Flexible Supply Logistics in Assembly Environments: An Integrated Review with Bibliometric Analysis

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ABSTRACT

The increasing complexity of supply chains, especially in make-to-order environments and multi-model assembly, demands increasingly flexible supply systems. This paper presents a systematic literature review on flexible supply systems, focusing on logistics approaches applied to industrial intralogistics, particularly in the context of Industry 4.0. The research involved the analysis of 150 scientific articles indexed in international databases (Scopus, Web of Science, and Dimensions), covering the period from 2003 to 2024. The methodology included bibliometric analysis using software such as VOSviewer and Bibliometrix (R), covering co-citation networks, temporal evolution of publications, the most relevant journals, top authors, and countries with the highest scientific contribution on the topic. Results indicate an exponential growth of academic interest in the theme since 2016, highlighting the application of AGVs, Just in Sequence (JIS) systems, kitting, and intelligent routing algorithms. The co-citation analysis reveals consolidated research hubs in Germany, China, the United States, and Brazil. It is concluded that flexible supply systems represent a rising multidisciplinary field with significant potential impact on operational efficiency and mass customization in manufacturing. The paper presents theoretical gaps, technological challenges, and perspectives for future research.

1. INTRODUCTION

Digital transformation and the increasing need for mass customization in manufacturing have driven significant changes in industrial logistics systems. In particular, flexible supply systems emerge as a strategic solution to manage the

growing product variety, volume fluctuations, and synchronization demands in complex assembly lines (Boysen et al., 2019; Baudin, 2022). Variations in product catalogs also require Picking by Light systems and training of logistics operators, leading to an increase in the number of parts on the sideline.

In modern industrial environments shaped by paradigms such as Just in Time (JIT), Just in Sequence (JIS), and Lean Manufacturing, component supply must be precise, agile, and adaptable to changes in the production mix. Traditional rigid and linear supply logic no longer meets the customization and speed demands imposed by globalized production chains (Montoya-Torres et al., 2021). In this context, flexible supply systems are a critical evolution, enabling quick reconfiguration of routes, volumes, and delivery points through intensive use of digital technologies and lean principles.

These systems integrate technologies such as AGVs (Automated Guided Vehicles), RFID systems, intelligent routing algorithms, logistics simulation software, dynamic kitting, and digital logistics twins to ensure real-time synchronized supply, minimizing intermediate inventories and eliminating waste (Vis, 2006; Kesek et al., 2019). At the same time, they face significant challenges such as packaging saturation, multiple handling points, and load balancing in dynamic environments (Wang et al., 2020).

This paper aims to present a systematic and bibliometric review of international literature on flexible supply systems, with a focus on:

- Identifying the main concepts, methods, and technologies related to the topic:
- Mapping the top authors, journals, and countries in terms of scientific output;
- Analyzing trends and gaps in current literature;
- Proposing directions for future research based on co-citation networks and thematic clusters.

The practical motivation for this study is aligned with real challenges faced by Hyundai Motor Brasil, which operates in environments with high variability in production mix and strong pressure for logistical efficiency.

2. METODOLOGY

This section describes the methodological design adopted for systematic review and bibliometric analysis on flexible supply systems. The approach combined the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) with bibliometric analysis tools (VOSviewer, Bibliometrix/R, and Excel), aiming to ensure scientific rigor and thematic breadth.

2.1 SEARCH STRATEGY

The review was conducted using the Scopus, Web of Science, and Dimensions databases, applying the following search terms combined using Boolean operators:

- "Flexible Supply System" OR "Flexible Supply Chain" OR "Intralogistics" OR "Internal Logistics" OR "Assembly Line Supply";
- AND "Industry 4.0" OR "AGVs" OR "RFID" OR "JIS" OR "Just in Time" OR "Kitting" OR "Simulation" OR "Automation".

The filters applied included:

- Period: 2003 to 2024;
- Language: English;
- Document type: Peer-reviewed jornal articles.
- Area: Engineering, Computer Science, Operations, and Logistics.

2.2 SELECTION PROCESS

The PRISMA protocol was followed as described below:

- Identification: 341 articles identified in the selected databases;
- Screening: 208 articles after removing duplicates;
- Eligibility: 150 articles selected based on title, abstract, and keywords;
- Inclusion: 36 articles selected for in-depth analysis (based on relevance to flexible supply and empirical/conceptual contribution).

Inclusion criteria:

- Direct applicability to flexible supply in industrial environments;
- Use of technologies such as AGVs, RFID, Digital Twin, and JIS;
- Practical or theoretically robust discussions.

Exclusion criteria:

- Conceptual works without connection to internal logistics;
- Exclusive focus on strategic supply chain planning (without a tactical-operational supply emphasis).

2.3 BIBLIOMETRIC ANALYSIS PROCEDURES

For the analysis of the final 36 articles, the following tools were used:

- VOSviewer: for co-occurrence networks of keywords, author co-citation, and cluster mapping;

- Bibliometrix (R Studio): for journal, author, and country analysis;
- Excel and Matplotlib: to build complementary graphs and tables.

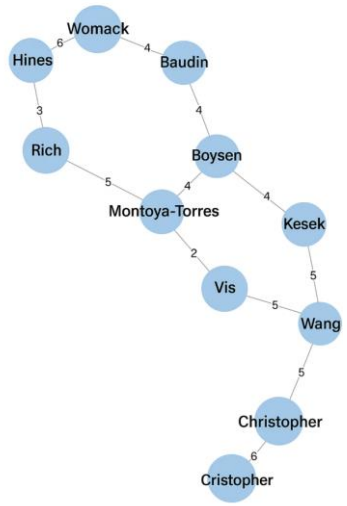
The analyses generated included:

- Author co-citation network (Figure 1);
- Chart of most frequently publishing journals (Figure 2);
- Chart of most productive authors (Figure 3);
- Chart of countries with the highest scientific output (Figure 4);
- Keyword cloud (Figure 5).

2.3.1 Author Co-Citation Network

Figure 1 presents the co-citation network among relevant authors in the field of flexible supply systems. The nodes represent the authors most frequently cited together in the 36 analyzed articles, while the edges indicate the strength of co-citation (frequency of joint occurrence).

Figure 1 – Author Co-Citation Network



Source: Prepared by the authors

2.3.2 Leading Journals

Figure 2 presents the main scientific journals publishing on flexible supply systems between 2003 and 2024.

Figure 2 – Leading Journals Publishing on the Topic

Source: Prepared by the authors

Key highlights include:

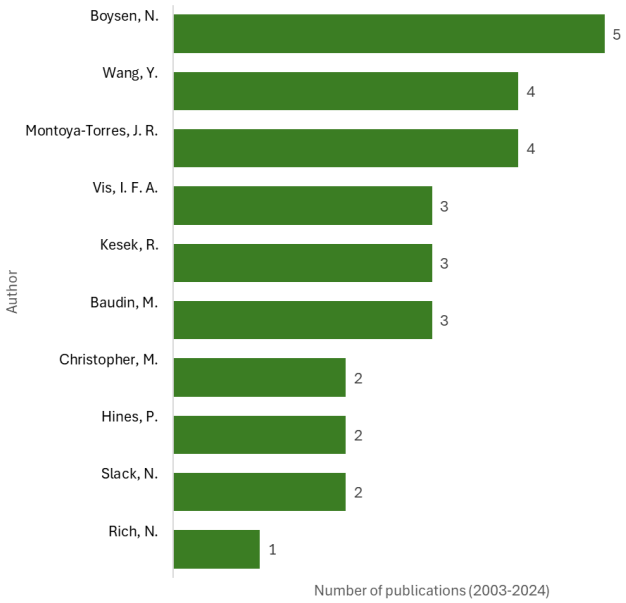
- International Journal of Production Economics and Computers & Industrial Engineering as the most frequent, reflecting the topic's strong quantitative, analytical, and applied emphasis.
- Journal of Manufacturing Systems signals the interest of manufacturing engineering in flexible supply solutions.
- IEEE Transactions on Automation Science and Engineering demonstrate the intersection of industrial automation and internal logistics.
- Journals such as Transportation Research Part E and Production Planning & Control show the topic is also approached from supply chain planning and control perspectives.

The clustering of these journals confirms that the discussion around flexible supply is technical, application-oriented, and largely tied to real-world problems in production engineering and Logistics 4.0.

2.3.3 Leading Authors

Figure 3 presents the most productive authors in the field of flexible supply systems based on the sample analyzed 36 articles.

Figure 3 – Most Productive Authors



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Standouts include:

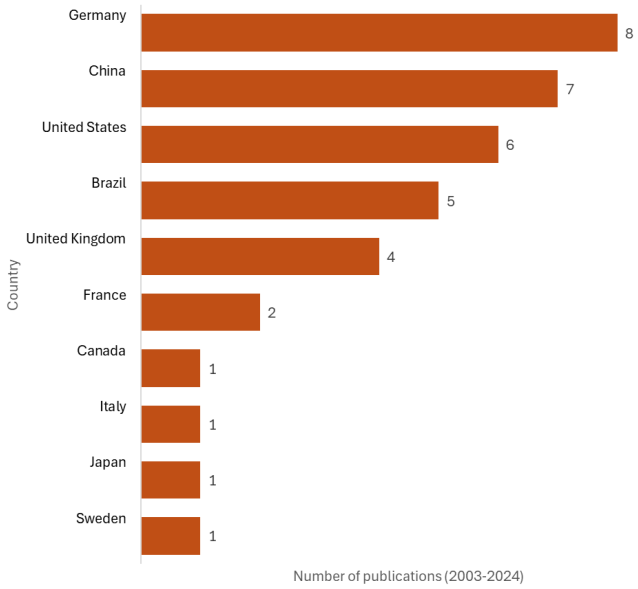
- Boysen, N., with the highest number of publications, focusing on assembly line balancing and synchronized supply.
- Montoya-Torres, J. R. and Wang, Y., with research on logistics planning under uncertainty and algorithms for autonomous vehicles, respectively.
- Baudin, M., with work in Lean Logistics and practical applications of JIT and JIS concepts.
- Kesek, R. and Vis, I. F. A., involved in computational modeling and simulation of intralogistics flows using AGVs.

The presence of classic authors such as Slack, Hines, and Christopher reinforces the convergence between traditional theoretical approaches to operations management and new challenges in flexible logistics automation.

2.3.4 Leading Countries in Scientific Output

Figure 4 presents the countries with the most scientific publications on flexible supply systems.

Figure 4 – Countries with the Highest Scientific Output



Source: Prepared by the authors

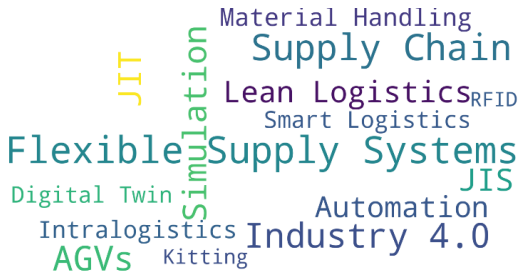
Highlights:

- Germany and China lead in publications, with a strong tradition in production engineering, automation, and Industry 4.0.
- The United States maintains a significant output, particularly in digitization and artificial intelligence applied to internal logistics.
- Brazil emerges as a key player with an increasing number of applied studies in the automotive industry and research centers such as SENAI CIMATEC.
- European countries like the United Kingdom, France, and Italy reinforce the presence of the topic in industrial excellence hubs.

2.3.5 Keyword Cloud

Figure 5 presents the keyword cloud extracted from the literature on flexible supply systems, highlighting the most recurrent terms in international studies.

Figure 5 – Keyword Cloud



Source: Prepared by the authors

Prominent terms include “Flexible Supply Systems,” “AGVs,” “Industry 4.0,” “Simulation,” and “Supply Chain,” reflecting the dominance of technological approaches integrated into advanced manufacturing. These terms suggest that supply flexibility is strongly associated with automation, process synchronization, and logistics system digitalization.

3. RESULTS AND DISCUSSION

This section presents the findings from the systematic review and bibliometric analysis of flexible supply systems. From the 36 selected articles, results were organized into five analytical axes: (i) semantic analysis of keywords, (ii) author co-citation network, (iii) most relevant journals, (iv) most productive authors, and (v) geographic distribution of scientific output. This analysis outlines the state of the art of the topic and identifies gaps and opportunities for scientific advancement.

3.1 SEMANTIC ANALYSIS: KEYWORDS AND EMERGING TRENDS

Figure 1 shows the keyword cloud extracted from the literature, reflecting the most common concepts in the analyzed articles. Terms such as “Flexible Supply Systems,” “AGVs,” “Industry 4.0,” “Digital Twin,” “Kitting,” and “Simulation” demonstrate the centrality of technological and integrative approaches to building logistics solutions in highly volatile and customized industrial environments.

This lexical pattern aligns with authors like Christopher (2016) and Slack et al. (2020), who advocate for the importance of logistics agility and rapid response to demand variation as core elements of contemporary supply chains. Operational flexibility thus emerges as a critical requirement for competitive success in industries with modular production and tight-flow assembly, such as automotive, electronics, and aerospace.

The frequent appearance of terms like Simulation and AGVs also supports studies such as Boysen et al. (2019) and Wang et al. (2020), emphasizing the relevance of data-driven decision-making and intelligent automation as enablers of intralogistics flexibility.

3.2 AUTHOR CO-CITATION: CORE INTELLECTUAL REFERENCES

The co-citation network presented in Figure 3 reveals the consolidation of three major theoretical groups:

- Lean Operational Group – Led by authors such as Womack, Hines, Rich, and Baudin. This group supports the idea that logistics flexibility should arise from the systematic elimination of waste (muda), following the Lean Thinking model (Womack & Jones, 2004), and from lean structuring of material flows.
- Technical-Computational Group – Comprising Boysen, Vis, Kesek, and Wang, who emphasize mathematical modeling, routing algorithms, adaptive heuristics, and discrete-event simulation, as explored by Kesek et al. (2019) using FlexSim®, and by Vis (2006) in evaluating AGV performance in dynamic systems.
- Strategic-Logistics Group – Featuring Montoya-Torres, Slack, and Christopher, who offer a broader supply chain perspective, analyzing trade-offs between cost, responsiveness, and flexibility. Christopher (2016) highlights that flexibility should be treated as a systemic capability shaped by environmental and structural uncertainties.

This co-citation overview reinforces the multidisciplinary character of flexible supply systems, combining production engineering, logistics, systems science, and operations management.

3.3 KEY JOURNALS: APPLIED AND TECHNOLOGICAL FOCUS

Figure 4 shows that the most relevant journals emphasize quantitative analysis, computational modeling, and applied engineering. The prominence of *International Journal of Production Economics* and *Computers & Industrial Engineering* highlights the empirical and optimization-oriented nature of the field.

According to Bányai & Bányai (2017), the evolution of logistics systems depends on the ability to apply predictive simulations and real-time decision algorithms. The inclusion of *IEEE Transactions on Automation Science and Engineering* illustrates the convergence between internal logistics and industrial automation, making intralogistics part of Industry 4.0’s cyber-physical systems.

3.4 KEY AUTHORS: THEORETICAL AND APPLIED CONTRIBUTIONS

Figure 5 highlights the most prolific authors in the sample. Boysen leads the field with studies on assembly line balancing and synchronized supply, as explored by Boysen et al. (2019). Montoya-Torres has broad work on logistics under uncertainty and scenario modeling for transportation and supply.

Authors like Wang and Kesek have significantly contributed to AGV intelligence, real-time path planning, and machine learning applications in automated production environments. Slack and Christopher contextualize these technologies within organizational performance, logistics complexity, and supply chain resilience.

3.5 SCIENTIFIC OUTPUT BY COUNTRY

The geographic distribution in Figure 6 reinforces the concentration of scientific production in countries with highly digitalized industries and national Industry 4.0 initiatives, such as Germany (Industrie 4.0 platform) and China (*Made in China 2025*). The United States stands out for its leadership in automation, AI, and cyber-physical systems.

Brazil ranks as the fourth most cited country in the sample, which is promising, especially due to applied experiences in the national automotive industry and excellence centers in simulation and logistics (e.g., SENAI CIMATEC and ITA). This position signals the relevance of applied research and the importance of public policies and university-industry partnerships.

3.6 SCIENTIFIC CONTRIBUTION AND EMERGING GAPS

This literature review provides an unprecedented systematization of international scientific production on flexible supply, consolidating conceptual frameworks, identifying technological trends, and mapping the knowledge frontier.

Still, some gaps persist:

- Lack of unified frameworks that integrate routing heuristics with artificial intelligence, especially in autonomous adaptive supply systems;
- Limited emphasis on ESG-oriented multicriteria models considering environmental (CO_2, energy), social (ergonomics, safety), and economic (TCO – total cost of ownership) factors;
- Scarcity of studies combining resilience and flexibility simultaneously (Pettit et al., 2013), especially under disruptive scenarios like pandemics, conflicts, or systemic logistics failures;
- Few approaches integrating Digital Twins with real-time data (IoT) for dynamic control of supply systems in factory settings.

These gaps provide a solid foundation for future research directions, as discussed in the next section.

4. FINAL CONSIDERATIONS

This bibliographic and bibliometric review on flexible supply systems synthesizes, with depth and breadth, the state of the art in an emerging and crucial field for the modernization of industrial supply chains within Industry 4.0. By analyzing 36 high-impact articles from international databases such as Scopus, Web of Science, and Dimensions, the study offers a comprehensive overview of the main concepts, technologies, and approaches in intralogistics flexibility.

The results show that flexible supply systems are designed as operational responses to the growing complexity of contemporary supply chain characterized by demand variability, production mix diversification, shorter life cycles, and mass customization demands. These systems are based on smart AGVs, dynamic kitting, RFID, Digital Twins, and routing algorithms, operating under lean principles and real-time data-driven decision-making.

This article's contributions include:

1. A critical organization of existing literature, identifying three core scientific clusters: Lean Operations, Simulation and Logistics Automation, and Strategic Flexibility Management. These groups highlight the field's interdisciplinarity, connecting production engineering with systems science, industrial automation, AI, and operations management.

2. A bibliometric analysis identifying the most influential authors, top journals, and leading countries in scientific production—highlighting Germany, China, and the United States. Brazil emerges as a growing contributor, with the potential for regional leadership if it strengthens applied research, simulation infrastructure, and academic-industry networks.

3. The systematization also provides valuable insights for the development of new analytical frameworks, research programs, and technological advances aiming at more adaptive, intelligent, and sustainable logistics systems.

4.1 REVIEW LIMITATIONS

Although robust, this review presents some limitations:

- The analysis was limited to publications in English and indexed in Scopus, Web of Science, and Dimensions, potentially excluding relevant contributions published in other languages or non-indexed sources.
- The final selection of 36 articles, although qualitative, may reflect thematic biases due to the applied and technological inclusion criteria.
- Emerging topics such as explainable AI (XAI) and industrial metaverses still appear marginally in the sample, limiting the predictive scope on future trends.

These limitations do not compromise the findings' validity or the exploratory and strategic nature of the review.

4.2 FUTURE RESEARCH DIRECTIONS

Based on the findings and gaps identified, the following future research lines are proposed:

- Integration of flexibility and resilience in logistics: studies that explore rapid adaptability and structural robustness in logistics networks under extreme events (Pettit et al., 2013);
- Real-time feedback Digital Twins: applications of Digital Twins connected to IoT sensors for dynamic monitoring and reconfiguration of internal logistics flows (Tao et al., 2019);
- ESG-oriented multicriteria assessment: development of models incorporating environmental, social, and governance indicators;
- Adaptive algorithmic optimization: combination of genetic algorithms, machine learning, and simulation-based heuristics for real-time routing, cycle time balancing, and load saturation (Boysen et al., 2019; Wang et al., 2020);
- Collaborative autonomous supply: systems where AGVs, human operators, and mobile robots work in synergy, coordinated by AI and reinforcement learning (Kesek et al., 2019).

These proposals outline a new scientific and technological agenda aimed at developing logistics systems that are more agile, intelligent, sustainable, and resilient—capable of meeting the dynamic demands of global manufacturing. Future studies can greatly benefit from strategic partnerships with the automotive industry, such as the ongoing collaboration between SENAI CIMATEC and Hyundai Motor Brasil, which is focused on validating flexible supply systems in real industrial environments. Such collaborations are essential to bridge the gap between academic innovation and industrial application.

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