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A Review of Data Mining Techniques in the Development of Decision Support Systems

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Abstract. This study aims to examine the role and effectiveness of various data mining techniques in improving the performance of Decision Support Systems (DSS). Using a systematic literature review method, relevant academic papers and recent studies from the last decade were analyzed to identify common approaches, applications, and challenges. The findings show that classification, clustering, association rule mining, and anomaly detection are the most widely adopted data mining techniques in DSS development. Machine learning methods such as decision trees, neural networks, and support vector machines further contribute in improving prediction accuracy and decision quality. This discussion highlights that although data mining significantly strengthens the analytical capabilities of DSS, challenges such as data quality, model interpretability, and computational complexity remain important issues. Overall, this review underscores the importance of integrating advanced data mining approaches into DSS frameworks to support smarter, scalable and adaptable decision-making processes.

Keywords: Data Mining, Decision Support Systems, Machine Learning, Data Analysis.

1. Introduction

The increasing volume and complexity of data generated in various fields have made efficient and accurate decision-making processes critically important. Decision Support Systems (DSS) are designed to assist decision-makers by providing tools for data analysis, interpretation, and recommendation, enabling more informed and strategic choices. As traditional DSS struggled with handling large-scale and heterogeneous datasets, the adoption of data mining techniques emerged as a solution to extract meaningful patterns, trends, and knowledge from complex data [1]. By incorporating data mining, DSS have evolved into more dynamic and intelligent systems, capable of addressing diverse decision-making challenges. In this context, "A Review of Data Mining Techniques in the Development of Decision Support Systems" explores how these techniques have been integrated to enhance the efficiency and effectiveness of DSS.

Data mining refers to the set of computational techniques aimed at discovering hidden patterns, correlations, and anomalies in large datasets [2]. Techniques such as classification,

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clustering, association rule mining, and anomaly detection have become fundamental in enhancing DSS capabilities. Moreover, the integration of machine learning algorithms, including decision trees, neural networks, and support vector machines, enables DSS to improve predictive performance and adapt to changing data patterns [3]. Through these advancements, DSS can now offer more accurate predictions, actionable insights, and automated decision support across sectors like finance, healthcare, marketing, and public administration.

This study aims to explore the application of data mining techniques in the development of Decision Support Systems (DSS). A qualitative research method was employed through an extensive literature study, analyzing scholarly articles, conference papers, and research reports published over the past decade. The results indicate that techniques such as classification, clustering, association rule mining, and anomaly detection are predominantly utilized to enhance the analytical capabilities of DSS. Furthermore, the integration of machine learning algorithms, including decision trees and neural networks, significantly improves the predictive performance of these systems. The discussion highlights the major benefits of applying data mining in DSS, such as improved decision accuracy and efficiency, while also addressing ongoing challenges like data quality issues and algorithm complexity. This review emphasizes the need for continued research to optimize the synergy between data mining methods and decision support frameworks, ensuring more robust and intelligent decision-making tools in various fields.

Based on the background above, the problems formulated in this research are: (1) How are data mining techniques applied in the development and enhancement of Decision Support Systems? (2) What are the dominant data mining methods employed in DSS? (3) What challenges are encountered in integrating data mining within DSS environments? Answering these questions is crucial to understanding the full potential and limitations of data mining in improving decision-making processes through intelligent systems.

The objective of this research is to systematically review and analyze the use of data mining techniques in DSS development. Specifically, it aims to identify the most commonly used methods, examine their impact on decision-making accuracy and efficiency, and evaluate the current challenges in their application. Furthermore, the study intends to provide recommendations for future improvements and highlight opportunities for integrating emerging machine learning techniques into DSS frameworks, thus contributing to the ongoing evolution of intelligent decision-making tools.

Although prior studies have discussed the individual roles of data mining and DSS, few have provided a comprehensive and integrative review focusing on the synergy between both fields. This study offers research novelty by systematically mapping the relationships between specific data mining techniques and DSS functionalities across various application domains. Additionally, it emphasizes new perspectives on unresolved challenges, such as data quality management and model interpret-ability, which are increasingly critical in dynamic data environments [4]. Thus, this research contributes to bridging the existing gap and supports the development of more adaptive, intelligent, and reliable decision support frameworks.

2. Method

This study employs a qualitative research approach using a systematic literature review (SLR) to examine the role of data mining techniques in improving the development and performance of Decision Support Systems (DSS). The literature review method was chosen because it allows for an in-depth analysis of existing knowledge and a critical synthesis of

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findings from multiple sources. The study focused on articles published from 2020 to 2023, using a comprehensive search strategy across the Scopus database. The search was conducted using keywords such as "data mining in DSS," "machine learning techniques in decision support," and "predictive analytics in DSS," to ensure that the selected studies were up-to-date and relevant.

The selection criteria for the studies involved focusing on peer-reviewed articles, conference papers, and research reports that explicitly discussed the integration of data mining techniques in DSS development. To maintain the quality and relevance of the sources, only studies that discussed specific techniques such as classification, clustering, association rule mining, anomaly detection, and machine learning methods (e.g., decision trees, neural networks) were included. Studies that evaluated the challenges of implementing these techniques in DSS, such as data quality and computational complexity, were also prioritized. Studies were excluded if they did not provide empirical evidence or were not related to DSS or data mining methodologies. This ensured that only high-quality and focused studies were included in the review.

Data analysis was conducted by categorizing the findings of selected studies based on the techniques and challenges identified. Thematic analysis was used to extract key patterns and trends in the application of data mining techniques to DSS. This method enabled the identification of dominant techniques, their impact on decision accuracy and system efficiency, and ongoing challenges faced in the practical application of these methods. The synthesis of findings contributed to the development of a more integrated understanding of how data mining techniques enhance decision support capabilities, thereby providing a roadmap for future research and practical applications across industries. The methodology followed the guidelines set out by [5] and Rousseau et al. [5] for conducting systematic literature reviews in computational and applied sciences.

3. Results and Discussion

The integration of data mining techniques into Decision Support Systems (DSS) has fundamentally transformed how these systems operate, enabling them to handle larger and more complex datasets while delivering more accurate and actionable insights. By leveraging sophisticated algorithms, DSS can now provide decision-makers with tools that automate analysis, uncover hidden patterns, and predict outcomes with a higher degree of precision. This shift has been particularly impactful across various industries, from healthcare and finance to marketing and public administration, where data-driven decision-making is crucial.

However, despite the promising advancements in data mining applications within DSS, several challenges remain that hinder the full potential of these systems. These challenges include issues related to data quality, algorithmic complexity, and the interpretability of machine learning models. As DSS continue to evolve, understanding these challenges and finding ways to address them will be essential for realizing the full benefits of data mining in decision support processes.

In addition to analyzing simulation-based learning for hardware security, a broader bibliometric analysis was conducted to explore the research trends in the fields of data mining, decision support systems, machine learning, and data analysis. Understanding these trends provides valuable context, as simulation-based educational tools often integrate machine learning and data analysis techniques to enhance training effectiveness.

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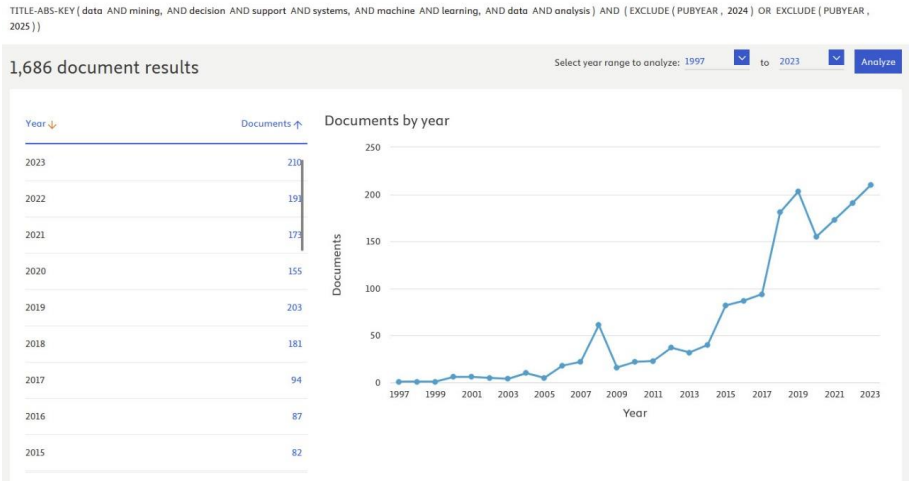

Figure 1. The number of publications related to this research

As shown in Figure 1, the number of publications related to these topics has grown significantly between 1997 and 2023. Early research activity between 1997 and 2006 remained relatively low, with fewer than 10 publications per year. However, a noticeable increase began around 2007, followed by a sharp spike in 2017. From 2017 onward, there has been a steady and substantial rise, culminating in 210 publications in 2023 alone. This trend highlights the growing importance and integration of machine learning and data-driven decision support in various domains, including education and cybersecurity. The increasing volume of research suggests an expanding interest in leveraging data-centric methods to enhance both theoretical and practical applications across multiple disciplines.

In the figure 1, trends in the number of publications related to data mining, decision support systems, machine learning, and data analysis from 1997 to 2023. The graph shows a steady increase in research output, with a significant surge after 2017, reflecting the growing importance of data-driven methodologies across various fields.

The trends seen in recent research publications align closely with the increasing sophistication of DSS, where data mining and machine learning techniques not only optimize decision-making but also respond to the challenges and opportunities presented by vast and dynamic datasets. The integration of these methods continues to evolve, offering promising directions for future DSS development, including hybrid models, advanced data preprocessing, and collaborative decision-making frameworks, all of which reflect the expanding potential of data-centric solutions in diverse sectors.

3.1. Dominant Data Mining Techniques Applied in DSS Development

The systematic review revealed a broad spectrum of data mining techniques utilized in the development of Decision Support Systems (DSS). Among the most common and frequently applied methods were classification, clustering, association rule mining, and anomaly detection. These techniques are fundamental in enhancing the analytical capabilities of DSS, making them more effective and adaptive in decision-making processes. Classification techniques, which group data into predefined classes or categories, were frequently applied in various domains such as healthcare for disease diagnosis and finance for fraud detection. Several studies indicated that classification methods, particularly decision trees and random forests, have been instrumental in improving DSS decision-making accuracy by providing

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interpret-able models [1]. By partitioning data into different categories based on specific attributes, classification techniques enable DSS to assist in decision-making processes where outcomes are discrete, and patterns are discernible.

Clustering techniques, on the other hand, are pivotal in uncovering hidden structures within datasets by grouping similar data points together. This method has proven invaluable in DSS, particularly in marketing and customer relationship management, where understanding customer segments is critical for targeted interventions. Clustering techniques like K-means and hierarchical clustering have been extensively employed in DSS to group users or transactions based on patterns found in data, allowing organizations to implement more tailored strategies [2]. Moreover, the application of clustering in DSS allows decision-makers to uncover insights into the natural grouping of data, making it an essential tool in data-driven decision-making. The role of clustering becomes even more pronounced when dealing with large, unstructured datasets, such as social media or customer feedback data, where the underlying structure is not immediately apparent.

In addition to classification and clustering, association rule mining has emerged as another key technique in DSS development. Association rule mining focuses on discovering relationships between variables in large datasets, helping DSS to offer recommendations based on identified patterns. In retail and marketing, association rule mining has been applied to identify product combinations frequently purchased together, forming the basis for recommendation systems. Recent studies highlighted its role in developing decision support tools that automate recommendations based on historical transactional data. By using association rules, DSS can predict the likelihood of future events based on the frequency of past occurrences, which is critical in sectors like e-commerce and finance [3]. The integration of these techniques within DSS allows for the automation of decision-making processes, reducing human error and improving efficiency in complex environments.

3.2. The Role of Machine Learning Algorithms in DSS

The integration of machine learning (ML) algorithms into Decision Support Systems (DSS) has become increasingly essential in enhancing their predictive capabilities and adaptability. The review highlighted that algorithm such as decision trees, neural networks, and support vector machines (SVMs) are being actively incorporated into DSS to improve decision-making accuracy. Decision trees, known for their simplicity and interpretability, play a significant role in the decision-making process by providing clear rules for classification tasks. These models have been widely adopted in areas like medical diagnostics, where clarity in decision-making is crucial. Several studies reported that decision trees, in combination with other techniques, provide transparent models, making them highly suitable for industries that require both accurate predictions and model transparency [4].

The use of neural networks, particularly deep learning models, has also gained momentum in DSS development. Neural networks excel at capturing non-linear relationships in large datasets, making them particularly effective in applications where traditional methods struggle to model complex data patterns. For instance, in finance, deep learning models are being employed to predict market trends, identify risks, and optimize portfolios. Recent advancements in deep learning, including convolutional neural networks (CNNs) and recurrent neural networks (RNNs), have expanded the scope of DSS, enabling them to handle sequential data and make time-series predictions [5]. These models are also being used in healthcare DSS to analyze medical imaging data and patient records, providing insights into disease prediction and treatment outcomes.

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Support vector machines (SVMs) have become another prominent machine learning technique used in DSS, especially in classification tasks involving high-dimensional datasets. SVMs have been successfully applied in areas like fraud detection, sentiment analysis, and image classification. SVM's ability to handle large feature spaces and its robust nature in dealing with non-linearly separable data make it a powerful tool for building predictive models. The review pointed out that, when integrated into DSS, SVMs enhance the system's ability to make accurate predictions under varying conditions, especially in complex decision environments where data is sparse or imbalanced [6]. However, one of the main challenges of using SVMs in DSS is the difficulty in tuning the model's parameters, which requires expertise and can be computationally expensive, especially with large datasets.

3.3. Challenges in Data Mining Integration within DSS

While data mining techniques significantly enhance the functionality and performance of DSS, several challenges persist in their integration and application. One of the most prominent challenges identified across the reviewed studies is data quality. The success of data mining in DSS heavily depends on the quality of the data being processed. Incomplete, inconsistent, or noisy data can severely affect the outcomes of the decision-making process, leading to inaccurate predictions and suboptimal decisions. Several studies discussed the importance of pre-processing data to handle missing values, outliers, and noise, which are common issues in real-world datasets. For instance, in healthcare DSS, missing patient data or incorrect diagnoses can lead to poor decision outcomes and even life-threatening consequences. Therefore, ensuring data integrity through robust data cleaning and preprocessing techniques is vital to the effectiveness of data mining methods in DSS [7].

Another challenge faced by researchers and practitioners is model interpretability. While machine learning models, such as neural networks and support vector machines, often provide high accuracy, they are frequently criticized for operating as "black-box" models. This lack of transparency can hinder the adoption of these models in domains where understanding the decision-making process is critical. In industries like healthcare, finance, and law, decision-makers need to understand how and why a model arrived at a particular decision to build trust and ensure compliance with regulatory standards. Studies have emphasized the need for developing more interpretable models, such as explainable AI (XAI), which aim to provide insights into the reasoning behind predictions and recommendations. As DSS continue to integrate more advanced machine learning methods, the demand for transparent and interpretable models is expected to increase [8].

Computational complexity is another significant barrier to the widespread use of data mining techniques in DSS. Advanced algorithms, particularly those involving deep learning and high-dimensional datasets, can be computationally expensive and require substantial processing power. This issue becomes particularly relevant when DSS need to operate in real-time or with large-scale data, such as in the case of financial market predictions or emergency response systems. Several studies pointed out that the high computational cost of implementing complex machine learning models in DSS can limit their scalability and real-time application. As a result, there is a growing need for more efficient algorithms, parallel processing techniques, and hardware acceleration to mitigate these challenges. The development of cloud-based computing and edge computing technologies presents potential solutions to these issues, allowing DSS to scale efficiently without sacrificing performance [9].

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3.4. Future Directions and Opportunities

Looking ahead, several key opportunities for improving the integration of data mining techniques in DSS were identified. One promising direction is the development of hybrid models that combine multiple data mining techniques to enhance decision support capabilities. For example, combining classification methods with clustering algorithms could improve the accuracy of predictions while providing a deeper understanding of the underlying data structures. Several studies indicated that hybrid models, such as ensemble methods or neural network-based clustering, offer significant improvements in both predictive accuracy and interpret-ability. These hybrid approaches have the potential to address some of the existing challenges in DSS, such as model transparency and computational efficiency, by leveraging the strengths of different techniques [10]. Moreover, the integration of emerging unsupervised learning and reinforcement learning techniques into DSS could open up new avenues for real-time decision-making and adaptive systems capable of learning from dynamic environments.

Another area of significant potential is the application of advanced data preprocessing and data quality enhancement techniques to improve the input data used in DSS. Given that the quality of the data directly impacts the performance of data mining algorithms, addressing issues like missing data, noise, and outliers before applying machine learning models is crucial. Researchers are increasingly exploring methods for automating the data cleaning process using advanced algorithms, such as deep autoencoders and anomaly detection models, to identify and rectify data inconsistencies. This could significantly improve the reliability of DSS and their ability to make accurate decisions in real-time applications. Furthermore, future research could explore the integration of more diverse data sources, including sensor data from IoT devices, to enhance decision-making in areas such as smart cities, healthcare, and transportation [11].

Finally, collaborative decision-making frameworks, where multiple DSS work together, can provide richer, more diverse perspectives on the decision-making process. This approach would involve sharing insights and models between various systems, creating a collective intelligence that could improve decision-making outcomes. By integrating multiple DSS and data sources, collaborative frameworks could enhance the scalability, adaptability, and reliability of decision support tools across industries. This development could lead to the creation of more robust, intelligent, and context-aware DSS, capable of addressing complex, multi-dimensional decision problems in rapidly changing environments [12].

4. Conclusion

In conclusion, this study has explored the significant role that data mining techniques play in the development and enhancement of Decision Support Systems (DSS). The review highlights that techniques such as classification, clustering, association rule mining, and anomaly detection are fundamental in improving DSS capabilities. Furthermore, the integration of machine learning methods like decision trees, neural networks, and support vector machines has contributed to enhancing the accuracy and predictive power of these systems. These advancements have enabled DSS to support more effective, data-driven decision-making across a wide range of industries, including healthcare, finance, marketing, and public administration.

Despite the promising contributions of data mining to DSS, several challenges remain, particularly related to data quality, model interpretability, and computational complexity. The review underscores the need for robust data preprocessing techniques to address issues like

missing values and noise, which can significantly impact the performance of DSS. Additionally, the lack of transparency in some machine learning models poses a barrier to trust and adoption in critical sectors such as healthcare and finance. As DSS continue to evolve, it will be crucial to address these challenges by developing more interpretable and efficient models, as well as optimizing data processing capabilities.

Therefore, there are numerous opportunities for future research and development in the integration of data mining techniques within DSS. Hybrid models combining various data mining methods, along with advancements in data quality enhancement techniques, promise to improve both the accuracy and reliability of decision support systems. Additionally, the potential for real-time decision-making, adaptive systems, and collaborative decision-making frameworks presents exciting avenues for further enhancing DSS. As technology continues to advance, the evolution of DSS powered by data mining and machine learning will continue to reshape decision-making processes, offering smarter and more adaptable solutions across multiple domains.

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