Exploring the Use of Explainable Artificial Intelligence (XAI) in Production and Operations: A Systematic Review

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ABSTRACT

Today, with the development of artificial intelligence, its application in different areas, including production and operations, has expanded. Explainable artificial intelligence (XAI) is a new research topic that has emerged with the development of artificial intelligence. This study aimed to investigate the applications of XAI in production and operations using the systematic review approach. For this purpose, a systematic review of the most recent studies published in the Science Direct, Scopus, and Emerald knowledge bases was conducted. After screening through different stages, 29 articles were reviewed and analyzed. The results showed that publications on XAI have been on an upward trend in recent years, with a significant increase observed from 2021 to 2024. Also, the fields of engineering, production, decision-making, and computer science are the major areas in which recent studies have been published. The results also suggested that the largest scope of XAI application was observed at the organizational level, followed by the industrial level. Based on the findings, the fields of production and operations, followed by logistics and supply chain, were the most frequently studied areas. Regarding the methods used, the SHAP method was the most commonly applied method in the XAI studies, followed by Integrated Gradient and SVM methods. In general, the results of this study showed that XAI is a new field of research that is gradually developing in terms of methodology and areas of application.

KEYWORDS

Artificial Intelligence, Explainable Artificial Intelligence, Production and Operations, Systematic Review.
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Introduction

In the digital age, various manufacturing and service sectors need to increase their customer access speed and enhance their understanding of businesses, governments, and communities. Accordingly, public and private organizations are adopting and applying emerging technologies to improve their efficiency and gain a competitive advantage. In this context, artificial intelligence (AI) plays a crucial role in achieving operational transformation within contemporary organizational structures. AI has become a fundamental aspect of today's business organizations. Technology companies and governments acknowledge the power of AI and attempt to develop machine learning, particularly deep learning, across a range of sectors, from health to national security. Moreover, civic groups, governments, and academic scholars are increasingly concerned with the impacts of AI on health, discrimination, racial differences, and the risks of applying AI in the military and governance settings. In fact, AI has demonstrated impressive applications across economic, healthcare, political, legal, social, security, and business sectors, and it is poised to have a close co-existence with human life in the near future. AI is generally defined as the ability to process and transform data into information to support purposeful behavior. Alongside advancements in technological innovation and the elimination of human-centered organizations, AI empowers companies to drive and manage innovation more efficiently.

AI has moved out of its infancy and is now in its youth, providing a variety of innovative and creative applications and services to businesses, people, and governments. Therefore, many service organizations, production companies, research institutes, and researchers have been drawn to this technology. In other words, AI has made significands tridents both in research and application across various fields, including the development of smart and networked vehicles, drones, agriculture, defense security, logistics, finance, industry, healthcare, robotics, energy, digital education, transportation, space exploration, and environmental management. These are among the most important areas in which AI is currently being seriously implemented.

Apart from these areas, both developed and developing countries- such as the USA, UK, France, Germany, Sweden, UAE, Lithuania, Mexico, Qatar, China, and Turkey- have made serious strides towards the optimal use of AI by developing strategic plans, infrastructures, and governance institutions.

Literature Review

Artificial Intelligence

AI is arguably one of the oldest disciplines of computer science, with its perceptual dimensions and functions designed to mimic the real world and create systems that think and learn like humans (Holzinger et al., 2019). AI has produced significant benefits and has successfully been applied in several areas of industry, including image classification, voice recognition, automated cars, and computer vision (Zhao et al., 2020). The main goal of AI is to solve human problems by modeling human capabilities- not only the physical

capabilities, but also the neural, mental, and perceptual capabilities. By modeling and imitating human perceptual functions, AI seeks to speed up progress in various fields such as medicine, transportation, economy, education, etc. Therefore, the closer the AI gets to replicating human intelligence, the more aligned it becomes to its goals.

An Analysis of theoretical foundations shows that research on the prioritization of applied areas of AI is a relatively new issue in the field of emerging technologies, despite the significant amount of research conducted on AI both domestically and internationally. One of the most recent studies is the research titled "Creativity and artificial intelligence" (Miller, 2019). In this research, creativity is considered as the main characteristic of human intelligence and the author believes that creativity presents considerable challenges for AI. The study suggests that AI techniques can be used in three ways to generate new ideas: by combining similar ideas, exploring potential conceptual spaces, and making changes that transforms previously impossible ideas into possible ideas. In another study, Zhang et al. (2022) investigated ethics and governance in AI. In this study, the authors suggest that researchers in machine learning (ML) and AI play an important role in the ethics and governance of AI, particularly in areas such as job creation, work force support, and career choice. Tolan et al. (2021) have addressed the impact of AI on community employment. By designing a framework for analyzing the impact of AI on employment, they ranked AI-related jobs and improved people's knowledge about employment opportunities in an AI-affected labor market (Tolan et al., 2021).

In Iran, some studies have been performed on AI, investigating the principles, techniques, and applications of AI. For example, Soroush and Monajemi (2018) in a study titled "Analysis and criticism of artificial intelligence in medicine from an epistemological perspective" addressed cognitive errors in medicine that led to the increased use of AI. They also reviewed medical epistemology, ultimately describing the following epistemological reasons for the failure of AI systems in this field of science: incorrect assumptions about the nature of knowledge, separation of knowledge from decision-making strategies, not paying attention to tacit knowledge, and separating knowledge from context (Soroush & Monajemi, 2018) .

Another study examined crime analysis using AI methods and data mining for the preemptive detection of crimes. This research examined the methods used by house bulgars, using neural networks - one of the existing AI methods- for the discovery and preemptive detection of crime (Keivanpour et al., 2009).

Many other studies have also examined the application of AI in various fields. For example, AI has been used to determine the maximum output discharge resulting from the fission of the earth dam (Babaeian et al., 2012), assist in medical decision-making with a focus on its advantages and challenges, optimize the operation of dam reservoirs, and improve energy consumption in Iran's transportation sector (Tahari-Mehrjerdi et al., 2012).

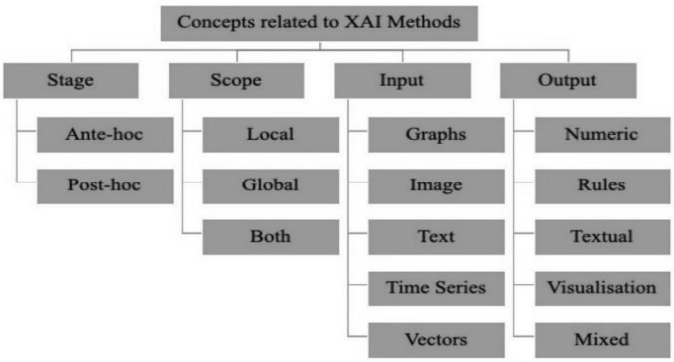
Explainable Artificial Intelligence (XAI)

Since 2020, explain ability has been identified as a key factor for the adoption of AI

systems in a wide range of contexts. Explainable Artificial Intelligence (XAI) has actually been developed to address the current limitations of AI systems. Explainable AI proposes the creation of a set of machine learning techniques that (1) generate more explainable models while maintaining high learning performance (e.g., greater predictive accuracy) and (2) enable humans to understand, trust, and effectively manage the emerging generation of AI partners. XAI also integrates findings from the social sciences (Miller, 2019) and the psychology of explanation.

The concept of explain ability relates to the relationship between decision-makers and humans. This interface is developed to be comprehensible to humans and accurately represents the decision-making process. In XAI, the interface between models and end users is called "explanatory", allowing the end user to understand the decisions made by the AI/ML model. Based on the literature, XAI concepts can be classified into different application areas such as stage, range, input, and output formats. Figure 1 summarizes the main concepts of XAI application development.

Figure 1.
Various Concepts on Methodological Development for XAI Derived from Studies by Villon and Longo



(Source: Vilone & Longo, 2020)

Artificial Intelligence and Production and Operations

The goal of AI is making computers smarter by processing large amounts of data, discovering hidden patterns and unknown correlations, learning from data, and finding the best possible solutions to real-world problems. Various tools are used to facilitate this process, including statistical tools, rule-based methods, machine learning (ML), deep learning (DL), reinforcement learning, probabilistic graphical models, soft computing, knowledge representation techniques like knowledge diagrams, game theory, and even traditional algorithms such as programming and search algorithms (Zhang & Lu, 2021).

AI is a set of tools used to process data, extract patterns, and learn from it. In academic literature, AI is also referred to by names such as big data analysis, data mining, predictive modeling, data science, pattern recognition, and data-driven systems, all of which aim to process large amounts of data, learn from it, and enhance computers' intelligence. AI offers the benefits of persistence, reliability, and cost-effectiveness, while also addressing uncertainty and accelerating the speed of problem solving or decision making (Chowdhury & Sadek, 2012). Today's manufacturing systems are increasingly becoming

complex, dynamic, and interconnected. Plant operations face nonlinear and stochastic challenges due to numerous uncertainties and interdependencies. Recent advances in AI have shown great potential to change production scope through advanced analytical tools for processing large volumes of generated data, commonly referred to as big data (Arinez et al., 2020).

AI solutions to existing problems have three important aspects: 1) optimal output, 2) input data, and 3) the modeling approach. AI begins by defining the desired outcome. To achieve that output successfully, the input data must be carefully defined. Understanding the type of input data is crucial to understanding how AI is used in problem-solving. Finally, the steps that are used in a given modeling approach, such as feature engineering, are determined to obtain the desired output from the input data (Subramaniyan et al., 2021).

Methodology

Given the large amount of information, inconsistent studies, contradictory results, and the reduction of time and capital, along with the need to identify research needs, a review study is necessary (Yarmohammadian et al., 2011). The method used in this research is a systematic review. One of the main features of a systematic review is its high stability, meaning that it is repeatable and follows several stages. Initially, the scope is very wide and highly sensitive, but in the later stages, it becomes more specific. This method is a powerful tool for the comprehensive analysis and diagnosis of relevant studies and answering the research questions (De Loë et. al., 2016).

In this study, a systematic review of applied research using one or more XAI methods has been conducted. While individual studies provide insights into one aspect of the larger picture, the value of a systematic review lies in combining discrete and synergistic results in an organized method, allowing researchers to obtain an overview of the subject under investigation (Sengers et al., 2019).

The process of conducting a systematic review in this study is based on Okoli and Shabram's (2010) guideline. Also, to ensure a more accurate selection of articles, the selection process outlined in Silva (2015) was adopted. Okoli and Shabram (2010) proposed a framework for illustrating the steps of conducting a systematic review, which has been widely adopted in systematic review studies. As shown in Figure 1, these steps are as follows: planning, selection, extraction, and implementation.

Given the importance of selecting the articles, the framework presented by Silva (2015) was used in the selection step. The selection process includes the following steps:

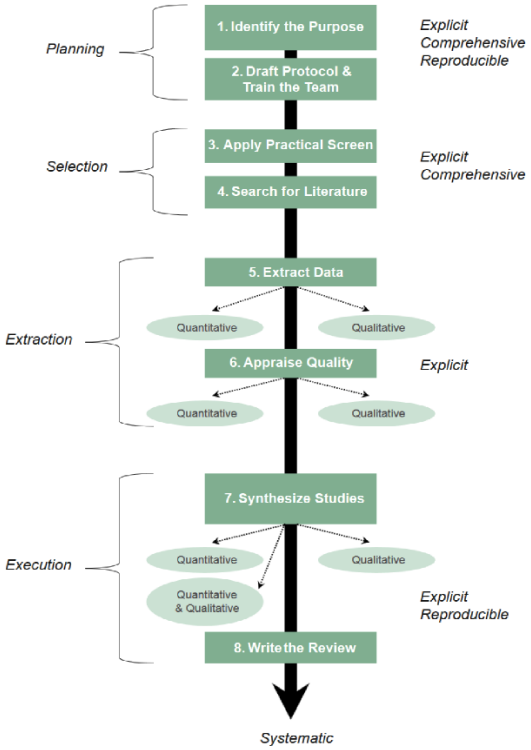
1. Identifying and extracting articles from scientific databases and removing duplicate records;
2. Screening through examining the title and abstract of the extracted articles, selecting relevant ones, and deleting unrelated ones.
3. Rescreening through reading the introduction and conclusion of the previously screened articles, selecting those that are relevant, and deleting unrelated ones.

4. The final evaluation of the articles through studying them, ensuring that they align with the research objectives, followed by the final selection of the related articles.

The combined application of these two frameworks and the overall process of conducting this study are illustrated in Figure 1. To determine the direction of article selection and analysis in a systematic review, the objectives and research questions must first be clarified (De Loë et al., 2016). Then, based on these goals, relevant articles are selected in order to answer the mentioned questions, and after several stages of screening and in-depth analysis of the relevant articles, final articles are selected.

Okoli and Schabram (2015) and Silva's (2015) selection steps for a systematic review are provided in Figure 2.

Figure 2.
A systematic Guide to Literature Review Development



(Source: Researcher's Findings)

In this study, to identify the prototype, the articles published in the journal of three databases-Science Direct, Scopus, and Emerald- were selected. These databases were selected for their maximum coverage, which led to achieving more comprehensive articles and obtaining more reliable and valid results (De Loë et al., 2016). The systematic review began by searching for articles whose title, abstract, or keywords were in English (last search date: 13th May 2024)

The literature search was performed using the following keywords: «XAI» ‹«Artificial Intelligence» ‹«Explainable» «AI», «Manufacturing» ‹«Production» ‹ «Operation». "AND" and "OR" were combined, and " * " wildcards were used to expand the search if necessary. A database of articles was then created, which included the following information:

- Citation information such as author/author name, year of publication, and journal name;
- Number of citations;
- The main approach of the paper in terms of practicality and theoretically (Vishnevskiy & Karasev, 2016);
- The context and scope of the study;
- The domain being investigated;
- Methods used and referred to in the paper;
- Nationality of authors;
- The country in which the study was conducted (in applied literature and case studies);
- The time horizon for applied studies;
- Objectives, methodology, and output of the paper

In the next step, the results of this search were combined and repeated items were removed. Titles and abstracts of the remaining articles were reviewed and irrelevant items were filtered out. In the next step, the introduction and conclusion of the remaining articles were studied, and a number of articles were excluded due to their lack of relevance to the research goals and questions. During the screening process, only studies that applied or combined explainable AI methods or focused on system design were considered. Accordingly, articles dealing with purely theoretical issues were also excluded.

To gain more accurate results, the remaining articles were evaluated through comparisons. At this stage, to assess the quality of articles, the criteria outlined by Quiñones and Rusu (2017) were used and the articles were evaluated in terms of:

Focusing on the use of one or more methods;

Following a clear and open process;

Being published in prestigious journals.

At this stage, 429 articles were identified. Based on the obtained quality score, the articles were evaluated in terms of the mentioned criteria, and the eligible ones were selected for in-depth study and analysis. Finally, 29 articles passed the screening process and were analyzed using systematic review techniques. The following table presents the questions used as the basis for screening and evaluation. Table 2 provides a sample of the papers that were selected in the final filter.

Table 1.
Research Questions

Category Questions	Questions
Methods	What methods of explainable artificial intelligence have been used in different years?
Year of publication	In what years have papers on XAI been published?
Scope/scale of application	What has been the scope of the research? (organization, industry, public)
Field of application	In what areas has each methods of XAI been used in the studies under investigation?
Topical Topics	What are the thematic topics of the journals in which the articles were published?

(Source: Researcher's Findings)

Table 2.
Sample of Selected Articles

Row	Title of the article	Year of publication	Authors	The method used	Magazine
1	Advancing solar energy integration: Unveiling XAI insights for enhanced power system management and Sustainable future	2024	M.K. Nallakaruppan, Nathan Shankar, Prahal Bhagavath Bhuvanagiri, Sanjeevikumar Padmanaban, Surbhi Bhatia Khan	LIME	Ain Shams Engineering Journal (Nallakaruppan, Shankar, Bhuvanagiri, Padmanaban, & Khan, 2024)
2	XAI-empowered Iota multisensory system for real-time milk adulteration detection	2024	Kashish Goyal, Parteek Kumar, Karun Verma	Shapley	Food Control (Goyal, Kumar, & Verma, 2024)
3	Harnessing explainable artificial intelligence for feature selection in time series energy forecasting: A comparative analysis of Grad-CAM and SHAP	2024	Van Zyl, Corne, Xianming Ye, and Raj Naidoo	Gradientweighted Class Activation Mapping (Grad-CAM) and Shapley Additive Explanations (SHAP),	Applied Energy (Van Zyl, Ye, & Naidoo, 2024)
4	Interpretable artificial neural networks for retrospective QbD of pharmaceutical tablet manufacturing based on a pilot-scale Developmental dataset	2023	Brigitta Nagy, Szabados-Nacsa, Fülöp, Anikó Nagyné, Dorián Galata, Attila Farka Alexandra Zsombor Kristóf Nagy, György Marosi Ágnes Gergő Turák László s, Lilla Mészáros,	Interpretable Artificial Neural Network	International Journal of Pharmaceutics (Nagy et al., 2023)
5	Fault Diagnosis using explainable AI: A transfer learning-based approach for rotating machinery exploiting augmented Synthetic data	2023	Lucas Costa Brito, Gian Antonio Susto, Jorge Nei Brito, Marcus Antonio Viana Duarte	Gradientweighted Class Activation Mapping (Grad-CAM) with 1D Convolutional Neural Network (1D CNN)	Expert Systems with Applications (Brito, Susto, Brito, & Duarte, 2023)

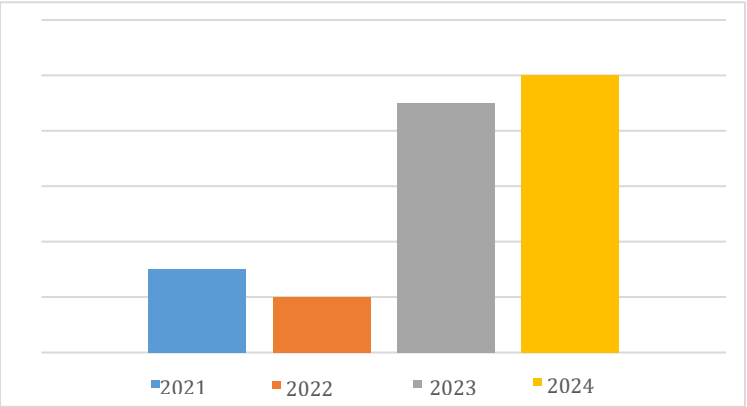
(Source: Researcher's Findings)

Findings

Year of Publication

One of the aims of this research is to study the publication years of the articles. As the chart below shows, there has been an upward trend in the publication of articles over the past few years, with a significant increase from 2021 to 2024. This indicates that AI is a relatively new field of study and highlights the growing interest of the scientific community in addressing this issue. The results are shown in Figure 3.

Figure 3.
Publication Year of the Articles

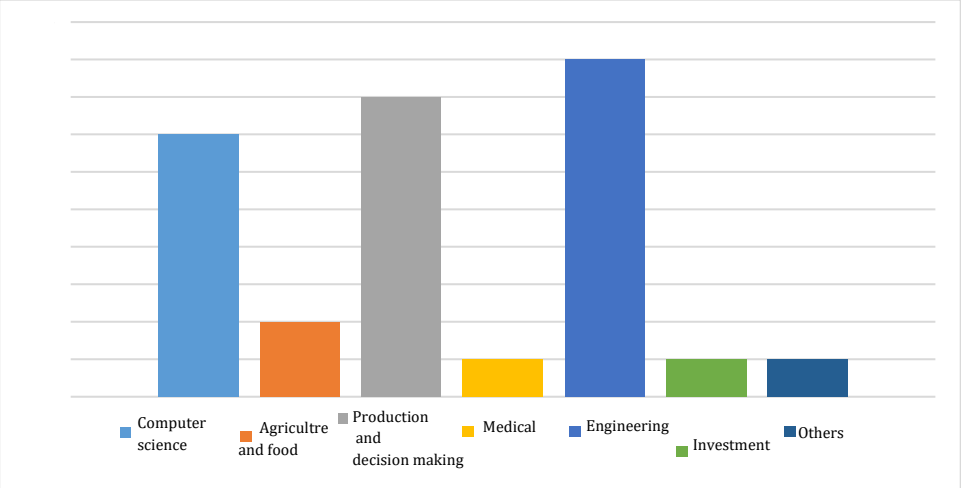


(Source: Researcher's Findings)

Thematic Topics of Journals

Another aim of this research is to identify the thematic focus of the journals in which the articles have been published. As shown in the diagram below, the most common thematic areas include engineering, production and decision-making, and computer science. The results are shown in Figure 4.

Figure 4.
Thematic Topics of Journals

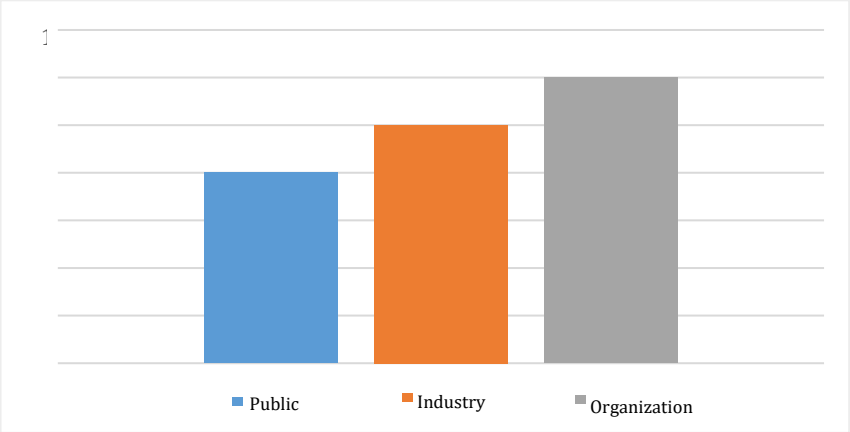


(Source: Researcher's Findings)

Scope and Scale of Application

Articles usually define the scope and application scale of their results, which can be at a micro (i.e., the organization), or macro level (i.e., the industry). In the reviewed articles, the most common application scope was the organization level, with 12 cases. This was followed by the industry level with 10 cases, and the general level with 8 cases. These findings suggest a greater interest in using XAI to solve the operational problems within organizations. The results are provided in Figure 5.

Figure 5.
Scope and Scale of Application

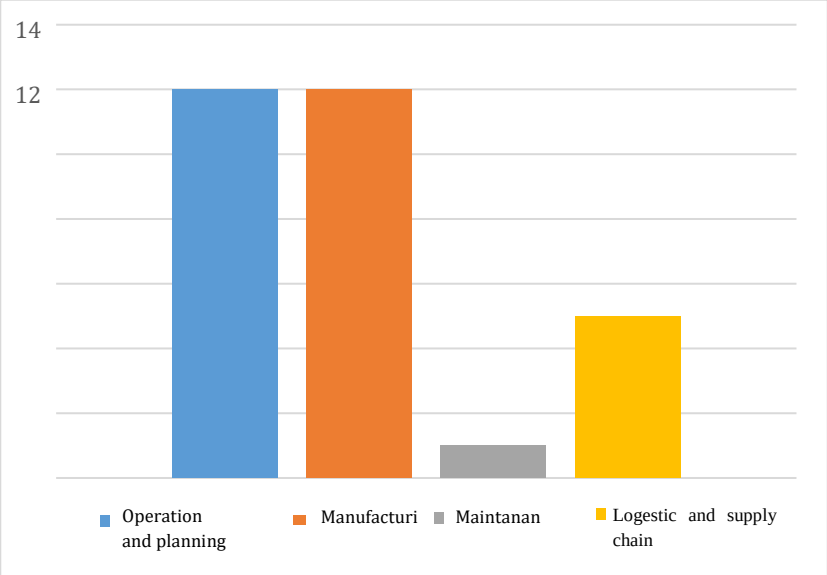


(Source: Researcher's Findings)

Field of Application

Another purpose of this research is to identify articles' field of application. According to the review, the most common field of application was production and operations with 24 cases. This was followed by logistics and supply chain with 5 items, and maintenance and repairs with 1 item. The results are shown in Figure 6.

Figure 6.
Field of Application

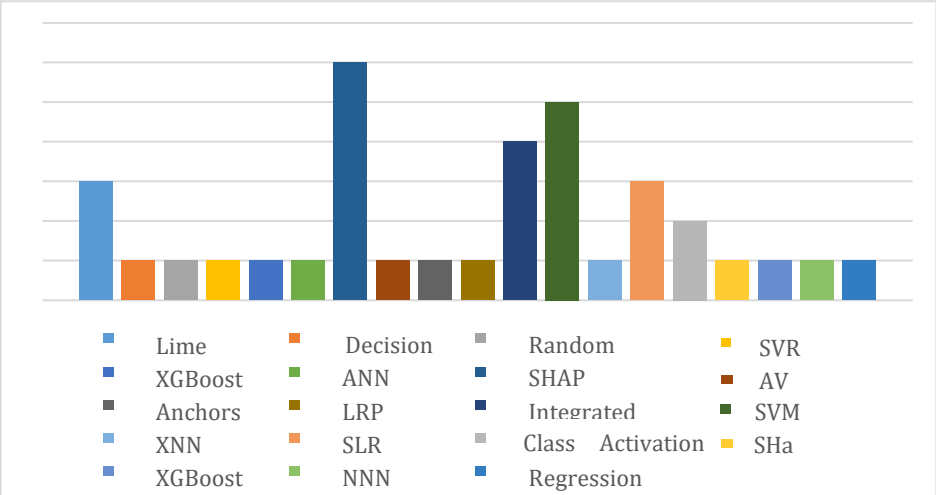


(Source: Researcher's Findings)

Methodology

The other objective of this study was to identify the techniques and methods used in the literature. According to the results, the Shap method with 6 cases was the most used method. Then, "Integrated Gradient" and "SVM" methods with 5 and 4 cases, respectively were the most commonly-used methods. The results are presented in Figure 7.

Figure 7.
Methods Used



(Source: Researcher's Findings)

Discussion and Conclusion

Regarding the period and publication years of articles, the results reveal that, researchers have mainly focused on XAI in recent years. The volume of published articles has significantly increased in the last two years compared to the previous years, indicating the novelty XAI. Accordingly, the number of studies in this field is expected to increase, alongside the development of applications, methods, and functional areas of XAI.

According to the results, XAI has been applied in fields such as engineering, food and agriculture, finance and investment, medicine, production and decision-making, and computer science. Although in some areas, such as engineering, its application has been more than in other areas, the diversity of fields suggest that we will see the use of AI in new fields.

Regarding the scope and scale of AI approaches, it could be said that because of the optimization nature of these methods, they are mostly used at the micro level (i.e. the organization) with operational goals. However, their application across the macro level (i.e. industry) is also significant. Also, the potential of their use at the general level is promising and they may expand into other fields in the future.

As for the methods and techniques used, the results revealed that a wide range of methods have been used in the literature. Several factors have been effective in choosing the appropriate method, including type of research strategy, previous experience, available financial resources, appropriateness with other methods, desired output, scope of the project, available knowledge and information, the time horizon of research, uncertainty, research approach (top-down or bottom-up), review period, technology, industry or organization characteristics, and the user group. These factors can justify the selection of appropriate method and technique for conducting research.

In general, the findings of this study suggest that we are likely to see a growing application of interpretable AI techniques and methods in various fields in the future.

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