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A STUDY ON THE APPLICATION OF ARTIFICIAL INTELLIGENCE IN MATERIAL MOVEMENT BASED ON SCIENTIFIC PUBLICATIONS

UM ESTUDO SOBRE A APLICAÇÃO DA INTELIGÊNCIA ARTIFICIAL NA MOVIMENTAÇÃO DE MATERIAIS A PARTIR DE PUBLICAÇÕES CIENTÍFICAS

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Abstract

Artificial intelligence is one of the information and communication technologies that has promoted major transformations in organizations and their production processes, especially material handling. The growing number of published studies led to the development of this study, which aimed to describe the main characteristics of studies that report the application of artificial intelligence in material handling. The method used was the conceptual bibliographic, bibliometric design based on four stages: formulation of research questions, collection of bibliographic data, analysis, organization of the collected data, and generation of answers to the guiding questions. The results showed that the focuses of the applications are a) improvement and optimization of the logistics process, increased rationality of human-machine actions, and optimization of the decision-making process, b) use of several simultaneous methods and techniques, c) facing problematic situations aimed at problem-solving and generation of technologies, d) application of multiple artificial intelligence tools, e) successful results have increased competitiveness and rationality in material handling and f) opening for new and interconnected applications. The conclusion shows that using artificial intelligence has provided an environment for enhancing human cognitive capacity. The main contribution of this study to science is the finding that professional training in logistics needs to incorporate mastery of artificial intelligence.

Keywords: Artificial intelligence; Material handling; Smart technologies; Internal logistics; Material

logistics.

Resumo

A inteligência artificial é uma das tecnologias da informação e comunicação que tem promovido grandes transformações nas organizações e seus processos produtivos, especialmente no que tange à movimentação de materiais. A crescente quantidade de estudos publicados levou à realização deste estudo, que teve como objetivo descrever as principais características dos estudos que relatam a aplicação da inteligência artificial na movimentação de materiais. O método utilizado foi o bibliográfico conceitual, delineamento bibliométrico assentado em quatro etapas: formulação das questões de pesquisa, coleta dos dados bibliográficos, análise e organização dos dados coletados e geração das respostas às questões norteadoras. Os resultados mostraram que os focos das aplicações são a) melhoria e otimização do processo logístico, aumento da racionalidade das ações homem-máquinas e otimização do processo decisório, b) uso de vários métodos e técnicas simultâneos, c) enfrentamento de situações problemáticas voltadas para solução de problemas e geração de tecnologias, d) aplicação de múltiplas ferramentas de inteligência artificial, e) resultados bem-sucedidos têm elevado a competitividade e a racionalidade nas movimentações e f) abertura para novas e interconectadas aplicações. A conclusão mostra que o uso da inteligência artificial tem proporcionado ambiente de elevação da capacidade cognitiva humana. A principal contribuição deste estudo para a ciência é a constatação de que a formação profissional em logística precisa incorporar o domínio sobre inteligência artificial.

Palavras-chave: Inteligência artificial. Movimentação de materiais. Tecnologias inteligentes. Logística interna. Logística de materiais.

1. Introduction

Artificial intelligence is one of the so-called information and communication technologies (Castillo et al., 2019; Prasetya, 2024; Noviana et al., 2024). These technologies have caused profound transformations in practically all spheres of associated human life, configuring a true planetary revolution, as is the case of Industry 4.0 (Lagarinhos; Azevedo, 2025; Ogidan; Olawale; Dimililer, 2025; Singh et al., 2025). Organizations have been the target and the radiating center of this revolution so that their production processes and operations have become increasingly efficient and competitive (Rehman et al., 2025; Shahzad et al., 2025; Marak et al., 2025) while reducing the serious consequences of environmental damage that previous production models generated (Marak et al., 2025; Sklavos et al., 2025; Shamsuddoha et al., 2025).

In general terms, and although much contested, artificial intelligence can be understood as a way of imitating human cognitive capacity (Yildiz, 2025; He et al., 2025; Mu et al., 2025). Logistics has been one of the most promising fields of application for artificial intelligence, so much so that in 2024 alone, approximately 93,800 studies were published and made available on Google Scholar. Perhaps the main reason for this profusion of studies involving artificial intelligence is that logistics is the scientific and practical field responsible for meeting human needs (Konecka; Lupicka, 2023; Tanriverdi; Aydin, 2024). Since these needs are unlimited, improving production and distribution systems is necessary to increase the availability of products to satisfy them. Moving an increasing number of materials has been an increasingly growing challenge.

In this sense, this study aimed to identify the main characteristics of studies that show the application of artificial intelligence in the movement of materials. For this purpose, ten scientific studies published in high-impact international scientific journals were selected, seeking to find out what the studies intended to achieve, what problematic situations they analyzed, what main research methods and techniques were used, what applications of artificial intelligence were made, what results were achieved, and what the conclusions of the studies were.

2. Artificial Intelligence: Conceptual Scope

Artificial intelligence is the application of technology using algorithms that facilitate the learning of machines and systems, focusing on making them resemble human thoughts (Bar-Gil; Ron; Czerniak, 2024). Through this learning, technologies like these can be more efficient and capable of performing activities independently, only with algorithms. It can also be said that AI is the use of technologies that help to know how to use and, much more than that, to expand the use of limited resources, making the best use and utilizing their capabilities to the maximum. The study by Patel (2024) brings up the idea that artificial intelligence uses all available resources and information to maximize the efficiency of such activity. Studies show that the use of this intelligence applied to machines and systems increases the efficiency of operations, making these machines simulate human thoughts only with the data provided, which are the resources, like the robots currently found in many factories, which move around transporting material and information independently, only with algorithms that they receive and are applied in their system. In the movement of materials, it is of utmost importance that technologies think humanly and are more assertive, as they are based on data and facilitate the transport of loads without manual labor. In the study by Özbek (2024), artificial intelligence is a type of intelligence that connects the world of computing and intelligent behaviors. Emerging from this mixture, AI is nothing more than the learning of reasoning or decision-making that systems analyze and interpret. Kan (2024) says that artificial intelligence is a capacity that seeks to reason actions through computers, developing interactive systems with technology. These studies are widely seen in practice in companies. Pasang et al. (2024) describe the process of simulating human intelligence and technologies using systems and data with the ability to reason like a person with more accurate and confident responses, reducing errors in decision-making. These systems are essential for movement, as they reduce errors in calculations for the movement of sensitive and dangerous loads and the calculation system for logistics in general.

AI can be understood as analysis, using various data in the form of numbers to arrive at a result, as shown in the research by Chizoba, Ishola, and Temitope (2024), which is based on the methodical analysis and use of mathematical models of various data to obtain an accurate answer to something, so that one can predict, make decisions and identify patterns. The study by Tyndall (2024) is a theory of developing programs or systems that perform challenging activities through human intelligence. This is a critical study for logistics activities, which are often manual activities with a high degree of complexity of execution. AI facilitates movement within the company, reducing the number of accidents among employees and maximizing the efficiency of activities.

Artificial intelligence can be understood as a set of techniques focused on problem-solving. Borghi et al. (2024) present the idea of artificial intelligence, a technology replicating human intelligence. This shows that AI is a highly effective technology in interpreting, acting, and making decisions like a person, without even needing human assistance for actions and decisions to be made. According to the research by Zafrullah, Meisya, and Ayuni (2024), artificial intelligence is an innovative branch. These advanced technologies are new to the market, especially in Industry 4.0. They are almost the discovery of this era, constantly undergoing constant improvements to obtain advanced results in the form of innovations, capable of acting individually, without assistance or commands. As mentioned in the study by Yáñez-Valdés and Guerrero (2024), they are systems capable of analyzing and responding autonomously and highly assertively. In logistics, artificial intelligence is becoming an indispensable technology. Companies implementing this intelligence in their operations are achieving significant positive results, automating processes, reducing costs, and increasing efficiency with a focus on movement. AI has brought benefits, as it helps robots create the best routes, systems that calculate the best paths, and programs that analyze numerous data at once to indicate the best decisions, among other benefits.

3. Research Methodology

This research falls into the qualitative category, and its objects of study were ten articles that describe the application of artificial intelligence in material handling. This analysis unit was developed to generate an understanding encompassing only this group of articles (level of analysis) without any intention of generalizing its results. The perspective of analysis was synchronous or transversal because the explanation generated is only valid for the time of publication of the articles studied, which represented the first four months of 2024.

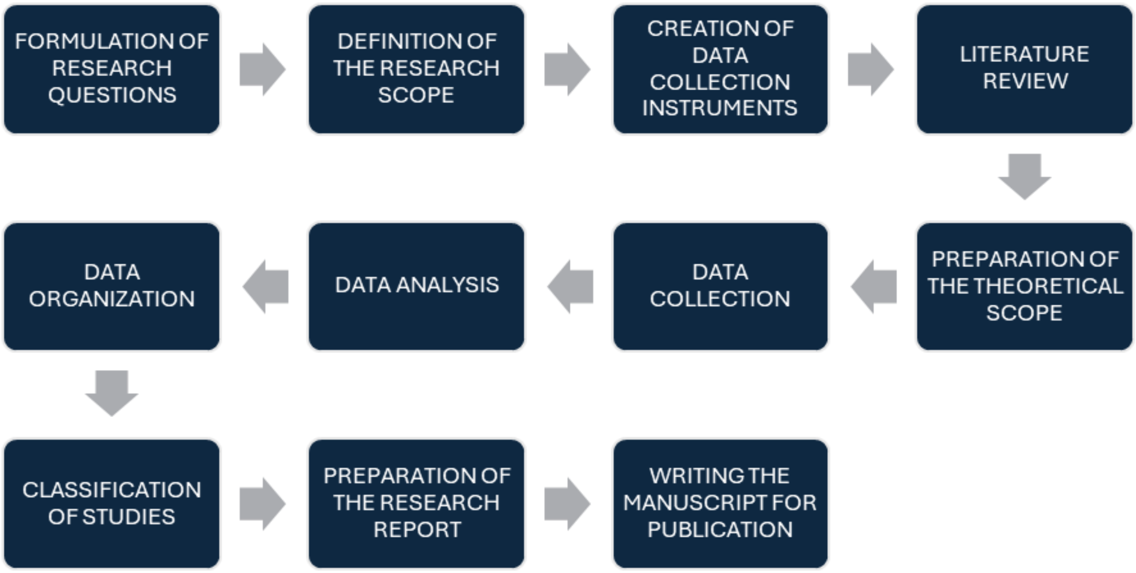
3.1 Guiding questions

The general objective of this study was to identify the main characteristics of studies on material handling using artificial intelligence. Thus, five specific objectives were defined and transformed into guiding questions, as recommended by the studies by Nascimento-e-Silva (2020; 2021a; 2021b; 2021c): 1) what were the intended objectives of the investigations, 2) what were the methods used by the researchers, 3) what were the problematic situations targeted by the studies, 4) what were the AI technologies used in the studies, 5) what were the results achieved and 6) what did the studies reach the conclusions. This section will provide methodological details on how these questions were answered.

3.2 Study design

The work was divided into eleven stages, as shown in Figure 1. In the first phase, we defined the research question and the guiding questions, our work's theme, Artificial intelligence in material handling, and the division of subthemes. In the second phase, the scope of the research was defined, namely, which studies would be helpful in the study. The data collection instrument was created in the third phase based on ten international scientific studies published in high-impact scientific journals.

Figure 1. Study design.



Source: Prepared by the authors.

In the fourth phase, the literature was reviewed, AI was defined, and its impact on material handling was assessed, optimizing processes and increasing efficiency. In the fifth phase, the semantic groups were separated, which generated the theoretical architecture of the study. In the sixth phase, we mapped the impact of artificial intelligence on material handling processes. We translated these studies to ensure a more profound understanding, ensuring no details were missed. In the seventh phase, we collected data using a multi-column table. In the eighth phase, the collected data was organized for better understanding, and a table was created that connects the specific objectives described by the authors with the applications of AI in material handling. The reasoning used to classify the study groups was developed in the ninth phase based on each research's objectives and focus areas. In the tenth phase, the research methods and conclusions were described, and we clarified the entire process carried out during the study with more information. The last phase was the writing of the manuscript for publication.

3.3 Research objects

The objects of this study were ten articles published in 2024 and available on Google Scholar for free. The research protocol excluded course completion studies (monographs, dissertations, and theses), publications in event proceedings, and technical documents. These exclusions intended to include only studies that had undergone peer review, representing the international scientific community's validation of their results. The first ten studies that contained all the answers to this study's guiding questions were chosen.

3.4 Data collection instrument

The data were collected from the academic databases Google Scholar, SciELO, and Scopus, selecting the first ten articles that answered the research questions. After critically reading all the studies, we extracted as much information as possible, separating the data we obtained into tables, each with a theme for better identification. In the first table, we separated the objectives found in each article; in the second, the methods found in the studies; in the third, the problems; in the fourth table, we listed the application of artificial intelligence; in the fifth, the results found, in the sixth and last table, the conclusions of each article. We used this method to make it easier to understand and separate the data. Through these instruments and methods that we established to focus more clearly on what we wanted to collect, we studied ten articles focusing on different areas with different technologies, as Nascimento-e-Silva (2023) recommended.

3.5 Data collection strategy

The first stage of data collection was the selection of ten articles published in 2024 for analysis. Since they were initially published in English, we worked in the first week to translate them into Portuguese, seeking to facilitate analysis and understanding. After translation, we read critically and in detail, looking for the information to answer each guiding research question. At this stage, notes were made of the most critical information, which was placed in a table containing a) publication date, b) study objectives, c) methods used, d) problematic situations, e) results achieved, d) uses of artificial intelligence and e) conclusions. The table shows how we organized the data in a single image for better visualization, clarity, and simplicity. In the second week, we created the tables and placed the information extracted from the studies, separated by tables and groups. All tables have groups using the criterion of “similar or identical themes” (Nascimento-e-Silva, 2021d).

3.6 Data organization and analysis techniques

The data were analyzed individually by guiding questions. After being collected, tables with two columns were created. The bibliographic sources of the articles analyzed were placed in the left column, while the answers to the guiding research questions obtained from each source were placed in the right column. This procedure was followed for each guiding question, generating six tables. The data were then organized. The organization began by identifying similar answers, which formed groups with something in common. For example, answers to the questions related to the problematic situations of the studies that focused on rationalizing and optimizing some movement processes were placed in the same group. At the same time, those who presented the challenge of generating some decision-making mechanism were organized into another group. This procedure was applied to all tables, referring to the answers to the guiding questions.

3.7 Techniques for generating and interpreting results

The results were generated based on the organization that appeared in each table created. The results consisted of identifying the logic of each group contained in each table. For example, in the table relating to the goals of the studies researched, three groups of responses were identified, each with its particular logic but generally comprising a global logic. This global logic represented the result of each table, presented in the text below each one. The interpretation of the results consisted of comparing the results of each table with the knowledge available in the scientific literature, which was the theoretical framework of our research.

4. Results and Discussion

In this section, the study's results will be presented, following the logical sequence of the research's guiding questions: what were the objectives of the scientific articles analyzed, what methods were used, what were their problematic situations, what were the applications of AI, what were the results obtained, and what were the conclusions of the studies?

4.1 Goals of the studies

The results related to the question that sought to identify the goals intended by the studies on material handling that used artificial intelligence showed concentration in three small groups. The first study focused on the improvement and optimization of logistics processes, represented by the studies of Aksysonov et al. (2024), which concentrate on internal logistics processes, Taheri and Falahati (2023), focused on the processing and transportation of products, and Rahardjo et al. (2023), to make processes more efficient and effective. The second group focused on characterizing the uncertainty of actions in individual tasks (Chih-Hsing; Dawiromate (2024)) and identifying weaknesses in internal logistics processes (Muelbauer et al., 2024) to increase the degree of rationality of human-machine actions. The third and last groups concentrated on the most significant number of studies. Still, practically all of them were focused, in some way, on the cause-effect relationship of a series of events to optimize the decision-making process. Thus, the study by Huang and Romano (2024) focused on choices that influence human decisions, that by Navarro et al. (2024) outlined the probabilities of people's actions, while Mishra and Dwivedi (2024) focused on the solution via multi-agent path, that by Annant et al. (2024) focused on the decision configuration of intelligent vehicles on the factory floor, and that by

Smetana et al. (2024) analyzed the causes of accidents in the movement of materials during highway construction. Table 1 summarizes these findings.

Table 1. Summarized goals of the studies analyzed.

References	Goals of the studies
Aksysonov et al. (2024)	Test an automated system to solve problems relating to analyzing and optimizing internal logistics processes.
Taheri; Falahati (2023)	Optimize the processing and transportation of products.
Rahardjo et al. (2023)	Develop a sustainable innovation framework for designing excellence in efficient and effective processes.
Chih-Hsing; Dawiromate (2024)	Simulate a system to characterize the uncertainty introduced by individuals in manual tasks.
Muelbauer et al. (2024)	Analyze transaction data to identify weaknesses in internal logistics processes.
Huang; Romano (2024)	Explore how design choices and psychological values influence user emotions within an aesthetic experience design approach.
Navarro et al. (2024)	Learn whether manufacturing SMEs that establish technological collaboration agreements are more likely to adopt actions aimed at environmental preservation.
Mishra; Dwivedi (2024)	Find a solution using the multi-agent pathfinding approach
Anant et al. (2024)	Configure AGV on the factory floor for decision-making logistics applications
Smetana et al. (2024)	Analyze the leading causes of accidents in highway construction.

Source: Data collected by the authors.

These results indicate a dynamic application of artificial intelligence in material handling that begins with efforts to reduce uncertainties moves on to the establishment of probability schemes, and culminates with the application of machine learning to process optimization. This dynamic also seems to follow the logical learning scheme, which often begins with understanding what is unknown and configuring efforts to reduce uncertainties; at this point, the main forces and variables that outline the reality one wants to understand are identified. The learning continues with calculating or defining probabilities and establishing cause-effect relationships to test the knowledge obtained in the previous stage. This second stage could be called the simulation stage. After the simulations, the third stage begins, representing the materialization or application of the solution found in the mathematical and computational simulations in real situations.

4.2 Methods used

The results related to the methods used in the studies on intelligence and movement presented a multiplicity of methodological procedures, almost all originating from AI applications, here organized in the form of methodological groupings. The first group is characterized by process analysis, simulation, and modeling methods. Process analysis and simulation methods are applied to analyze and predict the behavior of systems. This group focused its efforts on optimizing process steps, using techniques for applying genetic algorithms for optimization, as done by Aksysonov et al. (2024), and studies such as those by Chih-Hsing and Dawiromate (2024) and Taheri and Falahati (2023), which used simulation and optimization metrics as the primary research direction, using transportation strategies, clustering, and behavior analysis. The second group focuses on extracting information and analyzing processes to identify weaknesses and trends. These methods began with a detailed process analysis, dividing it into subsystems to extract necessary information. This step is required to identify points that need to be improved. Muelbauer et al. (2024) focused on identifying weaknesses using machine learning, while Navarro et al. (2024) analyzed trends and variables, identifying positive or negative relationships.

Table 2. Methods used by the studies

References	Methods used in the studies
Aksysonov et al. (2024)	Modeling of resource conversion processes (RTP); hybrid method for analysis and elimination of bottlenecks; genetic algorithm (GA) for process optimization; Student's t-test to validate the adequacy of the simulation model developed
Chih-Hsing; Dawiromate (2024)	Statistical analysis; simulation and modeling; transportation strategy; clustering and behavior analysis; validation and adjustments; technical considerations and limitations.
Taheri; Falahati T. (2023)	Performance analysis; mathematical modeling; optimization and simulation; practical evaluation.
Muelbauer et al. (2024)	Analysis of the process and subsystems; extraction of information and process KPIs; identification of weaknesses, identification based on machine learning, and description of recommendations for action.
Navarro et al. (2024)	Sample; empirical analysis; differentiation of variables; positive relationship and trend analysis
Anant et al. (2024)	Technological method; Algorithms
Smetana et al. (2024)	Embedding Model; K-means Clustering Algorithm; t-SNE reduction; GPT-3.5.

Huang; Romano (2024)	Survey
Slambhavi; Rajendrs (2024)	Conflict-based search (CBS); Shared experience action critique (SEAC); Comparison and evaluation; Average flow time; Average makespan time.
Rahardjo et al. (2023)	SIF-RIDEM (Requisitos; Iniciação; Design; Execução e Monitoramento).

Source: Data collected by the authors.

The third group is distinguished by using machine learning models and algorithm-based technologies to solve specific problems. These processes involve continuous updating, interaction, and efficient execution of tasks. Anant et al. (2024) focused on robot navigation and interaction tasks, while Smetana et al. (2024) focused on data analysis tasks such as data clustering and dimensionality reduction. The fourth group includes methods for validating behaviors and emotions and analyzing them. Huang and Romano (2024) measured valence and performed a thematic analysis of interviews, while Slambhavi and Rajendrs (2024) used metrics such as mean flow time and mean makespan in addition to the shared experience action criterion (SEAC). Both studies used data collection, evaluations, surveys, and experiments to validate hypotheses or improve systems. The fifth and final group deals with project execution using the SIF-RIDEM method, which ensures that all critical aspects of a project are considered and well-managed. Rahardjo et al. (2023) applied a comprehensive and robust methodology to ensure that all essential phases of the projects achieve their goals.

4.3 Problematic situation of the studies

The problems identified in the studies were classified into four main groups. The first group is called automation and logistics processes because it raises central issues related to efficiency and using technologies and data to optimize logistics and operational processes. In this group, we find the studies by Aksysonov et al. (2024), which address logistics bottlenecks; Anant et al. (2024), which discuss the need to automate material handling; Muelbauer et al. (2024), which points out the lack of use of data by organizations, and Taheri and Falahati (2023), which addresses the problem of vehicle routing with time windows. The second group addresses the challenges of sustainability and Industry 5.0, as is the case of the study by Rahardjo et al. (2023), which discusses the effectiveness of implementing new technologies and methodologies, while Navarro et al. (2024) focuses on the challenges faced by SMEs in adopting sustainable practices, showing the difficulties of adaptation and implementation.

Table 3. Problems researched by the studies

References	Researched problems
Aksysonov et al. (2024)	Need to eliminate bottlenecks in internal logistics processes.
Anant et al. (2024)	Need to optimize and automate the movement of materials within an industrial environment.
Muelbauer el al. (2024)	Rare organizations that use data generated by logistics systems in daily operations to analyze processes, identify problems, and improve processes.
Taheri; Falahati (2023)	Vehicle routing problem with time windows (VRPTW) and perishable goods domain
Rahardjo et al. (2023)	Need to face the challenges and seize the opportunities brought by Industry 5.0
Navarro et al. (2024)	Difficulties of SMEs in implementing sustainable practices
Smetana et al. (2024)	Discover the types and causes of accidents in the road construction industry, such as run over and falls.
Slambhavi; Rajendrs (2024)	Collection and delivery of materials by agents without collisions
Chih-Hsing; Dawiromate (2024)	Accommodation of individual differences during manual tasks
Huang; Romano (2024)	We need to understand the relationship between user perceptions and movements of shape-shifting soft robots.

Source: Data collected by the authors.

The third group, which aims to characterize industrial accidents and ensure safety, focuses on accident prevention and safety in industrial environments. Smetana et al. (2024) investigate risk identification and accident prevention in highway construction, while Slambhavi and Rajendrs (2024) focus on safety while collecting and delivering materials and avoiding collisions. Both studies seek to minimize risks and improve operational safety using AI, even in different contexts. Finally, the fourth group, focused on the implementation objectives of robotics and the impact on human interaction, brings the context of interaction between humans and robotic systems, exploring how these technologies can be adjusted to meet human needs better. Chih-Hsing and Dawiromate (2024) examine the difficulty of accommodating individual differences in manual tasks. Meanwhile, Huang and Romano (2024) investigate how robot movements affect user perceptions; both studies highlight the importance of adapting technologies to improve user interaction and experience.

4.4 AI applications in studies

The applications of artificial intelligence in the analyzed studies were organized into four groups. The first group covers AI applied to process optimization and automation. In this group, Aksysonov et al. (2024) used AI for automated modeling to produce metallurgical products, solve bottlenecks, and optimize limited resources. Anant et al. (2024) focused on material handling automation using automated guided vehicles (AGVs) to maximize flow in industrial environments. Taheri and Falahati (2023) applied AI to develop a multi-objective mixed integer programming model that optimizes complex logistics processes in multi-cross-docking systems, addressing vehicle routing problems. These applications aim to improve efficiency in industrial or logistics systems through resource management and allocation. The second group focuses on AI applied to data modeling and analysis. Muelbauer et al. (2024) used machine learning models like Random Forest, Gradient Boost, and Multilayer Perceptron to optimize logistics processes and identify patterns. Navarro et al. (2024) applied AI to statistical analysis and modeling in Industry 4.0, enabling more assertive decisions and the creation of intelligent processes. Smetana et al. (2024) used OpenAI's GPT-3.5 language model to analyze accident data in highway construction, identifying root causes and implementing protective measures. These applications show how AI can transform raw data into valuable process optimization and risk mitigation insights.

Table 4. AI applications in studies

References	Application of AI in studies
Aksysonov et al. (2024)	A method based on automated system modeling
Anant et al. (2024)	Automation of material handling with automated guided vehicles (AGVs)

Taheri; Falahati (2023)	The multi-objective mixed integer programming model in the multi-cross-docking system
Muelbauer el al. (2024)	Machine learning (ML) models; Random Forest Classifier (RFC); Gradient Boost Classifier (GBC); Multilayer Perceptron (MLP)
Navarro et al. (2024)	Statistical Analysis and Modeling; Industry 4.0 Technologies; Automation and Intelligent Processes
Smetana et al. (2024)	GPT-3.5 from OpenAI
Chih-Hsing; Dawiromate (2024)	Extended reality (XR), Virtual reality (VR), Augmented reality (AR), and Mixed reality (MR).
Huang; Romano (2024)	Coral Morph
Slambhavi; Rajendrs (2024)	Conflict-based search (CBS); Shared experience action critique (SEAC).
Rahardjo et al. (2023)	Lean 5.0; RIDEM (Requirements, Initiation, Design, Execution, and Monitoring); LSS 5.0

Source: Data collected by the authors.

The third group explores AI in human-machine interaction, especially in extended reality. Chih-Hsing and Dawiromate (2024) use AI to facilitate user interaction with extended reality (XR) and virtual reality (VR) technologies, integrating sensory modalities to create more responsive experiences. Huang and Romano (2024) apply AI in the Coral Morph installation to create robotic interactions and sensory experiences that influence user perceptions and reactions. These studies highlight the use of AI to make interactions with technology more intuitive, immersive, and tailored to human needs. The fourth and final group focuses on AI for conflict monitoring and resolution. Slambhavi and Rajendrs (2024) applied AI in conflict-based search (CBS) and shared experience action (SEAC) to avoid collisions in material collection and delivery processes. Rahardjo et al. (2023) used AI in methodologies such as Lean 5.0, RIDEM, and LSS 5.0 to monitor and improve industrial processes, facilitating the integration of new technologies and promoting continuous improvements. These applications focus on identifying and resolving conflicts, ensuring operational efficiency in logistics and industrial environments.

4.5 Study results

The results of the studies were separated into four groups. This group addresses the application of AI to optimize industrial and logistics processes, solve complex problems, and automate critical tasks. For example, Aksysonov et al. (2024) used AI to optimize casting machine operations, resulting in natural gas savings and pollutant reduction; Taheri and Falahati (2023) developed an optimization model for logistics processes, achieving practical solutions for complex processes; and Anant et al. (2024) focused on the automation of material handling with automated guided vehicles (AGVs), improving operational efficiency in industrial environments.

Table 5. Study results

References	**Results of the studies**
Aksysonov et al. (2024)	1) The maximum downtime of the continuous casting machines in the workshop cannot exceed 12 seconds, a technological value considered acceptable; 2) the continuous operation of the continuous casting machines eliminates the additional use of natural gas for heating ladles and reduces the amount of harmful emissions into the atmosphere.
Taheri; Falahati (2023)	1) The proposal is effective in solving the optimization problem; 2) the solutions presented an acceptable gap percentage and reasonable solution times
Anant et al. (2024)	A prototype of the AGV was designed and successfully used to test several cases of automation of material handling within the industry.
Muelbauer et al. (2024)	1) The ML classification model was able to classify five different classes in unseen data with an average accuracy of 60%; 2) the approach took advantage of low-level data and offered insights into the analyzed process to a more informative level, which provided a deeper understanding of the problems studied.
Smetana et al. (2024)	There was a significant expansion of the scope of identification of the main categories of accidents and their causes.
Rahardjo et al. (2023)	1) There was a significant reduction of more than 80% in the number of defects and DPPM; 2) The project resulted in direct savings of NT$104,000 and a total implementation cost of NT$89,000; 3) It highlights tangible benefits of adopting LSS 5.0 methodologies.
Chih-Hsing; Dawiromate (2024)	The procedure improved system performance, particularly with the K-Mode clustering-based decision support tool.
Huang; Romano (2024)	Coral Morph evoked positive emotions and was perceived as lively, friendly, engaging, safe, and emotionally and socially intelligent.
Slambhavi; Rajendrs (2024)	1) Continuous conflict-based search is the best solution for the multi-agent pickup and delivery problem with fewer agents and when environments are not too dense; 2) The shared experience action critique should be used when the number of agents is more significant.

Navarro et al. (2024)	1) It discusses the effect of company size on SA and clarifies the existing discrepancy; 2) It differentiates the type of partner in the supply chain and introduces the behavior of SMEs in their relationships with customers and suppliers, distinguishing between investment and expenditure when developing SA.

Source: Data collected by the authors.

The second group achieved significant results in data extraction and analysis using AI. Muelbauer et al. (2024) applied machine learning models to extract valuable insights, helping to understand and improve processes. Smetana et al. (2024) analyzed large volumes of data to identify categories of accidents and their causes. Rahardjo et al. (2023) applied the LSS 5.0 methodology to reduce defects and maximize savings, demonstrating the positive impact of data analysis on process optimization. This group focused on creating more emotional and efficient experiences using AI. Chih-Hsing and Dawiromate (2024) explored how AI can adjust systems to meet user needs, providing more aligned and efficient interactions. Huang and Romano (2024) used AI to create real-time interactions that meet functional and emotional needs, resulting in personalized and practical experiences. The last group focused on applying artificial intelligence to manage conflicts in environments with multiple agents and variables. Slambhavi and Rajendrs (2024) obtained results by dynamically adjusting the number of agents and the density of the environment in real-time, preventing them from colliding. Navarro et al. (2024) showed how AI can differentiate types of partnerships in the supply chain, understand the behavior of SMEs in terms of investments and expenses, and optimize the management of conflicts and entities in the supply chain.

4.6 Conclusions of the studies

To conclude this research stage, we separated the conclusions from the studies analyzed into four groups. The first of them concluded that in the automation and optimization of projects, they focused on improving the efficiency of their processes, even with identical results, and each study focused on its problems. Aksysonov et al. (2024) created a model to optimize logistics processes evaluated with statistical tests that showed efficiency when AIs were applied.

Taheri and Falahati (2023) worked on supply chain optimization through cross-docks, reducing inventory retention, and improving customer satisfaction, and also had good results in lowering shipping and distribution times. Anant et al. (2024) explored automation with automated guided vehicles (AGVs), increasing efficiency in material handling in industrial environments and speeding up the process. Muelbauer et al. (2024) focused on automation to identify problems and improve operational efficiency by reducing human intervention and allowing the rapid identification of areas that needed improvement. The second group brings together studies that highlight sustainability. Navarro et al. (2024) showed that technological collaboration with suppliers and customers positively influences the sustainable behavior of SMEs, especially in long-term partnerships. Rahardjo et al. (2023) showed that implementing the Lean Six Sigma (LSS) method in the context of Industry 5.0 led to significant effectiveness in creating human-centered, resilient, and sustainable environments, reducing waste, and improving processes. Both studies use technology to promote sustainability.

Table 6. Conclusions of the studies

References	Conclusions of the studies
Aksysonov et al. (2024)	The developed model was found to be suitable for logistics processes.
Taheri; Falahati (2023)	Cross-docks optimize customer satisfaction by strengthening supply reliability and reducing distribution and shipping times.
Anant et al. (2024)	AGVs can handle the movement of materials for rapid processing, covering large areas within the industry.
Muelbauer el al. (2024)	Continuous application is a method for automating problem identification. Thus, the approach's high degree of automation is a significant advantage.
Navarro et al. (2024)	SMEs establishing technological agreements with suppliers tend to invest more in sustainable practices, reflecting a long-term strategic approach. In contrast, companies tend to spend on sustainable practices to meet immediate consumer demands when the technology collaboration is with customers.
Rahardjo et al. (2023)	The successful implementation of LSS in Industry 5.0 is a testament to its adaptability and relevance. Furthermore, the study highlights the practicality and effectiveness of SIF within a human-centric, resilient, and sustainable environment.
Smetana et al. (2024)	The optimized approach to data clustering has generated datasets that indicate the leading causes of accidents.
Slambhavi; Rajendrs (2024)	Methods such as restricted learning sharing help agents work in heterogeneous scenarios
Chih-Hsing; Dawiromate (2024)	Mixed reality-based simulation can improve human adaptability to changing conditions and reduce uncertainty.
Huang; Romano (2024)	Coral Morph was reported to be an enjoyable experience that entertained

	users and, over time, induced a positive and calm state.

Source: Data collected by the authors.

The third group of studies focuses on data analysis to identify patterns and optimize processes. Smetana et al. (2024) used an optimized approach to data clustering, which helped determine the leading causes of accidents, improving employee safety. Slambhavi and Rajendrs (2024) explored restricted shared learning methods, which allow agents in heterogeneous environments to make real-time decisions more efficiently based on controlled shared knowledge. The last group focuses on studies aimed at human impact, providing entertainment, and improving people's sensory and emotional experiences. Chih-Hsing and Dawiromate (2024) concluded that mixed reality-based simulation could improve users' adaptation to changing conditions, reducing uncertainty and increasing trust. Huang and Romano (2024) presented the application "Coral Morph," which was reported to be an enjoyable experience, capable of inducing a positive and calm emotional state, improving users' well-being and mood. Both studies use artificial intelligence to influence human emotional states positively.

4.1 Discussion of Results

The findings of this study regarding the research questions addressed by the studies analyzed presented a wide variety of focuses. This means, among other things, that artificial intelligence has been called upon to contribute to the movement of materials in various aspects and sectors of activity, from the monitoring of external transport (Li, 2024; Moskvichenko; Stadnik; Kushnir, 2024), to the development of internal transport vehicles (Quy et al., 2024; Sharma; Bhardwaj; Chantola, 2025) and even in the psychosocial dimension of warehouse operators, with their emotions and all the substantive load (Mathur; Chandel, 2025). The methods used show how challenging the objectives intended by the investigations have been because, generally, they involve applying various techniques and procedures to obtain the targeted solutions and the expected technologies to facilitate the movement of materials.

The problematic situations the studies sought to explain can be quite complex because they involve several theoretical and practical fields, such as logistical, technological, and environmental challenges. They involve the need to automate some aspect of internal or external movement, seeking to optimize movements without worsening other elements, such as costs and the environment (Dhand; Singh; Le, 2025; Wang; Jiao, 2025). The application of artificial intelligence technologies to overcome problematic situations represents a high degree of success in this regard, which also means the explicit demonstration that technologies can be essential allies in overcoming logistical issues and problems without generating serious harmful externalities.

The results demonstrate the effectiveness of using artificial intelligence as a logistical tool and point to expanding its field of application. Technology dramatically increases productivity and safety in material handling and essentially shows that it is possible to make the work environment and warehouse operations much more intelligent and humanized (Malhotra; Kharub, 2025; Koley et al., 2025). The conclusions, in general, show that artificial intelligence represents a trend toward multiplying human capacity to identify and deal with complex issues by generating solutions that are not harmful to people and the environment, especially when dealing with tasks more likely to result in decision-making errors. In addition, artificial intelligence communicates with other technologies, such as automation, taking the burden of tedious and dangerous work off human bodies and placing it under the responsibility of intelligent machines.

5. Conclusion and Recommendations

This study identified the main characteristics of studies that show the application of artificial intelligence in material handling. The main characteristics indicate that the application focuses on three main areas: improvement and optimization of the logistics process, increased rationality of human-machine actions, and optimization of the decision-making process. Artificial intelligence has become an essential tool for choosing the most efficient and highly successful methods in different application fields in warehouse material handling, where essentially human practices generally fail. Furthermore, because it communicates efficiently with technological artifacts, such as robots and intelligent machines, it has promoted increasingly integrated interactions between operator actions and machines, gradually reducing errors and logistics failures. Since machines are more capable than the human mind in speed and handling large amounts of data, artificial intelligence has dramatically helped choose the most promising decision-making alternatives.

These results indicate at least two essential developments. The first relates to the breadth and depth of artificial intelligence applications in the movement of materials, precisely, and in logistics. While this tool increases the chances of success in human endeavors, it also forces human capacity to improve by learning new patterns and procedures for cognitive and interpreting reality. The second is the need for logistics professionals to learn and master artificial intelligence from the beginning of their technical and scientific training. This means that it is almost impossible for this technology not to be a mandatory application at some point in their current or future professional practice.

To expand and deepen the findings of this study, at least three new investigations are recommended. The first is related to the main aspects of artificial intelligence that logistics professionals need to know how to apply. This investigation aims to develop a professional training plan that can be implemented throughout logistics training to master the technology. The second is about the challenges organizations have faced in implementing artificial intelligence in moving materials. This research would aim to develop a system for implementing the technology more efficiently and with more effective results. The third involves mapping the benefits organizations have obtained from implementing artificial intelligence in internal logistics services so that there is a more accurate understanding of the cost-benefit ratio of the technology.

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