

Capability–Attractiveness Analysis of the Application of Industry 4.0 Technologies in Smart Warehousing of Chain Stores with a Sustainability Approach

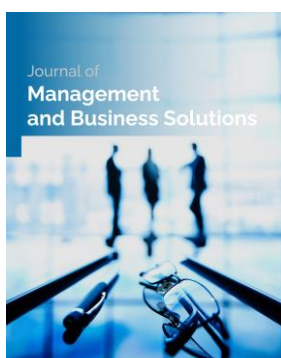
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ABSTRACT

Chain stores have expanded significantly in recent years. Warehouse management is one of the critical activities in the chain store industry, as improper execution can lead to delays in the supply and distribution of required goods, customer dissatisfaction, increased waste, employee overtime, and higher operational costs. Therefore, it is evident that utilizing the technologies emerging from the Fourth Industrial Revolution can substantially reduce time, energy consumption, and costs. Conversely, neglecting these technologies not only results in financial and operational losses but may also lead to the loss of competitive market position. One aspect that has received limited attention so far is the necessity of ranking and prioritizing the applications of these technologies based on their capability–attractiveness and scope of application. Accordingly, the present study was conducted with the aim of analyzing the capability–attractiveness of Industry 4.0 technology applications in smart warehousing of chain stores with a sustainability approach. A comprehensive analysis was conducted on data collected from an expert population consisting of academic specialists, artificial intelligence experts, and software engineers. Given this group's extensive knowledge and expertise in Industry 4.0 technologies and smart warehousing systems for chain stores, their perspectives were considered essential for weighting the indicators. For this purpose, specialized questionnaires were distributed among the experts in order to collect their evaluations regarding the “attractiveness” and “capability” indicators. In the analysis section, the weights of the indicators were first determined using the Best–Worst Method (BWM). Subsequently, various applications of Industry 4.0 technologies in smart warehousing of chain stores were evaluated using the VIKOR ranking method. The findings indicate that the ability to search for and locate required goods in the warehouse in the shortest possible time, together with the automatic recording of inventory reductions from shelves or pallets within the warehouse management system, reflects a high level of attractiveness and capability of the system. In addition, the capability of identifying the most appropriate placement of items based on the latest layout configuration, which demonstrates low attractiveness but high capability, was identified as a notable feature. On the other hand, access to real-time warehouse inventory, elimination of human errors in loading and dispatch processes, and optimal utilization of warehouse space based on awareness of optimal order quantities demonstrate high attractiveness but lower capability. Furthermore, accurate inventory counting in the shortest possible time, automatic recording of inspection, maintenance, and repair data, establishment of intelligent communication among machinery and equipment in warehouse management processes, and awareness of the exact inventory status of shelves or pallets during placement operations were all identified as indicators with limited attractiveness and capability.

Keywords: Capability–Attractiveness, Industry 4.0 Technology, Smart Warehousing, Chain Stores, Sustainability



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Introduction

The rapid expansion of chain stores and the transformation of retail business models in recent years have fundamentally altered supply chain structures and warehousing operations worldwide. The acceleration of e-commerce, digital retailing, and omnichannel distribution systems has intensified the need for intelligent, agile, and sustainable warehouse management systems capable of responding to increasingly dynamic customer demands (1, 2). Traditional warehousing approaches, which are often characterized by labor-intensive operations, fragmented information systems, and limited real-time visibility, are no longer sufficient to support modern retail logistics environments. As a result, organizations have increasingly turned toward Industry 4.0 technologies to enhance operational efficiency, inventory visibility, automation capabilities, and supply chain responsiveness (3, 4). In this context, smart warehousing has emerged as one of the most significant applications of Industry 4.0 within retail and logistics systems because it integrates intelligent technologies such as the Internet of Things (IoT), artificial intelligence (AI), robotics, cloud computing, cyber-physical systems, blockchain, and real-time data analytics into warehouse operations (5, 6).

Industry 4.0 technologies have transformed warehousing from a traditional storage-oriented function into an intelligent and data-driven operational ecosystem capable of supporting sustainable supply chain performance. Smart warehouses provide real-time inventory monitoring, automated order processing, optimized storage allocation, predictive maintenance, intelligent routing, and seamless communication among machines and operational systems (7, 8). The integration of interconnected technologies has enabled retailers to minimize operational delays, reduce inventory inaccuracies, decrease labor dependency, and improve customer responsiveness. Research demonstrates that the application of intelligent manufacturing systems and interconnected technologies significantly improves the adaptability and resilience of supply chains in highly competitive retail environments (5). Furthermore, AI-driven retail systems support intelligent forecasting, demand prediction, and operational optimization, thereby contributing to more efficient warehouse management and supply chain coordination (2, 7).

The emergence of digital retail ecosystems has also intensified concerns regarding sustainability and environmental performance within warehousing and logistics activities. Warehouses are major consumers of energy and resources, while logistics activities contribute substantially to greenhouse gas emissions, waste generation, and environmental degradation (9, 10). Consequently, organizations are increasingly expected to adopt sustainable warehousing strategies that balance operational efficiency with environmental and social responsibilities. Industry 4.0 technologies have been recognized as key enablers of sustainable logistics and green supply chain management because they improve resource utilization, reduce energy consumption, optimize transportation processes, and support circular economy initiatives (11, 12). In addition, intelligent warehouse systems facilitate waste reduction, operational transparency, and optimized inventory turnover, thereby contributing to sustainable operational performance (13, 14).

Sustainability in supply chain and logistics systems is generally conceptualized through economic, social, and environmental dimensions. From an economic perspective, smart warehousing technologies can reduce operational costs, improve inventory management, and increase productivity and profitability (13, 15). Social sustainability dimensions include improving customer satisfaction, enhancing employee safety, accelerating order fulfillment, and increasing organizational innovation capabilities (16, 17). Environmental sustainability dimensions

emphasize pollution reduction, energy efficiency, waste management, and carbon emission mitigation (10, 11). Studies have shown that organizations adopting digital supply chain systems and smart logistics technologies achieve superior sustainability outcomes compared with traditional operational models (12, 18). Accordingly, sustainability-oriented smart warehousing has become a strategic priority for modern retail chains operating in highly dynamic competitive markets.

Recent developments in Logistics 4.0 and smart supply chain management have further accelerated the adoption of advanced warehousing technologies in retail industries. Logistics 4.0 refers to the integration of digital technologies and automation systems into logistics and warehouse operations in order to achieve intelligent, interconnected, and autonomous operational processes (4). Smart warehousing systems within Logistics 4.0 environments rely heavily on automation technologies such as autonomous mobile robots, smart sensors, RFID systems, machine learning algorithms, digital twins, and predictive analytics tools (3, 6). These technologies enhance warehouse visibility and operational synchronization while improving decision-making accuracy and reducing human intervention in repetitive tasks. Research indicates that technologically integrated logistics systems significantly improve warehouse operational efficiency and supply chain flexibility, particularly in retail environments characterized by fluctuating customer demand and high inventory turnover (7, 8).

One of the most important operational challenges in chain store warehousing relates to inventory management and order fulfillment processes. Retail warehouses are required to manage extensive product diversity, rapid inventory movement, and continuous customer demand changes. Inaccurate inventory control, inefficient storage allocation, delayed product retrieval, and human operational errors can lead to increased operational costs and reduced customer satisfaction (19, 20). Smart warehousing technologies address these challenges by enabling real-time inventory visibility, automated stock updates, intelligent product placement, and rapid order processing systems (6, 21). Moreover, technologies such as IoT and AI facilitate predictive inventory management and data-driven operational planning, thereby improving warehouse responsiveness and reducing supply chain risks (19, 22).

The increasing importance of resilience and risk management in retail supply chains has also highlighted the strategic role of smart warehousing systems. The COVID-19 pandemic demonstrated the vulnerability of traditional retail supply chains and accelerated the transition toward digitalized and automated logistics systems (1, 17). Organizations recognized the necessity of real-time data sharing, intelligent operational visibility, and flexible warehousing systems capable of responding to unexpected disruptions. Consequently, Industry 4.0 technologies became central to building resilient and adaptive supply chain infrastructures (8, 20). Studies indicate that digital supply chain transformation improves organizational responsiveness, operational continuity, and crisis management capabilities in retail logistics environments (18, 23).

Despite the growing importance of Industry 4.0 technologies in warehousing and supply chain management, the implementation of smart warehousing systems remains associated with multiple technological and managerial challenges. These challenges include high investment costs, technological complexity, cybersecurity concerns, integration difficulties with ERP systems, workforce adaptation issues, and uncertainty regarding implementation feasibility (3, 7). Moreover, organizations often face difficulties in prioritizing Industry 4.0 applications because different technologies provide varying levels of attractiveness, operational capability, sustainability impact, and implementation practicality (5, 14). Consequently, decision-makers require structured evaluation frameworks capable of assessing technological applications from both attractiveness and capability perspectives.

Capability–attractiveness analysis represents one of the most effective strategic evaluation approaches for technology prioritization and decision-making. The attractiveness dimension reflects the strategic value and sustainability benefits associated with a technology, whereas the capability dimension evaluates organizational readiness, technological maturity, implementation feasibility, and operational effectiveness (24, 25). Integrating these two dimensions enables organizations to identify technologies that simultaneously provide high strategic value and strong operational applicability. Although numerous studies have investigated Industry 4.0 applications in logistics, supply chain management, and retail operations, limited research has specifically focused on analyzing the capability–attractiveness dimensions of Industry 4.0 technologies in smart warehousing systems for chain stores with a sustainability orientation (6, 14). Most existing studies primarily emphasize operational performance, technological adoption, or sustainability outcomes independently, without integrating these dimensions into a comprehensive evaluation framework.

Additionally, prior research has largely concentrated on manufacturing industries, industrial production systems, and general logistics networks rather than retail warehouse environments (5, 25). Chain stores possess unique operational characteristics, including high product diversity, continuous inventory replenishment, rapid order fulfillment requirements, and strong customer responsiveness expectations. Therefore, the evaluation and prioritization of Industry 4.0 applications in retail smart warehousing require context-specific analytical approaches capable of addressing both sustainability and operational capability considerations. Furthermore, the increasing adoption of digital technologies such as big data analytics, IoT systems, AI-driven automation, and blockchain-based operational monitoring has expanded the strategic complexity of technology selection and implementation processes in retail supply chains (26, 27).

Another critical gap in the literature concerns the limited integration of sustainability dimensions into smart warehousing evaluation frameworks. Existing research often focuses either on technological performance or environmental sustainability without comprehensively considering economic, social, environmental, and operational capability factors simultaneously (11, 16). However, sustainable smart warehousing requires a balanced evaluation framework capable of integrating cost efficiency, customer satisfaction, operational effectiveness, environmental protection, and technological feasibility. Such an integrated perspective is particularly important for chain stores operating within highly competitive and customer-oriented retail markets.

Given the strategic importance of Industry 4.0 technologies in enhancing warehouse efficiency, sustainability, and supply chain resilience, there is a clear need for systematic evaluation models capable of prioritizing smart warehousing applications based on capability and attractiveness dimensions. Multi-criteria decision-making approaches such as the Best–Worst Method (BWM) and VIKOR method provide robust analytical tools for addressing complex technology evaluation problems involving multiple conflicting criteria (5, 14). These approaches enable researchers and practitioners to evaluate technological alternatives objectively while incorporating expert judgments and sustainability considerations into the decision-making process.

Therefore, the present study aims to analyze the capability–attractiveness of Industry 4.0 technology applications in smart warehousing of chain stores with a sustainability approach using the Best–Worst Method (BWM) and the VIKOR multi-criteria decision-making technique.

Methods and Materials

This study is categorized as an analytical–survey research design. In terms of the temporal scope, the research was conducted in 2025. The collected data were obtained from an expert population consisting of academic specialists, artificial intelligence experts, and software engineers. Given the extensive knowledge and expertise of this group in Industry 4.0 technologies and smart warehousing systems for chain stores, their perspectives were considered essential for weighting the indicators. Accordingly, specialized questionnaires were distributed among these experts in order to record and collect their opinions regarding the “attractiveness” and “capability” indicators. In the analysis phase, the weights of the indicators were first determined using the Best–Worst Method (BWM). Subsequently, the various applications of Industry 4.0 technologies in smart warehousing of chain stores were evaluated using a ranking method.

Findings and Results

Based on the initial list and following the conduct of focus group sessions and specialized expert discussions, the final list of attractiveness and capability indicators for identifying, analyzing, prioritizing, and implementing Industry 4.0 technologies in smart warehousing of chain stores was developed. According to the consensus of the focus group members, the final list of Industry 4.0 applications in smart warehousing included ten major applications. In addition, the final indicators used for the capability–attractiveness analysis were classified into two main categories: sustainability dimensions and operational–managerial capability dimensions. The sustainability dimensions consisted of economic, social, and environmental criteria, while the capability dimensions included technological maturity, warehouse operational efficiency, inventory control accuracy, ERP integration, and implementation feasibility.

Table 1. Ten Major Applications of Industry 4.0 Technologies in Smart Warehousing of Chain Stores

No.	Applications (Decision Alternatives)
1	Intelligent interconnection of machinery and equipment in warehouse management
2	Identifying the most appropriate location for goods based on the latest layout
3	Awareness of the exact inventory status of shelves or pallets during placement
4	Accurate inventory counting in the shortest possible time
5	Access to real-time warehouse inventory
6	Warehouse space optimization based on optimal order quantity awareness
7	Ability to search for and locate a specific product in the shortest possible time
8	Automatic recording of inventory reduction from shelves or pallets in the warehouse management system
9	Elimination of human errors during loading and dispatching
10	Automatic recording of inspection, maintenance, and repair data

The attractiveness indicators extracted from the focus group analysis consisted of three sustainability dimensions. The economic dimension included warehouse cost reduction, investment cost, operational cost improvement, and expected return. The social dimension comprised order processing speed, competitive advantage for the store, customer satisfaction improvement, and enhancement of organizational maturity and innovation. The environmental dimension consisted of sustainable development, pollution control, energy consumption control, and waste management. All indicators were evaluated using a Likert scale. Furthermore, the capability indicators included technological maturity, warehouse operational efficiency, inventory control accuracy, ERP integration, and implementation feasibility.

At the weighting stage, the Best–Worst Method (BWM) was applied. The pairwise comparisons provided by the experts demonstrated acceptable consistency ratios for all attractiveness and capability indicators. Since all calculated consistency ratios were below one, the reliability and consistency of expert judgments were confirmed, indicating adequate stability and validity of the weighting process.

Table 2. Final Weights of Sustainability Dimensions (Attractiveness Indicators)

Code	Dimension	Final Weight
SO	Social	0.788
EC	Economic	0.527
EN	Environmental	0.108

The results revealed that the social dimension obtained the highest importance among sustainability dimensions, accounting for approximately 65% of the overall relative importance. In contrast, the environmental dimension demonstrated the lowest priority. Within the economic sub-dimensions, “operational cost improvement” achieved the highest local weight (0.508), whereas “warehouse cost reduction” showed the lowest importance (0.109). Within the social dimension, “increasing order processing speed” was identified as the most significant sub-indicator (0.302). Regarding environmental indicators, “waste management” demonstrated the highest relative importance (0.333), while “pollution control” showed the lowest importance (0.157).

Table 3. Final Weights of Capability Indicators

Code	Capability Indicator	Final Weight
CAP5	Implementation and execution feasibility	0.259
CAP1	Technological maturity level	0.239
CAP3	Inventory control accuracy	0.218
CAP2	Warehouse operational efficiency	0.178
CAP4	ERP systems integration	0.106

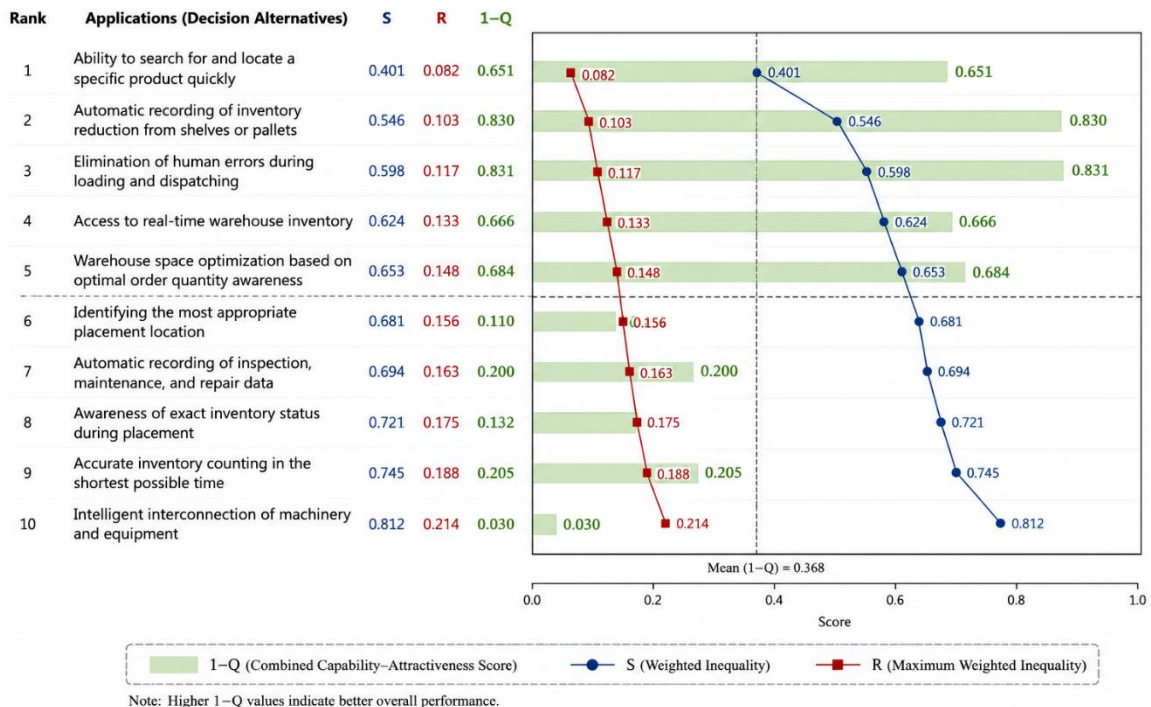


Figure 1. Ranking of Industry 4.0 Applications in Smart Warehousing Based on the VIKOR Method

Among capability indicators, “implementation and execution feasibility” achieved the highest priority with a weight of 0.259, indicating the critical role of practical applicability in Industry 4.0 implementation. Conversely, “ERP systems integration” demonstrated the lowest relative importance among capability dimensions.

In the next stage, the VIKOR multi-criteria decision-making method was employed to rank Industry 4.0 applications in smart warehousing. The decision matrix was formed based on expert evaluations collected through specialized questionnaires. The opinions of the experts were aggregated using the geometric mean in Excel. Among all evaluation criteria, only “ERP integration” and “implementation feasibility” were treated as cost criteria, while the remaining indicators were considered benefit criteria.

The calculated S and R values showed substantial variation among the alternatives. For attractiveness indicators, “access to real-time warehouse inventory” achieved the highest S value, whereas “identifying the most appropriate location for goods based on the latest layout” demonstrated the lowest S value. In terms of capability indicators, “automatic recording of inspection, maintenance, and repair data” obtained the highest S value, while “elimination of human errors during loading and dispatching” showed the lowest S value.

To facilitate interpretation, the value of $1-Q$ was considered as the combined capability–attractiveness score. The dominance parameter (V) was set at the standard value of 0.5. The computed values of weighted inequality and maximum weighted inequality confirmed the differentiation among the alternatives and enabled the final ranking process.

Table 4. Final Ranking of Applications Based on Capability Dimension

Rank	Application
1	Elimination of human errors during loading and dispatching
2	Automatic recording of inventory reduction from shelves or pallets
3	Warehouse space optimization based on optimal order quantity awareness
4	Access to real-time warehouse inventory
5	Ability to search for and locate a specific product quickly
6	Accurate inventory counting in the shortest possible time
7	Automatic recording of inspection, maintenance, and repair data
8	Awareness of exact inventory status during placement
9	Identifying the most appropriate placement location
10	Intelligent interconnection of machinery and equipment

Table 5. Final Ranking of Applications Based on Attractiveness Dimension

Rank	Application
1	Ability to search for and locate a specific product quickly
2	Identifying the most appropriate placement location
3	Automatic recording of inventory reduction from shelves or pallets
4	Automatic recording of inspection, maintenance, and repair data
5	Intelligent interconnection of machinery and equipment
6	Awareness of exact inventory status during placement
7	Elimination of human errors during loading and dispatching
8	Warehouse space optimization based on optimal order quantity awareness
9	Accurate inventory counting in the shortest possible time
10	Access to real-time warehouse inventory

The results indicate that the capability-oriented perspective prioritized operational reliability and automation efficiency, especially in minimizing human intervention and improving inventory tracking accuracy. Conversely, the attractiveness-oriented perspective emphasized customer responsiveness and intelligent product accessibility, particularly rapid product identification and optimal placement mechanisms.

To construct the capability–attractiveness matrix, the mean value of capability scores (1–Q) was calculated as 0.368 and used as the vertical cutoff point. Similarly, the average attractiveness score was calculated as 0.306 and considered the horizontal cutoff point. These thresholds divided the matrix into four strategic regions.

Table 6. Capability–Attractiveness Matrix Positioning of Industry 4.0 Applications

Code	Application	Attractiveness Score	Capability Score	Region
A1	Ability to search for and locate a specific product quickly	1.001	0.651	4
A2	Identifying the most appropriate placement location	0.620	0.110	3
A3	Automatic recording of inventory reduction from shelves or pallets	0.472	0.830	4
A4	Accurate inventory counting in the shortest possible time	0.032	0.205	1
A5	Automatic recording of inspection, maintenance, and repair data	0.315	0.200	1
A6	Intelligent interconnection of machinery and equipment	0.283	0.030	1
A7	Awareness of exact inventory status during placement	0.278	0.132	1
A8	Access to real-time warehouse inventory	0.001	0.666	2
A9	Elimination of human errors during loading and dispatching	0.222	0.831	2
A10	Warehouse space optimization based on optimal order quantity awareness	0.103	0.684	2

The final matrix analysis demonstrated that the applications related to rapid product retrieval and automatic inventory reduction registration occupied the most strategically favorable positions, exhibiting simultaneously high attractiveness and high capability. In contrast, applications such as intelligent interconnection of machinery and exact shelf inventory awareness were positioned in the low-attractiveness and low-capability region. Furthermore, access to real-time inventory, elimination of human errors, and warehouse space optimization exhibited high capability but comparatively lower attractiveness.

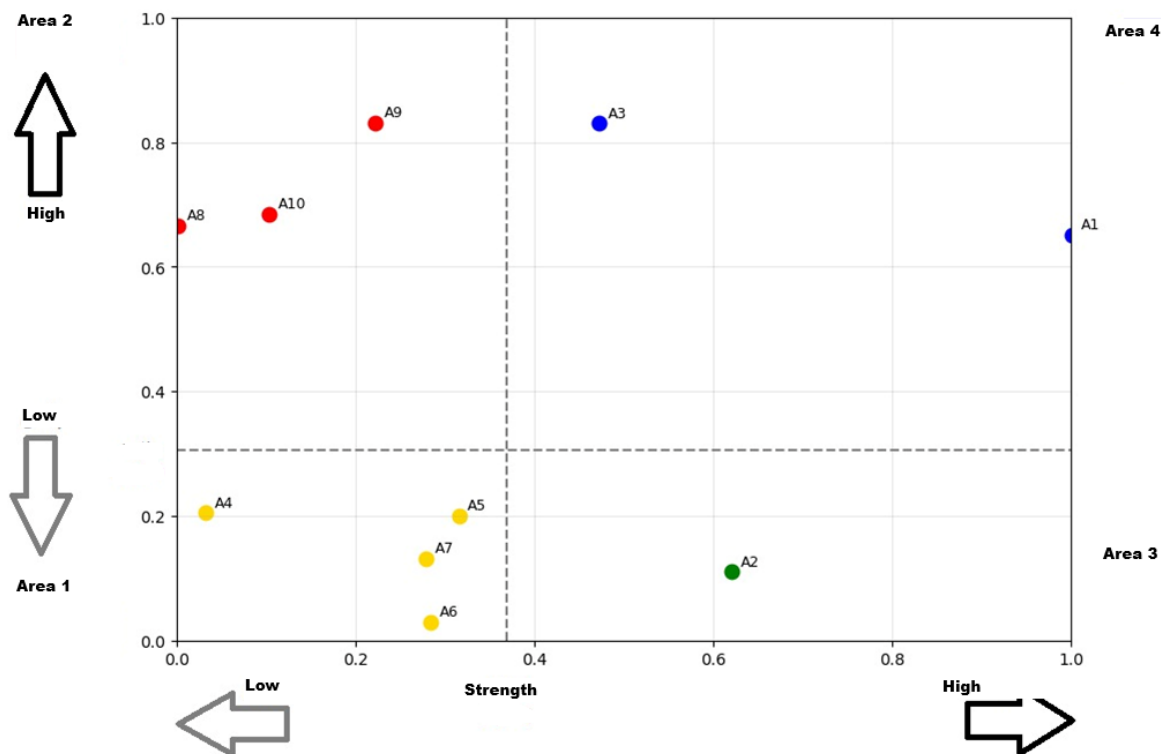


Figure 2. Final Capability–Attractiveness Matrix of Industry 4.0 Applications in Smart Warehousing of Chain Stores

Discussion and Conclusion

The present study aimed to analyze the capability–attractiveness of Industry 4.0 technology applications in smart warehousing of chain stores with a sustainability approach. The findings demonstrated that Industry 4.0 technologies possess different strategic positions in terms of attractiveness and operational capability, and therefore require differentiated managerial prioritization for implementation within smart warehousing systems. The results revealed that social sustainability dimensions achieved the highest relative importance among the three sustainability dimensions, while environmental dimensions received comparatively lower weights. In addition, among the capability indicators, implementation and execution feasibility emerged as the most significant criterion in evaluating Industry 4.0 technologies in smart warehousing systems.

The prioritization of social sustainability dimensions indicates that retail organizations place substantial emphasis on customer responsiveness, operational speed, service quality, and organizational competitiveness within smart warehousing environments. This finding is consistent with previous studies emphasizing that digital retail transformation and smart logistics systems primarily aim to improve customer satisfaction, accelerate order fulfillment, and increase competitive advantage in highly dynamic retail markets (1, 2). Similarly, Hrouga and Sbihi argued that Logistics 4.0 technologies significantly improve customer-oriented supply chain performance through real-time operational responsiveness and intelligent process coordination (4). The high weight assigned to social sustainability dimensions also reflects the increasing importance of service agility and operational flexibility in modern chain store systems where customer expectations regarding delivery speed and inventory availability continue to increase.

The findings further demonstrated that “increasing order processing speed” represented the most important social sub-indicator. This result highlights the strategic role of rapid order processing in retail warehouse performance and aligns with previous studies indicating that smart warehousing technologies improve operational responsiveness and reduce order fulfillment delays (20, 21). Retail environments are characterized by continuous demand fluctuations and extensive product diversity; therefore, the capability to process customer orders rapidly becomes a key source of operational competitiveness. The integration of IoT systems, AI-driven warehouse management, and automated picking systems enables organizations to reduce processing time and improve customer experience simultaneously (6, 7). This finding also supports the argument that digital transformation in retail logistics increasingly focuses on service-oriented operational optimization rather than solely cost reduction objectives (16, 23).

Within the economic sustainability dimension, “operational cost improvement” achieved the highest relative importance. This finding demonstrates that organizations perceive Industry 4.0 technologies primarily as mechanisms for enhancing operational efficiency and reducing logistics-related expenditures. Previous studies have similarly reported that smart warehousing systems improve inventory turnover, reduce labor dependency, optimize storage utilization, and minimize operational inefficiencies (13, 15). Intelligent inventory tracking, automated replenishment systems, and predictive operational analytics contribute significantly to reducing warehousing costs and improving supply chain productivity (5, 8). Moreover, the increasing operational complexity of retail supply chains has intensified the need for cost-efficient warehousing solutions capable of maintaining service quality while minimizing operational expenditures.

The relatively lower importance assigned to environmental sustainability dimensions does not necessarily indicate the irrelevance of environmental concerns, but rather reflects the operational priorities of retail organizations in the early stages of smart warehousing implementation. This finding partially contrasts with studies emphasizing the growing strategic role of green logistics and sustainable supply chain management in Industry 4.0 environments (11, 12). However, it can be argued that many retail organizations continue to prioritize immediate operational and customer-oriented benefits over long-term environmental considerations, especially in developing digital warehousing infrastructures. Nevertheless, among environmental indicators, “waste management” received the highest weight, indicating that organizations recognize the importance of minimizing operational waste and improving resource utilization within warehouse systems. This result is supported by studies demonstrating that smart logistics technologies contribute to circular economy objectives through optimized resource consumption and waste reduction practices (10, 11).

The capability analysis revealed that implementation and execution feasibility represented the most important capability indicator. This finding highlights the practical orientation of organizations toward Industry 4.0 adoption. Retail organizations appear to prioritize technologies that can be implemented effectively within existing operational infrastructures while minimizing organizational disruption. Previous studies have similarly emphasized that technological complexity, organizational readiness, and implementation feasibility are critical determinants of successful Industry 4.0 adoption (3, 7). Smart warehousing technologies often require significant investments in digital infrastructure, employee training, systems integration, and operational restructuring. Consequently, organizations tend to prioritize applications that demonstrate high operational applicability and manageable implementation requirements.

In contrast, ERP integration received the lowest relative weight among capability indicators. This finding may indicate that retail organizations perceive ERP integration as a technical support requirement rather than a direct determinant of warehouse performance. Although ERP integration remains important for operational synchronization and information sharing, organizations may prioritize immediate operational improvements such as automation efficiency, inventory visibility, and process accuracy over deeper system integration considerations. Previous research suggests that many organizations implementing Industry 4.0 technologies initially focus on isolated operational improvements before achieving full enterprise-wide digital integration (24, 27). Therefore, the lower relative importance of ERP integration may reflect a phased approach to digital transformation within retail supply chains.

The VIKOR ranking results demonstrated that “elimination of human errors during loading and dispatching” represented the highest-ranked application from the capability perspective. This finding confirms the significant operational value of automation technologies in reducing manual errors and improving logistics accuracy. Human errors in warehouse operations frequently result in inventory discrepancies, delayed deliveries, operational inefficiencies, and customer dissatisfaction. Industry 4.0 technologies such as RFID systems, AI-based tracking systems, automated picking technologies, and smart monitoring systems substantially reduce these operational risks (6, 7). Previous studies have similarly emphasized that intelligent automation systems improve operational reliability and minimize error-related costs within warehouse environments (3, 20).

From the attractiveness perspective, “the ability to search for and locate a specific product in the shortest possible time” achieved the highest ranking. This result demonstrates the strategic importance of rapid product accessibility in customer-oriented retail logistics systems. Modern consumers increasingly expect rapid delivery services and

real-time inventory availability, particularly within e-commerce and omnichannel retail environments (1, 2). Smart warehousing systems equipped with AI-based search algorithms, automated storage systems, and intelligent inventory tracking technologies enable organizations to improve retrieval speed and order fulfillment efficiency significantly. This finding aligns with previous studies reporting that warehouse responsiveness and rapid product retrieval represent critical competitive factors in digital retail supply chains (4, 21).

The capability–attractiveness matrix analysis revealed that some applications simultaneously possessed high attractiveness and high capability, while others demonstrated imbalances between these dimensions. The applications related to rapid product search and automatic inventory reduction registration occupied the most favorable strategic positions within the matrix. These technologies provide both operational feasibility and substantial strategic value, making them ideal priorities for implementation in smart warehousing systems. The strategic positioning of these applications is consistent with prior studies emphasizing the importance of real-time inventory visibility, intelligent tracking systems, and automated operational monitoring in sustainable logistics environments (13, 22).

Conversely, applications such as intelligent interconnection of machinery and exact shelf inventory awareness were located within the low-attractiveness and low-capability region. This result may reflect the relatively high implementation complexity and uncertain short-term operational benefits associated with these technologies. While interconnected machinery systems and cyber-physical operational networks represent advanced Industry 4.0 capabilities, their implementation often requires sophisticated technological infrastructures and extensive organizational adaptation (5, 25). Therefore, organizations may perceive these technologies as long-term strategic investments rather than immediate operational priorities.

The findings of this study also reinforce the growing importance of sustainability-oriented digital transformation in retail supply chain management. Smart warehousing technologies contribute not only to operational optimization but also to broader sustainability objectives including resource efficiency, waste reduction, customer satisfaction improvement, and supply chain resilience (12, 18). The integration of Industry 4.0 technologies into warehousing systems enables organizations to achieve more intelligent, adaptive, and environmentally responsible logistics operations. Furthermore, the findings confirm that multi-criteria decision-making approaches such as BWM and VIKOR provide effective analytical frameworks for evaluating complex technological alternatives within sustainability-oriented supply chain contexts.

One of the important theoretical contributions of this study lies in integrating sustainability dimensions with capability–attractiveness analysis for Industry 4.0 applications in retail smart warehousing. Previous studies have often examined operational performance, technological readiness, or sustainability independently, whereas the present study provides a comprehensive evaluation framework incorporating economic, social, environmental, and operational capability dimensions simultaneously. Moreover, the study contributes to the limited literature addressing Industry 4.0 implementation specifically within chain store warehousing systems rather than manufacturing-oriented environments.

Another important implication of the findings concerns the strategic prioritization of Industry 4.0 investments in retail supply chains. Organizations frequently face budgetary limitations and implementation uncertainties when adopting digital warehousing technologies. The capability–attractiveness matrix developed in this study provides a practical decision-support framework enabling managers to identify technologies with the highest strategic value

and implementation feasibility. This framework can support phased digital transformation strategies and improve resource allocation decisions within retail logistics systems.

The findings also demonstrate that smart warehousing should not be viewed solely as a technological transformation process, but rather as a comprehensive organizational and sustainability-oriented strategic initiative. Successful implementation requires balancing operational efficiency, customer responsiveness, technological capability, and sustainability objectives simultaneously. Consequently, organizations adopting Industry 4.0 technologies should develop integrated digital transformation strategies incorporating technological readiness, workforce adaptation, operational redesign, and sustainability planning.

One limitation of the present study relates to the limited number of experts participating in the weighting and evaluation processes. Although the selected experts possessed substantial academic and professional expertise in Industry 4.0 technologies and smart warehousing systems, broader expert participation from different industrial sectors and international retail environments could increase the generalizability of the findings. In addition, the study relied primarily on expert judgments and multi-criteria decision-making approaches rather than empirical operational performance data obtained from real-world warehouse systems.

Future research could extend the present study by examining the empirical implementation outcomes of Industry 4.0 technologies in operational retail warehouses. Comparative studies across different retail sectors, geographical regions, and organizational sizes could provide deeper insights into contextual differences in smart warehousing adoption. In addition, future studies may integrate advanced analytical approaches such as fuzzy decision-making methods, machine learning techniques, or simulation modeling to improve the precision of capability–attractiveness evaluations and sustainability assessments.

From a practical perspective, retail managers and supply chain decision-makers should prioritize Industry 4.0 applications that simultaneously demonstrate high operational capability and high strategic attractiveness. Organizations should initially focus on technologies related to intelligent inventory tracking, automated inventory updates, rapid product retrieval, and human error reduction because these applications provide immediate operational and customer-oriented benefits. Furthermore, managers should adopt phased digital transformation strategies emphasizing implementation feasibility, employee readiness, technological integration, and sustainability performance in order to maximize the long-term effectiveness of smart warehousing systems.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adhered in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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