Predictive Analysis of Patient Risk of Death in ICU: A Bibliometric Analysis

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Abstract. This bibliometric analysis explores the synergy of artificial intelligence (AI), particularly machine learning, and biomedical signal processing in predicting patient mortality risk within the intensive care unit (ICU). Utilizing a comprehensive literature review, the study assesses the research landscape by applying these techniques to ICU data. Examining diverse data sources like vital signs and electronic health records, the analysis identifies trends and gaps in existing work, emphasizing AI's potential for resource allocation and preventative care to enhance ICU outcomes. Structured within a bibliometric framework, the review encompasses methodological approaches, results, and discussions, while addressing clinical and ethical perspectives on mortality prediction. Challenges related to data, model performance, and fairness are evaluated through a bibliometric lens. The research questions underscore the importance of understanding past literature trends in predictive analysis for ICU patients. The review methodologically explores recent studies employing word representation models, impact assessments, and risk prediction of vital signs. Global research trends in AI for critical care are identified based on bibliographic data between 2013 and 2022. Noteworthy contributions, such as a sepsis dataset, are highlighted within the bibliometric analysis. In conclusion, this bibliometric analysis positions itself at the intersection of AI and critical care, emphasizing the importance of bibliographic data in understanding past trends, methodologies, and impactful contributions. It sets the stage for future directions in the evolving landscape of ICU predictive analytics within a bibliometric framework.

1. Introduction

Artificial intelligence (AI), specifically machine learning and biomedical signal processing techniques, show promise for predicting patient risk of death in the intensive care unit (ICU) [1]. AI has fundamentally changed how traditional computer programming works. AI algorithms learn from exposure to numerous examples in the ICU setup and are now capable of making predictions about patient health. Models have been developed to obtain important information in a patient’s chart [2] and identify high-cost patients [3]. Accurately assessing prognosis allows for better resource allocation and preventative care, ultimately leading to improved outcomes. Predictive modeling of survival and length of stay in ICU based on specific conditions such as heart failure, etc., are now in practice \([4,5]\).

This literature review in the form of a bibliometric analysis aims to provide a comprehensive overview of research applying these methods to predict mortality using ICU data. Studies utilizing various data sources like vital signs, laboratory tests, and electronic health records will be examined and compared. Trends and gaps in existing work will be identified. The implications of mortality prediction in the ICU will also be discussed from clinical and ethical perspectives. While AI shows potential to enhance care, challenges regarding data, model performance, and fairness must be addressed.

To structure this review, the following sections are proposed: methods, results and discussion, implications, and future directions. This framework will allow for a thorough evaluation of past and ongoing research efforts and help identify open questions warranting further exploration. By surveying predictive analytics in critical care, this paper aims to advance both the use of AI to improve patient outcomes and our understanding of its appropriate application in healthcare.

1.1. The Problem Statement

The application of predictive analytics in judging Intensive Care Unit (ICU) patient outcomes is a complex endeavor characterized by various challenges. The diversity of critical illnesses within the ICU patient...
population, coupled with the dynamic nature of their conditions, presents a formidable task for predictive models. Patients in the ICU often exhibit a broad range of medical conditions and comorbidities, necessitating models that can account for this heterogeneity. The rapid and unpredictable changes in patient conditions pose a challenge for real-time predictions, requiring models to adapt swiftly to evolving scenarios. Moreover, the multifactorial nature of influences on ICU patient outcomes adds to the complexity. Physiological variables, laboratory results, medical history, and interventions all play roles, demanding sophisticated models that can appropriately weigh and integrate these diverse factors. The quality and variability of data further contribute to the intricacy, as missing or inaccurate information, differing data collection methods, and variations in data quality across healthcare institutions can impact the performance of predictive models.

Ethical considerations are paramount in healthcare analytics, with issues of patient privacy, informed consent, and potential biases in the data requiring careful attention. The interpretability of models is crucial for healthcare professionals to trust and comprehend the predictions, especially in critical care where decisions have profound consequences. Seamless integration into the clinical workflow is essential for the practical application of predictive analytics in the ICU setting. Ensuring that healthcare professionals can easily access and interpret predictions is vital for successful implementation. The validation and generalizability of predictive models are critical aspects to consider, as models must be rigorously tested to ensure their applicability to diverse patient populations and healthcare settings. Overfitting to specific datasets can compromise the performance of models when applied to new and unseen data. In summary, while the potential benefits of predictive analytics in improving ICU patient outcomes are significant, addressing the complexity of the healthcare environment, ensuring ethical use, and refining models to meet the unique challenges of critical care are essential for their successful implementation in clinical practice.

2. Research Questions

Concerning predictive analysis for ICU patients, it will be interesting to delve deep into the literature and try to explore a few questions - and that’s the research issue that this study seeks to address. Some important conclusions can be drawn from a thorough examination of current research trends, techniques used, and significant studies that have been completed to date.

According to the research, the main focus of predictive analysis for ICU patients has been on building models by utilizing various machine learning and data mining approaches to examine vital signs and patient record data [6]. To predict outcomes including mortality risk, length of stay in the intensive care unit, and transfer to critical conditions, a range of classification and language models have been tried on benchmark datasets. The idea is to benchmark critical care outcomes based on machine learning [7]. Applications of neural networks, natural language processing, and statistical techniques are notable works {[8], [9]}. Additionally, research has evaluated how predictive analytics technologies might enhance clinical judgment and optimize the use of resources in intensive care units.

Predictive analysis is generally portrayed in previous research as a promising field that is still developing. Although earlier studies investigated various modeling techniques, more recent studies have begun assessing the effectiveness and performance of models in practical contexts. The field would gain from maintaining its focus on improving current procedures, investigating cutting-edge deep learning techniques, and carrying out validation studies with a range of ICU populations and clinical specialists. Additional multi-source data integration and explainable modeling could further propel the potential of predictive analytics in enhancing complex ICU care and patient outcomes.

In summary, the present analysis of the literature using bibliometric analysis lays the groundwork for subsequent investigations that will expand upon principal discoveries and bridge current gaps, ultimately reinforcing the function of data-driven decision-support systems in critical care. A thorough examination of the methodological development and impact patterns observed in earlier academic works involving predictive analysis for ICU patients provides an answer to the main study topic.

3. Literature Review

Predictive analysis for ICU patients has emerged as a critical area of research, employing diverse models and methodologies to enhance decision-making in critical care settings. This literature review aims to provide a comprehensive analysis of existing research in the field, focusing on three key aspects: the importance of literature review, methodologies employed in recent studies, and global research trends in artificial intelligence (AI) for critical care. Through this review, we seek to answer the research question: What does the past literature show regarding predictive analysis for ICU patients? A foundational understanding of the current research
landscape is crucial for establishing a clear research direction. The literature review plays a pivotal role in achieving this clarity by identifying key issues and ensuring the chosen direction is not only current but also practically significant. Furthermore, it offers insights into existing theoretical frameworks and methodologies, laying the groundwork for robust research. The review of various methods helps researchers avoid less applicable approaches, thereby enhancing methodological quality.

3.1. Methodology for Literature Review:

The literature review methodology focuses on key studies that employ diverse techniques in predictive analysis for ICU patients. These studies encompass word representation models, impact assessments in surgical and trauma ICUs, risk prediction of critical vital signs, and multi-task recurrent neural networks for hospital mortality prediction.

A few recent trends in the literature are worth noting:

1. Word Representation Models for ICU Mortality Prediction (Krishnan, 2019) [10]:
   This study, utilizing the MIMIC-III dataset, employs NLP techniques, applying tokenization to nursing notes. Word2Vec and FastText models with skipgram and CBOW approaches are used for word embedding. Experiments involve analyzing various dimensions, learning rates, and training times. The classifier, a Random Forest with 5-fold cross-validation, assesses metrics such as accuracy, precision, recall, F-score, and AUROC.

2. Impact of Predictive Analytics in Surgical and Trauma ICU (Ruminski et al., 2019) [11]:
   Conducted as a retrospective cohort study, this research compares pre- and post-implementation scenarios in medical and surgical ICUs. Statistical methods such as rate ratio calculation and the Wilcoxon rank sum test are applied. R version 3.3 is used for analysis, focusing on outcomes like sepsis cases, emergent intubation, hemorrhage, mortality, and length of stay.

3. Risk Prediction of Critical Vital Signs for ICU Patients (Chang et al., 2019) [12]:
   This study, utilizing the MIMIC-III dataset, focuses on predicting vital signs transitioning to abnormal within the next hour. Employing a Recurrent Neural Network (RNN) with Long Short-Term Memory (LSTM) units, data preprocessing involves fixed data collection rates, outlier removal, and balancing target classifications. Feature extraction is performed on past 3 and 5-hour windows.

4. Multi-task Recurrent Neural Network for Hospital Mortality Prediction (Zheng et al., 2019) [13]:
   Summarizing ICU records into a matrix, this study employs attention mechanisms in both reconstruction and classification tasks. LSTM is used for feature extraction, and a GRU decoder with attention is applied for reconstruction. The research aims to predict hospital mortality by incorporating attention mechanisms in reconstruction and classification tasks.

Global Research Trends in AI for Critical Care: The paper on global research trends in AI for critical care presents a comprehensive summary of research patterns based on 1992 publications between 2013 and 2022. It highlights the significant growth in publications over the past 5 years, with a focus on countries and academic institutions leading in AI research. The use of chord network charts (CNC) is proven to be more effective in understanding author collaborations and keyword cooccurrences (Cheng et al., 2023) [14].

Impactful Contributions: The literature review identifies notable papers focusing on the sepsis datasets, significantly contributing to predictive analysis in the ICU. Some of these studies focus on machine learning for the early prediction of sepsis in the ICU (Alanazi et al., 2023) [15], while another study focused on the prediction of sepsis in the ICU with minimal electronic health record data (Desautels et al., 2016) [16]. This dataset spans over a decade, comprising detailed information on more than 53,000 patients. Its accessibility and clear classification have propelled research capabilities in the field.

In conclusion, the literature review showcases the evolution of predictive analysis for ICU patients, emphasizing the importance of a comprehensive understanding of current research trends. The methodologies employed in recent studies provide insights into the diverse approaches to predictive modeling. Global trends underscore the collaborative nature of research, while impactful datasets contribute substantially to advancements in the field.
The literature review positions predictive analysis for ICU patients as a dynamic and promising area, with potential for further exploration and improvement in predictive model performance. This collective knowledge serves as a foundation for future research, guiding the field toward more personalized, data-driven healthcare management.

4. Methods

The abstract outlines a comprehensive bibliometric analysis of the field of artificial intelligence (AI)-based predictive analysis for ICU patients. The study focuses on a reference that utilizes the MIMIC-III dataset, specifically examining non-structured nursing text from ICU patients. The evaluation involves a Random Forest classifier and three-word embedding models applied to unstructured nursing notes from a substantial patient sample.

The results highlight the superiority of Word2Vec Skipgram over traditional methods, emphasizing the importance of early identification of high-risk patients in ICU treatment decisions. The integration of AI is seen as a crucial element not only for improving healthcare efficiency but also for enhancing patient outcomes, representing a transformative moment in medical care evolution.

Anticipated future innovations in patient care are linked to advancements in technology, particularly in biomedical signal processing, with the potential to refine treatment strategies. The abstract underscores the importance of timely dissemination of medical knowledge to drive innovation, reduce errors, and translate theoretical knowledge into practical medical innovations.

The methodology overview provides insight into the selection of references from various literature sources, emphasizing methods, results, and relevance. The study suggests future research directions, including field validation, clinical application, specific case, and population studies, and data enrichment through multi-modal information integration.

In conclusion, the research contributes a comprehensive framework for improving outcomes in ICU patient care through AI-based predictive analysis. It emphasizes the early identification of at-risk patients and optimal resource allocation, providing a theoretical foundation for future research to conduct field experiments and observe real-world impacts on clinical decisions and patient outcomes. The findings are expected to enhance our understanding of mortality risk prediction in ICU patients, offering practical approaches to improve clinical practice and patient care.

4.1. Use of VOSViewer for Bibliometric Analysis

VOSviewer is a powerful and user-friendly visualization application designed to aid in the analysis and exploration of large sets of bibliographic data, such as academic literature, authors, journals, and citations. Its primary objective is to simplify complex research outcomes into intuitive visual representations, facilitating comprehension and aiding researchers, academics, and professionals in uncovering relationships within their respective fields.

One of the key features of VOSviewer is its ability to generate visual maps that allow users to explore research domains comprehensively. These maps are constructed based on various metrics, such as co-citation, bibliographic coupling, or co-authorship, depending on the specific analysis requirements. By visually representing the connections between different elements, such as authors, documents, or keywords, VOSviewer enables users to identify clusters, trends, and influential nodes within their research landscape.

Moreover, VOSviewer employs sophisticated algorithms and visualization methods to transform complex data sets into visually appealing and interactive graphics. This enables non-professionals and experts alike to easily interpret the results of model analyses, without requiring extensive technical expertise. The intuitive nature of the visualizations helps users grasp the underlying patterns and insights present in their data, fostering deeper understanding and informed decision-making.

Furthermore, VOSviewer supports customization options, allowing users to adjust parameters, colors, and layouts according to their preferences and research objectives. This flexibility enhances the tool's usability and adaptability across diverse research contexts and disciplines.

In summary, VOSviewer serves as a valuable tool for knowledge discovery and exploration, empowering users to navigate vast amounts of scholarly literature and uncover meaningful insights. Its user-friendly interface, powerful visualization capabilities, and customizable features make it an indispensable asset for researchers, academics, and professionals seeking to gain deeper insights into their respective fields of study and explore the evolving trends in research (https://www.vosviewer.com/).
4.2. **Keyword Search Criteria**

Our research analysis primarily had two levels of keyword and article search.

**Level 1:**

(predictive) OR (analysis) OR (ICU)

AND

Year range: (2022) OR (2023) OR (2024)

**Level 2: Find Articles from Google Scholar:**

<table>
<thead>
<tr>
<th>With all the Words</th>
<th>predictive analytics</th>
</tr>
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<tbody>
<tr>
<td>With the Exact Phrase</td>
<td>&quot;predictive analytics&quot;, &quot;patient mortality&quot;, &quot;intensive care&quot;</td>
</tr>
<tr>
<td>With at least one of the words</td>
<td>ICU mortality</td>
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<tr>
<td>Without the words</td>
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<tr>
<td>Where my words occur</td>
<td>anywhere in the article</td>
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</tbody>
</table>

**Articles authored by**

**Articles published in**

**Articles dated between**

2010-2023

Level 2 returned 285 results as of 1st January 2024. If we only keep “predictive analytics” as the exact phrase, and with at least one of the words, ICU or mortality, then 15, 100 search results are obtained.

Figure 1. Basic Network Visualization (VoViewer)
With mortality being the central node, readers should examine any attributes associated with nodes, such as size, color, or shape. These attributes may convey additional information about the nodes, such as their importance, type, or status. Attributes like thickness, color, or directionality may provide information about the strength, type, or nature of connections between nodes. Nodes with higher degrees may be more central to the network, while those with lower degrees may be more peripheral. Readers should also assess degree centrality, betweenness centrality, or closeness centrality. These measures identify the most central or influential nodes within the network.

4.3. Clustering Analysis

"Clustering AI Themes" involves employing a data analysis method to group elements in artificial intelligence with similar features or characteristics together, forming clusters or groups. Understanding these themes is crucial in business environments as it provides insight into the role of artificial intelligence. This comprehension contributes to discovering new business opportunities, formulating more effective strategic decisions, and enhancing the competitiveness of enterprises in highly competitive markets. Through clustering AI themes, businesses can better grasp trends and dynamics in their industries, enabling them to swiftly respond to market changes, improve operational efficiency, and foster long-term success and sustained growth.

Alternatively, researchers may also use a visualization tool or programming library (such as Python with Matplotlib or Seaborn) to create a 2D or 3D scatter plot representing the clustered data. Each point on the plot corresponds to a patient, and the color or shape of the points indicates the assigned cluster. Interestingly, researchers in the field should look for clusters with a high concentration of mortality cases and assess whether the AI predictions within those clusters were accurate. The clusters could be developed such that researchers can calculate performance metrics such as precision, recall, and accuracy for the AI predictions within each cluster. This provides a quantitative assessment of the AI's effectiveness in predicting ICU mortality within different patient groups. The researchers then may refine their clustering analysis iteratively based on insights gained from the visualization. The idea would be to iteratively adjust clustering parameters, feature selection, or algorithm choice as needed to improve the interpretability and utility of the results.

4.4. Density Analysis

Density visualization is a technique used to represent the distribution and concentration of data points within a dataset. It provides a graphical representation of the density or frequency of occurrences across different regions or intervals. This visualization method aids in identifying patterns, clusters, and outliers within the data by highlighting areas of high and low density. In various fields such as statistics, data analysis, and machine learning, density visualization plays a crucial role in understanding the underlying structure of the data and making informed decisions based on its characteristics. By visually depicting the density of data points, researchers and analysts can gain insights into the distribution patterns, trends, and relationships present in the dataset, facilitating deeper exploration and interpretation of the data's significance.
For this density analysis (Figure 3), we have tried to create a word cloud to represent the density of keywords and terms associated with predictive analytics and ICU mortality. This provides insights into the prevalent themes and topics in the literature. Alternatively, we could have also done the following:

- used a timeline to visualize the density of publications related to predictive analytics of ICU mortality over time. This can help identify trends, peaks, or shifts in research focus.
- visualize the density of authorship in the field. Identify prolific authors or research groups contributing to the literature on predictive analytics in ICU mortality.
- show the distribution of publications across different journals. Highlight journals that are central to the field, and assess the impact factor or influence of these journals.
- illustrate the density of citations within the literature. Identify seminal works or highly cited papers, indicating the influence of specific studies in the field.
- create a visualization of the institutions contributing to research on predictive analytics in ICU mortality. This can help identify leading institutions and collaborative networks.
- represent the geographic distribution of research contributions. This can provide insights into the global landscape of predictive analytics in ICU mortality studies.
- visualize collaboration networks between authors, institutions, or countries. Identify key collaborative hubs and patterns of interdisciplinary research.
- represent the density of different document types (e.g., articles, reviews, conference papers). This can provide insights into the types of publications prevalent in the field.
- visualize the density of research methodologies used in predictive analytics studies for ICU mortality. This can include machine learning algorithms, statistical methods, or other analytical approaches.
- show the density of research focused on specific diseases or conditions within ICU mortality prediction.

The primary idea in this type of analysis is to customize the density visualization to suit the specific questions and objectives of your bibliometric analysis. Researchers doing a bibliometric analysis could also utilize appropriate visualization tools such as density plots, heatmaps, or network graphs to effectively convey the patterns and relationships within the bibliographic data related to predictive analytics in ICU mortality.

5. Discussion

The ultimate goal of this study is to advance the application of early intervention in medical practice, providing patients with more personalized and efficient healthcare. By emphasizing early intervention, we have achieved the timely identification of high-risk patients, enabling healthcare providers to administer proactive and timely
treatments in the early stages of disease development, significantly improving patient outcomes. This marks not only a fundamental change in healthcare dynamics but also ensures that every patient receives precise care when needed. In terms of research and development, our commitment lies in the continuous improvement and refinement of predictive models. This journey involves not only fine-tuning existing methodologies but also exploring new technologies, keeping us at the forefront of medical predictive analytics. It signifies a comprehensive embrace of innovation, shaping the future direction of healthcare analytics. Regarding cost-effectiveness, our core efforts focus on optimizing the allocation of healthcare resources and preventing unnecessary medical expenses through proactive interventions. Our approach is not just about immediate savings but also about reducing long-term treatment and healthcare-related costs, contributing to a healthier financial future. In collaboration, we actively seek partnerships with pharmaceutical companies and research institutions to propel further advancements in science and technology. Through collaborative efforts, we aim to foster innovation, create synergies, and promote knowledge sharing in the medical field, all for the overall benefit of healthcare. Overall, our study highlights the significant potential of artificial intelligence in medical decision-making, particularly in the intensive care unit (ICU) environment. This not only provides insights for businesses applying AI in healthcare but also underscores the advantages of AI in enhancing predictive accuracy and efficiency. The success cases in ICUs empower businesses to manage healthcare resources more effectively, thus improving overall efficiency. Data-driven decision-making is becoming mainstream in business, and the success of ICU demonstrates the indispensable role of big data and artificial intelligence in clinical decision-making.

6. Potential Future Studies and Conclusion

The future development of ICU technology will focus extensively on the widespread adoption of advanced machine-learning techniques to enhance predictive model performance. By exploring advanced technologies such as deep learning, we are moving towards a more personalized and data-driven approach to healthcare management, creating an efficient and innovative future. Research into specific cases and populations will be a key direction to ensure the broad applicability of the models. In practical applications, early identification of high-risk cases and more effective allocation of medical resources will elevate the level of patient care. To further enhance predictive model performance, continuous exploration of advanced machine learning techniques, such as deep learning methods, is essential. Simultaneously, conducting in-depth research into specific cases and populations, considering different age groups or patients with specific diseases, will ensure the model's applicability across diverse demographics. Conducting more field experiments in actual clinical settings to observe the real impact of predictive models on clinical decisions and patient outcomes is imperative. In summary, the future of ICU predictive analytics will evolve under the guidance of advanced technology, with a focus on creating a more efficient, accurate, and reliable healthcare management system through in-depth research into specific cases and populations, along with field validation. While driving future development, attention to ethical considerations and safety measures is crucial to ensure the ethical compliance of technological applications.

References:


