSE tools [9].

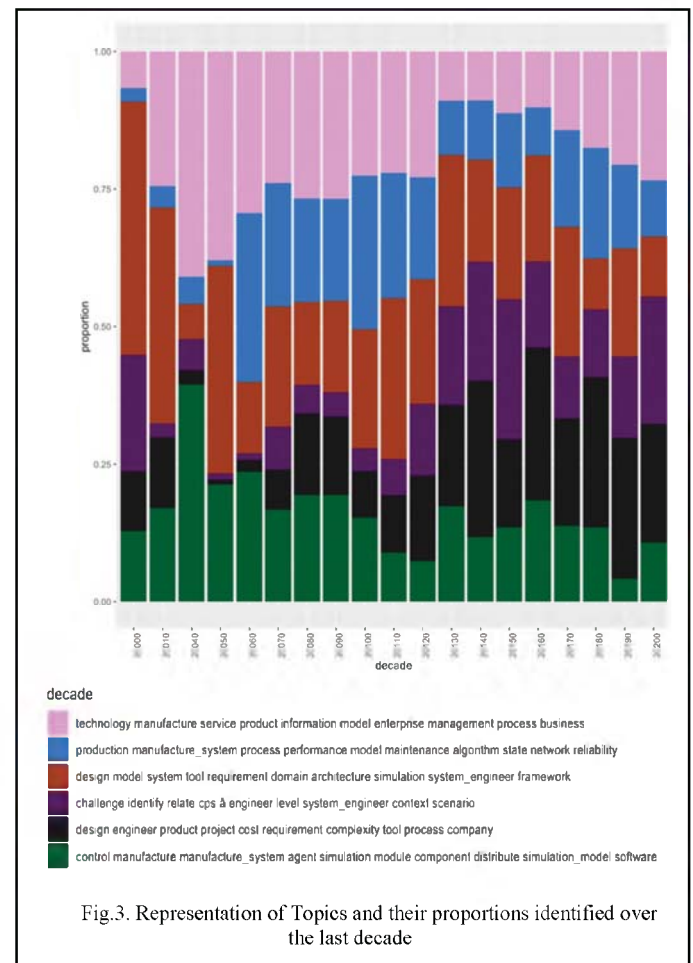


Referring to the most often used modeling languages for implementing MBSE in manufacturing ad production engineering domain, as illustrated in Fig. 2. UML and SysML were identified. Unified Modeling Language (UML) is a standardized language notation comprising of a set of integrated diagrams to visualize, represent, construct and document system artifacts of both software and non-software systems [16]. The Systems Modeling Language (SysML) is an extension of UML that enables capturing contexts, requirements, and architectural parameters of complex systems [16]. Further, to explore the context of modeling languages in application of MBSE to manufacturing and production engineering systems, the abstracts data extracted were carefully analyzed resulting in identification of tailored extensions of SysML and UML such as SysML4Mechatronics [17], SysML for Automation (SysML-AT) [18], and UML4IoT [19].

The intent of using topic modeling is to determine and identify the distribution of thematic aspect observed over the data. For identifying the topics from a given text data using LDA the number of topics need to identified is predetermined. Based on several trials, the number topics to be identified were chosen to be 6. Fig. 3. visualizes the aggregated topic proportions over the last 10 years of article published referring to the use of MBSE in manufacturing and production engineering domains. Table I represents the topics identified, the top terms of each topic, and the number of abstracts characterized into the topics.

Topic 1 characterized by the terms identified in Table 1 addresses the theme of manufacturing processes and enterprise management representing a proportion of 17.8% of the dataset used. Considering the terms associated with Topic 2 it can be seen that this topic addresses the theme of system

performance, maintenance, and reliability representing 16.1% of the data.



Topic 3 characterized by the terms design, model, requirements, architecture, framework signifies the theme of the use of MBSE for systems development and design process approximately representing approximately 18.9% of the data. Topic 4 characterized by the terms identified in Table I represents theme on the use of MBSE for addressing and identifying the challenges in Cyber Physical Systems representing an approximate 13.7% of the data. Similar to Topic 3, Topic 5 also seems to represent the application of MBSE on manufacturing and production engineering systems, specifically related to the aspects of system complexity and cost, representing a majority of data i.e. approximately 20%. Finally, Topic 6 represents the thematic aspect on the use and application of MBSE for manufacturing systems and product simulation, representing approximately 13.8% of the data.

TABLE I. TOPICS IDENTIFIED AND THEIR REPRESENTATION ACROSS THE DATASET

	Topic Terms	Number of Documents Characterized
Topic 1	Technology, manufacture, service, product information, model, enterprise, management, process, business	88
Topic 2	Production, manufacture, system, process, performance, model, maintenance, algorithm, state, network, reliability	76

Topic 3	Design, model, system, tool, requirement, domain, architecture, simulation, system engineer, framework	101
Topic 4	Challenge, identify, relate, cps, engineer, level, system engineer, context, scenario	44
Topic 5	Design, engineer, product, project, cost, requirement, complexity, tool, process, company	110
Topic 6	Control, manufacture, manufacture_system, agent, simulation, module, component, distribute, simulation model, software	52

Aggregating the proportions of topics and their distribution over the last decade, as illustrated in Fig. 3, a rising interest is seen among the research community in the thematic topics related to the application of MBSE on manufacturing and production engineering systems, addressing the aspects of complexity and systems requirements, and on the aspects of the use of MBSE for identifying and addressing the challenges related to Cyber Physical Systems. This trend illustrates the possible pathway for future researchers to further explore the aforementioned thematic aspects utilizing MBSE techniques.

IV. CONCLUSION

In this paper with a goal of identifying the tools and languages that are most often used referring to the use of MBSE in manufacturing and production engineering domain, text mining techniques were applied to 471 abstracts downloaded from IEEE and Science Direct databased with the combination of key terms ““MBSE + Manufacturing”, “MBSE +Production” and the phrase “Model-based Systems Engineering” in the metadata. The use of only IEEE and Science Direct databases is due to the limited availability of articles and full text data from the data based at the authors institution. Following the research method described, it is identified that to implement MBSE in manufacturing and production engineering domain, based on the data analyzed, several tailored extensions of SysML are preferred. This can be mapped to the fact that SysML is an extension of UML that enables capturing contexts, requirements, and architectural parameters of complex systems. Modelica and Eclipse are observed to be the commonly used tools based on the data analyzed, and there is a need to explore the reason behind this. Further, using topic mining technique the evolution of the thematic topics in relation to the use of MBSE was identified.

The results obtained here are subject to validity based only on the 471 abstracts analyzed that were downloaded from IEEE and Science Direct databases. There is a scope for the change in the results by incorporating the full text documents of the data and well as by increasing the scope of the data used when gathered from several other databases. This effort helps the researchers across the domain to explore the reason behind and understand the change of the thematic perspectives of MBSE application over the last decade. In addition, the finding of the growing interest in addressing the aspects of complexity and systems requirements, and on the aspects of the use of MBSE for identifying and addressing the challenges related to Cyber Physical Systems help in paving a path for future research.

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