BIBLIOMETRIC STUDY ON AHP AND INVESTMENT DECISIONS IN INDUSTRY 4.0

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Highlights

- AHP is highlighted as an effective method for supporting investment decisions in Industry 4.0 technologies by integrating financial and non-financial criteria.
- AHP's use in advanced manufacturing investment evaluation has been limitedly explored; a gap exists in decision-support tools for Industry 4.0.
- Opportunities include developing AHP to incorporate sustainability aspects.

ABSTRACT

This work presents a bibliometric study on the Analytic Hierarchy Process and investment decisions in Industry 4.0 technologies. We identified essential elements, such as keywords in documents indexed in the Scopus database, and we mapped the recent trending topics using VOSviewer. Industry 4.0 was selected due to its relevance to economic development. The survey was carried out in September 2024, resulting in 74 documents published since 1992. One significant finding is the absence of scientific production relating the Analytic Hierarchy Process to decisions regarding Industry 4.0 technologies.

Keywords: Analytic Hierarchy Process, bibliometrics, Industry 4.0, investment.

1. Introduction

This article explores the application of the Analytic Hierarchy Process (AHP) to support investment decisions in Advanced Manufacturing Technologies (AMT), also known as Industry 4.0 (I4). The industry is moving toward integrating smart manufacturing and supply chains, focusing on Smart Working in the coming years (Meindl et al., 2021). Adopting these technologies offers significant benefits (Bednar & Welch, 2020), but many companies face difficulties in implementing digital transformation due to the complexity of the processes and uncertainties in investments (Frank et al., 2019).

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Traditionally, financial criteria such as net present value (NPV), internal rate of return (IRR), payback, and return on investment (ROI) are used to evaluate investments (Lefley, 1996; Sureka et al., 2022; Swamidass & Waller, 1991). However, these methods are limited when dealing with the interdisciplinary complexity of I4 (Almeida et al., 2023). Decisions are often based solely on financial analysis or managerial intuition, which restricts the advancement of technologies (Bertoncel et al., 2018). This reveals a gap in the literature on investment appraisal in the context of I4.

Multi-criteria decision-making (MCDM) has been applied to allocate resources for I4, and AHP stands out as one of the most widely used MCDM methods. Its solid mathematical foundation and wide acceptance make it versatile and already applied in different sectors (Salomon & Gomes, 2024).

This paper proposes to answer the question of how the AHP has been applied to support investment decisions in I4 and what research opportunities exist. The aim is to combine strategic needs with the AHP, offering a management tool that facilitates digital transformation in industries.

2. Literature Review

Bibliometrics has been used as a quantitative analysis method for scientific research (Donthu et al., 2021). As a reference, bibliometric studies, trends, or gaps can be identified to conduct new research. Bibliometric data makes it possible to profile the evolution of research, highlighting emerging trends and patterns. This analysis allows authors to identify hot topics that can direct new research efforts (Tamala et al., 2022).

There is a lack of studies explicitly addressing investment appraisal in the context of I4, which creates a research opportunity to develop tools to help companies make decisions (Almeida et al., 2023). While some studies have explored the expected benefits of I4.0 (Frank et al., 2019) or focused on criteria for selecting technologies (Santos et al., 2023), few have addressed investment evaluation as a critical factor for driving I4 adoption (Beier et al., 2020; Oesterreich & Teuteberg, 2016). Understanding how AHP techniques have been used to decide on investments in I4 technologies can help develop new models and applications that benefit industrial unit managers and researchers.

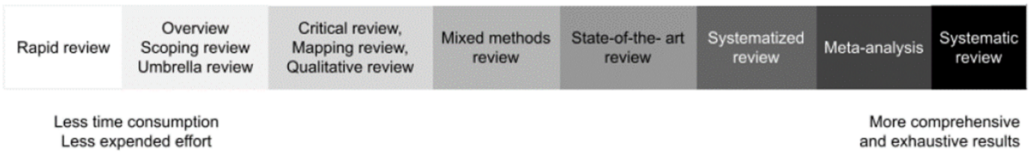
3. Objectives

This paper's primary objective is to provide an overview of the application of the AHP as a support tool for investment decision-making in I4 technologies. It also aims to identify research gaps and propose future research directions. The paper is structured into three more sections: Section 4 outlines the research methodology, Section 5 presents a discussion and summarizes the findings, and Section 6 concludes with recommendations for future research.

4. Methodology

Figure 1 presents different approaches to literature reviews:

Figure 1. Spectrum of literature review approaches

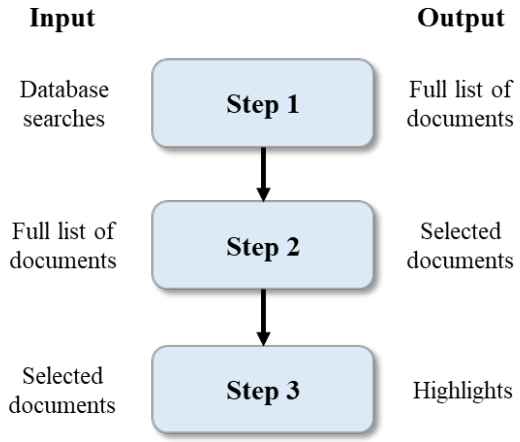


Source: Bargueño et al. (2021).

A literature overview was conducted to meet the objectives proposed in Section 3. This review was conducted using the Scopus database, a platform widely recommended for conducting literature reviews (Burnham, 2006; Oliveira et al., 2018). While both Clarivate's Web of Science and Elsevier's Scopus databases provide similar content (Mongeon & Paul-Hus, 2016), Scopus was chosen to ensure data consistency, standardized search methods, and reliable results.

The review followed the four-step method for state-of-the-art reviews proposed by Bargueño et al. (2021). However, this paper focuses on the steps presented in Figure 2 for research purposes.

Figure 2. Literature review method



In step one, the Scopus database (www.scopus.com (accessed on 10 September 2024)) was searched in September 2024. Therefore, the number of documents was reduced in step two. Step three involves a keyword analysis using the network analysis software VOSViewer (www.vosviewer.com). The review presented in this paper goes further, highlighting years of publication (Figure 2), areas (Figure 3), countries (Figure 4), and keyword co-occurrence (Figure 5). No complementary software was necessary, making the method more efficient. Here, the three-step method was performed solely with the figures provided by Scopus.

5. Results

Initial searches with the title, abstract, and keywords (TITLE-ABS-KEY) in the Scopus database resulted in the data shown in Table 1:

Table 1. Documents on AHP, I4, and investment decisions

TITLE-ABS-KEY	Articles	Reviews	Others	Total
"Industry 4.0"	55,582	5,586	63,335	124,503
"ahp" OR "analytic hierarchy process"	38,602	750	20,083	59,435
"investment decision" OR "capital allocation" OR "acquisition" OR "investment allocation" OR "investment assessment" OR "investment appraisal"	462,976	42,205	265,503	770,684
"Industry 4.0" AND "analytic hierarchy process" AND "investment decision"	52	1	21	74

TITLE-ABS-KEY with AHP, I4, and investment only resulted in 74 documents.

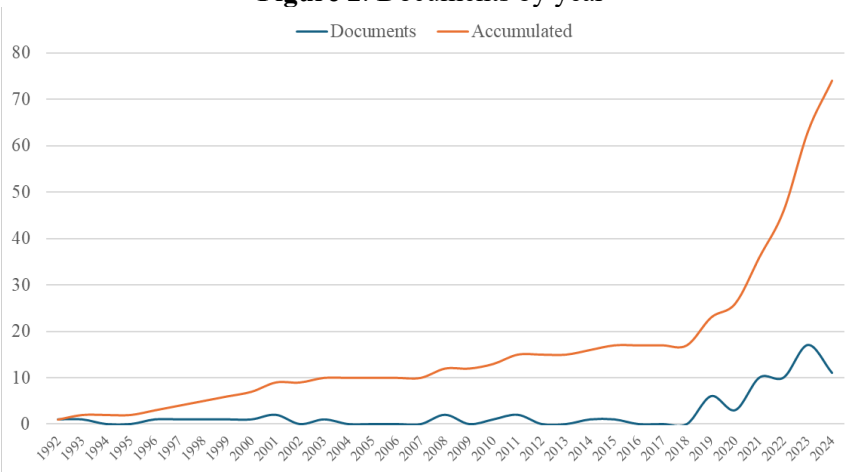
Table 2 analyzes the ten most cited documents in the Scopus database on AHP, I4, and investment decisions. Operational and technological criteria are the most recurrent, highlighting the importance of improvements in operational efficiency and technological maturity when making decisions. Other factors, such as cost-benefit, organizational culture, energy sustainability, and digital maturity, are also mentioned, reflecting a multidisciplinary approach. The most cited document, Durán & Aguilo (2008), focuses on operational impacts, while Madurai et al. (2021) emphasize sustainability, indicating an evolution of concerns over time.

Table 2. Most cited documents on AHP, I4, and investment decisions

Document	Citations	I4 Investment decision criteria
Durán & Aguilo (2008)	251	Operational impacts
Madurai et al. (2021)	144	Energy sustainability
Abdel-Kader & Dugdale (2001)	83	Financial, operational, and risks
Yusuff et al. (2001)	82	Economic, strategic, social, operational, and organizational
Mohanty & Deshmukh (1998)	78	Strategic, operational, and financial
Park & Kim (2021)	70	Technology, organizational, and business environment
Trushkina et al. (2020)	53	Technology, organizational culture, digital competencies, customer impact
Bademosi & Issa (2021)	52	Cost-benefit, technological readiness, regulatory compliance, organizational culture, market, and risks
Datta et al. (1992)	51	Operational, cost, and human factors
Saad et al. (2021)	38	Digital maturity and technological readiness

Figure 2 shows the number of documents per year since 1992 (represented by the blue curve) and the cumulative total over the years (represented by the orange curve). This last piece of information is relevant for analyzing the evolution of the maturity of the topic under investigation, considering the volume of publications.

Figure 2. Documents by year



Interestingly, research involving AHP and advanced manufacturing technologies predates the term Industry 4.0, which appeared in 2011. This means that the interest in decision-making techniques applied to new manufacturing technologies precedes the term's popularization and indicates an intrinsic need in the industry, regardless of the technological level addressed.

Another point to note is the significant growth in publications from 2020 onward, which reveals an interest among researchers in techniques that can facilitate managers' decisions about allocating their resources.

Figure 3 illustrates the distribution of articles on AHP applied to I4.0 investment decisions by subject area. The predominant areas are engineering, computer science, management, mathematics, social sciences, decision sciences, and environmental sciences. Decision sciences and mathematics comprise less than 15% of the publications, reinforcing the practical nature of the work.

Figure 3. Documents by subject area

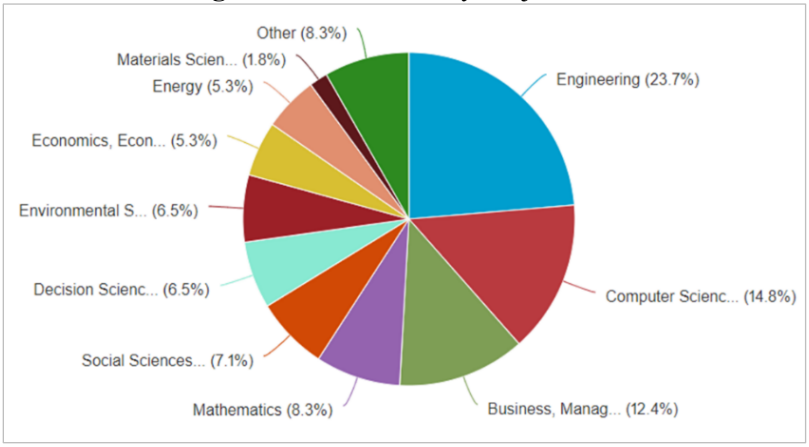
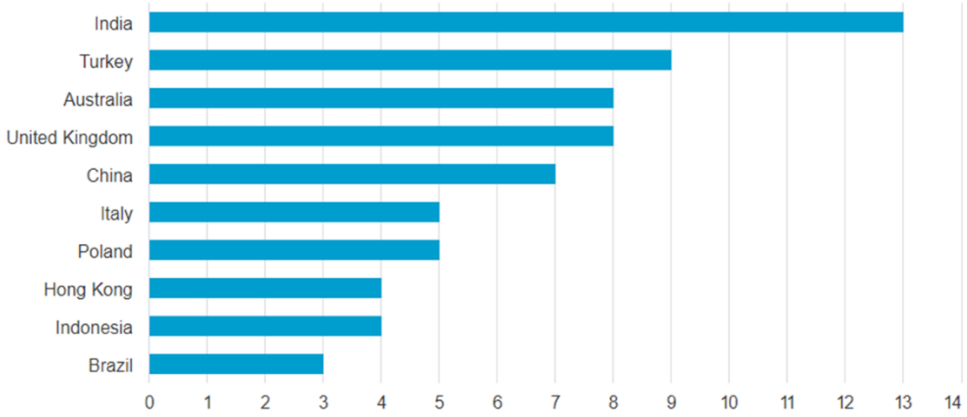


Figure 4 presents the top ten countries with first authors of affiliated documents. These are the so-called emerging countries, such as India, China, Brazil, Turkey, and Indonesia. This reveals a demand from countries with recent technological developments for tools to help them allocate their investments.

Figure 4. Documents by country



An additional analysis was to look for trending topics by analyzing the keywords of the most recent documents found in Scopus from 2020 to 2024, which corresponds to 51 documents, or 68.9% of the total (Figure 5).

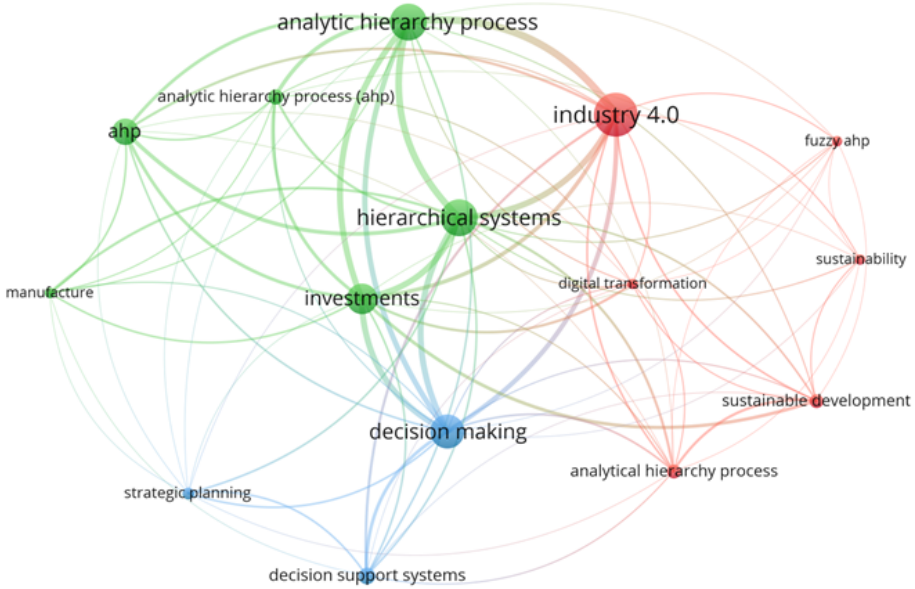
The data were analyzed using VOSviewer, a tool for constructing and visualizing bibliometric networks. It employs the graph creation feature based on bibliographic data to analyze co-occurrences among all keywords. A total of 15 keywords with at least five occurrences were identified, leading to 15 interconnected cores. Full counting was used to create the graph. The size of the circles represents the strength of co-occurrence, while the distances between items and lines illustrate their relationships and connections.

The network graph shows three Clusters (6-6-3 items), distributed as follows: **Cluster 1 (Green)** focuses on the AHP Multicriteria Decision Methodology and manufacturing environments ("*analytic hierarchy process,*" "*manufacturing,*" and "*investments*"); **Cluster 2 (Red)** focuses on sustainability ("*sustainability*" and "*sustainable development*"); and **Cluster 3 (Blue)** focuses on decision systems for strategic planning ("*decision making,*" "*decision support systems,*" and "*strategic planning*").

The co-occurrence analysis highlights three main areas of study: (1) the use of AHP and hierarchical systems to assist in complex investment decisions, (2) the application of these decisions in the context of Industry 4.0 and its interface with sustainability, and (3) the importance of structured decision-making and support for strategic planning within these areas.

Each cluster offers a unique yet interconnected view of how the AHP supports decision-making, particularly in the context of technological innovations and industrial transformations brought about by I4.

Figure 5. Network of co-occurrences of documents from 2020 to 2024.



6. Conclusions

This bibliometric study provides an overview of applying the AHP to investment decision-making in I4 technologies. Analyzing 74 documents from the Scopus database, we identified a significant gap in the literature concerning the integration of AHP and investment decisions in I4. The research shows an increasing publication trend since 2020, indicating a growing interest. Keyword analysis reveals three main clusters: AHP in manufacturing environments, sustainability, and strategic decision-support systems. These findings meet our objectives by highlighting the current state of research and identifying opportunities for future studies, such as developing sector-specific AHP frameworks and incorporating sustainability and risk analysis into investment appraisals.

7. Limitations

The Scopus database helped identify critical topics of particular importance in studies focused on different areas. Despite the significant publications, finding well-organized bibliographic data for bibliometric analysis to construct indicators remains challenging (Okubo, 1997). The next step in developing a new bibliometric approach involves identifying models that have already been successfully implemented. This will be done by considering various I4 technologies and their impacts, incorporating real-world experiences with implementation, assumed risks, and necessary model improvements.

8. Key References

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