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Matheuristics in Scheduling Problems: A Global Bibliometric Analysis

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Abstract: Matheuristic approaches, which seamlessly combine exact mathematical programming with heuristic algorithms, have gained significant momentum in solving complex, NP-hard scheduling problems. Despite their growing popularity and effectiveness, there is a notable lack of comprehensive bibliometric mapping in this specific subfield. This study conducts a quantitative bibliometric analysis to uncover the structural and dynamic characteristics of literature at the intersection of matheuristics and scheduling. A total of 370 peer-reviewed articles and conference papers, published between 2007 and 2025, were extracted from the Scopus database and analyzed using the bibliometrix R package. The findings reveal a steady, logarithmic increase in scientific production, driven by the demands of complex, large-scale industrial applications. Co-occurrence network analyses confirm that current research is heavily centered on the integration of Mixed-Integer Linear Programming (MILP) with heuristic frameworks. The analysis identifies critical research gaps, suggesting that future studies should focus on energy-efficient scheduling, dynamic environments with stochastic constraints, and algorithm hybridization with machine learning.

Keywords: Bibliometric analysis, Matheuristics, Scheduling, Science mapping, Mixed-integer linear programming

Introduction

Scheduling is the process of allocating limited resources to various tasks or operations in the most efficient manner, subject to specific constraints and within a given time frame. It plays a critical role in optimizing operational processes across many different industries, such as manufacturing, logistics, healthcare, and transportation. In complex production environments and Industry 4.0/5.0 applications, scheduling problems are inherently considered “NP-hard” from a combinatorial optimization perspective, making it extremely difficult to find the optimal production or service plan (Kriouich & Sarir, 2024).

Traditional exact methods, particularly approaches like MILP, while yielding optimal results for small-scale problems, face significant challenges in terms of scalability and computation time as problem size increases. On the other hand, while traditional heuristic and meta-heuristic methods can solve large problems within reasonable time frames, they cannot guarantee the discovery of the optimal solution (Ouhadi et al., 2024). To overcome the limitations of these two approaches, mathematical heuristics—or exact-heuristic hybrid methods—which combine the strengths of mathematical programming techniques with those of heuristic algorithms, have gained significant momentum in recent years (Sidki et al., 2025; Fanjul-Peyro et al., 2017).

Despite the effectiveness of matheuristic approaches in scheduling problems and their growing popularity, there is no comprehensive study mapping the development, knowledge structure, and research trends in this field. The aim of this study is to identify global trends, author-institution collaborations, and the conceptual framework of

the literature at the intersection of “matheuristics” and “scheduling” through a bibliometric analysis. The goal is to identify existing gaps in literature and provide researchers with a robust reference source for future studies.

A review of the literature in the field of scheduling reveals a large number of bibliometric analyses and systematic reviews focusing on specific problem types or solution methods. For example, Coelho et al. (2021) mapped the 30-year evolution of Flexible Job Shop Scheduling (FJSP) problems, while İnce et al. (2024) examined group scheduling problems in flow-shop workshops. Similarly, Merdane et al. (2025) investigated hybrid flow shop scheduling problems and Çölbay & Engin (2025) provided a bibliometric perspective on fuzzy-based hybrid flow shop with multiprocessor scheduling. Furthermore, Shargh et al. (2024) conducted a bibliometric analysis of scheduling problems in service systems. In addition, various scientific mapping studies addressing the applications of Artificial Intelligence (AI) and Constraint Programming (CP) in scheduling problems are available (Bahroun et al., 2023; Kriouich & Sarir, 2024; Prata et al., 2024).

When examining the literature regarding specific solution methods; in scheduling problems for independent parallel machines, in the routing and scheduling of home care services, and in the scheduling of battery-constrained Autonomous Guided Vehicles (AGVs), there are numerous highly cited original research articles reporting that mathematical programming approaches have been successfully applied and have demonstrated superior performance compared to traditional mathematical models (Fanjul-Peyro et al., 2017; Fikar & Hirsch, 2015; Singh et al., 2022).

However, in light of these detailed studies, although bibliometric analyses of specific algorithms, there is no bibliometric study in the literature that directly addresses the use of “matheuristics” methods in scheduling problems (Rahimi et al., 2022). This gap necessitates the development of a comprehensive academic profile for an extremely effective and emerging solution paradigm such as matheuristics. As the first bibliometric study in this specific subfield, the present work fills this significant gap in literature.

The remainder of this paper is organized as follows: Section 2 (Method) details the research methodology. Section 3 (Results and Discussion) presents the comprehensive results of the bibliometric analysis. Finally, Section 4 (Conclusion) concludes the study by summarizing the main findings and providing strategic recommendations for future research directions in the field of matheuristics and scheduling.

Method

In this study, a quantitative bibliometric analysis methodology was adopted to examine the structural and dynamic characteristics of scientific publications at the intersection of matheuristics and scheduling problems. Bibliometric analysis is a highly reliable method used to identify research trends, productivity, and conceptual networks through the statistical examination of quantitative data derived from scientific publications.

Data Collection and Search Policy

The research data was obtained from the Scopus database, which offers the broadest coverage in the fields of engineering and operations research and provides robust features for citation analysis. To fully capture the scope of the study, an advanced search query was created that includes mathematical heuristics (matheuristics, exact-heuristic, etc.) and basic scheduling terms (scheduling, job shop, flow shop, etc.). The search query used in the Scopus database is as follows:

TITLE-ABS-KEY ((“matheuristic*” OR “math-heuristic*” OR “hybrid mathematical programming” OR “MIP-based heuristic*” OR “exact-heuristic hybrid”) AND (“scheduling” OR “job shop” OR “flow shop” OR “open shop”)) AND PUBYEAR > 2006 AND PUBYEAR < 2026

Inclusion, Exclusion, and Data Cleaning Criteria

The search query above initially yielded 420 studies from the Scopus database. Strict exclusion criteria were applied to this raw dataset to ensure the maintenance of quality and focus. Only peer-reviewed research articles and conference papers were included in the analysis. Studies not directly related to the topic, book chapters, review articles, and editor’s notes were excluded. Following these filtering steps, a final set of 370 studies was identified for use in the analysis.

Data Analysis and Scientific Mapping Tools

Complete bibliographic metadata such as author names, affiliations, abstracts, keywords, and citation information for the 370 filtered studies were exported. The bibliometrix package, which is based on the open-source R programming language, and its no-code web interface, biblioshiny, were used for data performance analysis and scientific mapping. The resulting visual networks will shed light on the current state of the field as mapped by matheuristics algorithms and highlight potential future research areas.

Results and Discussion

An examination of the graph in Figure 1, which reflects the evolution of literature over time, reveals that academic interest in the application of matheuristic algorithms to scheduling problems has shown a steady upward trend, particularly in recent years. This growth is driven by the increasing need for these hybrid approaches in large-scale problems where traditional exact methods are constrained by solving time limits.

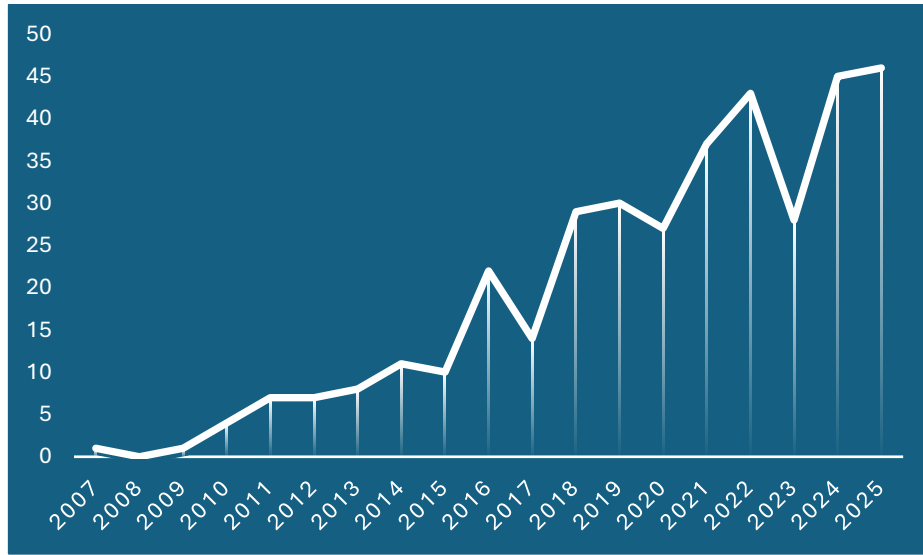


Figure 1. Annual scientific production

Figure 1 also shows a logarithmic growth trend, particularly in recent years. This can be attributed to the fact that the complex datasets generated by Industry 4.0/5.0 applications cannot be addressed using traditional methods, leading researchers to inevitably turn to hybrid (matheuristic) approaches. Figure 2 shows the journals where research is concentrated.

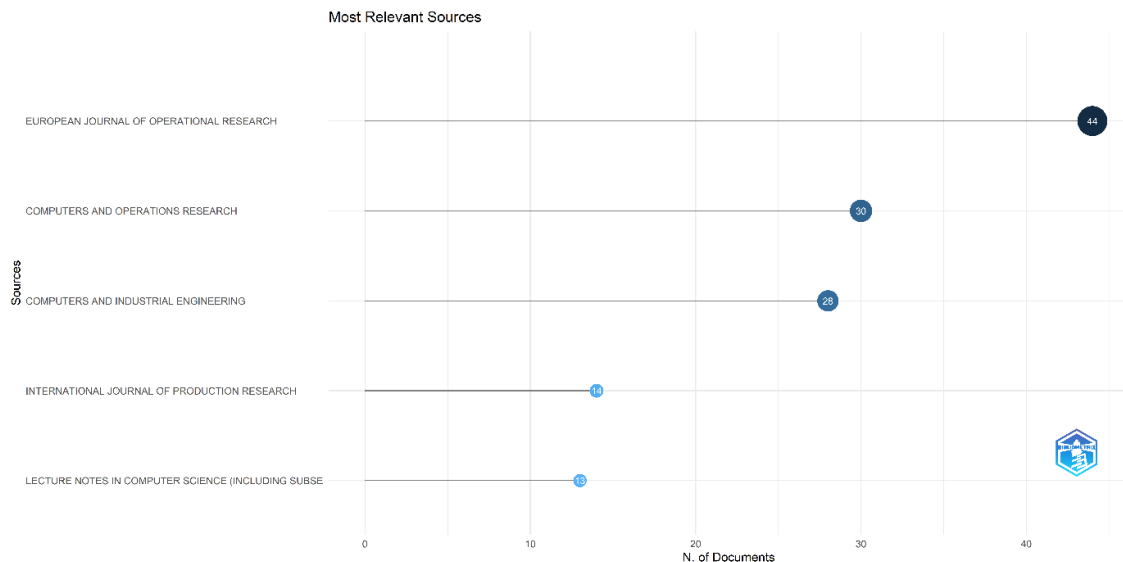


Figure 2. Most relevant sources

Figure 3 illustrates the journals with the highest citation counts within this dataset and demonstrates that prestigious journals in the fields of operations research and industrial engineering form the core of the field's knowledge base.

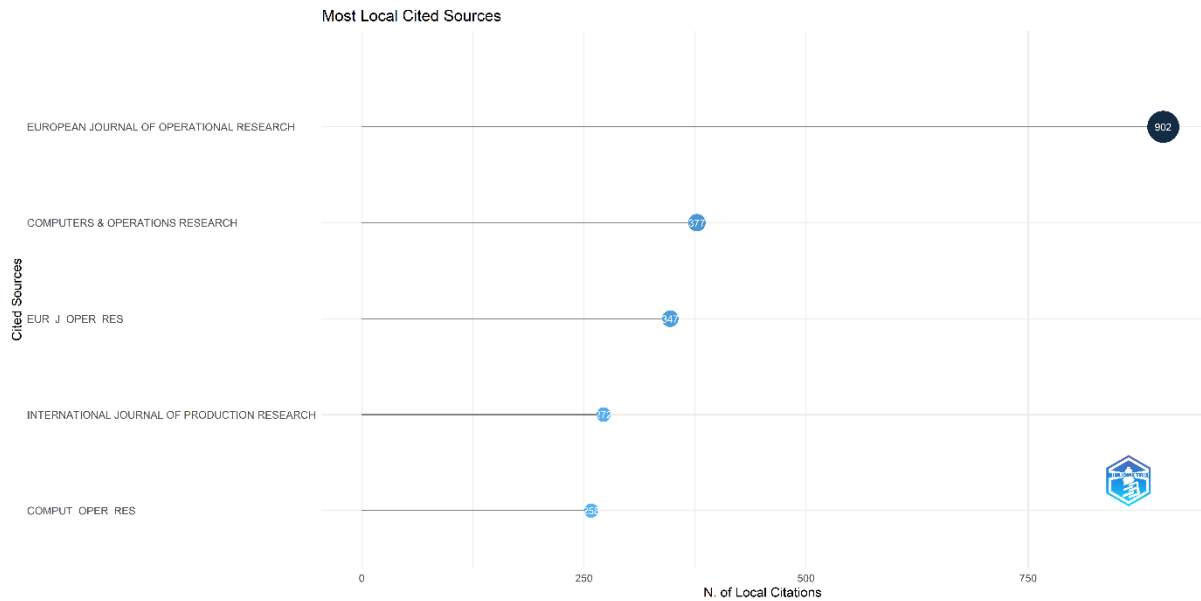


Figure 3. Most local cited sources

The fact that the European Journal of Operational Research (EJOR) and Computers & Operations Research are by far the leaders in both the number of publications and local citations in Figure 3, demonstrates that the theoretical and methodological foundations of this field are largely built upon publications in these prestigious journals. The fact that EJOR has achieved a very high citation count of 902 indicates that the benchmarks in the discipline originate from this journal.

The graph in Figure 4, which ranks the academic institutions with the highest number of publications in the field of matheuristics and scheduling, highlights which universities or research laboratories are leading the way in this specific subfield of optimization on a global scale.

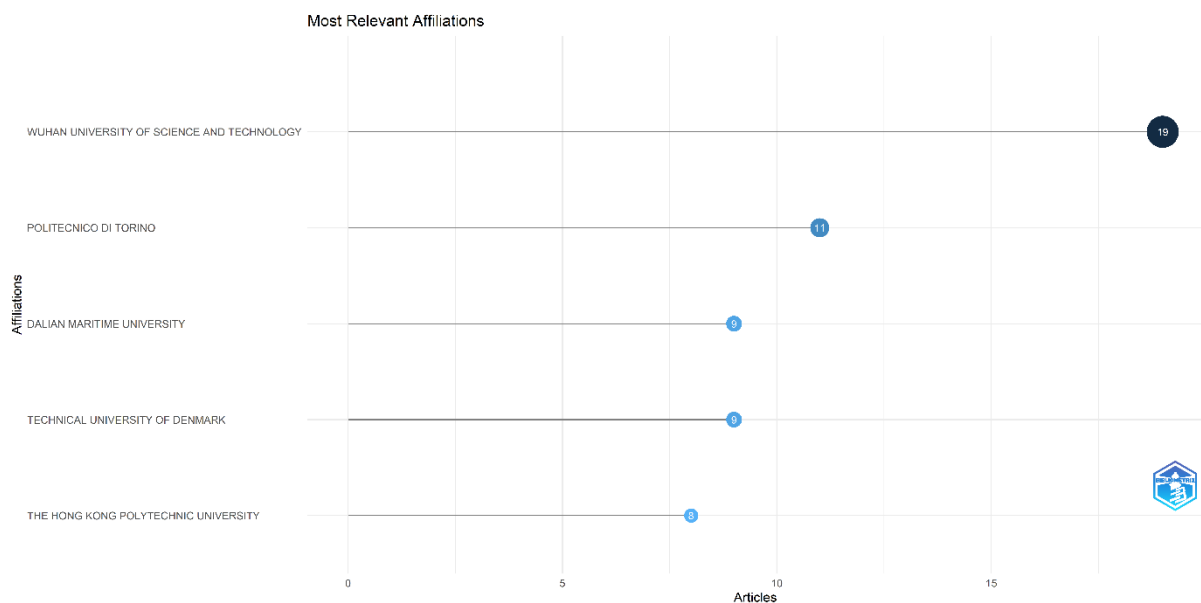


Figure 4. Most relevant affiliations

The prominence of institutions such as Wuhan University of Science and Technology and Dalian Maritime University in Figure 4, reflects the significant academic resources being invested in supply chain, maritime, and production planning optimization, particularly in the Asian region. The presence of Politecnico di Torino,

meanwhile, demonstrates that Europe continues to uphold its strong theoretical tradition in this field. The map in Figure 5 shows the distribution of countries based on their total number of publications.

Country Scientific Production

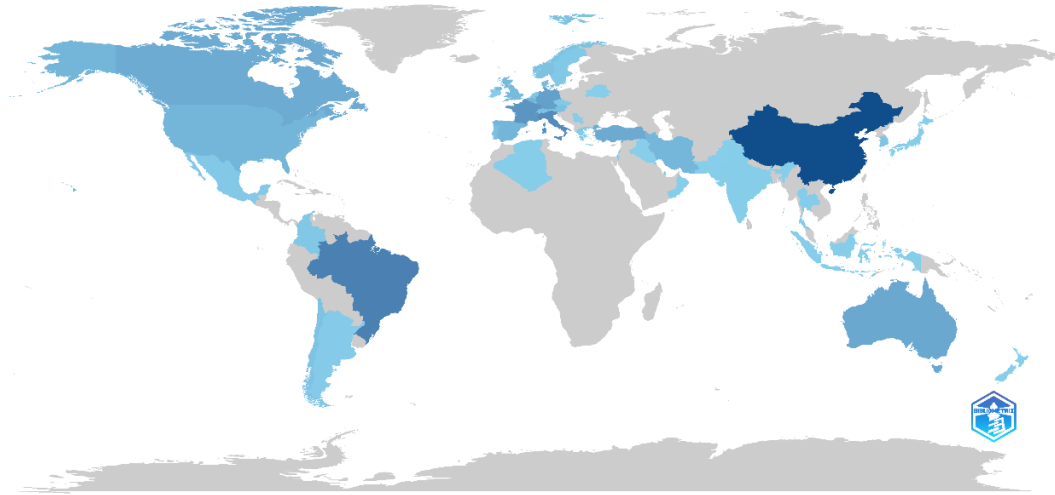


Figure 5. Country scientific production

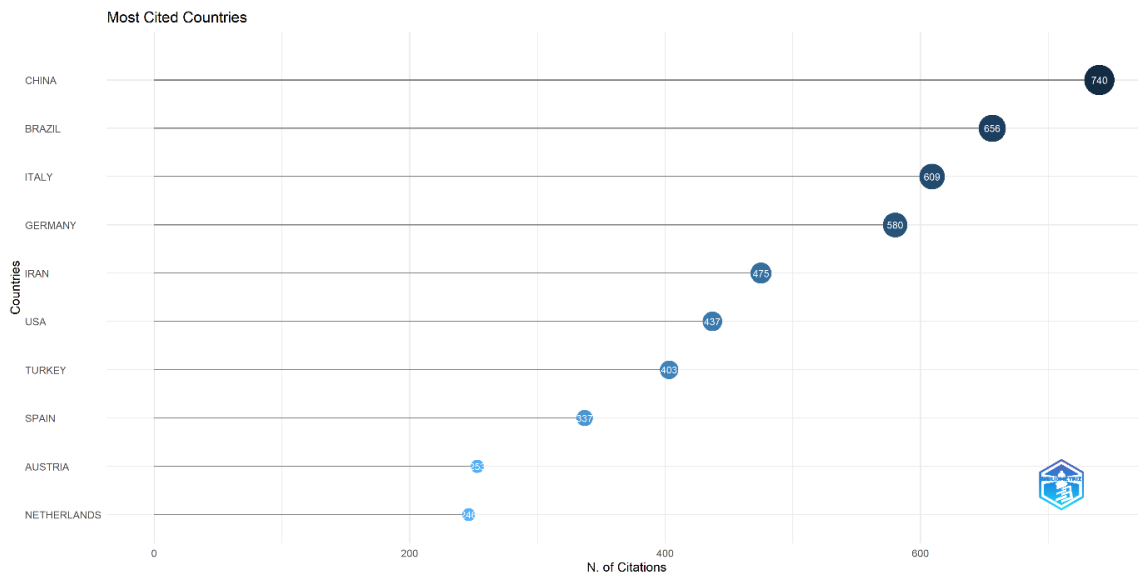


Figure 6. Most cited countries

Figure 6 illustrates countries' international impact and reveals that the matheuristics literature is geographically clustered in specific centers (particularly in countries with advanced industrial and technological infrastructure). It is evident that China holds a dominant position in terms of total publication output and the number of citations with 740. However, the fact that Brazil (656) and Italy (609) have also achieved very high citation counts demonstrates that these countries have developed highly effective and globally recognized solution approaches in the field of operations research. Turkey's ranking among the top countries with 403 citations underscores its potential to become a regional research hub.

Figure 7 reflects the concepts most frequently cited by authors. This word network provides a direct summary of the problem types in which algorithmic hybridizations are concentrated. It is quite significant that the concept of MILP occupies a central position among the keywords with 26 occurrences. This indicates that researchers have made it standard practice to establish hybrid architecture by integrating heuristic algorithms with powerful mathematical modeling tools such as MILP, rather than using them independently. Although a wide variety of scheduling problems exist, the keyword network implicitly reveals that research predominantly focuses on classic environments like flow-shop and parallel machine scheduling. Methodologically, integrating exact solvers with evolutionary or variable neighborhood search algorithms stands out as the most preferred matheuristic framework.

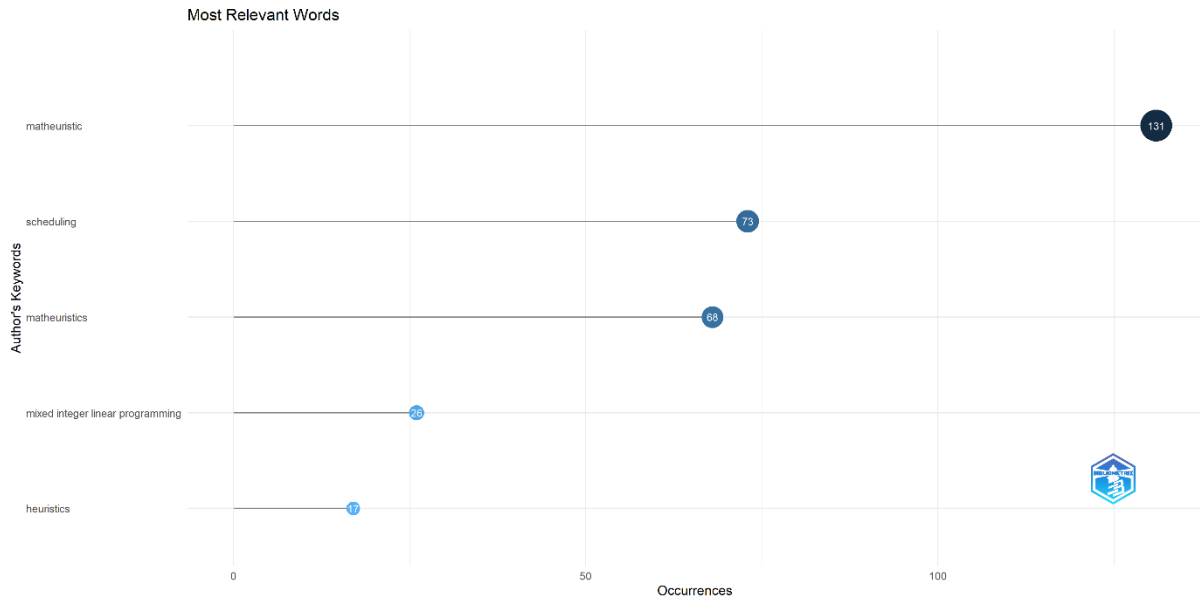


Figure 7. Most relevant words

Figure 8, which illustrates countries' tendencies toward joint publications and their international academic networks, maps the intensity and direction of the global collaborations established by researchers in this field of advanced optimization.

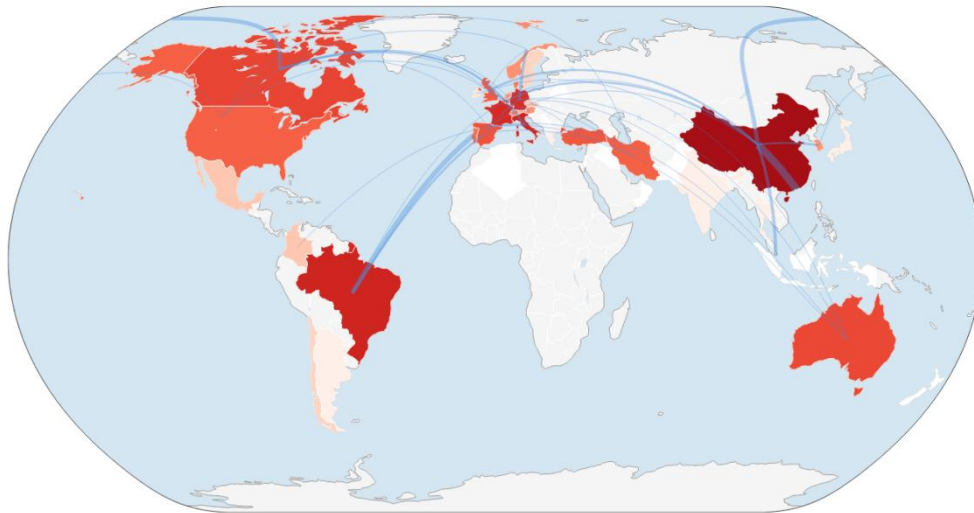


Figure 8. Countries' collaboration world map

The dark red areas and thick connecting lines on the map in Figure 8 demonstrate that the flow of information—particularly along the China-U.S.-Europe axis—serves as the main artery fueling this subdiscipline. This intense intercontinental academic traffic is an indication that matheuristics problems involve global-scale and universal industrial challenges.

Conclusion

In this study, a comprehensive bibliometric analysis was conducted on 370 articles at the intersection of scheduling problems and matheuristics, and the overall state of the literature was examined. Quantitative and visual findings demonstrate that matheuristic approaches, which combine the strengths of mathematical programming and heuristic methods, are increasingly becoming a dominant solution paradigm for solving complex and NP-hard scheduling problems. Data obtained from author, institutional, and country collaboration networks indicate that this field is characterized by an open and rapidly evolving structure driven by intensive global collaborations. Crucially, an analysis of the core keyword occurrences confirms that current research is heavily centered on the integration of "mixed integer linear programming" with heuristic frameworks, illustrating

that the literature is focusing on methodological hybridizations rather than being strictly limited to "makespan" minimization or specific classic problem sets.

Recommendations

In light of the bibliometric trends identified and the research gaps detected, the following recommendations are offered for future studies:

Filling Conceptual Gaps: In Figure 7, multi-objective mathematical heuristics models that address “energy-efficient scheduling” and “sustainability” objectives—currently viewed as niche or emerging fields—alongside classical optimization objectives (cost/time) should be prioritized. **Models for Dynamic and Uncertain Environments:** Most studies are based on static constraints. There is a need to develop robust matheuristics approaches enhanced with stochastic elements that address machine failures, order cancellations, or process duration uncertainties in real-world scenarios. **Hybridization with Machine Learning:** To enhance the efficiency of matheuristics methods and automate parameter optimization, new-generation intelligent solution architectures should be designed that integrate algorithms with machine learning techniques. **Expanding Global Collaborations:** In Figure 8, researchers in regions where the manufacturing sector is developing should be encouraged to conduct joint projects with leading institutions in the field (Figure 4). This will increase the number of universal case studies based on real Industry 4.0/5.0 datasets.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest.

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