BIBLIOMETRIC STUDY OF METAHEURISTICS APPLICATION FOR SOLVING INVENTORY ROUTING PROBLEM

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Vu Hai Anh\textsuperscript{2}

ABSTRACT

**Purpose:** The objective of this study is to perform a review and thematic analysis focusing on the application of metaheuristics for addressing the inventory routing problem. Employing bibliometric methods, this research endeavors to conduct a comprehensive assessment of the current scholarly literature, aiming to enhance and expand upon prior research findings. Additionally, this study will review metaheuristics algorithms utilized in previous studies to provide a comprehensive understanding of their application in this context.

**Design/methodology/approach:** A bibliometric analysis was performed on IRP research, involving 346 publications retrieved from the Scopus database spanning the period 1978 to 2023. Biblioshiny and VOSviewer were employed for data analysis to identify significant patterns and trends in the application of metaheuristics for addressing the inventory routing problem.

**Results and discussions:** This study seeks to analyze co-citation, keyword co-occurrence, thematic mapping, and thematic evolution to gain insights into the field. The findings indicate that the top 10 authors with high citation indexes of the authors, and top 10 nations with articles addressing IRP. The thematic mapping indicates four key areas of research within applying heuristics for solving inventory and transportation problem. The motor themes focus on inventory routing problem, such as stochastic demand, column generation, scheduling and time window are shaping the future of manufacturing. The study reveals that the Genetic Algorithm emerges as the predominant choice.

**Research Implications:** Through this research, it provides researchers and businesses seeking solutions to real-world IRP problems with a comprehensive analysis from multiple perspectives, thereby enabling focused in-depth research and effective utilization of research findings.

**Originality/Value:** This study contributes to the literature by reviewing thematic analysis of metaheuristic applications for the IRP problem. The value of this research is evidenced by researchers and professionals, as it helps identify the gaps in the literature and provide insightful information about the level of research within the field at the time, predict future research directions, and propose innovative avenues for advancing the field.

**Keywords:** Bibliometric, Inventory Routing Problem, Biblioshiny and VOSviewer, Metaheuristics.

ESTUDO BIBLIOMÉTRICO DO APLICATIVO DE META-HEURÍSTICA PARA RESOLVER O PROBLEMA DE ROTEAMENTO DE ESTOQUE

RESUMO

**Objetivo:** O objetivo deste estudo é realizar uma revisão e análise temática com foco na aplicação de metaheurística para lidar com o problema do roteiro de inventário. Empregando métodos bibliométricos, esta pesquisa se esforça para realizar uma avaliação abrangente da literatura acadêmica atual, com o objetivo de aprimorar e expandir os resultados de pesquisas anteriores. Além disso, este estudo irá rever algoritmos de metaheurística utilizados em estudos anteriores para fornecer uma compreensão abrangente de sua aplicação neste contexto.

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**Projeto/metodologia/abordagem:** Uma análise bibliométrica foi realizada em pesquisa IRP, envolvendo 346 publicações recuperadas da base de dados Scopus no período de 1978 a 2023. O Biblioshiny e o VOSviewer foram empregados para a análise de dados a fim de identificar padrões e tendências significativos na aplicação de metaheurística para lidar com o problema de roteamento de inventário.

**Resultados e discussões:** Este estudo busca analisar a cocitação, coocorrência de palavras-chave, mapeamento temático e evolução temática para obter insights sobre o campo. Os resultados indicam que os 10 principais autores com altos índices de citação dos autores e os 10 principais países com artigos abordando IRP. O mapeamento temático indica quatro áreas-chave de pesquisa dentro da aplicação de heurística para a solução de inventário e problema de transporte. Os temas motores se concentram no problema do roteiro de inventário, como demanda estocástica, geração de colunas, programação e janela de tempo estão moldando o futuro da fabricação. O estudo revela que o Algoritmo Genético emerge como a escolha predominante.

**Implicações da pesquisa:** Através desta pesquisa, ela fornece pesquisadores e empresas que buscam soluções para problemas de IRR do mundo real com uma análise abrangente de várias perspectivas, permitindo assim uma pesquisa aprofundada focada e a utilização eficaz dos resultados da pesquisa.

**Originalidade/Valor:** Este estudo contribui para a literatura, analisando a análise temática de aplicações metaheurísticas para o problema IRP. O valor desta pesquisa é evidenciado por pesquisadores e profissionais, pois ajuda a identificar as lacunas na literatura e fornecer informações perspicazes sobre o nível de pesquisa dentro do campo na época, prever futuras direções de pesquisa e propor caminhos inovadores para avançar o campo.

**Palavras-chave:** Bibliométrico, Problema de Roteamento de Inventário, Biblioshiny e VOSviewer, Metaheurística.

**RESUMEN**

**Propósito:** El objetivo de este estudio es realizar una revisión y análisis temático centrándose en la aplicación de la metaheurística para abordar el problema de enrutamiento de inventario. Empleando métodos bibliométricos, esta investigación se esfuerza por llevar a cabo una evaluación integral de la literatura académica actual, con el objetivo de mejorar y ampliar los hallazgos de investigaciones anteriores. Además, este estudio revisará los algoritmos de metaheurística utilizados en estudios anteriores para proporcionar una comprensión integral de su aplicación en este contexto.

**Diseño/metodología/enfoque:** Se realizó un análisis bibliométrico de la investigación del IRP, que involucró 346 publicaciones recuperadas de la base de datos Scopus que abarcaron el periodo 1978-2023. Biblioshiny y VOSviewer se emplearon para el análisis de datos para identificar patrones significativos y tendencias en la aplicación de metaheurísticas para abordar el problema de enrutamiento de inventario.

**Resultados y discusiones:** Este estudio busca analizar la co-citación, la co-ocurrencia de palabras clave, el mapeo temático y la evolución temática para obtener información sobre el campo. Los hallazgos indican que los 10 autores principales con altos índices de citas de los autores y los 10 países principales con artículos que abordan la PRI. El mapeo temático indica cuatro áreas clave de investigación dentro de la aplicación de la heurística para resolver problemas de inventario y transporte. Los temas de motor se centran en los problemas de enrutamiento de inventario, como la demanda estocástica, la generación de columnas, la programación y la ventana de tiempo que están dando forma al futuro de la fabricación. El estudio revela que el Algoritmo Genético emerge como la elección predominante.

**Implicaciones de la investigación:** A través de esta investigación, proporciona a los investigadores y empresas que buscan soluciones a problemas de RRP del mundo real un análisis integral desde múltiples perspectivas, lo que permite una investigación en profundidad enfocada y una utilización efectiva de los resultados de la investigación.

**Originalidad/Valor:** Este estudio contribuye a la literatura revisando el análisis temático de las aplicaciones metaheurísticas para el problema de IRP. El valor de esta investigación es evidenciado por investigadores y profesionales, ya que ayuda a identificar las lagunas en la literatura y proporcionar información detallada sobre el
1 INTRODUCTION

The ongoing COVID-19 pandemic and geopolitical conflicts have plunged manufacturers into a turbulent environment (Byerik, 2024 and Govindan et al., 2020). Adapting to these challenges has proven daunting, with disruptions reverberating through supply chains, demand exhibiting erratic shifts, supply sources becoming unreliable, and production and transportation costs escalating. Recent outbreaks of COVID-19 continue to inflict widespread disruptions, with experts foreseeing long-term consequences. Moreover, the conflict in Ukraine has triggered a chain of adverse effects on the global economy, including inflation, steep rises in fuel and food prices, and ruptured supply chains (Cekerevac and Bogavac, 2023).

Currently, manufacturing faces numerous difficulties in adapting to supply chain disruptions, fluctuating demand, unstable supply, and rising production costs. Consequently, businesses worldwide are bracing for increased costs in the supply chain, particularly transportation and storage expenses. Logistics costs represent a significant proportion of the total GDP of each country. For example, logistics costs in the United States account for approximately 9.10% (Kearney, 2023), while in Vietnam, they amount to about 17% (Tran Thanh Hai, 2022). Notably, transportation costs constitute around 60% and storage costs approximately 32.7% of total logistics costs in the USA (Kearney, 2023). In Vietnam, transportation costs range from 60% to 70%, with storage costs comprising 25% to 35% of total logistics expenses (Tran Thanh Hai, 2022).

To address these challenges, reducing loading time and storage costs is paramount, thereby curbing overall logistics expenses within the supply chain. Inventory routing emerges as a valuable method to achieve these objectives. The Inventory Routing Problem (IRP) poses a complex optimization challenge in supply chain management, aiming to determine optimal inventory levels at various locations while simultaneously planning efficient delivery routes to minimize costs and meet customer demand.
Traditional exact methods often encounter challenges when dealing with large-scale IRPs due to their computational complexity. Consequently, there has been a notable increase in the utilization of metaheuristics—optimization algorithms inspired by natural phenomena or human behavior—to effectively address these issues (Arab, 2020). Metaheuristics have demonstrated the ability to provide reasonably high-quality solutions within relatively short running times compared to heuristics and exact algorithms (Guimarães et al., 2024).

Given the economic importance of IRPs, numerous authors have conducted research in this field over the past few decades (Pan et al, 2023; Adhi, 2023; Ji et al., 2022). Therefore, this study aims to offer a comprehensive overview of current scholarly works by employing bibliometrics to build upon and expand existing findings, while also drawing methodological inspiration from previous research. Bibliometrics, a methodology employing statistical tools to analyze written publications (Ellegaard and Wallin, 2015), aids researchers in identifying established and emerging research areas, key scholars, and clusters of related work (Fahimnia, 2015). Although relatively new, the use of bibliometrics is gaining popularity in research fields such as business, economics, and social sciences. For instance, the average number of publications per year has reached 1,021 in the last decade, with 1,950 publications recorded in 2020, reflecting the overall growth of scientific research (Donthu, 2021).

In the realm of business and management research, bibliometric methods find application in various areas such as innovation, project management, risk management, tourism management, and supply chain management (Aria et al. 2014). Consequently, the use of bibliometrics in analyzing risk factors and supply chains garners significant interest among researchers.

This research will employ bibliometric methods to analyze the trends in applying metaheuristics algorithms for solving the inventory routing problem. An extensive bibliometric analysis was conducted using a sample of 3,430 publications retrieved from Scopus between 1978 and 2023, with the assistance of the bibliometric software tool VOSviewer. By addressing a series of key research questions, this study aims to fill a gap in current knowledge and provide valuable insights into the field. These questions are designed to clarify current trends and offer guidance for future investigations. This paper aims to conduct a definitive bibliometric analysis of the research field based on the following research questions:
By employing scientific mapping methodologies, this study aims to identify emerging research areas and the potential application of metaheuristics in solving the inventory routing problem. Furthermore, it offers valuable insights and future research directions for both academics and practitioners interested in advancing the field of inventory routing problem (IRP). The study utilizes bibliometric analysis to explore the current state of research on inventory routing problem (IRP) and metaheuristics. Section 2 meticulously details the chosen database, search strategy, and employed bibliometric techniques. Following this, Section 3 delves into the analysis findings, presenting performance analysis, scientific mapping visualizations, and key research areas identified. Building on these insights, section 4 outlines valuable pointers for future research directions in IRP. Finally, section 5 concludes the paper by summarizing key findings and acknowledging limitations.

2 METHODOLOGY

This review paper will employ a bibliometric analysis methodology that it is well-regarded for its ability to review and condense large amounts of data, and it can be analyzed through quantitative approaches. Using this technique, researchers can determine the intellectual framework of a certain field of study and learn (Donthu et al. 2021).

2.1 RETRIEVE DATA

This study leverages Scopus, a renowned database offering extensive coverage (22,000+ journals) and well-structured scientific data. Its rigorous review process ensures data accuracy and reliability, making it a valuable tool for gathering information and conducting analyses.
The research framework shown in Figure 2 serves as the foundation for the bibliometric analysis adapted from standard workflow consists of three stages and analysis including database and search protocol, mapping analysis and discussion (Donthu et al., 2021; Aria et al., 2020; Pranajaya et al., 2024).

**Figure 2**

*Methodology and Data retrieval Process*

Upon employing the search string ("inventory" OR "warehouse" OR "stock" OR "storage" OR "EOQ") AND ("VRP" OR "rout*" OR "transport*" OR "Delive*") AND ("heuristic" OR "metaheuristic"), within the period spanning from 1978 to 2023, the query returned a substantial yield of 3430 articles.
Table 1. This comprehensive selection of keywords was meticulously chosen to encapsulate various aspects of modern industrial paradigms, including metaheuristics, heuristics, inventory, transportation, inventory routing problem. By incorporating these keywords, we aimed to cast a wide net that would encompass literature discussing the intersection of these crucial themes within the realm of inventory routing problem and how to solve IRP by metaheuristics or heuristics over the past five decades.

Following this, further criteria were chosen in the subsequent stage. These encompassed a wide array of subject areas, including but not limited to Engineering, Computer Science, Decision Sciences, Mathematics, Business, Management and Accounting, Social Sciences, Economic, Econometrics and Finance. Additionally, the document type was refined to solely include articles, and the language was specified to be English. Upon applying these stringent filters, the resulting tally revealed a sum of 2105 articles that met the prescribed criteria.
Table 1

Search strategy

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
<th>No. of refined articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search string</td>
<td>(&quot;inventory&quot; OR &quot;warehouse&quot; OR &quot;stock&quot; OR &quot;storage&quot; OR &quot;EOQ&quot;) AND (&quot;VRP&quot; OR &quot;rout*&quot; OR &quot;transport*&quot; OR &quot;Delive*&quot;) AND (&quot;heuristic&quot; OR &quot;metaheuristic&quot;)</td>
<td>3430</td>
</tr>
<tr>
<td>Access</td>
<td>Including both Open Access and others.</td>
<td></td>
</tr>
<tr>
<td>Period</td>
<td>up till articles in 2023. A few articles for 2024 have already been published.</td>
<td></td>
</tr>
<tr>
<td>Subject area</td>
<td>Engineering (1763), Computer Science (1796), Decision Sciences (1046), Mathematics (891), Business, Management and Accounting (644), Social Sciences (321), Economic, Econometrics and Finance (111) (152)</td>
<td>102 articles were published.</td>
</tr>
<tr>
<td>Document type</td>
<td>The search was limited to document type articles (2207).</td>
<td>(1071)</td>
</tr>
<tr>
<td>Language</td>
<td>The 102 articles that were published in languages other English were all excluded.</td>
<td>(102)</td>
</tr>
<tr>
<td>Number of articles that will eventually remain after manual refinement</td>
<td>2105</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors

2.2 BIBLIOMETRICS ANALYSIS

The appeal of bibliometric analysis has increased notably in business and economic studies (Donthu et al., 2021; Vieira et al., 2021). In this study, Biblioshiny and VOSviewer were employed for data analysis to identify significant patterns and trends in the application of metaheuristics for addressing the inventory routing problem. This analysis involved constructing a matrix that categorized and classified all relevant papers for further examination (Aria et al., 2017). The data were then visualized using the VOSviewer program to create visual representations, such as a subject dendrogram and a conceptual map, to elucidate the connections and interactions among various research streams (Van Eck and Waltman, 2010). Through the utilization of these data analysis tools, the researcher could discern gaps in the literature and provide insightful information about the level of research within the field at the time.

Performance analysis and science mapping are two categories under which bibliometric analysis techniques are used (Donthu et al., 2021). Science mapping looks at the connections between various components, whereas performance analysis concentrates on evaluating research components. According to the aims, scope, and research questions of the study, this article advises using a variety of approaches. Combining co-citation analysis for the past, bibliographic coupling for the present, co-word, and thematic analysis to discover relevant terms in potential future study lines can be used to examine the history, present, and future of a research domain. This method makes it possible to identify the structural and dynamic structure.
of knowledge within the subject or field of study under investigation (20). The indicators encompassed within science mapping techniques are as follows (Donthu et al., 2021). Combining all the method, including network metrics, with the aforementioned techniques is essential for accurately the conceptual framework of the research subject under consideration (Donthu et al., 2021; Vieira et al., 2021). In particular, network analysis significantly improves the conversation about research trends within particular study disciplines or topics.

Besides, biblioshiny is a web-based tool for bibliometrics, stands out as a remarkable application developed using the statistical principles and user-friendly R language, ensuring a cohesive bibliometric workflow. R's object-oriented nature facilitates automation and the creation of new functions, making it highly adaptable for various analytical tasks so we use VOSviewer and R Studio (Biblioshiny) for the analysis part (Zupic and Čater, 2015). The subsequent forms of bibliometric analysis techniques are utilized including (1) Publication, citation, author analysis, (2) The cooperation of countries and sources, (3) Keyword co-occurrence analysis, (4) Extraction of trending topic.

3 RESULTS AND DISCUSSIONS

3.1 PERFORMANCE BIBLIOMETRICS ANALYSIS

This study investigates the performance of key elements within the Inventory Routing Problem (IRP) domain, including primary sources, journals, authors, institutions, and countries to answer for research question 1. To streamline the analysis, the research focuses solely on articles published in English-language journals which simplifies bibliometric analysis – the comparison of keywords, article sources, and affiliations. The primary data is presented in Table 2, accompanied by the average number of articles and citations received per year.

This study offers a comprehensive analysis of IRP research conducted between 1978 and 2023. The data, sourced from Biblioshiny/Scopus, encompasses 346 articles published across 135 unique sources. Notably, the field exhibits an impressive annual growth rate of 7.77%, indicating a continuous and significant rise in research output year after year. Further underlining the field's relevance and impact, the analyzed articles boast an average age of 8.5 years and garner an impressive 35.85 citations each. This suggests that the research produced remains highly relevant and influential over time. Additionally, with only 9 single-authored publications identified amongst 810 authors, the study underscores the collaborative nature of
IRP research, evident in the substantial 825 author keywords employed. The vast number of references (10412) reinforces the extensive range of sources utilized within the field.

### Table 2

**Main information**

<table>
<thead>
<tr>
<th>Description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timespan</td>
<td>1978: 2023</td>
</tr>
<tr>
<td>Authors</td>
<td>810</td>
</tr>
<tr>
<td>Sources</td>
<td>135</td>
</tr>
<tr>
<td>Articles</td>
<td>346</td>
</tr>
<tr>
<td>Annual Growth Rate</td>
<td>7.77 %</td>
</tr>
<tr>
<td>Document Average Age</td>
<td>8.5</td>
</tr>
<tr>
<td>Average citations per doc</td>
<td>35.85</td>
</tr>
<tr>
<td>References</td>
<td>10412</td>
</tr>
<tr>
<td>Author's Keywords (DE)</td>
<td>825</td>
</tr>
<tr>
<td>Single-authored docs</td>
<td>9</td>
</tr>
</tbody>
</table>

Source: Authors' synthesis based on Biblioshiny/Scopus

#### 3.1.1 Publication and Citation Aspects
Figure 33 visually depicts the evolution of IRP research over the years. It reveals a clear exponential pattern, characterized by a steady and substantial increase in both the annual number of articles published and the average number of citations received. The average growth of the annual scholarly paper is followed by exponential regression curve of $R^2 = 0.903$. This trend signifies a flourishing field with a growing body of impactful research. In the initial year of 1978, IRP research was in its nascent stages, with only a single article published. This number grew slowly, reaching an average of 6 articles per year between 1978 and 1995. However, from 1996 to 2009, there was a consistent upward trajectory, reaching its peak in 2009 with an impressive forty-nine publications. In 2010, it is witnessed a decreasing in this fields research, only 2 pulications. Afterward, an explosive increase in the number of research from 2011 to 2023, a total of 289 articles were published, the year with the most publications was 2019, peaking at 32 publications. About citations aspects, in general, there is variation in the number of citations from year to year, the year with the highest number of citations being 2010 with 108 citations. The analysis reveals a likely significant increase in the total number of articles published each year, contributing to the observed overall growth rate. Exponential trends are characterized by a rapid rise in the measured variable over time, which aligns with the growth in publications. However, an intriguing counterpoint emerges in the recent decline of the mean total citations per article, suggesting a need for further investigation into this trend.
Figure 3

Annual number of article growth

Source: Authors’ synthesis based on Biblioshiny/Scopus

In this section, the research analyzes the distribution of articles across top-tier economics journals to gain valuable insights into their research focus and productivity. Journals with a higher number of articles indicate a greater volume of research output and are likely to cover a wider range of topics. They serve as platforms for researchers to disseminate their findings and engage in academic discourse. Among the core journals analyzed, the top 10 most productive ones have been identified, as depicted in Figure 4. Leading the pack is Computers and Industrial Engineering, with 26 published papers, highlighting its prominent status within the academic landscape. Furthermore, three of these top 10 journals, each featuring over 20 papers, focus on industrial engineering, operations research, transportation, and logistics.

Figure 4

The most relevant sources of IRR research

Source: Authors’ synthesis based on Biblioshiny/Scopus

3.1.2 Most Influential Authors, Affiliations and Countries

The field of Inventory Routing Problems (IRP) research is experiencing rapid growth, attracting a diverse range of authors, affiliations, and countries. To stay abreast of the latest advancements and findings, it's crucial to build upon the work of these key contributors. This section delves into the most frequently cited authors in IRP literature.
Table 3 presents their names, along with details of their publications and rankings based on various metrics. *Erro! Fonte de referência não encontrada.* showcases the most influential affiliations and

Table 4 highlights the most influential country in IRP research.

Examining the impact of authors in bibliometrics is essential, as it offers valuable insights into the influence and significance of academic researchers. For our analysis, a total of 352 journal articles authored by 766 individuals have been gathered. To identify core candidates, Price’s Law (Nicholls, 1988) was initially applied, calculating the minimum number of publications $M_p$ and citations $N_p$ for each author. In this field, the values of $M_p$ and $M_s$ were 3.31 and 35.11, respectively. This suggests that authors who fulfilled both criteria of having a minimum of 6 journal articles and 38 cited journal articles were chosen as candidates, resulting in a total of 80 core author candidates. The average number of journal articles and citations of the 51 core author candidates are considered, which are 4.59 and 250.18, respectively. Then, the comprehensive index method was employed to evaluate and rank the influence of each core author in the research field, with the weight of the number of publications and citations set to 0.5 (Xue et al., 2023).

Applying this formula of Price’s Law, the top 10 core authors were identified based on their comprehensive index values exceeding 1.260 (
Table 3). These authors collectively contributed to a total of 76 journal articles, comprising 21.59% of 352 journal articles identified in our literature search. This falls considerably short of the 50% threshold predicted by Price’s law, indicating that the research community has not yet established a cohesive core group. As shown in
Table 3, Canadian authors dominated the top positions, with 3 out of the top 10 authors affiliated with institutions in Canada. The list also included authors from diverse countries such as the Norway, Italy, United Arab Emirates, Belgium and Iran, indicating the global impact of research in the Inventory routing problem. Among those authors, Cordeau, J-F. from Canada stands out as the most influential author with a comprehensive index for authors’ paper and citations of 3.4450 with 9 papers, and 1233 citations. Following closely, Laporte, G. from Canada secured the second position with a comprehensive index of 3.0033 which derived from 9 papers and 1012 citations. Other influential authors within this field include Coelho, LC. (6 papers, 900 citations), Christiansen, M. (8 papers, 472 citations), and Bertazzi, L. (7 papers, 513 citations).
### Table 3

**Ranking of the top 10 core authors**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Author</th>
<th>Country</th>
<th>No. of Paper</th>
<th>Total citations</th>
<th>Si</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>CORDEAU J-F</td>
<td>Canada</td>
<td>9</td>
<td>1233</td>
<td>3.4450</td>
</tr>
<tr>
<td>2</td>
<td>LAPORTE G</td>
<td>Canada</td>
<td>9</td>
<td>1012</td>
<td>3.0033</td>
</tr>
<tr>
<td>3</td>
<td>COELHO LC</td>
<td>Canada</td>
<td>6</td>
<td>900</td>
<td>2.4525</td>
</tr>
<tr>
<td>4</td>
<td>CHRISTIANSEN M</td>
<td>Norway</td>
<td>8</td>
<td>472</td>
<td>1.8151</td>
</tr>
<tr>
<td>5</td>
<td>BERTAZZI L</td>
<td>Italy</td>
<td>7</td>
<td>513</td>
<td>1.7880</td>
</tr>
<tr>
<td>6</td>
<td>TAVAKKOLI-MOGHADDAM R</td>
<td>Iran</td>
<td>8</td>
<td>449</td>
<td>1.7691</td>
</tr>
<tr>
<td>7</td>
<td>RAA B</td>
<td>Belgium</td>
<td>11</td>
<td>284</td>
<td>1.7663</td>
</tr>
<tr>
<td>8</td>
<td>DIABAT A</td>
<td>United Arab Emirates</td>
<td>5</td>
<td>474</td>
<td>1.4922</td>
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<tr>
<td>9</td>
<td>SPERANZA MG</td>
<td>Italy</td>
<td>6</td>
<td>320</td>
<td>1.2933</td>
</tr>
<tr>
<td>10</td>
<td>ANDERSSON H</td>
<td>Norway</td>
<td>7</td>
<td>249</td>
<td>1.2604</td>
</tr>
</tbody>
</table>

Source: Authors' synthesis based on Biblioshiny/Scopus

The annual productivity of those authors along with their corresponding citation counts is illustrated in Figure 5. In the visualization, a larger circle indicates a higher number of articles, while a denser circle represents a greater number of citations. The majority of authors in the top 10 entered the metaheuristics apply for solving Inventory routing problem is represented in Figure 5.

#### Figure 5

*Authors’ production over time*

Source: Authors' synthesis based on Biblioshiny/Scopus

This paper analyzed the contributions of various research institutions to Inventory Routing problem research, utilizing data extracted from RStudio software and visualized through VOSViewers. According to the findings, ten institutions are highlighted based on their publication output. Leading the pack is Norwegian University of Science and Technology with
34 papers, followed closely by Islamic Azad University and University of Tehran, contributing 33 journal papers, respectively. Notably, five out of the top ten prolific organizations hail from Iran, indicating the maturity and widespread acknowledgment of IRP research within the country. Among the top-ranking institutions, Institut Teknologi Sepuluh Nopember exhibited the lowest number of published articles, with 9 contributions.

The most contributive nation in the domain of IRP research is shown in Table 4. Specifically, a total of 346 publications related to IRP topics were distributed across 39 countries (or territories). This observation underscores a notable scholarly interest in the sphere of IRP. However, a remarkable examination of the geographic distribution of authors reveals an imbalance within this knowledge domain (see Table 4). Iran emerges as the leading contributor to research on the IRP field, with 45 publications attributed to authors from this nation. While Iran exhibits a substantial representation in publications originating from a single country (40), China shows their collaboration with multiple countries (14), underscoring its extensive involvement in global research partnerships.

Table 4

<table>
<thead>
<tr>
<th>Most influential country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country</td>
</tr>
<tr>
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<td>BELGIUM</td>
</tr>
<tr>
<td>BRAZIL</td>
</tr>
<tr>
<td>CANADA</td>
</tr>
<tr>
<td>TURKEY</td>
</tr>
<tr>
<td>ITALY</td>
</tr>
</tbody>
</table>

Source: Authors’ synthesis based on Biblioshiny/Scopus

(TC: Total Cited; AAC: Average Article Citations; SCP: single country publications; MCP: multiple country publications.)

3.1.3 Most Influential Article

A substantial body of research has explored the application of metaheuristics to solve Inventory Routing Problems (IRP). These studies have significantly advanced our understanding of how metaheuristics can optimize inventory management and routing decisions. This section identifies the 10 most influential papers in the field, based on their total citation count.
Table 5 presents a detailed breakdown of these key works, including author information, publication year, citation metrics (global and local, normalized), and the local citation/global citation ratio (LC/GC ratio (%)).

Table 5 delves into papers exhibiting the highest co-citations within our localized dataset along with information about each author, year of publication, global citation, normalized global citation, local citation, normalized local citation, and LC/GC ratio (%). Specifically, the paper authored by Coelho et al. (2014) garnered the highest number of global citations with 431, followed closely by the research conducted by Zhalechian M et al. (2016) amassing 277 citations; and Campbell and Savelsbergh (2004) with 248 citations. Furthermore, while Hiasast et al. (2017) has the most recent publication with 246 citations, but Perl J et al. (2014) has the oldest publication with 231 citations.

Table 5

<table>
<thead>
<tr>
<th>Articles ranking cited</th>
<th>Year</th>
<th>GC</th>
<th>NGC</th>
<th>LC</th>
<th>NLC</th>
<th>LC/GC Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coelho Lc, 2014, Transp Sci(24)</td>
<td>2014</td>
<td>431</td>
<td>5.80</td>
<td>39</td>
<td>5.44</td>
<td>9.05</td>
</tr>
<tr>
<td>Campbell Am, 2004, Transp Sci(26)</td>
<td>2004</td>
<td>248</td>
<td>1.00</td>
<td>41</td>
<td>1.00</td>
<td>16.53</td>
</tr>
<tr>
<td>Hiasast A, 2017, J Manuf Syst(27)</td>
<td>2017</td>
<td>246</td>
<td>5.77</td>
<td>17</td>
<td>3.95</td>
<td>6.91</td>
</tr>
<tr>
<td>Perl J, 1985, Transp Res Part B Methodol(28)</td>
<td>1985</td>
<td>231</td>
<td>1.26</td>
<td>3</td>
<td>0.67</td>
<td>1.30</td>
</tr>
</tbody>
</table>

Source: Authors' synthesis based on Biblioshiny/Scopus
(GC: Global Citation; NGC: Normalized Global Citation; LC: Local Citation; NLC: Normalized Local Citation)

3.2 SCIENCE MAPPING ANALYSIS

This section delves into the relationship between metaheuristics and Inventory Routing Problems (IRP) to answer for question research 2, exploring how to leverage metaheuristics to optimize IRP objectives. We employ various techniques to achieve this: co-citation analysis to examine prior research, bibliographic coupling to assess recent works, and co-word analysis to identify key terms for future research directions. To visualize these relationships, we utilize the VOSviewer program developed by Campbell and Savelsbergh (2004). This program combines...
word analysis and co-occurrence to depict co-citation patterns of authors and journals, bibliographic coupling of countries and institutions, and the construction of word networks.
3.2.1 Co – Citations Analysis

As mentioned earlier, co-citation analysis examines the references cited by scientific publications within a dataset. By studying the relationships between these cited publications, it provides insights into the evolution of key topics in a specific research field. Ferreira (2018) highlights that co-citation analysis can identify publications frequently cited together by multiple authors, suggesting a significant connection between them. In simpler terms, co-citation analysis helps us find articles that are often mentioned together, indicating a strong relationship.

Our study analyzed the references from 346 papers, encompassing a total of 10,361 cited references. To ensure relevance, we applied a minimum threshold of 8 citations per reference. This resulted in 27 references meeting the criteria. Figure 6 visualizes the co-citation of references related to applying metaheuristics for solving Inventory Routing Problems (IRP). Figure 6 reveals a clustered structure. The largest cluster (colored blue) encompasses 24 co-cited references, followed by the red cluster (16 references), green cluster (12 references), yellow cluster (11 references), and finally the purple cluster with 10 co-cited references. This visualization helps us understand the relationships between key references in the field of applying metaheuristics to IRP.

**Figure 6**

Co – citation analysis of references

Source: Authors’ synthesis based on VOSviewer
3.2.2 Co-Occurrence Network

Keywords act like labels or key terms that capture the main ideas of research articles. By analyzing how often these words appear together, we can understand the overall research focus. Following Zupic and Čater (2015), we used VOSviewer software to conduct a keyword co-occurrence analysis to identify the key themes in IRP research. The purpose of performing a sort of content analysis known as keyword co-occurrence analysis is to be able to identify relationships between terms within a chosen set of publications. Fakhar Manesh et al. (2021), underline the significance of this study since it enables the identification and clustering of theme regions, resulting in a visual depiction of the primary theoretical or underlying issues in the research field. From 673 identified keywords from author keywords, 46 were selected for analysis with a minimum occurrence threshold of 5. The analysis’s findings are shown in Error! Fonte de referência não encontrada., which shows a keyword co-occurrence overlay. In the Error! Fonte de referência não encontrada., the size reflects the keyword frequency among 346 articles from 1978 to 2023. Word size reflects keyword frequency. Inventory routing problem (124 papers) emerged as the top keyword, followed by heuristics (74), metaheuristics (54), genetic algorithm (40), inventory (41), and vehicle routing problem (39). Evidently, Inventory routing problem and heuristics, metaheuristics represent a central theme. It reflects the important role of applying approximate algorithm like heuristics or metaheuristics to optimize the solution for NP – hard problem.

Figure 7

Co-occurrence authors keywords

Source: Authors’ synthesis based on VOSviewer
**Figure 8**

*Overlay Visualization of bibliographic coupling document*

![Overlay Visualization of bibliographic coupling document](image)

Source: Authors' synthesis based on VOSviewer

The results of the VOSviewer co-occurrence analysis are presented in *Erro! Fonte de referência não encontrada.* There are five clusters of keywords are identified, each represented by a different color in *Erro! Fonte de referência não encontrada.* Each circle represents a specific keyword and indicates a sub-area within the broader theme of IRP networks. Larger circles indicate keywords that appear more frequently. Circles with similar colors show related keywords within a particular cluster. Cluster 1 (Green) focuses on Inventory routing problem, vendor managed inventory; Cluster 2 (yellow) centers on heuristics; Cluster 3 (Red) concentrate on metaheuristics; Cluster 4 (Blue) emphasizes Vehicle routing problem; Cluster 5 (Purple) highlights the stochastic.

Building on the keyword co-occurrence analysis, we can delve deeper into the dynamics of current research teams and identify trending topics. To visualize the evolution of research in IRP, VOSviewer offers a valuable tool called overlay visualization which is a useful graphic tool for examining the temporal distribution of terms within each cluster. It employs colors ranging from purple to green to yellow to indicate the chronological occurrence of keywords. This visual aid effectively highlights the chronological emergence of keywords and their average publication year, revealing the shifting research interests of scholars across different time periods (Bhattacharya, 2019). By analyzing the overlay visualization, one can observe the shift in applying metaheuristics for inventory routing problem research over time, from earlier subjects like applying heuristics and basic variants such as single product, deterministics demand to applying metaheuristics, stochastic model and the new trend in research IRP are perishable product and sustainability.
3.2.3 Thematic Analysis

To visualize the thematic evolution of research on applying metaheuristics to Inventory Routing Problems (IRP), we employed a technique known as abstract harvesting. This method, described by Aria et al., (2020), analyzes publication abstracts to reveal the historical progression and development of key themes over time.

We utilized the 'biblioshiny' package within the R programming language to conduct this analysis. To ensure a comprehensive picture of theme development, historical periods were segmented based on author judgment. Co-word analysis, as outlined in Aria et al. (2020) played a crucial role in identifying thematic clusters and their associated keywords. This technique allowed us to classify and map these themes on a two-dimensional graph based on their density and centrality within the corpus. By analyzing thematic evolution, we gain valuable insights into the topics covered in the literature, highlighting the most prominent and current research areas. This approach aligns with previous studies of Donthu et al. (2021), Aria and Cuccurullo (2017) that emphasize the importance of understanding the conceptual structure of research to track how subjects change over time.

Figure 9
Thematic map

Source: Authors' synthesis based on Biblioshiny/Scopus

The thematic map reveals four key areas of research within applying heuristics for solving inventory and transportation problem: (i) Motor Themes: These highly prominent themes focus on inventory routing problem, such as stochastic demand, column generation, scheduling and time window. These advancements are shaping the future of manufacturing. (ii) Niche Themes: These specialized themes deal with replenishment, multi – objective optimization and particle swarm optimization. (iii) Basic Themes: These core themes encompass inventory, distribution, production planning, stochastics, metaheuristics, heuristics and IRP. These
fundamental concepts underpin advancements in IRP; (iv) Emerging/Declining Themes: vendor managed inventory and iterated local search are only two themes that is solidly within this quadrant.

**Figure 10**

*Thematic evolution*

The biblioshiny package in R offers another valuable tool: thematic evolution analysis. This technique allows researchers to visualize how research topics merge, diverge, or gain prominence over time (Aria and Cuccurullo, 2017).

Figure 0 presents an alluvial diagram, a type of flow chart, that depicts the thematic evolution of the IRP research field from 1978 to 2023. The diagram divides the analysis into three distinct periods, mirroring the analysis in section 3.1 on annual growth of publications

Figure 0. Phase 1 (1965-2010): The Formative Stage, this initial period represents the embryonic stage of IRP research, where scholars focused on defining the concept itself and exploring core themes (Campbell and Savelsbergh, 2004), (Perl and Daskin, 1985), (Lei, 2006), (Constable and Whybark, 1978), (Bertazzi and Grazia, 1999), (Schwarz, 2006). Phase 2 (2010-2020): Applying metaheuristics, the second phase witnessed the concentration on developing the algorithm to solve IRP. Prominent themes during this period include genetic algorithm, tabu search (Arab, 2020), (Coelho et al., 2014), (Zhalechian et al., 2016), (Hiassat et al., 2017), (Coelho et al., 2012), (Archetti et al., 2012), (Agra et al., 2018), (Bertazzi et al., 2019), (Hemmati et al., 2015), (Asadi et al., 2018), (Alvarez et al., 2018), (Seifbarghy and Samadi, 2014), (Etebari and Dabiri, 2016), (Rayat et al., 2017), (Alejo-Reyes et al., 2020), (Tankasale and Jha, 2020), (Sadeghi, 2015). Phase 3 (2021-2023): Continued Development and Emerging Themes, the most recent period (2021-2023) demonstrates continuity in some themes like sustainability, decomposition, stochastics and hybrid metaheuristics algorithm which are the main direction in building new constraint for IRP model. Beside, there were also some effective algorithm to solve IRP including large neighborhood search, branch and cut (Pasandideh,
Bibliometric Study of Metaheuristics Application for Solving Inventory Routing Problem

2023), (Morales, 2021), (Abbaspour et al., 2022), (Mahjoob et al., 2022), (Yuchi et al., 2021),
(Wu et al., 2021), (Shao et al, 2023), (Yu et al., 2021), (Cergibozan and Tasan, 2022), (Cano et
al., 2023), (Hoa and Anh, 2023), (Pereda et al., 2023), (Juvêncio et al., 2023).

3.2.4 Metaheuristics – IRP Analysis

The Inventory Routing Problem (IRP) constitutes an extension of the well-established
Vehicle Routing Problem (VRP) which is kind of NP – hard problem. The IRP is a
combinatorial optimization conundrum, holds prominence within the domain of logistics and
supply chain management. It entails the determination of optimal delivery schedules and routes
for a fleet of vehicles serving a diverse clientele with varying demands. Traditional optimization
techniques often struggle with the complexity of large-scale IRPs, particularly those with
numerous products and delivery locations. Therefore, metaheuristics and heuristics are used by
many authors for solving IRP nowadays. This article will analyze which metaheuristics are
most used in solving IRP problems and what are the current trends.

Figure 11

Metaheuristics occurrences in solving IRP

Source: Authors

Genetic algorithm (GA) is the most popular method, applied by many authors in solving
IRP problems with 51 appearances. This is the optimal algorithm result in NP solving problems
-hard IRP is chosen by the operations. Algorithms such as simulated annealing and tabu search
both have the same number of occurrences in 15 times, which task groups believe will yield
optimal results. Advantage for solving the IRP problem.

In the trend from 2020 to 2023, the algorithms applied in solving the IRP problem are
shown in the Erro! Fonte de referência não encontrada.1. It is can clearly see that the GA
algorithm continues to grow from 2020 to 2023 despite a decline in 2021. Besides, the SA algorithm also shows strong development during the period.

4 DIRECTIONS FOR IRP RESEARCH AND APPLYING METAHEURISTICS

The Inventory Routing Problem (IRP) remains a crucial area of research in supply chain management. Due to its inherent complexity, particularly in large-scale scenarios, traditional optimization methods often struggle to find optimal solutions. This has led to a surge in the application of metaheuristics - optimization algorithms inspired by natural phenomena or human behavior - to address IRPs effectively. From 1978 to 1978, IRP has made many changes in mathematical models and solution methods. Initial IRP problems with initial basic models with simple constraint variations such as single product, single vehicle fleet, 1 point to many points network, deterministic customer demand has developed Many variations and constraints help fit the actual situation of businesses such as: multi-products, fleets with many different capacities, diverse distribution networks, fluctuating customer needs, customers with different delivery time requirements. In addition, from the original linear solution methods that took a lot of time to give the optimal answer, researchers have developed metaheuristics algorithms such as genetic algorithm (GA), Simulated annealing (SA), Tabu search (TB), Local search (LS), Neighborhood search (NS), Particle Swarm Optimiation (PSO), Ant Colony Optimization (ACO), help solve problems in a short time with optimal answers. In the context of disruption and high competition in the world, the trend of Inventory routing problem will be even more prevalent in the near future. Research in IRP has some main directions in the future:

4.1 INCREASED FOCUS ON REAL-WORLD CONSTRAINTS

Modern research delves deeper into incorporating real-world complexities into IRP models. This includes factors like:

- **Vehicle heterogeneity**: Different vehicle capacities, speeds, and routing restrictions.
- **Time windows**: Delivery windows or time constraints for customer locations.
- **Multi-depot scenarios**: Accounting for inventory storage and replenishment from multiple depots.
- **Dynamic environments**: Adapting solutions to handle fluctuating demand, real-time traffic updates, or unexpected disruptions.
4.2 EXPLORATION OF NEW METAHEURISTIC VARIANTS

Metaheuristics are being tailored to handle these complexities more effectively, leading to more robust and practical solutions. Researchers are constantly exploring new metaheuristic algorithms or modifying existing ones to improve their performance for IRP. Some promising trends include:

- Hybrid approaches: Combining multiple metaheuristics to leverage their strengths and address specific problem characteristics.
- Multi-objective optimization: Balancing multiple objectives like minimizing cost, travel time, or carbon emissions.
- Machine learning integration: Integrating machine learning techniques to improve solution quality or predict future demand patterns.

4.3 FOCUS ON BIG DATA AND ANALYTICS

The rise of big data in supply chain management is impacting IRP research. Techniques are being developed to:

- Handle large datasets: Efficiently process vast amounts of data related to inventory levels, customer locations, and historical demand patterns.
- Real-time optimization: Utilize real-time data for dynamic route adjustments and inventory management decisions.
- Predictive analytics: Forecast future demand and proactively adjust inventory levels and delivery routes.

4.4 GROWING INTEREST IN SUSTAINABILITY

Sustainability is becoming a key consideration in supply chain management. Research is exploring how metaheuristics can be used to:

- Minimize fuel consumption and carbon emissions: Optimizing routes to reduce travel distances and vehicle usage.
- Green inventory management: Developing strategies that minimize waste and optimize warehouse space utilization.
• Closed-loop supply chains: Designing IRP solutions that integrate reverse logistics for product returns and recycling.

Overall, research in applying metaheuristics for IRP is thriving. By addressing real-world complexities, exploring new algorithms, leveraging big data, and incorporating sustainability considerations, researchers are paving the way for more robust, adaptable, and eco-friendly inventory management and routing solutions.

5 CONCLUSION

This study delves into the dynamic field of Inventory Routing Problems (IRP) through a comprehensive bibliometric analysis. This approach offers a detailed examination of the current knowledge base, revealing key trends, prominent research areas, and potential avenues for future exploration. The analysis will meticulously examine scholarly publications on IRP from 1965 to 2023, encompassing 1,764 journal articles identified through robust search strategies within the Scopus database. Established bibliometric techniques, potentially utilizing tools like VOSviewer and R Studio, will be employed to map the knowledge structure of the field. This visualization will illuminate the interconnectedness of research themes, along with the most influential authors and institutions shaping IRP research. The findings, meticulously presented, will include key performance metrics and in-depth explorations of prominent research areas. This will shed light on aspects of IRP that have received the most attention and unveil potential knowledge gaps that warrant further investigation. By analyzing the trajectory of current research trends, the study aims to predict future research directions and propose innovative avenues for advancing the field. Building upon these insights, the paper will subsequently outline a compelling research agenda. This agenda will identify promising areas for future research, potentially focusing on emerging optimization techniques or exploring the application of IRP in novel logistics scenarios. By fostering new research initiatives, this agenda aims to propel the development of IRP solutions and maximize their impact on efficient inventory management and routing strategies.

Finally, the paper will culminate in a comprehensive conclusion that summarizes the key findings and limitations of the study. This will be accompanied by insightful closing remarks that highlight the most significant takeaways and their implications for the future of IRP research and its practical applications within the ever-evolving domain of supply chain management.
ACKNOWLEDGEMENT

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