Integrated Analysis of Industry 4.0 Technologies in Warehouse Management of Chain Stores Based on the BWM-TOPSIS Technique

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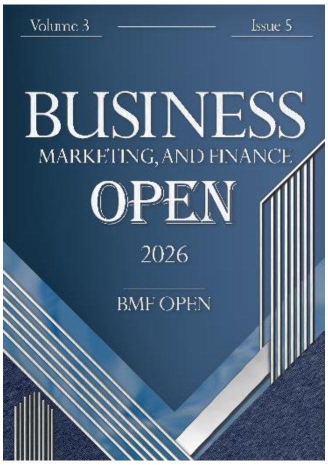

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Citation: Shirani, A., Momeni, M., & Saghafi, F. (2026). Integrated Analysis of Industry 4.0 Technologies in Warehouse Management of Chain Stores Based on the BWM-TOPSIS Technique. *Business, Marketing, and Finance Open*, 3(5), 1-16.

Received: 01 January 2026
Revised: 07 May 2026
Accepted: 14 May 2026
Initial Publication: 29 May 2026
Final Publication: 01 September 2026

Abstract: In the era of the Fourth Industrial Revolution, the retail industry is facing extensive technological transformations and sustainability challenges. Chain stores, as the main actors in this industry, require transformation in their warehousing processes in order to enhance operational efficiency while also responding to environmental and social requirements. Within such a framework, the selection and implementation of Industry 4.0 technologies require precise analysis from the perspectives of organizational capability and strategic attractiveness. Therefore, the main objective of this study is to provide an integrated analysis of Industry 4.0 technologies in warehouse management of chain stores based on the BWM-TOPSIS technique. In this research, an introduction was first presented to introduce the subject, followed by a review of the relevant theoretical foundations and previous studies. Subsequently, the procedure for implementing the research methodology was explained. During the research process, the main criteria were extracted through a survey of experts, and a set of linguistic expressions proposed by specialists was utilized for the integrated analysis and evaluation of Industry 4.0 technologies in warehouse management of chain stores with respect to each criterion. These qualitative expressions were converted into corresponding numerical values, and in the final stage, multi-criteria decision-making methods, including BWM and TOPSIS, were employed to identify and rank the influencing factors. The findings indicate that the interval estimation BWM-TOPSIS method is used to enhance decision-makers' ability to identify indicators that may mislead high-risk decisions or inefficiently influence them. This capability enables secondary or unnecessary factors to be eliminated from the decision-making process, thereby improving decision-making accuracy and efficiency. One of the key advantages of the interval estimation BWM-TOPSIS method lies in its ability to decompose complex decision-making problems into manageable components and create a hierarchical structure that clarifies the relationships among individual indicators. This structured approach assists decision-makers in achieving a comprehensive understanding of the decision-making process and facilitates the targeted elimination of inefficient indicators. The results demonstrate that the designed indicator system for the implementation of Industry 4.0 technologies in warehouse management of chain stores was screened using the interval estimation BWM-TOPSIS method. Consequently, technical innovation and waste management were eliminated, whereas the remaining indicators were retained.

Keywords: Analysis, Industry 4.0 Technologies, Warehouse Management, Chain Stores, BWM-TOPSIS

1. Introduction

The rapid evolution of digital technologies and the emergence of the Fourth Industrial Revolution have fundamentally transformed the structure and operational mechanisms of global supply chains. Industry 4.0 technologies, including artificial intelligence, the Internet of Things (IoT), cloud computing, blockchain, big data analytics, robotics, and cyber-physical systems, have reshaped organizational strategies and operational models across manufacturing, logistics, and retail industries. In recent years, the retail sector has experienced unprecedented changes due to the expansion of e-commerce, growing customer expectations, accelerated digitalization, and increasing environmental concerns. These transformations have intensified the need for smart and integrated warehouse management systems capable of improving efficiency, responsiveness, sustainability, and competitiveness [1, 2]. Warehouse management has consequently evolved from a conventional storage-oriented function into a strategic operational domain that directly influences organizational performance, customer satisfaction, and supply chain resilience. The integration of Industry 4.0 technologies into warehouse management systems has therefore become one of the most significant priorities for modern chain stores and retail organizations.

The retail industry, particularly chain stores, operates within highly dynamic and competitive environments characterized by demand uncertainty, inventory complexity, fluctuating consumer behavior, and time-sensitive distribution requirements. Traditional warehouse management approaches are increasingly unable to cope with the complexity and speed required in modern retail supply chains. Conventional warehousing systems often suffer from operational inefficiencies, inventory inaccuracies, excessive energy consumption, labor-intensive activities, and delayed order fulfillment. Consequently, organizations have turned toward smart warehousing solutions to improve operational performance and optimize logistics activities [3, 4]. Automated warehouse systems supported by robotics, autonomous guided vehicles, and intelligent inventory systems have demonstrated substantial potential in reducing operational costs, minimizing human error, and enhancing warehouse productivity. Furthermore, digital technologies have enabled real-time data collection and analytics, improving decision-making quality and supply chain visibility.

Industry 4.0 technologies also play a critical role in enhancing sustainability and environmental responsibility within warehouse operations. Sustainability has become a central concern for organizations due to increasing regulatory pressures, environmental degradation, and consumer awareness regarding sustainable business practices. Smart warehouse technologies contribute significantly to energy optimization, waste reduction, resource efficiency, and carbon emission mitigation. The implementation of intelligent energy monitoring systems, optimized transportation routes, automated inventory systems, and reverse logistics mechanisms can improve environmental performance while simultaneously reducing operational expenditures [5, 6]. Sustainable warehouse management has therefore emerged as an essential component of green supply chain management and circular economy initiatives. The integration of Industry 4.0 technologies enables organizations to achieve economic growth while maintaining environmental and social responsibilities.

The increasing digital transformation of supply chains has further accelerated the adoption of smart technologies in retail logistics. Advanced digital platforms facilitate seamless coordination among suppliers, warehouses, transportation systems, and customers. Technologies such as cloud computing and IoT enable continuous communication and synchronization among supply chain actors, thereby improving operational flexibility and responsiveness. Research has shown that digitalized supply chains are more resilient to disruptions and better equipped to respond to unexpected market changes [7, 8]. Particularly after the COVID-19 pandemic, organizations recognized the strategic necessity of resilient and agile warehouse systems capable of ensuring uninterrupted product availability and timely delivery. Smart warehousing solutions therefore gained substantial importance as organizations sought to strengthen supply chain continuity and operational reliability.

Artificial intelligence and data analytics have become among the most influential technologies in modern warehouse management systems. AI-driven systems can optimize inventory placement, predict demand fluctuations, automate order-picking operations, and improve warehouse space utilization. Intelligent algorithms are capable of analyzing vast volumes of operational data and generating predictive insights that support managerial decision-making. AI technologies also facilitate autonomous operations and reduce dependency on manual labor, thereby improving productivity and reducing operational risks [9, 10]. In large-scale chain stores, where inventory turnover rates are extremely high and product diversity is substantial, AI-supported warehouse management systems can significantly improve operational efficiency and customer service quality.

The Internet of Things has similarly transformed warehouse operations by enabling real-time monitoring and communication among interconnected devices and systems. IoT-enabled sensors can track inventory movement, environmental conditions, equipment performance, and transportation status throughout the warehouse environment. These technologies improve inventory accuracy, reduce stock discrepancies, and enhance operational transparency. Moreover, IoT integration supports predictive maintenance practices that reduce equipment downtime and maintenance costs [11, 12]. Through the integration of IoT and intelligent automation technologies, warehouse management systems can operate with greater flexibility, accuracy, and reliability.

Automation technologies have become central to the modernization of warehouse operations. Automated storage and retrieval systems, robotic picking systems, conveyor technologies, and automated guided vehicles significantly reduce processing time and labor dependency while increasing operational precision. Studies have demonstrated that automated warehouse systems improve order fulfillment speed, reduce workplace accidents, and optimize warehouse capacity utilization [3, 13]. In chain store environments, where rapid inventory turnover and accurate order processing are essential, automation technologies provide substantial competitive advantages. The increasing integration of robotics and intelligent systems has therefore redefined the operational architecture of modern warehouse facilities.

In addition to operational efficiency, Industry 4.0 technologies contribute significantly to supply chain sustainability and environmental resilience. Green logistics practices have become critical for reducing environmental impacts associated with warehousing and transportation activities. Smart technologies facilitate optimized transportation planning, efficient energy utilization, and improved waste management processes. Reverse logistics and carbon reduction initiatives supported by digital technologies have shown considerable potential in minimizing greenhouse gas emissions and supporting sustainable retail operations [14, 15]. Similarly, sustainable supply chain strategies adopted by leading e-commerce organizations have demonstrated the importance of integrating environmental objectives into logistics and warehouse management practices [16, 17]. These developments indicate that sustainability considerations are no longer optional but rather strategic necessities within modern supply chain systems.

The emergence of smart manufacturing and interconnected technologies has further strengthened the integration between warehouse operations and broader supply chain ecosystems. Industry 4.0 technologies create interconnected operational environments in which warehouses function as intelligent nodes within digitally integrated supply chains. This interconnectedness enhances information sharing, operational synchronization, and strategic coordination across organizational functions [11]. Smart warehousing therefore contributes not only to operational performance but also to overall supply chain integration and strategic agility. Organizations capable of implementing integrated Industry 4.0 systems can achieve greater adaptability, innovation capability, and market responsiveness.

The retail sector has also witnessed the growing influence of advanced communication technologies such as 5G networks, which facilitate faster data transmission and real-time operational coordination. The implementation of 5G-supported systems improves connectivity among warehouse devices, transportation systems, and retail platforms, enabling faster and more accurate operational processes [18]. Enhanced connectivity allows organizations to implement advanced automation systems and real-time analytics with greater efficiency. The integration of communication technologies with warehouse management systems therefore represents a major step toward intelligent retail ecosystems.

Despite the significant advantages associated with Industry 4.0 technologies, the implementation of smart warehouse systems also presents substantial managerial and operational challenges. Organizations often encounter financial limitations, technological complexity, workforce resistance, cybersecurity concerns, and integration difficulties during digital transformation processes. The successful implementation of Industry 4.0 technologies requires strategic planning, skilled human resources, organizational readiness, and effective change management practices [5, 19]. Furthermore, many organizations struggle to prioritize technological investments due to the large number of available technologies and the uncertainty associated with implementation outcomes. Consequently, identifying and prioritizing the most influential dimensions and technologies becomes essential for effective warehouse modernization strategies.

Safety considerations also represent a critical component of smart warehouse implementation. Advanced warehouse technologies may reduce human exposure to hazardous activities; however, they simultaneously introduce new technological and operational risks. Automated systems, robotics, and interconnected digital infrastructures require comprehensive safety management frameworks to prevent accidents, operational disruptions, and cybersecurity vulnerabilities. Personnel safety, equipment reliability, and disaster resilience must therefore be integrated into warehouse technology evaluation processes [10, 20]. In highly automated warehouse environments, organizations must balance operational efficiency with workplace safety and system reliability.

Recent studies have emphasized the growing importance of Industry 4.0 maturity and digital transformation frameworks across different industries. Digital maturity models enable organizations to assess their technological readiness, operational capabilities, and strategic alignment with Industry 4.0 principles. Such frameworks support organizations in identifying implementation gaps and prioritizing technological development initiatives [21, 22]. In the context of retail warehouse management, maturity assessment and integrated decision-making models are particularly important because warehouse systems involve complex interactions among technological, environmental, managerial, and operational dimensions.

Multi-criteria decision-making approaches have increasingly been employed to evaluate and prioritize Industry 4.0 technologies due to the complexity and multidimensional nature of implementation processes. Techniques such as TOPSIS and BWM provide systematic frameworks for evaluating alternatives based on multiple qualitative and quantitative criteria. These methods facilitate the identification of critical success factors and support strategic decision-making under uncertainty. The integration of fuzzy logic with multi-criteria decision-making models further improves analytical precision by incorporating expert judgments and linguistic evaluations into the decision-making process [23, 24]. Consequently, integrated analytical approaches are highly valuable for evaluating smart warehouse technologies within complex retail environments.

The transformation of retail supply chains toward intelligent and sustainable operational systems has therefore created an urgent need for comprehensive evaluation models capable of analyzing Industry 4.0 technologies from multiple perspectives. Existing studies have often focused on isolated technological dimensions or specific operational outcomes, while limited attention has been devoted to integrated analyses combining economic, environmental, safety, managerial, and supervisory considerations within warehouse management systems of chain stores. Moreover, the prioritization of smart warehousing technologies through integrated BWM-TOPSIS approaches remains relatively underexplored in the context of retail warehouse management. Therefore, the present study aims to provide an integrated analysis of Industry 4.0 technologies in warehouse management of chain stores based on the BWM-TOPSIS technique.

2. Methodology

In this study, the orientation or objective layer of the research was considered applied in nature, such that its primary focus was on solving a specific problem and applying knowledge within a practical context. Accordingly, the present research was designed and implemented as a systematic study. Within this framework, quantitative strategies are mainly employed for the purpose of describing and explaining phenomena, whereas qualitative strategies focus on the exploration, interpretation, and deeper understanding of issues. Mixed-method strategies, depending on the type of research design, provide the possibility of simultaneously benefiting from description, explanation, understanding, and exploration. In the present study, the methodological layer is grounded in a quantitative approach, and the research is classified as a descriptive, non-experimental study. At the strategic layer of the present research, the survey method was selected. In this context, the questionnaire is considered one of the most common instruments for data collection. Accordingly, the environmental layer of the present study falls within the category of natural descriptive research. In the present study, the layer related to data collection methods was designed based on the combined use of library research, document and record review, and questionnaires, and these methods were employed as the primary instruments for data collection. In the continuation of the study, following the preliminary review, the process of collecting the main criteria from experts' perspectives was explained, and experts' verbal expressions were utilized for the integrated analysis of Industry 4.0 technologies in the field of warehouse management. After conversion into quantitative values, these data were analyzed using the BWM and TOPSIS techniques in order to determine the significance and priority of the influential criteria.

3. Findings and Results

The findings of the present study indicate that the dimensions extracted through expert opinions during the research process consisted of economic, environmental, safety, managerial, and supervisory dimensions. The economic dimension included investment costs, operational costs, and expected returns. Investment costs encompassed all capital expenditures related to the establishment and development of technology infrastructure and directly influenced financing requirements and capital allocation arrangements. Operational costs represented the ongoing expenditures associated with the implementation stages of warehouse management and were considered essential for long-term effectiveness. Expected return measured the profitability and revenue generation of the implementation plan and played a significant role in economic feasibility assessments.

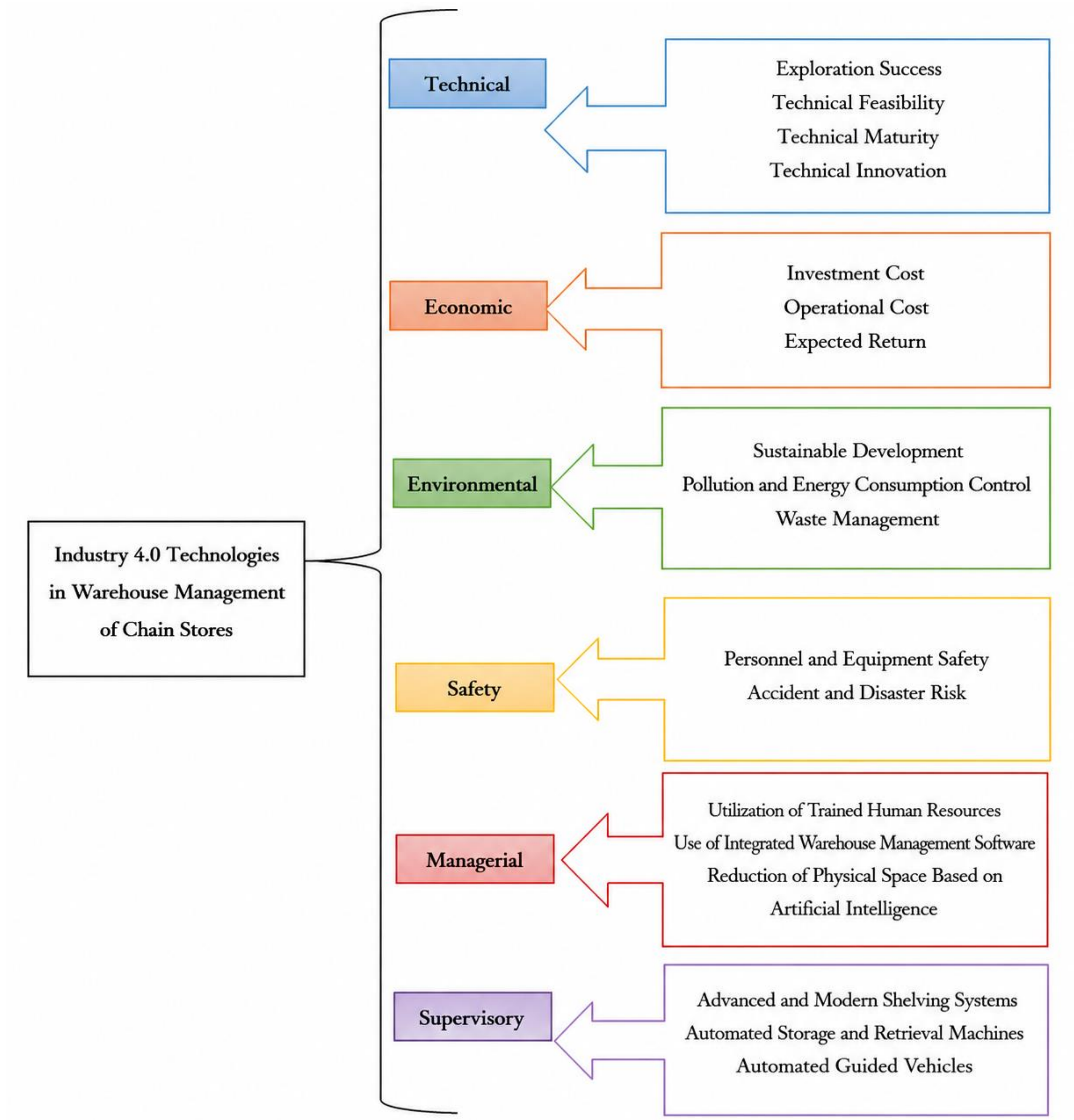

Figure 1. Indicator System for the Implementation of Industry 4.0 Technologies in Warehouse Management of Chain Stores

The environmental dimension included sustainable development, pollution control, energy consumption control, and waste management. Sustainable development aimed to ensure a balance between economic growth, environmental protection, and operational performance in warehouse management systems of chain stores. Pollution control assessments were conducted to minimize negative impacts on environmental resources and preserve ecosystem quality and workplace conditions. Energy consumption control emphasized reducing energy usage through optimized lighting systems, HVAC systems, insulation technologies, and intelligent monitoring systems. Effective waste management and recycling throughout the supply chain and logistics operations were also identified as strategic necessities for improving warehouse management performance.

The safety dimension comprised personnel safety, equipment safety, and disaster and accident risk management. Personnel safety focused on protecting employees working within chain store environments. Equipment safety evaluated the operational reliability and safety performance of warehouse equipment, while disaster and accident risk management assessed resilience and contingency planning capabilities against potential disruptions.

The managerial dimension included the employment of trained human resources, utilization of integrated warehouse management software, and reduction of physical space through artificial intelligence technologies. Skilled human resources were recognized as one of the most valuable organizational assets, particularly in the retail and FMCG sectors. Integrated warehouse management software contributed to process optimization, inventory transparency, reduction of human error, and enhanced delivery speed. Artificial intelligence-based reduction of physical warehouse space minimized manual activities and enabled personnel to focus on strategic operations.

The supervisory dimension consisted of advanced shelving systems, automated storage and retrieval machines, and automated guided vehicles. Advanced shelving systems improved operational efficiency and customer satisfaction while reducing warehousing costs. Automated storage and retrieval machines were identified as critical components of modern warehousing systems due to their ability to perform loading and unloading operations without direct human intervention. Automated guided vehicles also enhanced transportation efficiency by replacing traditional forklifts and manual carts.

The TOPSIS method was applied as a multi-criteria decision-making approach integrating both qualitative and quantitative aspects. The interval estimation principle emphasized that only indicators with significant contributions to the decision-making objective should be retained as evaluation criteria. However, constructing precise judgment matrices in hierarchical analyses may generate inconsistencies that influence the resulting weight vectors. Consequently, indicators with lower relative importance were removed to improve decision-making accuracy and reduce analytical complexity.

The screening process for indicators depended on whether the constructed judgment matrix satisfied the consistency criterion. For consistent matrices, screening was performed directly based on indicator weights. For inconsistent matrices, interval estimation techniques were applied before screening weak indicators.

The consistency ratio was calculated using the following relationship:

$$CR = \frac{CI}{RI}$$

where CIrepresents the consistency index and RIdenotes the random consistency index.

The consistency index was determined through the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

where $\lambda_{max}$is the maximum eigenvalue of the judgment matrix and $n$denotes the order of the matrix.

The probabilistic linguistic term set (PLTS) was expressed as follows:

$$L(P) = \{L^{(k)}(P^{(k)}) \mid k = 1,2,\dots,n\}$$

The normalization equation for PLTS was defined as:

$$\tilde{P}^{(k)} = \frac{P^{(k)}}{\sum_{k=1}^{n} P^{(k)}}$$

The score function of the probabilistic linguistic term set was calculated using:

$$S(L(P)) = \sum_{k=1}^{n} r_k \, P^{(k)}$$

The deviation function was expressed as:

$$\sigma(L(P)) = \sqrt{\sum_{k=1}^{n} (r_k - S(L(P)))^2 P^{(k)}}$$

The hesitation degree of the PLTS was obtained through:

$$H(L(P)) = 1 - \sum_{k=1}^{n} P^{(k)}$$

Finally, the transformation function converting probabilistic linguistic terms into crisp values was formulated as:

$$T(L(P)) = S(L(P))(1 - H(L(P)))$$

The linguistic scale used for pairwise comparisons ranged from 1 to 9, where 1 represented equal importance between two criteria, 3 indicated slight importance, 5 represented significant importance, 7 denoted strong importance, and 9 indicated extreme importance. Intermediate values of 2, 4, 6, and 8 represented compromise judgments between adjacent scales. Furthermore, the random consistency index (RI) values ranged from 0 for matrices of order 1 and 2 to 1.51 for matrices of order 10.

At the next stage, the six main dimensions were weighted and prioritized. The dimensions included technical (C1), economic (C2), environmental (C3), safety (C4), managerial (C5), and supervisory (C6) criteria.

Table 1. Weighting and Prioritization of Main Dimensions

Dimension Code	Dimension	Crisp Weight	Normalized Weight	Rank
C1	Technical	0.198	0.192	1
C2	Economic	0.131	0.127	5
C3	Environmental	0.111	0.107	3
C4	Safety	0.194	0.188	2
C5	Managerial	0.168	0.162	4
C6	Supervisory	0.232	0.224	6

The results of Table 1 demonstrate that the technical dimension obtained the highest normalized weight (0.192), followed closely by the safety dimension (0.188). The environmental and managerial dimensions ranked third and fourth, respectively, while the economic and supervisory dimensions occupied the fifth and sixth positions. These findings indicate that technological capability and safety-related considerations are the most influential criteria in the implementation of Industry 4.0 technologies within warehouse management systems.

The pairwise comparison matrices generated from expert evaluations satisfied the required consistency conditions. The inconsistency ratios calculated by the software were $CR_m = 0.011414$and $CR_g = 0.032545$, both indicating acceptable consistency levels because the obtained values were below the threshold of 0.10.

A total of 18 alternatives were evaluated during the ranking process. These alternatives included exploration success (A1), technical feasibility (A2), technical maturity (A3), technical innovation (A4), investment cost (A5), operational cost (A6), expected return (A7), sustainable development (A8), pollution and energy consumption control (A9), waste management (A10), personnel and equipment safety (A11), disaster and accident risk (A12), trained workforce utilization (A13), integrated warehouse management software (A14), AI-based physical space reduction (A15), advanced shelving systems (A16), automated storage and retrieval machines (A17), and automated guided vehicles (A18).

Table 2. Evaluated Alternatives and Their Codes

Code	Alternative
A1	Exploration Success
A2	Technical Feasibility
A3	Technical Maturity
A4	Technical Innovation
A5	Investment Cost
A6	Operational Cost
A7	Expected Return
A8	Sustainable Development
A9	Pollution and Energy Consumption Control
A10	Waste Management
A11	Personnel and Equipment Safety
A12	Disaster and Accident Risk
A13	Utilization of Trained Human Resources
A14	Integrated Warehouse Management Software
A15	AI-Based Reduction of Physical Space
A16	Advanced Shelving Systems
A17	Automated Storage and Retrieval Machines
A18	Automated Guided Vehicles

The fuzzy evaluations of the alternatives were transformed into normalized matrices according to the weighting process. The resulting normalized weights are presented below.

Table 3. Normalized Weights of Alternatives

Alternative	Crisp Weight	Normalized Weight
A1	0.062	0.060
A2	0.075	0.069
A3	0.051	0.047
A4	0.053	0.051
A5	0.073	0.070
A6	0.067	0.063
A7	0.045	0.042
A8	0.019	0.015
A9	0.040	0.037
A10	0.055	0.051
A11	0.084	0.081
A12	0.050	0.044
A13	0.032	0.028
A14	0.069	0.064
A15	0.046	0.042
A16	0.065	0.062
A17	0.083	0.078
A18	0.098	0.096

The results in Table 3 reveal that automated guided vehicles (A18) achieved the highest normalized weight (0.096), followed by personnel and equipment safety (A11) with a normalized weight of 0.081 and automated storage and retrieval machines (A17) with a normalized weight of 0.078. In contrast, sustainable development (A8) and trained workforce utilization (A13) obtained the lowest normalized weights among the evaluated alternatives.

The inconsistency rates associated with the alternative-level analysis were also examined. The software-generated values were $CR_m = 0.034244$and $CR_g = 0.064436$, indicating that the comparison matrices remained within acceptable consistency thresholds.

Table 4. Consistency Ratios of the Alternative Evaluation Matrix

Consistency Measure	Value
CR_m	0.034244
CR_g	0.064436
Status	Consistent

The final ranking of the integrated Industry 4.0 dimensions in warehouse management of chain stores was subsequently determined based on the normalized weights.

Table 5. Final Ranking of Integrated Industry 4.0 Dimensions in Warehouse Management of Chain Stores

Rank	Alternative
1	A18 – Automated Guided Vehicles
2	A11 – Personnel and Equipment Safety
3	A17 – Automated Storage and Retrieval Machines
4	A5 – Investment Cost
5	A2 – Technical Feasibility
6	A14 – Integrated Warehouse Management Software
7	A6 – Operational Cost
8	A16 – Advanced Shelving Systems
9	A1 – Exploration Success
10	A4 – Technical Innovation
11	A10 – Waste Management
12	A3 – Technical Maturity
13	A12 – Disaster and Accident Risk
14	A7 – Expected Return
15	A15 – AI-Based Reduction of Physical Space
16	A9 – Pollution and Energy Consumption Control
17	A13 – Utilization of Trained Human Resources
18	A8 – Sustainable Development

According to the final TOPSIS ranking presented in Table 5, automated guided vehicles (A18) and personnel and equipment safety (A11) ranked first and second among the influential dimensions affecting the integration of Industry 4.0 technologies in warehouse management systems of chain stores. Automated storage and retrieval machines (A17) ranked third, reflecting the strategic importance of automation technologies in modern warehouse operations. In contrast, sustainable development (A8), trained workforce utilization (A13), and pollution and energy consumption control (A9) received comparatively lower priorities within the final ranking structure.

4. Discussion and Conclusion

The findings of the present study demonstrated that Industry 4.0 technologies play a fundamental role in improving warehouse management systems within chain stores, particularly through intelligent automation, integrated operational management, and smart logistics technologies. The results indicated that automated guided vehicles, personnel and equipment safety, and automated storage and retrieval systems obtained the highest priorities among the evaluated dimensions. These findings confirm that modern retail warehouse systems increasingly rely on intelligent automation technologies to enhance operational efficiency, reduce human intervention, and improve supply chain responsiveness. The prioritization of automated guided vehicles reflects the growing importance of autonomous transportation technologies in warehouse operations, especially in large-scale retail distribution environments where speed, accuracy, and flexibility are essential operational requirements. These findings are consistent with the arguments proposed by [3], who emphasized that automated warehouse systems significantly improve operational productivity and reduce warehousing inefficiencies through intelligent process automation. Similarly, [10] highlighted that artificial intelligence-driven warehousing solutions enhance organizational agility and optimize operational coordination within smart warehouse ecosystems.

The high ranking of personnel and equipment safety in the present study further demonstrates that safety considerations remain critical despite the expansion of automation technologies. While Industry 4.0 technologies reduce exposure to physically hazardous tasks, they simultaneously introduce technological and operational complexities requiring sophisticated safety management systems. Intelligent warehouse environments depend heavily on interconnected digital systems, automated machinery, and cyber-physical infrastructures that require continuous monitoring and preventive maintenance. Consequently, organizations prioritize personnel and equipment safety to ensure operational continuity and minimize technological risks. These findings are aligned with the study conducted by [20], which emphasized that risk management and operational safety are fundamental determinants of supply chain resilience in retail industries. Moreover, [19] argued that smart warehouse management systems must integrate technological functionality with operational safety frameworks to ensure sustainable implementation outcomes.

The results also revealed the significant importance of automated storage and retrieval systems within integrated Industry 4.0 warehouse environments. Such systems improve warehouse space utilization, inventory accuracy, and operational speed while reducing manual labor dependency. The strategic importance of these technologies is particularly evident in retail supply chains characterized by high inventory turnover and increasing customer expectations for rapid order fulfillment. These findings are consistent with the research conducted by [13], who demonstrated that intelligent order-picking and conveyor systems substantially improve warehouse operational efficiency and logistics performance. Similarly, [8] emphasized that advanced logistics technologies and intelligent warehouse infrastructures are essential for the development of modern logistics centers capable of responding to rapidly changing market conditions.

The prioritization results further indicated that investment cost and technical feasibility occupied relatively high positions among the evaluated dimensions. This finding suggests that organizations consider financial viability and technological readiness as key determinants in the adoption of Industry 4.0 technologies. Although intelligent warehousing systems offer substantial operational advantages, their implementation often requires considerable financial investment in infrastructure, software systems, robotics, and digital integration platforms. Consequently, organizations carefully evaluate the economic feasibility of smart warehouse projects before implementation. These findings support the observations of [18], who argued that the integration of advanced technologies such as 5G, artificial intelligence, and digital connectivity systems significantly influences supply chain operational costs and investment structures. Likewise, [11] emphasized that interconnected smart manufacturing technologies require substantial organizational investment and technological preparedness to achieve successful implementation outcomes.

Another important finding of the present study was the moderate ranking of integrated warehouse management software systems. This result highlights the strategic role of digital platforms in coordinating warehouse activities, improving inventory transparency, and facilitating data-driven decision-making. Intelligent software systems support real-time monitoring, inventory optimization, and process synchronization throughout warehouse operations. The growing significance of integrated software systems reflects the increasing digitalization of retail supply chains and the transition toward data-centric operational environments. These findings are consistent with the study by [7], which identified digital supply chain management systems as critical enablers of operational integration and organizational flexibility. Furthermore, [9] emphasized that artificial intelligence-driven digital systems substantially improve business process optimization and strategic decision-making in smart retail environments.

The findings additionally demonstrated that environmental dimensions such as sustainable development, pollution control, and waste management received comparatively lower priorities than automation and safety dimensions. Although sustainability has become an increasingly important concern in modern supply chain management, retail organizations may still prioritize operational efficiency and technological functionality over long-term environmental objectives during the early stages of digital transformation. Nevertheless, the inclusion of environmental criteria within the analytical framework indicates that sustainability considerations remain strategically relevant in smart warehouse management systems. These findings partially align with the arguments of [5], who emphasized the growing integration of socially and environmentally sustainable practices within warehouse management systems. Likewise, [6] argued that Industry 4.0 technologies significantly contribute to environmental resilience and circular economy initiatives through optimized resource utilization and intelligent operational management.

The relatively low ranking of sustainable development and trained workforce utilization may also indicate that retail organizations perceive technological infrastructure and automation capabilities as more immediate operational priorities than human resource development and environmental sustainability initiatives. However, this finding does not necessarily diminish the importance of human capital within smart warehouse systems. In fact, Industry 4.0 implementation requires highly skilled employees capable of operating, monitoring, and maintaining advanced digital infrastructures. The transition toward intelligent warehouse systems therefore demands continuous workforce development and organizational learning. These findings correspond with the observations of [2], who emphasized the importance of technological education and digital competencies within smart supply chain systems. Similarly, [21] highlighted that Industry 4.0 maturity frameworks depend heavily on organizational readiness and human resource capabilities.

The findings also confirmed the importance of supervisory dimensions such as advanced shelving systems and intelligent inventory transportation technologies. These technologies improve warehouse organization, storage optimization, and inventory accessibility while supporting automated operational processes. Smart shelving systems and automated transportation technologies contribute to higher warehouse capacity utilization and improved inventory management efficiency. These findings support the conclusions of [24], who argued that intelligent logistics systems transform transportation and warehousing operations into more sustainable and efficient infrastructures. Similarly, [4] demonstrated that Logistics 4.0 technologies significantly enhance retail supply chain performance by improving operational coordination and technological integration.

The consistency ratios obtained in the present study indicated that the expert evaluations and judgment matrices possessed acceptable reliability and analytical consistency. This finding demonstrates the effectiveness of the BWM-TOPSIS approach in analyzing complex Industry 4.0 implementation criteria within retail warehouse environments. The integration of fuzzy logic, probabilistic linguistic evaluations, and multi-criteria decision-making methods enabled a comprehensive assessment of technological priorities and operational dimensions. The effectiveness of integrated analytical models in evaluating complex technological systems has also been emphasized in previous studies. For instance, [23] argued that multi-criteria evaluation techniques provide valuable frameworks for prioritizing IoT-driven sustainability initiatives in retail chains. Likewise, [25] demonstrated that integrated digital evaluation frameworks significantly improve decision-making quality within Industry 4.0 supply chain systems.

The present findings additionally highlight the broader transformation occurring within retail logistics and warehouse management systems under the influence of Industry 4.0 technologies. Digital transformation has shifted warehouse operations from labor-intensive and isolated activities toward interconnected, intelligent, and data-driven systems capable of autonomous decision-making and adaptive operational control. This transformation has become increasingly important due to the expansion of e-commerce and omni-channel retailing. Organizations are now required to manage higher inventory complexity, shorter delivery times, and rapidly fluctuating customer demands. Consequently, intelligent warehouse systems have emerged as essential components of competitive retail supply chains. These findings are strongly supported by [1], who emphasized the growing strategic role of e-retailing and digital operational infrastructures in modern business environments. Additionally, [26] argued that sustainability and digital transformation have become inseparable dimensions of contemporary e-commerce and supply chain management systems.

The findings further indicate that the implementation of Industry 4.0 technologies within warehouse management systems requires a multidimensional strategic perspective that simultaneously considers technological, economic, environmental, managerial, and operational dimensions. The successful integration of intelligent warehouse technologies depends not only on technological capability but also on organizational readiness, managerial support, financial investment, and operational adaptability. These results are aligned with the perspective of [27], who highlighted that smart and sustainable supply chains require integrated strategic approaches capable of balancing operational efficiency, sustainability, and technological innovation. Likewise, [22] emphasized that Industry 4.0 technologies contribute significantly to sustainable operational transformation when implemented through integrated organizational frameworks.

One of the most important implications of the present study is that intelligent automation technologies appear to dominate organizational priorities within retail warehouse modernization strategies. Automated guided vehicles, robotic systems, and intelligent inventory technologies provide direct operational benefits that are immediately observable through increased efficiency, reduced labor costs, and faster order processing. Consequently, organizations tend to prioritize these technologies during Industry 4.0 implementation initiatives. However, the findings also suggest that sustainability, workforce development, and environmental management should receive greater attention to ensure balanced and sustainable technological transformation. Without adequate investment in human resources and environmental practices, organizations may face long-term operational and strategic challenges despite achieving short-term efficiency improvements.

The present study was subject to several limitations. First, the study relied on expert opinions and subjective evaluations collected through questionnaires, which may introduce perceptual bias into the weighting and ranking processes. Second, the research focused specifically on warehouse management systems within chain stores, limiting the generalizability of the findings to other industries or supply chain contexts. Third, the cross-sectional nature of the study prevented the examination of long-term technological implementation outcomes and dynamic changes in Industry 4.0 adoption over time. Additionally, the study evaluated technological dimensions primarily from a managerial and operational perspective without directly measuring actual organizational performance indicators following implementation.

Future research should investigate the long-term impacts of Industry 4.0 technologies on warehouse operational performance, supply chain resilience, and sustainability outcomes through longitudinal and empirical studies. Researchers may also examine the interactions among technological readiness, organizational culture, and employee acceptance within smart warehouse environments. Comparative studies across different industries and geographical contexts would further improve understanding of Industry 4.0 implementation challenges and success factors. In addition, future studies could integrate advanced analytical methods such as machine learning algorithms, simulation modeling, and real-time operational analytics into Industry 4.0 evaluation frameworks.

From a practical perspective, managers of chain stores and retail organizations should prioritize the gradual integration of intelligent automation technologies, particularly automated guided vehicles and automated storage systems, to improve operational efficiency and warehouse responsiveness. Organizations should simultaneously invest in workforce training, cybersecurity infrastructure, and digital integration capabilities to support sustainable technological transformation. Furthermore, retail managers should adopt comprehensive implementation strategies that balance operational efficiency with environmental sustainability and employee safety considerations. The use of integrated decision-making models such as BWM-TOPSIS can also assist organizations in prioritizing technological investments and identifying the most influential dimensions affecting smart warehouse implementation success.

Authors' Contributions

Authors equally contributed to this article.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all participants who participate in this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

References

[1] U. Ramanathan, M. Mathirajan, and S. Balakrishnan, "Role of E-Tailing: A New Way of Business During COVID Situation in India – A Critical View," *Benchmarking an International Journal*, vol. 31, no. 3, pp. 1062-1072, 2024, doi: 10.1108/bij-04-2024-785.

[2] T. Shi, S. J. Lee, and Q. Li, "Smart Supply Chain Management in Business Education: Reflection on the Pandemics," *Decision Sciences Journal of Innovative Education*, vol. 22, no. 1, pp. 19-32, 2023, doi: 10.1111/dsji.12303.

[3] O. F. Odeyinka and O. G. Omoegun, "Warehouse Operations: An Examination of Traditional and Automated Approaches in Supply Chain Management," 2024, doi: 10.5772/intechopen.113147.

[4] M. Hrouga and A. Sbihi, "Logistics 4.0 for Supply Chain Performance: Perspectives From A retailing Case Study," *Business Process Management Journal,* vol. 29, no. 6, pp. 1892-1919, 2023, doi: 10.1108/bpmj-03-2023-0183.
[5] D. Minashkina, "A Review and Research Agenda For recent Socially and Environmentally Sustainable Practices for Warehouse Management Systems," *The International Journal of Logistics Management,* vol. 35, no. 7, pp. 60-98, 2024, doi: 10.1108/ijlm-07-2023-0265.
[6] R. Singh, S. Rani, and V. Kandpal, "Driving Environmental Resilience: Integrating Industry 4.0 for Circular Economy," in *Green Futures: Navigating the Path to Environmental Resilience*. Singapore: Springer Nature Singapore, 2025, pp. 23-40.
[7] N. Chaplynska and Y. K. Chelombitko, "Digitalization of Supply Chain Management (Based on the Sports Industry Company Signa Sports United)," *Business Economics Sustainability Leadership and Innovation,* no. 10, pp. 64-80, 2023, doi: 10.37659/2663-5070-2023-10-64-80.
[8] M. D. Nguyen, K. T. Yeon, K. Rudzki, H. P. Nguyen, and N. D. K. Pham, "Strategies for Developing Logistics Centres: Technological Trends and Policy Implications," *Polish Maritime Research,* vol. 30, no. 4, pp. 129-147, 2023, doi: 10.2478/pomr-2023-0066.
[9] T. Guo and T. D. Palaoag, "Artificial Intelligence Driven E-Commerce Business Model Under New Retail Environment," 2023, doi: 10.4108/eai.2-12-2022.2328056.
[10] J. R. Hamilton, S. Maxwell, S. Ali, and S. Tee, "Adding External Artificial Intelligence (AI) Into Internal Firm-Wide Smart Dynamic Warehousing Solutions," *Sustainability,* vol. 16, no. 10, p. 3908, 2024, doi: 10.3390/su16103908.
[11] P. C. Kandarkar and V. Ravi, "Investigating the Impact of Smart Manufacturing and Interconnected Emerging Technologies in Building Smarter Supply Chains," *Journal of Manufacturing Technology Management,* vol. 35, no. 5, pp. 984-1009, 2024, doi: 10.1108/jmtm-11-2023-0498.
[12] G. Thanasas, G. Kampiotis, and C. Halkiopoulos, "Transforming digital accounting: Big data, IoT, and Industry 4.0 technologies-A comprehensive survey," *Journal of Risk and Financial Management,* vol. 19, no. 1, p. 92, 2026, doi: 10.3390/jrfm19010092.
[13] K. Czerniachowska, R. Wichniarek, and K. Żywicki, "A Model for an Order-Picking Problem With a One-Directional Conveyor and Buffer," *Sustainability,* vol. 15, no. 18, p. 13731, 2023, doi: 10.3390/su151813731.
[14] T. Mukherjee, I. Sangal, B. Sarkar, Q. Almaamari, and T. M. Alkadash, "How Effective Is Reverse Cross-Docking and Carbon Policies in Controlling Carbon Emission From the Fashion Industry?," *Mathematics,* vol. 11, no. 13, p. 2880, 2023, doi: 10.3390/math11132880.
[15] H. P. Gund and J. Daniel, "Q-Commerce or E-Commerce? A systematic State of the Art On comparative Last-Mile Logistics Greenhouse Gas Emissions Literature Review," *International Journal of Industrial Engineering and Operations Management,* vol. 6, no. 3, pp. 185-207, 2023, doi: 10.1108/ijieom-01-2023-0001.
[16] J. Luo, "Sustainable Supply Chain Strategies in E-Commerce: Case Studies of Amazon and Cainiao," *Advances in Economics Management and Political Sciences,* vol. 65, no. 1, pp. 181-187, 2023, doi: 10.54254/2754-1169/65/20231629.
[17] R. Li, W. Liu, and X. Ye, "Analysis of Green Supply Chain Construction and Driving Factors in the Context of New Retail: Case Study of JD.com," *Advances in Economics Management and Political Sciences,* vol. 112, no. 1, pp. 132-140, 2024, doi: 10.54254/2754-1169/112/20242310.
[18] W. L. Brown, O. Johnson, and G. Wilson, "The Impact of 5G Technology on Retail Marketing and Supply Chain Operations," 2024, doi: 10.20944/preprints202407.2073.v1.
[19] N. Khan, W. D. Solvang, H. Yu, and B. E. Rolland, "Towards the Design of a Smart Warehouse Management System for Spare Parts Management in the Oil and Gas Sector," *Frontiers in Sustainability,* vol. 5, 2024, doi: 10.3389/frsus.2024.1426089.
[20] Z. Liu, "On Supply Chain Risk in Retail IndustryTaking Costco as an Example," *Advances in Economics Management and Political Sciences,* vol. 92, no. 1, pp. 209-217, 2024, doi: 10.54254/2754-1169/92/20231300.
[21] B. Zeinati, M. Taleghani, and A. Sharj-Sharifi, "Designing Industry 4.0 maturity dimensions in the banking services supply chain and digital banking development using a grounded theory approach," 2025.
[22] J. Oliveira, D. Schreiber, and V. D. Jahno, "Sustainability in civil construction through Industry 4.0 and BIM technologies," *Automation in Construction,* vol. 182, p. 106729, 2026, doi: 10.1016/j.autcon.2025.106729.
[23] K. S. Karthikeyan and T. Nagaprakash, "Prioritizing IoT-driven Sustainability Initiatives in Retail Chains: Exploring Case Studies and Industry Insights," *Eai Endorsed Transactions on Internet of Things,* vol. 10, 2023, doi: 10.4108/eetiot.4628.
[24] F.-E. Bueno-Pascual, "Forces Transforming Transport and Logistics Into Smarter Sustainable Systems," 2024, doi: 10.5772/intechopen.1005001.
[25] Z. Raza, I. U. Haq, and M. Muneeb, "Agri-4-All: A Framework for Blockchain Based Agricultural Food Supply Chains in the Era of Fourth Industrial Revolution," *Ieee Access,* vol. 11, pp. 29851-29867, 2023, doi: 10.1109/access.2023.3259962.
[26] S. V. Jovanović, G. Đoković, A. Pušara, and A. Pavićević, "The Concept of Sustainability in E-Commerce and Busines," *Ecologica,* vol. 30, no. 109, pp. 67-75, 2023, doi: 10.18485/ecologica.2023.30.109.10.

[27] P. Golińska-Dawson, B. Mrugalska, K. K. Lai, and G. W. Weber, "Editorial: Smart and Sustainable Supply Chain and Logistics - trends, Challenges, Methods and Best Practices," *Annals of Operations Research,* vol. 324, no. 1-2, pp. 1-11, 2023, doi: 10.1007/s10479-023-05304-7.