Revista Multidisciplinar do Nordeste Mineiro, v.02, 2025
ISSN 2178-6925

ANALYSIS OF APPLICATIONS OF ARTIFICIAL INTELLIGENCE IN MATERIAL STORAGE: A BIBLIOGRAPHICAL STUDY

ANÁLISE DE APLICAÇÕES DA INTELIGÊNCIA ARTIFICIAL NA ARMAZENAGEM DE MATERIAIS: UM ESTUDO BIBLIOGRÁFICO

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Abstract

This study aimed to analyze ten publications that portray the application of artificial intelligence in material storage. The conceptual bibliographic method was used in its four stages: a) formulation of primary and accessory research questions, b) data collection in scientific databases, c) analysis and organization of the collected data, and d) generation and interpretation of the answers to the formulated research questions. The results showed that the goals of the studies focused on problematic situations that can be considered complex, the methods of the studies consisted of numerous techniques and procedures, the artificial intelligence tools applied in the studies were varied and in large quantity, and the results and conclusions of the studies show that artificial intelligence is a technology that can effectively solve problems and help to overcome storage challenges. The conclusion points out that the more complex the problem or challenge to be faced, the greater the effectiveness of artificial intelligence in solving or helping to overcome it. The study's main contribution to science highlights the need for logistics and storage professionals to know and know how to apply artificial intelligence in logistics practice.

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

Resumo

Este estudo teve como objetivo analisar dez publicações que retratam a aplicação da inteligência artificial na armazenagem de materiais. Foi utilizado o método bibliográfico conceitual em suas quatro etapas: a) formulação de questões principal e acessórias de pesquisa, b) coleta de dados em bases científicas, c) análise e organização dos dados coletados e d) geração e interpretação das respostas às questões de pesquisa formuladas. Os resultados mostraram que os objetivos dos estudos focaram situações problemáticas que podem ser consideradas complexas, os métodos dos estudos foram constituídos de inúmeras técnicas e procedimentos, as ferramentas de inteligência artificial aplicadas nos estudos foram variadas e em grande quantidade e os resultados e conclusões dos estudos mostram que a inteligência artificial é tecnologia que efetivamente consegue resolver problemas e ajuda a superar desafios de armazenagem. A conclusão pontua que quanto mais complexo for o problema ou desafio a ser enfrentado, maior a efetividade da inteligência artificial para resolvê-lo ou ajudar a superá-lo. A principal contribuição do estudo para a ciência é pontuar a necessidade de profissionais de logística e armazenagem conhecerem e saberem aplicar inteligência artificial na prática logística.
Palavras-chave: Inteligência artificial. Armazenagem de materiais. Tecnologias inteligentes. Logística interna. Logística de materiais.

1. Introduction

Logistics is an organizational effort to meet human needs (Tohir; Primadi; Indah, 2024; Majid; Rahman; Nur, 2024; Reikin, 2024). This concept is so deeply rooted in science and practice that logistics is often confused with the materials, goods, tools, and all the means an organization uses to meet its customers' needs. Another way to understand it is as the acquisition, storage, and distribution of materials, which marks the logistics of supply (acquisition), warehousing (internal logistics), and distribution logistics (deliveries to customers). Since logistics ultimately determines the degree of competitiveness between organizations, their activities and functions have increasingly incorporated cutting-edge knowledge and technologies in search of speed, agility, and efficiency.

Storage is one of the pillars of logistics. It allows production systems to operate without interruptions, supplying them with their master production plans, just as the synchronization between product demands and replenishment times will enable retailers to deliver the products their customers desire. Furthermore, the availability of materials at the appropriate time, quantity, quality, and location allows services of all types to be performed appropriately. When storage functions properly, logistics systems effectively contribute to increasing organizational competitiveness because they generate customer satisfaction. Competitiveness and customer satisfaction are two factors that have led organizations to increasingly incorporate technological resources into their storage efforts, with special attention to artificial intelligence.

In this sense, this study aimed to analyze scientific publications that report the application of artificial intelligence in material storage. The intention was to find out what goals and problem situations these studies focused on, what methods and technologies were used, and what results and conclusions they reached. For this purpose, the conceptual bibliographic method developed by Nascimento-e-Silva (2020; 2021a; 2021b; 2021c; 2023) was used, which consists of formulating the leading and guiding research questions, followed by data collection on scientific bases, analysis, and organization of the data collected for the generation and interpretation of the responses obtained.

2. Artificial Intelligence and Material Storage

One conception of artificial intelligence sees it as a computer program (Ametbekovna; Ugli, 2025; Fadila, 2024). The logic of this conception is related to the actions that computers, which are the physical and material part of a system, are driven and led to do things, such as collecting and analyzing data, as well as making decisions, through the guidelines emanating from an immaterial and invisible artifact, which are the programs. When these programs learn by themselves, imitating human intelligence, they make computers behave similarly to humans, naturally keeping the due proportions. Developing these programs so that the physical part of computers in all their formats simulate human actions, as is the case with robots and automatic machines, is called programming, as seen from the study by Dei (2025). Programming uses algorithms and instructions for computers to perform specific tasks, including vision, language, knowledge, and research, similar to humans.

Another common conception in the literature sees artificial intelligence as a machine (Aydin; Ince, 2024). Machines have increasingly resembled human beings, not only in their formal aspect, as with humanoid robots, but fundamentally in what people do, with special attention to their abilities to understand, perceive, learn, and act according to specific previously defined standards. In human actions, for example, the standards can be of various types, such as moral references, which establish what is and what is not considered morally acceptable; in artificial intelligence actions, the standards are the most diverse, depending on the goals to be achieved and the programming resources available.

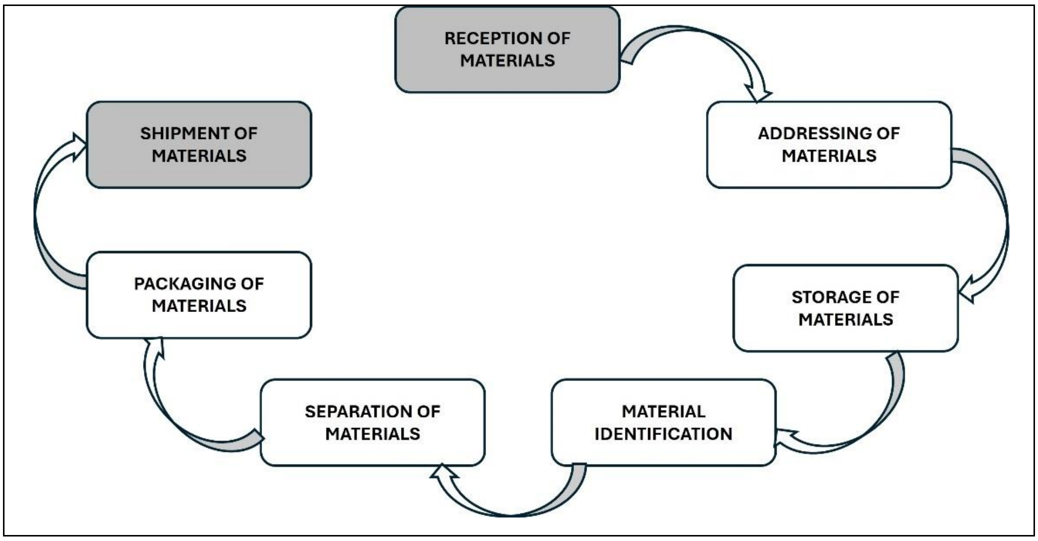
Studies by Chole, Gadicha, and Thawakar (2024) and Choudhary (2024) show that artificial intelligence is a process. A process can be understood as a logical sequence of activities with a beginning, middle, and end, and at the end of the execution of the last of the programmed activities, a particular product or service must materialize (Albuquerque et al., 2018; Brito et al., 2016; Almeida et al., 2022; Nascimento-e-Silva, 2020). Artificial intelligence can have several stages, such as thinking, reasoning, and acting judiciously by the programming that guides them. However, the ultimate goal of the sequence of programming activities and programs is to function similarly to human intelligence. The goal of making artificial intelligence resemble human faculties as much as possible is present in the literature under three terms of equivalence. The first is emulation (Dang et al., 2025), in which proximity to human cognitive processes is sought by applying algorithmic models to make computational structures based on heuristic systems work. The second is the simulation (El-Tallawy et al., 2024) of human intelligence so that machines of all types of applications, especially computers, think as if they were a human individual. The third is the pure and straightforward imitation of human intelligence (Savaş; Binici, 2024), both by a system and machine. In a way, scientists intend to go a little beyond the human capacity to be intelligent, mainly because they are limited in speed and the number of variables to which they can apply their intelligence. Every day, machines increase their processing speeds and capacity to deal with increasingly complex phenomena with an ever-increasing number of variables.

This is where another conception or approach to artificial intelligence that can currently be measured in the scientific literature comes from: as a part of science. Here, two aspects predominate. The first is related to artificial intelligence as a discipline (Ghasemi; Khosravi, 2024), a specialized area of human activities. From this aspect, artificial intelligence is handled based on contributions from mathematics, statistics, and computer science, as if it were the materialized product of the contributions of these three areas of human knowledge generated from methods that imitate human intelligence. The second aspect is that as a branch of computer science (Luger, 2025), which combines knowledge from this area with other areas, such as biology and neurology, machines and other material artifacts have intelligent behavior similar to humans. The prevailing conception in science takes artificial intelligence as a capacity (Nwadinobi et al., 2024; Kaplan, 2024; Singh, 2024; Wajiya; Saleh, 2024). Being capable is having the ability to do things and act. Artificial intelligence increasingly seeks the ability to do what humans do, imitating, emulating, and simulating. This continuous search is done through cognitive capabilities that allow systems, machines, and computers to collect and analyze data and information, generate results from the data and information collected, and interpret these results so that they can solve problems, increase and refine their learning capabilities, just as more intelligent and capable human beings would do. All these learning efforts are directed towards solving problems or meeting some needs based on cognition that individuals and their organizations need to solve or meet. Among this varied range of needs are those related to storage activities.

Storage is considered one of the fundamental activities of the logistics process, along with the acquisition, inventory, transportation, storage, packaging, security, and handling of goods and services in the form of raw materials, finished products, and materials (Barata; Febrianto; Yasin, 2022; Sofhia; Manawan, 2023). From a longitudinal point of view, storage is part of the so-called internal logistics, which occurs within the organization that processes (industry), resells (commerce), and provides services (services). Internal logistics integrates and gives meaning to external logistics, called supply logistics (which connects the organization to its suppliers) and distribution logistics (which connects the organization to its customers). Supply logistics supplies the organization with raw materials, while distribution logistics supplies the organization with what it produces or resells to its customers. The sum of these three logistics is known as the supply chain (Nozari et al., 2025; Shahriari, 2025).

Figure 1 represents the storage of materials as a subprocess (Kumar; Kumar; Chaudhary, 2023) or subsystem (Bucko; Schindlerova; Sajdlerova, 2023), which is the sequence of steps that must be followed so that this internal logistics activity can achieve its goals. This logistics is generally practiced in a specific physical space where the products are handled (Goggins, 2022), whose management requires the execution of functions of locating materials, dimensioning areas, physical arrangement, dock projects, berthing, and several others (Santos et al., 2022; Costa, 2023), in addition to essentially logistical activities. In general, these activities can be summarized in three: receiving materials and raw materials, storing and meeting needs (of customers internal and external to the organization). Artificial intelligence has been increasingly used to make the execution of each of the three logistics components of the supply chain more agile and accurate, as shown in the studies by Gao, Keoy, and Lim (2025), Wang et al. (2025), Weisz et al. (2025) and Veloso and Nascimento-e-Silva (2025).

Figure 1. Material storage gears



Source: drawn from Tedgue et al. (2023).

The storage activities shown in Figure 1 have also been contemplated with the application of numerous programs and solutions based on artificial intelligence for the execution of each of them and for interconnecting them. These technologies can be applied explicitly to the storage of different materials, as in the studies by He et al. (2024) and Kuppusamy et al. (2024), as well as in specific stocks, as pointed out in the studies by Sarhir, Benmamoun and Mamoun (2024) and Abdollahi et al. (2024). This research focuses on this last aspect, as it seeks to take stock of the main characteristics of studies that show the applications of artificial intelligence in storage activities, both of different materials and raw material stocks.

3. Research Methodology

This section will detail the procedures of the study that sought to analyze ten scientific publications that report the application of artificial intelligence in storing materials, seeking to identify their main characteristics. It is a qualitative study that used the conceptual bibliographic method developed by Nascimento-e-Silva (2020; 2021a; 2021b; 2021c; 2023), having as a unit of analysis ten studies published and available in the Google Scholar database, group analysis level, since the results presented only apply to this group of studies analyzed, and synchronic analysis perspective, given that the findings portray a static reality, unlike longitudinal studies, which are concerned with explaining changes over time in the behavior of the phenomena studied.

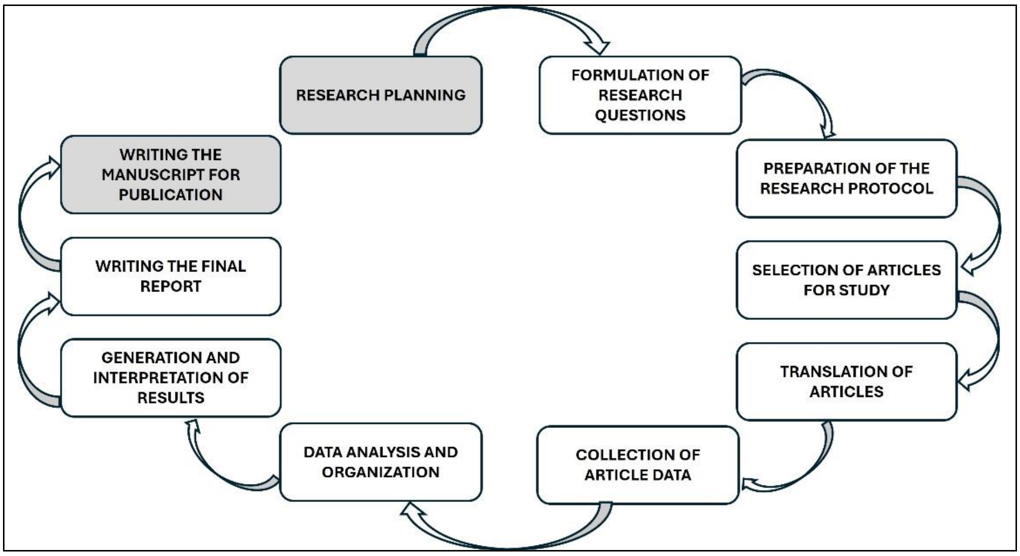
3.1 Guiding questions

The main research question of this study was "What are the main characteristics of scientific publications that portray the application of artificial intelligence in material handling?". This question was operationalized by formulating six guiding questions focused explicitly on each essential characteristic of scientific studies, namely: a) what were the goals of the studies? b) What problematic situations were studied? c) what were the methods used? d) What applications of artificial intelligence were used in the studies? e) what were the results achieved? and f) What were the conclusions of the studies? It was possible to answer the main research question through the answers to the guiding questions.

3.2 Study design

The results of this research were achieved through the execution of ten steps. The first consisted of research planning, where the type of research, methods to be used, unit, and level of analysis were defined—the second step involved formulating the study goals and their consequent transformations into research questions. In the third stage, the research protocol was developed, specifying the types of studies that would be collected and the exclusion criteria and guidelines for data analysis and organization. In the fourth stage, the articles were selected from the previously defined database using the protocol developed in the previous stage. The fifth stage consisted of translating the articles since they were published in English, as described in the research protocol.

Figure 2. Study design



Fonte: elaborado pelos autores.

In the sixth stage, data were collected using a data collection instrument suggested by Nascimento-e-Silva (2023), which included identifying the articles in the left column and the characteristics sought in the remaining columns. In the seventh stage, the data were analyzed by characteristics and organized in a table format, as shown in the results section. In the eighth stage, the results were generated using semantic analysis and interpreted by comparing them with the literature. In the ninth stage, the general research report was written, and in the tenth stage, the report was written in the format of a scientific article for submission for publication (Nascimento-e-Silva, 2021d).

3.3 Population and sample

The population of this study was formed by all scientific studies published in the Google Scholar database that described the application of artificial intelligence in material storage. According to the research protocol, the population did not include undergraduate, master's, and doctoral degree papers, nor technical and institutional documents, such as management reports. It was decided to prioritize only articles published in scientific journals and conference proceedings because all of them would have to be evaluated by the scientific community for publication. In addition, only studies that presented the application of artificial intelligence to solve problems or overcome specific storage challenges should be included in the sample, even if they focused on other organizational aspects. The first ten articles that met these requirements were selected.

3.4 Data collection instrument

The data were collected over one week from the Google Scholar database. A table with seven columns and 11 rows was used. The first column on the left contained the bibliographic references of the studies, and in the other columns, in sequence, the objectives of the studies, problematic situations, methods used, applications of artificial goals used in the articles, results of the studies, and conclusions presented by the studies. Each study represented a row of the table. The first line recorded the types of data presented in each column. This procedure was recommended by the studies by Nascimento-e-Silva (2020; 2021a; 2021b; 2023).

3.5 Data collection strategy

Data collection consisted of using the phrases in the Portuguese language, “inteligência artificial” and “armazenagem de material,” translated into English as “artificial intelligence” and “material storage.” After translation, the phrases were pasted into the Google Scholar search space so that the platform could display the results. Since science prioritizes studies published last year, 2024 was selected for the search for articles, which is why all the studies consulted were published that year. The data collection procedure consisted of adopting the first ten studies that met all the requirements: a) being a scientific article published in a scientific journal or annals of international events, b) being written in English, c) presenting the application of artificial intelligence in material storage and d) presenting all previously defined characteristics (goals, problematic situation, methods, applications of artificial intelligence, results, and conclusions). The protocol provided for the collection of data from studies from previous years if the minimum quantity of 10 articles was not reached.

3.6 Data organization and analysis techniques

After the data collection, the data collection instrument was divided into six spreadsheets. Each spreadsheet contained the bibliographic source and the data for each guiding question. For example, in the goals spreadsheet, the bibliographic sources were in the left column, and the goals of each study were in the right. This analysis and division procedure gave an in-depth understanding of the data set's logic. This facilitated the data organization process. The data were organized in a table format, leaving only the “author (year)” format and the desired summary, except the data related to the goals and problematic situation, which were left full. For example, the organization of the method data made it easier to identify each of them, including facilitating their quantification to clarify the various studies presented. These procedures facilitated the generation and interpretation of the results.

3.7 Techniques for generating and interpreting results

The results were generated with the help of semantic analysis. Semantic analysis consisted of identifying similarities and differences between the data. For example, when two or more studies had “simulation” as their goal, the word “simulation” signaled similarity, unlike those that proposed “modeling” or “creation” of intelligent artifacts. The results were interpreted by comparing the results generated with the scientific literature. For example, the literature shows that simulation, modeling, and creation of artifacts are typical procedures for applying artificial intelligence. When this happened, it was found that what was being portrayed was indeed artificial intelligence in material storage. Similar methods were performed to generate answers to all guiding questions and, by extension, to the main research question of this study.

4. Results and Discussion

This section presents the results obtained for each guiding question in the following order: first, the goals of the studies analyzed will be shown, followed by the problematic situations they focused on. Next, the findings will be presented regarding the methods and artificial intelligence technologies applied in the investigations. Next, the results and conclusions of the studies will be offered. The section ends with a brief discussion of the results.

4.1 Goals of the studies

The analyzed studies aimed to deal with storage problems and challenges with interfaces with other organizational aspects, as shown in the data in Table 1. Some seek solutions to specific storage problems, such as risk assessment (Kamil et al., 2024; Ayyildiz et al., 2024), search for efficiency (He et al., 2024; Ekren; Arslan, 2022; Di, 2024), interfaces between machines (Franco et al. (2024) and solutions to specific problems, such as energy planning in the warehouse (Servare Junior et al. (2024), auto parts production (Beinabadi et al. (2024) and detection of defects in parts (Çelik et al. (2024).

Table 1. Goals of the studies

References	Goals of the studies
Kamil et al. (2024)	To assess the role of chemical storage equipment and protective systems in enhancing safety and sustainability in warehousing practices and functions
Ayyildiz et al. (2024)	To propose a Fuzzy Bayesian Networks model for risk assessment in a warehouse
Wang et al. (2024)	To provide an overview of recent advances in cold thermal energy storage (CTES) in refrigeration cooling systems
He et al. (2024)	To provide an efficient method for real-world two-stage hybrid flow shop scheduling problems with small batches in automotive glass manufacturing system
Franco et al. (2024)	To present an innovative model of cooperation and communication between a collective of Marxbot robots
Ekren; Arslan (2024)	To enhance the performance of SBS/RS by applying a machine learning (ML) (Q-learning) approach in layer-to-layer SBS/RS design
Servare Junior et al. (2024)	To propose a new large-scale mixed integer nonlinear programming (MINLP) model for stockyard-port energy planning
Di (2024)	To improve the efficiency of warehouse operation
Beinabadi at al. (2024)	To present an integrated data-driven approach tailored to address challenges in auto parts production. Detect defects in plastic parts produced in a company operating in the automotive sub-industry using the YOLOv8 object detection model.
Çelik et al. (2024)	Objectives of the studies

Source: Data collected by the authors.

These results indicate that using artificial intelligence in warehousing activities is not aimed at solving specific problems in each of them. For example, no studies were found exclusively on warehouse addressing or identifying stored materials. The applications presented in the literature are more complex, involving more than one of the central warehousing activities and at least one other that is not exclusive to internal logistics. For example, when Servare Junior et al. (2024)

proposes to create a new model for energy planning, the focus is on the storage yard, which involves some storage activities, but also must deal with aspects of other areas, such as the supply of energy itself and optimization of this resource.

4.2 Methods used in the studies

The methods used in the studies are almost all typical of artificial intelligence. This means that methodologies for analyzing specific warehousing issues hardly appear among the studies' methods. The exceptions are the study by Kamil et al. (2024), which applies the documentary method or document analysis, and that of Wang et al. (2024), which conducts a literature review using the bibliographic method. The most common methods found in the literature are simulations (Franco et al., 2024; Çelik et al., 2024) and modeling (Ayyildiz et al., 2024; Servare Junior et al., 2024; Beinabadi et al., 2024). Other methods include the application of combined techniques, as is the case of the studies by He et al. (2024), Ekren and Arslan (2024), and Di (2024).

Table 2. Methods used by the studies

References	Methods used by the studies
Kamil et al. (2024)	Literature review of a decade of articles, patents, and industry reports
Ayyildiz et al. (2024)	Bayesian network model using Pythagorean fuzzy sets
Wang et al. (2024)	Literature review
He et al. (2024)	Two stages: 1) significant setup time in the first stage; 2) second stage served by non-interruptible machines
Franco et al. (2024)	Robotic simulations and analysis
Ekren; Arslan (2024)	Comparative analysis method: ML-based solution compared to traditional scheduling approaches
Servare Junior et al. (2024)	Equivalent MILP modeling for minimization of energy and material flows.
Di (2024)	Application of the penalty optimization function as a measure of each solution found
Beinabadi at al. (2024)	Mathematical modeling using data envelopment analysis
Çelik et al. (2024)	Computer simulation

Source: Data collected by the authors.

The results in Table 2 have profound implications for the training of logistics professionals, specifically those specialized in warehousing, because they show that their training needs to be enriched and empowered through mastery of artificial intelligence applications. In the same way that computer systems have made the execution of storage techniques based on manual physical artifacts obsolete, artificial intelligence has proven to be a fundamental tool for speeding up and making more precise the execution of these same traditional internal logistics activities, especially warehousing. In short, logistics professionals need to learn how to use and apply artificial intelligence.

4.3 Problematic situations of the studies

The problematic situations that gave rise to the objectives of the studies confirm the transdisciplinary or interdepartmental nature of the studies. The survey by Kamil et al. (2024) combines safety and environmental issues to solve logistics problems; Ayyildiz et al. (2024) focused on other mathematical techniques to solve warehousing problems; while He et al. (2024) and Wang et al. (2024) deal with purely economic situations, but their solutions are centered on warehouses and physical production spaces. These highly complex situations require more robust and efficient tools for understanding and formulating problems and proposing solutions. In this scenario, artificial intelligence has become an essential technology for contemporary organizational management. Table 3 summarizes these findings.

Table 3. Problematic situations in the studies

References	Problematic situations
Kamil et al. (2024)	Increasing chemical dependence requires storage solutions to ensure safety and environmental sustainability.
Ayyildiz et al. (2024)	The traditional Bayesian approach has limitations when dealing with ambiguity and continuous variables.
Wang et al. (2024)	Cold storage technology helps alleviate the mismatch between demand and supply of cold energy, but the literature on it needs to be reviewed.
He et al. (2024)	The increasing demand for automotive glass requires improving the efficiency of manufacturing systems to fully utilize production resources and reduce the waste of natural and social resources.
Franco et al. (2024)	Evolutionary robotics is a technique that can be used in the framework of Industry 4.0 to endow robots with autonomy (coordinating groups of robots and developing communication systems). It is essential to equip them with effective coordination, communication mechanisms, and challenging environments for control systems.
Ekren; Arslan (2024)	With the recent increase in commercial practices, Fast delivery requirements for low-volume orders have increased, forcing faster processing.
Servare Junior et al. (2024)	Planning for the efficient use of electricity in warehousing operations is a strategic issue due to the constant price increase and its impact on production costs.
Di (2024)	The problem of location and allocation of goods is addressed by analyzing the efficiency of automated warehouses and shelf stability through mathematical modeling.
Beinabadi at al. (2024)	The automotive parts manufacturing sector faces multifaceted challenges ranging from production planning to sustainability imperatives, requiring innovative solutions.
Çelik et al. (2024)	Quality is the critical key for companies to gain a competitive advantage because faulty products improve their performance and help them achieve a larger market share.

Source: Data collected by the authors.

These results seem to signal the need for contemporary organizations to deal with situations beyond their borders. Since external environmental problems, factors, and variables are uncontrollable, organizations must develop intelligent schemes to deal with them. For example, issues of demand or low competitiveness originating from product quality and price can have their solutions initiated by restructuring their production and storage systems (inventories are always idle capital that does not yield profits). In these situations, artificial intelligence is a powerful instrument that goes beyond the human capacity to understand conditions, present proposed solutions, test these proposals, and decide on the one most likely to adapt to environmental adversities.

4.4 Applications of AI in the studies

The data contained in Table 4 show the applications of AI that were used in the studies analyzed. It is worth noting the multiplicity of techniques and methods used, representing a small part of the stock of applications that artificial intelligence has available, the results of which have already been documented by scientific studies. These applications also have different natures. For example, there are those based mainly on mathematical modeling, such as the study by Wang et al. (2024), programming and algorithms, as shown in the study by He et al. (2024) and Servare Júnior et al. (2024), as well as those that focus more on physical artifacts, such as computer vision described in the study by Çelik et al. (2024). The fact is that, even if the applications are extraphysical (such as equations and algorithms), it is always necessary to refer to at least one physical development, as is the case with sensors, actuators, and computer vision, among others.

Table 4. Applications of AI in research

References	AI applications in research
Kamil et al. (2024)	IoT, AI, sophisticated detectors and sensors
Ayyildiz et al. (2024)	Pythagorean fuzzy sets and risk assessment criteria development
Wang et al. (2024)	Predictive models, parametric regression, and artificial neural network
He et al. (2024)	Mixed integer linear programming, genetic algorithm
Franco et al. (2024)	Artificial neural networks, genetic algorithms, autonomous robotics simulation and analysis
Ekren; Arslan (2024)	Ultra-high-speed automated storage system (SBS/RS), machine learning

ISSN 2178-6925

Servare Junior et al. (2024)	Innovative energy scheduling algorithm, rolling horizon algorithm, mixed integer nonlinear programming
Di (2024)	Enhanced Tabu Search algorithm, mathematical modeling, machine learning, neural network
Beinabadi at al. (2024)	Convolutional and recurrent neural networks, Moth-flame algorithm (MFO)
Çelik et al. (2024)	Computer vision (YOLO models), algorithms, machine learning, convolutional modules, neural networks

Source: Data collected by the authors.

The results in Table 4 show that artificial intelligence is the marriage of physical and extraphysical dimensions in searching for solutions to organizational problems, such as those related to storage. In no study analyzed was the application of only one technique or resource of artificial intelligence found, which goes back to the essence of the term intelligence, which is always the application of some knowledge that has been understood. This variety of resources indicates the need to capture multiple types of data, including a wide variety of them so that the cognition of programs and machines can begin to function and continuously improve themselves until artificial intelligence approaches natural human intelligence.

4.5 Finds of the Studies

Table 5 shows the results of the studies analyzed. Some aspects are perceptible, such as the effectiveness of artificial intelligence in solving the problems for which it was used, the simultaneous contribution of the application to the practice of storage and expanding scientific knowledge, and the number of discoveries made by each study. Studies such as that of Ayyildiz et al. (2024) and Ekren and Arslan (2022) powerfully demonstrate this dual contribution, science, and practice, while the others are typical examples showing the different ways in which artificial intelligence can collaborate to solve complex organizational and internal logistics problems. Other aspects are more indirect and not so explicit, such as the risk reduction that artificial intelligence presents, as shown in the studies by Kamil et al. (2024), Ayyildiz et al. (2024), and Franco et al. (2024).

Table 5. Finds of the studies

References	Study Findings
Kamil et al. (2024)	1) Advances in sensor technologies, 2) AI system integration and algorithms for real-time monitoring of storage facilities, 3) hazard identification, and 4) predictive analytics
Ayyildiz et al. (2024)	Provides valuable insights to enhance occupational health and safety practices in pharmaceutical warehouses
Wang et al. (2024)	1) Passive and active cooling systems with cold storage technology are in various applications; 2) Cold storage unit can be coupled with refrigeration or chiller as a cooling system; 3) Main operational control can be divided into priority operation strategy of the refrigeration unit and optimal control strategy; 4) Cold load evaluation mainly contains traditional parametric regression method and neural network method; 5) Economic analysis includes project cost and operating cost.
He et al. (2024)	1) An improvement scheme is proposed to decrease the algorithm execution time; 2) the scheme can reduce the execution time by a maximum of 280 seconds from the average results of problems of different scales
Franco et al. (2024)	1) Homogeneous groups of robots using emergent communication via light-emitting diodes (LEDs) outperform those with predefined signal systems or without communication capabilities; 2) The superior performance is attributed to the organizational structure that arises from the signal emergence within the group dynamics and environmental interactions.
Ekren; Arslan (2024)	1) Reinforcement learning outperforms the FIFO scheduling rule; 2) Reinforcement learning produced values close to the shortest process time results considered; 3) when considering batch arrivals, reinforcement learning results produce slightly better results than the shorter process time results
Servare Junior et al. (2024)	The presence of the battery in the storage yard-port power grid allows energy cost reduction of up to 17.88% compared to the case without the battery.
Di (2024)	1) The specific process sequence of logistics warehousing is optimized, 2) the use of neural networks can effectively shorten the task completion time
Beinabadi at al. (2024)	1) The model achieves an accuracy of over 90%, 2) DEA evaluates suppliers with an average efficiency of 0.75, and 3) the best-worst method identifies suppliers with an average score of 0.8. 1) The highest mean average accuracy value of 0.990 was obtained in the YOLOv8s model, 2) the lowest training time was obtained in the YOLOv8n model, 3) the YOLOv8s model gave the highest mAP value, and hyperparameter tuning was done according to batch size and learning rate values
Çelik at al. (2024)	Study Findings

Source: Data collected by the authors.

The analyzed studies confirm that artificial intelligence can effectively improve warehousing services compared to other techniques and methods used, such as through increasingly broader interconnections of the activities of each logistics chain until encompassing the entire supply chain. This means that the understanding of how the whole supply chain works can be obtained through artificial intelligence technologies simultaneously, from the execution of each logistics function's activities to the complete integration of all types of logistics (supply, internal, and distribution). The more this integration is performed, the more data and information are collected and processed so the systems can learn and continuously improve themselves.

4.6 Conclusions of the studies

Table 6 shows the conclusions of the studies analyzed. In practically all of them, substantial improvements were found in applying artificial intelligence. These results confirm that these technologies can improve the quality of warehousing services and, by extension, internal logistics because all the applications used in the studies analyzed were not restricted to a single warehousing activity. These findings align with the contemporary reality in which things and their functioning are not isolated but in harmony with others, marking connections and interconnections. For example, storage has specific activities that need to be connected. Still, the storage system, which is the whole, needs to be interconnected with other internal logistics functions, such as purchasing. This multiplicity of activities and functions can be carried out more quickly and efficiently with the help of artificial intelligence.

Table 6. Conclusions of the studies

References	Conclusions of the studies
Kamil et al. (2024)	Shows how technology improves safety and sustainability.
Ayyildiz et al. (2024)	Contributes to improving occupational health and safety practices in pharmaceutical warehouses and provides a framework for future research.
Wang et al. (2024)	Adopting effective operational control strategies and cost-effective optimization methods for refrigeration systems with PCM-based CTES is essential to optimizing cold sources and improving time, cost, and performance efficiency.
He et al. (2024)	Regarding solution quality, the designed genetic algorithm (AGP) can produce better solutions than a basic genetic algorithm, simulated annealing, and optimizer.
Franco et al. (2024)	The findings emphasize the relevance of evolutionary robotics (ER) principles in meeting the demands of Industry 4.0.
Ekren; Arslan (2024)	We can obtain better results than the shorter process time if we use a more complex deep learning approach than a basic learning approach.
Servare Junior et al. (2024)	The proposed models support purchasing electricity from different energy suppliers or using batteries to reduce system costs while respecting the production flow.
Di (2024)	The proposed location assignment algorithm is highly complex. Its complexity and objective function increase the computation and occupy a certain amount of computer resources.
Beinabadi at al. (2024)	The integrative approach enables automotive parts manufacturers to optimize their production planning processes, aligning them with sustainable development goals.
Çelik et al. (2024)	The proposed method can detect different types of defects on the surfaces of plastic parts and can be executed by setting different hyperparameters.

Source: Data collected by the authors.

The results here point to improvements in storage systems and solutions to the problems for which they were created and tested because they combine human and artificial intelligence. This means that intelligence is still human intelligence, no matter how synthetic it may be. Even if this artificialized human intelligence achieves autonomy, it still needs natural human intelligence to guide it, whether in procedures or in evaluating the results achieved. However, one thing still seems indisputable: artificial intelligence, because it can deal with many more variables simultaneously, is better able to deal with highly complex problems than human intelligence. The studies analyzed demonstrate this.

4.7 Discussion of the results

The studies seem to confirm that many of the complex problems and challenges of material storage can be solved with the help of artificial intelligence. Studies such as those by Alexiou et al. (2025), Yogapriya, Subramanian, and Prakash (2025), and Wobo et al. (2025) show that artificial intelligence enables machines and systems to learn, adapt, and solve problems with many aspects dimensions, and variables in a way never thought possible before. More than that, this type of intelligence has found application in practically all sectors of human life, from construction (Yogapriya et al., 2025) to medicine (Alexiou et al., 2025; Wobo et al., 2025), from education (Nwadinobi et al., 2024) to production (Çelik et al., 2024).

Artificial intelligence has fertile ground in logistics because this field of knowledge and human practice is complex when viewed from a longitudinal perspective in the supply chain. This means that the more activities and functions that must be performed in a convergent and consequential manner, the greater the application of artificial intelligence and its technologies tends to be. Several reasons lead to this fertility, but two stand out visibly. The first is the requirement that logistics and storage solutions need to consider dozens and sometimes hundreds of variables that human intelligence cannot handle simultaneously; the second is that logistics and storage are increasingly performed by machines and equipment that, in turn, are continually becoming more intelligent. It is no exaggeration to say that artificial intelligence makes machines intelligent and makes them talk to each other. In this dialogue, carried out through data and information, learning increases their decisions and actions' agility, speed, and precision.

5. Conclusion and Recommendations

This study analyzed ten studies that portrayed the application of artificial intelligence in storing materials. The results indicated that the more complex the problem to be solved or the challenge to be overcome, the greater the effectiveness of artificial intelligence in dealing with them tends to be. This is because artificial intelligence does not deal with things, facts, and phenomena in the world in isolation but always in action, in movement, and in a way connected by its ontological nature. This means that artificial intelligence is an algorithm. It comprises a sequence of small guidelines and decisions, which function as an extremely long sequence of causes and effects. Since they always learn from what has been executed, the sequence tends to infinity.

Logistics activities, including storage, are complex and increasingly carried out using machines and technological artifacts. Here again, artificial intelligence shows its potential because it makes machines and artifacts acquire intelligence and begin to communicate through the algorithms and programs that animate them. As a result, logistics is increasingly becoming a field of activity for artificial intelligence, which requires that the training of professionals in these areas be remodeled so that they are familiar with and know how to apply this technology. To expand on the findings of this study, it is suggested that two studies be conducted. The first is a theoretical-empirical survey of artificial intelligence technologies organizations have used in their warehousing efforts. The second is to map the knowledge and skills logistics professionals need to acquire to use artificial intelligence daily.

References

ABDOLLAHI, A. et al. Intelligent distributed supply chain management in the pharmaceutical industry. **Journal of Strategic Management Studies**, v. 14, n. 56, p. 141-167, 2024. https://doi.org/10.22034/smsj.2023.366744.1742.

ALBUQUERQUE, A. S. F. et al. Processo de institucionalização: um estudo sobre a experiência do espaço da cidadania ambiental (ECAM). **Review of Research**, v. 7, n. 9, p. 1-13, 2018. https://doi.org/10.5281/zenodo.10388272.

ALEXIOU, V. G. et al. Artificial intelligence in diagnosing and managing vascular surgery patients: An experimental study using the GPT-4 Model. **Annals of Vascular Surgery**, v. 111, p. 260-267, 2025. https://doi.org/10.1016/j.avsg.2024.11.014.

ALMEIDA, A. S. et al. The operational steps of the evaluation processes: a balance of the literature. **Research, Society and Development**, v. 11, n. 12, p. 1-18, 2022. http://dx.doi.org/10.33448/rsd-v11i12.34288.

AMETBEKOVNA, E. D.; UGLI, M. F. D. Intellectual property and artificial intelligence: Regulatory challenges and solutions. **International Journal of Business, Law and Political Science**, v. 2, n. 2, p. 9-16, 2025. https://doi.org/10.61796/ijblps.v2i2.265.

AYDIN, B.; İNCE, M. Can artificial intelligence write news: A research on determining the effect of artificial intelligence on news writing practice. **Intermedia International E-journal**, v. 11, n. 20, p. 24-41, 2024.

AYYILDIZ, E.; ERDOGAN, M.; GUL, M. A comprehensive risk assessment framework for occupational health and safety in pharmaceutical warehouses using Pythagorean fuzzy Bayesian networks. **Engineering Applications of Artificial Intelligence**, v. 135, p. 108763, 2024. https://doi.org/10.1016/j.engappai.2024.108763.

BARATA, F. A.; FEBRIANTO, G. N.; YASIN, M. Supply chain management strategy in building a competitive advantage through the implementation of logistic 4.0. In: **19th International Symposium on Management (INSYMA 2022)**. Atlantis Press, 2022. p. 369-377. https://doi.org/10.2991/978-94-6463-008-4_47.

BEINABADI, H. Z.; BARADARAN, V.; KOMIJAN, A. R. Sustainable supply chain decision-making in the automotive industry: A data-driven approach. **Socio-Economic Planning Sciences**, v. 95, p. 101908, 2024. https://doi.org/10.1016/j.seps.2024.101908.

BRITO, Z. M. et al. Processo gerencial: uma análise para suporte à gestão em uma instituição federal de ensino. In: **XVI Colóquio Internacional de Gestión Universitaria – CIGU; Gestión de la Investigación y Compromiso Social de la Universidad**, Arequipa, Peru, 23 a 25 de novembro de 2016.

BUCKO, M.; SCHINDLEROVA, V.; SAJDLEROVA, I. Optimisation of the expedition process of shapes in the engineering company. **MM Science Journal**, (3), 6294-6303, 2023.

ÇELIK, M. T.; ARSLANKAYA, S.; YILDIZ, A. Real-tıme detectıon of plastıc part surface defects usıng deep learnıng-based object detectıon model. **Measurement**, 235, p. 114975, 2024. https://doi.org/10.1016/j.measurement.2024.114975.

CHOLE, V.; GADICHA, V.; THAWAKAR, M. Evolution of artificial intelligence through game playing in chess. In: GHONGE, M. M. et al. (eds.). **Data-driven systems and intelligent applications.** Boca Raton: CRC Press, 2024, p. 119-136.

CHOUDHARY, S. Prediction and recognition of drone magnetometer system using artificial intelligence with edge computing. In: **2024 IEEE International Conference on Big Data & Machine Learning (ICBDML)**. IEEE, 2024. p. 227-233. https://doi.org/10.1109/ICBDML60909.2024.10577328.

COSTA, P. H. D. D. **Aumento da eficiência das operações logísticas num armazém de óleos lubrificantes**. 2023. 52 p. Dissertação (Mestrado em Logística). Instituto Politécnico do Porto, Porto, 2023.

DANG, R. R. et al. The current landscape of artificial intelligence in oral and maxillofacial surgery–a narrative review. **Oral and Maxillofacial Surgery**, v. 29, n. 1, p. 1-11, 2025. https://doi.org/10.1007/s10006-025-01334-6.

DEI, H. Artificial intelligence in public administration: benefits and risks. **Management (Montevideo)**, v. 3, p. 137-137, 2025. https://doi.org/10.62486/agma2025137.

DI, H. Design and research of automated warehouse simulation platform based on virtual visualization framework. **PeerJ Computer Science**, v. 10, p. e1809, 2024. https://doi.org/10.7717/peerj-cs.1809.

EKREN, B. Y.; ARSLAN, B. A reinforcement learning approach for transaction scheduling in a shuttle-based storage and retrieval system. **International Transactions in Operational Research**, v. 31, n. 1, p. 274-295, 2024. https://doi.org/10.1111/itor.13135.

EL-TALLAWY, S. N. et al. Incorporation of “artificial intelligence” for objective pain assessment: A comprehensive review. **Pain and Therapy**, *Pain Ther,* v. 13, p. 293–317, 2024. https://doi.org/10.1007/s40122-024-00584-8.

FADILA, B. The impact of applying artificial intelligence on the quality of the accounting and auditing profession: A case study of Algeria. **International journal of economic perspectives**, v. 18, n. 12, p. 2669-2685, 2024.

FERREIRA, C. S. C. **Warehouse Management System (WMS) como fator de competitividade:** estudo de caso do centro de distribuição do grupo Editorial Plátano. 2021. 54 p. Dissertação (Mestrado em Ciências Empresariais – Ramo Logística). Instituto Politécnico de Setúbal, Setúbal, 2021.

FRANCO, A. F.; FRANCO, A. R; SANCHEZ, A. J. E., GONZALEZ, M. F., RETURETA, L. G. J. Emergent communication in simulated robotics: supporting supply chains through evolutionary computation. **Acta universitaria**, v. 34, 1-15, 2024. https://doi.org/10.15174/au.2024.3939.

GAO, C.; KEOY, K.-H.; LIM, A.-F. Adoption and impact of generative artificial intelligence on blockchain-enabled supply chain efficiency. **Journal of Systems and Information Technology**, Vol. ahead-of-print No. ahead-of-print, 2025. https://doi.org/10.1108/JSIT-04-2024-0143.

GHASEMI, S.; KHOSRAVI, H. Artificial intelligence-supported applications in radiotherapy treatment planning and dose optimization. **Frontiers in Biomedical Technologies**, v. 14, n. 4, p. 692-695, 2024. https://doi.org/10.18502/fbt.v11i4.16518.

GOGGINS, A. **Infrastructure, wash practices, and health**: A study of rural communities in São Tomé e Príncipe. 2020. 104 p. Dissertação (Mestrado em International Management). Technical University of Liberec, Liberec, Czech Republic, 2022.

HE, H. et al. Machine condition monitoring for defect detection in fused deposition modelling process: a review. **The International Journal of Advanced Manufacturing Technology**, v. 132, p. 3149–3178, 2024. https://doi.org/10.1007/s00170-024-13630-8.

HE, Y. F. et al. Scheduling analysis of automotive glass manufacturing systems subject to sequence-independent setup time, no-idle machines, and permissive maximum total tardiness constraint. **Engineering Applications of Artificial Intelligence**, v. 133, p. 108299, 2024. https://doi.org/10.1016/j.engappai.2024.108299.

KAMIL, S.; AL-TURFI, M.; ALMUKHTAR, R. Advancements in chemical materials: Exploring smart storage equipment and protection systems. **Journal of Applied Engineering and Technological Science (JAETS)**, v. 5, n. 2, p. 1086-1101, 2024. https://doi.org/10.37385/jaets.v5i2.4096.

KAPLAN, A. Fast fashion's fate: Artificial intelligence, sustainability, and the apparel industry. In: Walker, T., Wendt, S., Goubran, S., Schwartz, T. (eds.) **Artificial Intelligence for Sustainability**. Cham: Palgrave Macmillan, 2024, p. 13-30. https://doi.org/10.1007/978-3-031-49979-1_2

KUMAR, R.; KUMAR, R.; CHAUDHARY, S. **Advanced functional nanoparticles "boon or bane" for environment remediation applications**: combating environmental issues. Cham: Springer Nature, 2023.

KUPPUSAMY, M. et al. Advanced decision analytics with fuzzy logic integrating AI and computational thinking for personnel selection. **Journal of Fuzzy Extension and Applications**, v. 5, n. 4, p. 679-699, 2024. https://doi.org/10.22105/jfea.2024.477833.1621.

LUGER, G. F. **Artificial intelligence: Principles and practice**. Cham: Springer, 2025.

MAJID, Z. A.; RAHMAN, N. A. A.; NUR, N. M. An Insight into Logistics Management and Practices for Non-logistician. In: ISMAIL, A. et al.

(eds.). **Technological frontiers and sustainable innovations**. Cham: Springer Nature Switzerland, 2024, p. 65-72.

NASCIMENTO-E-SILVA, D. et al. Analysis of the effectiveness of the managerial process in a federal institution of education, science and technology in Northern Brazil. **Braz. J. of Bus.**, Curitiba, v. 2, n. 2, p.1420-1440, abr./jun. 2020. https://doi.org/10.34140/bjbv2n2-037.

NASCIMENTO-E-SILVA, D. **Manual do método científico-tecnológico**: edição sintética. Florianópolis: DNS Editor, 2020.

NASCIMENTO-E-SILVA, D. **Handbook of the scientific-technological method**: edição sintética. Manaus: DNS Editor, 2021a.

NASCIMENTO-E-SILVA, D. **O método científico-tecnológico**: fundamentos. Manaus: DNS Editor, 2021b.

NASCIMENTO-E-SILVA, D. **O método científico-tecnológico**: questões de pesquisa. Manaus: DNS Editor, 2021c.

NASCIMENTO-E-SILVA, D. **Metodologia da pesquisa e elaboração de projetos tecnológicos**. Manaus: DNS Editor, 2021d.

NASCIMENTO-E-SILVA, D. **O método científico-tecnológico**: coleta de dados. Manaus: DNS Editor, 2023.

NOZARI, H. et al. Optimizing cold chain logistics with artificial intelligence of things (AIoT): A model for reducing operational and transportation costs. **Future**

Transportation, v. 5, n. 1, p. 1-22, 2025. https://doi.org/10.3390/futuretransp5010001.

NWADINOBI, V. N. et al. The Impact of artificial intelligence on undergraduates' effectiveness in institutions of higher learning. **Educational Administration: Theory and Practice**, v. 30, n. 4, p. 6989-6996, 2024. https://doi.org/10.53555/kuey.v30i4.2501.

REIKIN, V. Genesis of conceptual approaches to «logistics» category. **Economic journal of Lesya Ukrainka Volyn National University**, v. 1, n. 37, p. 6-10, 2024. https://doi.org/10.29038/2786-4618-2024-01-6-10.

SANTOS, O. S. et al. A importância do código de barras na cadeia de suprimento para uma empresa do ramo de fundição. **Revista Educação-UNG-Ser**, v. 17, n. 2, p. 7-22, 2022. https://doi.org/10.33947/1980-6469-V17N2-4434.

SARHIR, O.; BENMAMOUN, Z.; MAMOUN, M. B. Prediction Analysis for Demand Forcasting in Automotive Industry. In: **2024 10th International Conference on Optimization and Applications (ICOA)**. IEEE, 2024. p. 1-6. https://doi.org/10.1109/ICOA62581.2024.10754474.

SAVAŞ, A.; BİNİCİ, H. İ. A bibliometric review on food and artificial intelligence. **7th International Anatolian Agriculture, Food, Environment and Biology Congress, Kastamonu/Türkiye**, *[S. l.]*, p. 409–413, 2024.

SERVARE JUNIOR, M. W. J. S.; ROCHA, H. R. O.; SALLES, J. L. F. A smart energy scheduling under uncertainties of an iron ore stockyard-port system using a rolling horizon algorithm. **Computers & Operations Research**, v. 164, p. 106518, 2024. https://doi.org/10.1016/j.cor.2023.106518.

SHAHRIARI, M. Unveiling key drivers of supply chain sustainability in the telecom sector: An information systems perspective. **International Journal of Nonlinear Analysis and Applications**, v. 16, n. 2, p. 37-49, 2025. http://dx.doi.org/10.22075/ijnaa.2024.33517.4996.

SINGH, G. Adoption of artificial intelligence in marketing: Legal and ethical perspectives. In: MALIK, R.; MALHAN, S.; ARORA, M. (eds.). **Neurosensory and neuromarketing impacts on consumer behavior**, Hershey: IGI Global, 2024, p. 1-32.

SOFHIA, M.; MANAWAN, J. F. W. M. Raw material weighing application through visual-based RS-232 cable port. **Sinkron: jurnal dan penelitian teknik informatika**, v. 7, n. 1, p. 590-594, 2023. https://doi.org/10.33395/sinkron.v8i1.12158.

TEDGUE, L. J. et al. Armazenagem e a movimentação de materiais. **Revista de Empreendedorismo, Negócios e Inovação**, v. 8, n. 1, p. 127-142, 2023. https://doi.org/10.36942/reni.v8i1.640.

TOHIR, M.; PRIMADI, A.; INDAH, D. D. Analysis of logistics technology, logistics infrastructure and quality of logistics services on e-commerce growth. **Siber International Journal of Education Technology (SIJET)**, v. 1, n. 4, p. 129-136, 2024. https://doi.org/10.38035/sijet.v1i4.77.

VELOSO, J. S.; NASCIMENTO-E-SILVA, D. A study on the application of artificial intelligence in material movement based on scientific publications. **REMUNOM**, v. 1, n. 1, p. 1-13, 2025. https://doi.org/10.61164/rmnm.v1i1.3420.

WAJIYA, F. M.; SALEH, S. H. Integrating artificial intelligence capabilities and organizational maturity on enhancing financial sustainability: A field study in Iraqi telecommunications companies (Zain Iraq and Asia Cell). **International Journal of Religion**, v. 5, n. 11, p. 431-442, 2024. https://doi.org/10.61707/9b0d2v97.

WANG, H.; XIE, B.; LI, C. Review on operation control of cold thermal energy storage in cooling systems. **Energy and Built Environment**, In Press, Corrected Proof, 1-15, 2024. https://doi.org/10.1016/j.enbenv.2024.01.007.

WANG, Y. et al. Is it necessary for the supply chain to implement artificial intelligence-driven sales services at both the front-end and back-end stages? **Transportation Research Part E: Logistics and Transportation Review**, v. 194, p. 1-25, 2025. https://doi.org/10.1016/j.tre.2024.103923.

WEISZ, E. et al. Artificial intelligence (AI) for supply chain collaboration: implications on information sharing and trust. **Online Information Review**, v. 49, n. 1, p. 164-181, 2025. https://doi.org/10.1108/OIR-02-2024-0083.

WOBO, K. N. et al. Medical students' perception of the use of artificial intelligence in medical education. **International Journal of Research in Medical Sciences**, v. 13, n. 1, p. 82, 2025.

YOGAPRIYA, G.; SUBRAMANIAN, C. V.; PRAKASH, K. Ashwin. Application of artificial intelligence in smart buildings. In: **AIP Conference Proceedings**. AIP Publishing, 2025. https://doi.org/10.1063/5.0247215.