

# Model-based Systems Engineering Papers Analysis based on Word Cloud Visualization

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**Abstract**—With the continuous improvement of system scale and complexity, model-based system engineering (MBSE) is of great importance in the practice of system engineering (SE). MBSE has been widely concerned in industry, especially in the field of complex equipment. At the same time, in academia, research articles about MBSE come into being and grow rapidly. In this paper, keywords and full-texts of 143 high quality articles related to MBSE field are extracted from relevant journals of IEEE and INCOSE communities, and the research contents of MBSE field are visualized and analyzed by using a third-party Python WordCloud library. The research focuses on: (a) identifying related concepts of MBSE; (b) exploring research contents of MBSE; (c) analyzing three pillars of MBSE: modeling languages, methods and tools based on articles. The results show that MBSE plays an important role in realizing system architecture design and developing system architecture models by applying modeling technology to support system requirements, design, analysis and evaluation, verification and validation in the whole life cycle of product development. SysML and OPM are the most popular modeling languages and modeling methods in MBSE research field respectively. This paper provides a technical route reference for exploring the current research field of MBSE by using WordCloud text analysis which is helpful to predict the future research of MBSE.

**Index Terms**—MBSE, Python, WordCloud, Modeling language, Modeling method, Modeling tool

## I. INTRODUCTION

In the early stages of system engineering (SE), the information generated by the system is recorded in the form of documents. With the ever-increasing number of functionalities of systems, the complexity of the system is increasing [1], and the drawbacks of the traditional document-based system design methods are gradually emerging, such as poor document consistency, ambiguous semantics, low communication efficiency, and inability to conduct pre-simulation verification. In order to better realize the early verification and validation of system design, and to improve the efficiency and quality control ability of system development, International Council on Systems Engineering (INCOSE) proposed the concept of

model-based system engineering (MBSE), and defined it as follows: "Model Based Systems Engineering is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities, beginning in the conceptual design phase and continuing throughout development and later life cycle phases" [2].

With the development of digital modeling and simulation technology [3]–[8], the advantages of MBSE are becoming more prominent. And Kaitlin Henderson and Alejandro Salado [9] searched for empirical evidence to prove the benefits of MBSE through 20 journals and conferences from the areas of systems engineering, engineering design, and space systems engineering, and called on researchers to take action to formally measure the benefits of MBSE. In the INCOSE SE Vision 2025 Report, MBSE methods and tools have been identified as the standards for implementing system engineering projects. This has resulted in MBSE research being obviously visible in emerging standards, scientific journals and papers, international conferences and academic programs in the field [10]–[33].

Aditya Akundi and Oscar Mondragon [34] collected data sets of 2,380 articles between the time period of the years 1995 to 2020 from IEEE Explore, Science Direct, Wiley Publishers and Web of Science, and made a comprehensive literature review of research contributions in MBSE field by using text mining technique. However, their analysis is limited to the bibliometric analysis based on published articles, mainly emphasizing the change in the frequency of key terms in MBSE over time. They summarized the tools, languages and diagrams mentioned by researchers and practitioners of MBSE through co-word analysis. And they proposed the six topics of MBSE literature.

In this paper, we are focus on the high-quality articles in order to understand what is mainly concerned by the researchers. Then such articles in the MBSE field from IEEE community and INCOSE community are analyzed by Python

and its third-party libraries. And word cloud is used to visually display the main content of articles in this research field, conduct analysis and exploration. The concept of MBSE is expounded, the research content of MBSE is reviewed, and the commonly used modeling methods, modeling languages and modeling tools related to MBSE are analyzed and summarized. This paper lays a foundation for the further exploration and future research direction of MBSE.

The remainder of the paper is organized as follows, Section II introduces the data sources and main research methods of this paper, Section III details on the research process of keywords and full-text, and analyzes the word cloud obtained from the research; Section IV summarizes and discusses the research results.

## II. DATA SOURCES AND RESEARCH METHODS

### A. DATA SOURCES

The data sources of this study are core journals related to MBSE in IEEE community and INCOSE community. With the help of Google Scholar, 44 search results are obtained by using "source:" IEEE Transactions ", MBSE " as the search condition. With the "source:" IEEE Systems Journal ", MBSE " as the search condition, a total of 42 results are obtained. Then in order to obtain the MBSE articles in INCOSE community, we enter the official website of Systems engineering INCOSE community with "Systems Engineering Journal INCOSE" as the search condition, and then with "MBSE" as the search condition, 82 retrieval results are obtained. After that, the PDF documents of 168 articles are downloaded, and the correlation between the articles and MBSE is validated. It is found that 13 of the 44 articles in IEEE Transactions have low correlation with MBSE. One of the 42 search results in IEEE systems journal has low correlation with MBSE. Among the 82 search results in Systems Engineering Journal INCOSE, 11 have low correlation with MBSE, which are mainly the introduction of systems engineering journals. So these 25 articles of low correlation with MBSE are removed, and finally 143 articles with high correlation with MBSE are retained as data sources for word cloud.

In TABLE I, the journals and the number of corresponding articles are shown. To facilitate analysis, the journals in IEEE TRANSACTIONS are classified, and the corresponding number of MBSE articles are shown in TABLE II.

TABLE I  
THE NAME OF THE JOURNAL AND THE CORRESPONDING NUMBER OF MBSE ARTICLES

Name of Journals	Number
IEEE SYSTEMS JOURNAL	41
IEEE TRANSACTIONS	31
SYSTEMS ENGINEERING JOURNAL INCOSE	71

TABLE II  
IEEE TRANSACTIONS "JOURNALS" AND THE NUMBER OF CORRESPONDING MBSE ARTICLES

Name of Journals	Number
IEEE TRANSACTIONS ON RELIABILITY	2
IEEE TRANSACTIONS ON TECHNOLOGY AND SOCIETY	1
IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS	1
IEEE TRANSACTIONS ON PROFESSIONAL COMMUNICATION	1
IEEE TRANSACTIONS ON PLASMA SCIENCE	2
IEEE TRANSACTIONS ON EDUCATION	2
IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS	3
IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS	1
IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS	1
IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS SYSTEMS	9
IEEE TRANSACTIONS ON SOFTWARE ENGINEERING	4
IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING	1
IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT	3

### B. RESEARCH METHOD

The main research method of text analysis using word cloud based on Python are shown in Fig. 1:

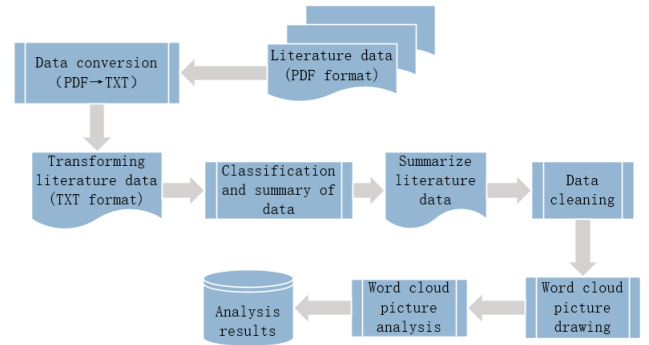


Fig. 1. Main research methods.

1) *Data conversion*: Data conversion is a process of transforming data from one format to another. Data conversion is very important for data analysis. In this study, as the articles retrieved are all in PDF format, in order to facilitate the analysis, the online conversion tool transforming from PDF to TXT is used to convert the 143 articles retrieved in PDF format into the TXT format.

2) *Data summarization*: In data processing process, it is often necessary to summarize a large amount of data. Data summarization refers to classifying the data according to a certain standard, and then summarizing the relevant data of each category as required on the basis of classification. In this study, after converting the finally reserved 143 articles to TXT format, they are firstly classified and summarized according to the classification of IEEE SYSTEMS JOURNAL, SYSTEMS ENGINEERING JOURNAL INCOSE, IEEE TRANSACTIONS ON RELIABILITY and IEEE TRANSACTIONS ON TECHNOLOGY AND SOCIETY and so on, and then

according to the research contents, they are classified and summarized from two modules of keywords and full-text respectively.

3) *Data cleaning*: Data cleaning is the basis of data analysis. The purpose of data cleaning is to maintain the quality and consistency of data [35]. It includes deleting duplicate information, correcting existing errors, dealing with invalid words and missing words and so on. In this study, duplicate annotations are deleted, missing words in the conversion process are corrected, and meaningless words are deleted to ensure the accuracy of the study.

4) *Word cloud generation*: The basic principle of generating word cloud is as follows: firstly, divide the whole text into different word segments based on the word library, secondly make statistics on the occurrence times of the same word in the text; finally according to the word frequency, the words are presented in the form of word cloud according to different font sizes and colors. Generally, the higher the frequency of words, the more prominent the presentation of words [36].

This study is based on the third party library WordCloud of Python to generate the word cloud. The WordCloud library regards a word cloud as a WordCloud object, and wordcloud.WordCloud () represents a word cloud corresponding to a text. A word cloud can be drawn according to parameters such as the frequency of words appearing in the text. And the shape, size and color of the word cloud can be set according to the actual application [37].

The steps of using WordCloud to generate a word cloud are shown in Fig. 2. Firstly, the wordcloud.WordCloud function is used to set the properties (or parameters) of the word cloud object. Secondly, wordcloud.generate (text) function is used to generate a word cloud. Finally, wordcloud.to\_file (file\_name) is used to output the word cloud to a visualization file.

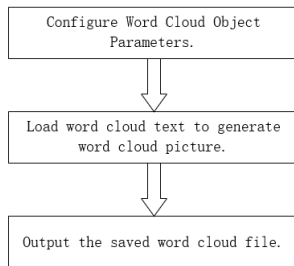


Fig. 2. Word cloud drawing steps.

### III. RESEARCH PROCESS

In order to discover and understand the research contents of the 143 high-quality articles which are highly correlated with MBSE in the IEEE community and INCOSE community, we use word cloud to analyze the keywords and full text of these 143 articles respectively.

#### A. KEYWORDS RESEARCH

1) *Data summarization*: Through Python, the keywords in 143 documents converted into TXT format are extracted

and summarized into a total keywords TXT document, which provide the data foundation for the data processing.

2) *Data cleaning*: At first, all the summarized keywords are converted into lowercase letters through Python, and then the common proper nouns are expressed in abbreviated form, and the abbreviations are kept in uppercase form. For example, the model-based systems engineering is uniformly expressed in MBSE, and the systems modeling language is uniformly expressed in SysML, systems engineering is uniformly expressed in SE, systems of systems is uniformly expressed in SoS, and object process method is uniformly expressed in OPM [38]. In addition, remove duplicate comments that may exist after these words, e.g. MBSE (Model-based Systems Engineering).

Then, we make use of the Python library to implement the counter method for getting keywords and their frequency. After sorting the frequency of keywords, take the top 31 keywords [39] with the highest frequency to clean up and analyze. Firstly, delete the word "and" which has no practical meaning to the topic analysis. Secondly, a total of 2 semantically identical or similar keywords such as "systems" and "system" are merged [40]. By adding up the frequencies of keywords with the same or similar semantics, 25 words with the highest frequency are obtained to analysis [41]. These 25 high-frequency words and their occurrence frequency are taken as the basic data for word cloud analysis.

3) *Word cloud generation*: Import WordCloud, a third-party library of Python, to draw a word cloud of keywords in articles, as shown in Fig. 3.

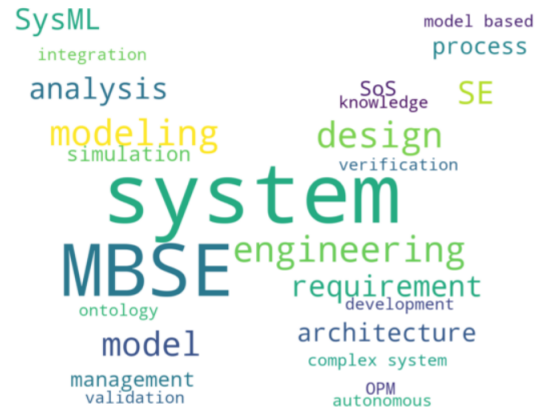


Fig. 3. Keywords analysis word cloud.

#### B. FULL-TEXT RESEARCH

1) *Data summarization*: Through Python, the 143 documents converted into TXT format are firstly summarized according to the classification of journals. And then all the TXT documents are merged which lays the data foundation for the next step.

2) *Data cleaning*: At first, manually remove the parts irrelevant to the main research content, including author information, appendix, references, figures, formulas and other



the development trend of the system. With the increasing scale of the system, the system is becoming more and more complicated. And model-based systems engineering (MBSE) is used to solve the problems of complex systems engineering. Meanwhile, "SoS" is observed from the word cloud. SoS is the abbreviation of system of systems. It is a collection of task-oriented or dedicated systems that pool their resources and capabilities together to create a new, more complex system which offers more functionality and performance than simply the sum of the constituent systems [47]. SoS has an important influence on architecture design. And it is also an indication of the trend towards system complexity. Besides, the appearance of "management" and "integration" shows that MBSE is important to system management and integration. The emergence of "process" shows that MBSE is applied in the processes of product development and MBSE pays attention to process management. While the appearance of "knowledge" shows the concern for knowledge management.

The appearance of "ontology" means the application of ontology in MBSE. Ontologies are formal descriptions of shared knowledge in a domain. [48]. Through ontology languages, the semantics of system design and their relationships can be clearly defined. And ontology can assist knowledge system to identify requirements and define specifications.

2) *Full-text word cloud analysis*: From the word cloud, "system" and "model" are the most conspicuous, which are consistent with the results of keywords analysis. In addition, words related to models, such as "model based", "design model" and "model system", appear frequently. This is because MBSE mainly targets at the system, and solves the problems of system design based on the model. The model can accurately, completely and uniformly define all aspects of the system, such as requirements, functions, detailed design, specification constraints, operating scenarios and sequences, etc. Moreover, compared with a large number of technical documents, it is easier for designers to form a unified and unambiguous understanding of details within the system, and it makes the communication between designers smoother and more efficient. The importance of the model in MBSE is emphasized. And the emergence of "system engineering (se)" and "system engineer" shows the high correlation between MBSE and system engineering.

It is also found from the word cloud that "data" and "information" are conspicuous, which reflects the importance of data and information in MBSE research. The words "entities", "object", "component", "value" and "parameter" illustrate some research objects of MBSE. Besides "requirement" and "design" in keywords, we observe words such as "need", "function", "scenario", "identify", "define", etc., which show that MBSE can accurately and uniformly define requirements, functions, detailed design, specification constraints, operation scenarios and order. Words such as "level" and "domain" are observed, which show that MBSE is hierarchical and domain-specific. And words such as "interface", "input", "output" and "interaction" show that MBSE focuses on the design interaction and modeling of interfaces. Besides, the

word "framework" implies the importance of the definition and construction of framework. Also, it reflects researchers' exploration and research on MBSE modeling framework. The appearance of "complete", "alternative", "physical", "consist", "integrated", "complexity", "specific" and "abstract" points out the characteristics of MBSE application. Among them, "physical", "complexity" and "abstract" indicate that MBSE is applied to complex systems whose parts are abstracted into physical models for design and other activities. The word "alternative" shows that MBSE's solution is not unique, it includes many alternatives. And "complete", "consist" and "specific" embody MBSE's characteristics of improving product quality by providing unambiguous and accurate system models that can evaluate consistency, correctness and completeness. And "integrated" reflects MBSE's emphasis on model integration.

Besides, "failure propagation" is observed in the figure, which reflects the exploration of applying MBSE method to solve the problem of fault propagation and improve system reliability.

In addition to the words with the same results as those obtained by keywords analysis, "language", "method" and "tools" are observed from the word cloud, and they emphasize the three pillars of MBSE. With regard to modeling languages and modeling methods, "SysML(sysml)" and "OPM(opm)" are observed from the word cloud, which are consistent with the results of keywords analysis, while the modeling tools are still not clearly pointed out. It is speculated that there are many modeling tools in the market at present, but there is no unified standard modeling tool.

#### IV. RESEARCH RESULTS AND DISCUSSION

In this study, 143 core journals related to MBSE in IEEE community and INCOSE community are analyzed by using WordCloud, a Python third-party library, in order to understand the research content and the three pillars of MBSE. From the research, we found that:

(1) MBSE plays an important role in realizing system architecture design and building system architecture models. And it can be used throughout the life cycle of product development. MBSE supports activities such as system requirements, design, analysis and evaluation, verification and confirmation, decision-making and development through the canonical application of modeling techniques, from conceptual design stage to later stages of life cycle.

(2) The research on modeling languages in the three pillars shows that SysML is the most used modeling language by researchers in MBSE field at present. SysML is the continuation and extension of UML in system engineering application field, and it is a multi-purpose modeling language for system architecture design proposed in recent years. And it is used for the description, analysis, design, verification and validation of integrated architecture of complex systems.

(3) According to the research on modeling methods in the three pillars of MBSE modeling, OPM is the modeling method with the highest frequency in MBSE research. It is a formal



and intuitive conceptual modeling method. OPM abstractly describes things using objects, states and processes. And it is the main choice of MBSE modeling methods at present.

(4) In the research of modeling tools, it is found that word "tools" appear frequently in the full-text word cloud analysis, but no unified MBSE modeling tools are found in the full-text word cloud analysis of 200 high-frequency words. Considering the terms associated with tools, tools such as MetaGraph, mediniQVT, Palladio bench, QPN-Tool and IBM Rhapsody are observed in the full-text search, indicating that there are many kinds of modeling tools related to MBSE at present. This discovery is of great significance to the future development of MBSE tools with unified and powerful functions.

(5) With the ever-increasing complexity of the system, MBSE method will become more and more popular. And the application of MBSE method in the whole life cycle of product development is the inevitable trend of system engineering development in the future. Besides, the application of ontology in MBSE is emerging. In the future, building ontology to normalize relevant conceptual models and improve the standardization and reusability of MBSE models will be an important research content of MBSE. Meanwhile, improving MBSE method to solve the problem of fault analysis and improve system reliability will also be a focus of MBSE.

In this paper, the method of exploring the current research field of MBSE by using word cloud text analysis is introduced in detail, the main research contents, including modeling languages, modeling methods and modeling tools are summarized, and the future development trend of MBSE is predicted, which is helpful to expand the research contents of MBSE in the future and predict the development trend of MBSE and its three pillars, especially the development of unified tools for MBSE modeling.

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