

A COMPREHENSIVE ANALYSIS OF BARRIERS TO AUGMENTED REALITY IMPLEMENTATION IN SUSTAINABLE INVENTORY MANAGEMENT

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ABSTRACT

Using the Best-Worst Method, this study investigates the barriers to adopting Augmented Reality (AR) in inventory management to attain sustainability. Data were collected from 53 experts across various roles in the supply chain and AR technology, including Logistics Coordinators, Warehouse Managers, IT Managers, Operations Managers, and AR Technology Providers. The study identified and ranked significant barriers, with financial barriers emerging as the most critical. These include high initial capital expenditure and uncertain return on investment. Operational barriers, such as the complexity of operations and maintenance support, and technological barriers, including high implementation costs and rapid technological changes, were also notable. The findings highlight the need for strategic approaches to address these challenges. For instance, phased implementation and cost-sharing models can help mitigate financial risks. Detailed implementation roadmaps and robust support systems are essential to manage operational complexities. Additionally, continuous learning programs and stringent data security protocols are necessary to address technological barriers. This research provides valuable insights for managers aiming to integrate AR into inventory management, emphasizing the importance of addressing financial, operational, and technological challenges. By tackling these areas, organizations can fully harness the potential of AR technology in transforming inventory management processes, enhancing efficiency, accuracy, and sustainability in the supply chain.

Keywords: Augmented reality; inventory management; sustainable supply chain.

Paper Type: Research paper

INTRODUCTION

Augmented Reality (AR) has emerged as a transformative technology with the potential to revolutionize various industries, including supply chain management. In inventory management, AR offers innovative solutions that enhance efficiency, accuracy, and sustainability. By overlaying digital information onto the physical world, AR can streamline

inventory tracking, optimize warehouse operations, and improve decision-making processes (Rohani et al., 2022). Despite these advantages, the adoption of AR in inventory management has been limited. This research aims to identify and rank the barriers to implementing AR in inventory management using the Best-worst Method (BWM) technique. By understanding these barriers, we can provide insights to help overcome them and promote the sustainable integration of AR technology.

Inventory management is a critical component of supply chain operations, influencing a company's efficiency, cost-effectiveness, and customer satisfaction. Traditional inventory management systems often rely on manual processes or basic automation, which can be error-prone and inefficient. AR, with its ability to provide real-time visualization and data integration, presents a significant advancement over conventional methods (Zaman et al., 2023). It can reduce human errors, speed up inventory audits, and provide more accurate stock levels. Moreover, AR can enhance worker productivity by providing step-by-step instructions and reducing the time needed to locate items within warehouses. These improvements not only boost operational efficiency but also contribute to sustainability by optimizing resource use and reducing waste.

Despite the clear benefits, the adoption rate of AR in inventory management remains low. Several factors contribute to this slow uptake, including technological, organizational, financial, environmental, legal, and social barriers (Sharma, 2011). Technological barriers such as high implementation costs and lack of technical expertise can deter companies from investing in AR. Organizational resistance to change and lack of top management support can further impede adoption. Financial concerns about uncertain return on investment and ongoing maintenance costs also play a significant role. Environmental considerations, such as increased energy consumption and e-waste generation, raise sustainability concerns. Legal issues related to regulatory compliance and intellectual property rights add another layer of complexity. Social factors, including user acceptance and cultural barriers, further complicate the integration process.

Addressing these barriers is crucial for the broader adoption of AR in inventory management. The BWM provides a robust framework for identifying and ranking these barriers (Singh and Kumar, 2024). BWM involves selecting the most and least significant barriers and comparing all others against these extremes to derive a ranking. This method offers a systematic approach to prioritize the barriers based on their relative importance, providing valuable insights for decision-makers.

The first step in this research involves a comprehensive literature review and expert consultations to identify potential barriers to AR adoption. These barriers are then categorized into six broad categories: technological, organizational, financial, environmental, legal, and social. Each category encompasses several sub-categories, capturing the multifaceted challenges faced by organizations. For instance, under technological barriers, issues such as high implementation costs, lack of technical expertise, data security concerns, and compatibility issues are considered. Organizational barriers include resistance to change, lack of top management support, integration challenges, and training requirements. Financial barriers encompass high maintenance costs, uncertain Return-on-Investment (ROI), cost of training, and

initial capital expenditure. Environmental barriers focus on energy consumption, e-waste generation, carbon footprint, and resource efficiency. Legal barriers address regulatory compliance, intellectual property issues, data privacy regulations, and liability concerns. Social barriers include user acceptance, cultural barriers, ethical concerns, and the impact on employment.

Once the barriers are identified, the BWM technique is applied to rank them. This involves engaging experts to rate the significance of each barrier compared to the best and worst barriers identified in each category. The data collected from these ratings are then analyzed to calculate the weights of each barrier, resulting in a prioritized list. This ranking highlights the most critical barriers that need to be addressed to facilitate the adoption of AR in inventory management.

The findings of this research are expected to provide actionable insights for both practitioners and policymakers. By understanding the key barriers to AR adoption, organizations can develop targeted strategies to overcome them. For instance, addressing high implementation costs might involve exploring cost-sharing models or phased implementation approaches. Enhancing technical expertise could be achieved through specialized training programs and collaborations with technology providers. To overcome organizational resistance, change management initiatives and strong leadership support are essential. Financial concerns can be mitigated by conducting detailed cost-benefit analyses and securing funding for pilot projects. Addressing environmental barriers requires integrating AR solutions with sustainable practices, such as energy-efficient technologies and e-waste recycling programs. Legal barriers can be navigated by staying informed about regulatory developments and seeking legal counsel. Social barriers can be addressed through user-centered design, cultural sensitivity, and ethical considerations.

The adoption of AR in inventory management presents significant opportunities for enhancing efficiency and sustainability. However, numerous barriers hinder its widespread implementation. This research aims to systematically identify and rank these barriers using the BWM, providing a clear roadmap for organizations to overcome these challenges. By addressing these barriers, businesses can leverage AR technology to transform their inventory management processes, driving operational excellence and sustainability in the supply chain.

To provide a comprehensive understanding of the study, the remaining of this paper is organized as follows. Section 2 presents a thorough literature review, discussing the current state of AR in inventory management and identifying key barriers to its adoption. Section 3 details the research methodology, including the data collection process and the application of the BWM for analysis. Section 4 outlines the results, highlighting the identified barriers and their respective rankings. Section 5 provides a detailed discussion of the findings, comparing them with existing literature and discussing their implications. Finally, Section 6 concludes the paper by summarizing the key insights, suggesting practical recommendations for overcoming the identified barriers, and proposing directions for future research.

LITERATURE REVIEW

AR is increasingly recognized for its potential to revolutionize inventory management within supply chain operations (Attaran, 2020). AR enhances the physical world with digital information, offering significant benefits such as improved accuracy, increased efficiency, and enhanced sustainability (Masood and Egger, 2019). Despite these advantages, the adoption of AR in inventory management remains limited, primarily due to several barriers. This literature review explores the current state of AR in inventory management, identifies key barriers to its adoption, and discusses implications for future research and practice.

AR technology has evolved rapidly, driven by advancements in computing power, sensor technology, and data processing capabilities. In the context of inventory management, AR can significantly streamline operations by providing real-time, accurate data overlays, reducing human errors, speeding up inventory audits, and optimizing warehouse layouts. Research has shown that AR can improve picking accuracy and efficiency, enhance worker productivity, and facilitate better training through immersive experiences.

A systematic review by Akbari et al. (2022) highlights the maturity and current trends of AR in operations and supply chain management. Their study indicates a growing body of literature focused on the benefits of AR, particularly in manufacturing and logistics. However, they also note that AR's application in inventory management is still in its nascent stages, with limited empirical studies exploring its full potential.

Another study by Rejeb et al. (2020) explores the applications of AR in logistics and supply chain management. They identify key areas where AR can provide significant benefits, such as real-time tracking, improved visibility, and enhanced decision-making. Their findings suggest that while the technology holds promise, practical implementation is hampered by various challenges, including technical limitations and high costs.

Despite the promising potential of AR, several barriers impede its widespread adoption in inventory management. Technological barriers are among the most significant challenges (Masood and Egger, 2020). According to their findings, high implementation costs and the lack of technical expertise are primary concerns. Integrating AR systems with existing inventory management software can be complex and resource-intensive. Additionally, issues related to data security and privacy pose significant risks, as AR systems often rely on extensive data collection and processing.

Organizational barriers also play a crucial role. Resistance to change from employees and managers can hinder the adoption of new technologies. Furthermore, the lack of top management support and the need for significant training to ensure employees are proficient in using AR technology add to the complexity of implementation. A study by Chuah (2018) highlights how organizational inertia and the fear of change can be significant obstacles to adopting innovative technologies.

Financial barriers, such as uncertain ROI and high maintenance costs, are significant deterrents. Companies are often reluctant to invest in new technologies without clear evidence of financial benefits. The initial capital expenditure required to implement AR technology can also be

prohibitively high for many organizations. According to Tikwayo and Mathaba (2023), the financial risk associated with new technology investments is a considerable hurdle for many companies.

Environmental barriers include concerns about increased energy consumption and electronic waste generation. While AR can enhance operational efficiency, its implementation must be carefully managed to avoid offsetting sustainability benefits. Moreover, the potential increase in the carbon footprint due to the deployment of AR technology needs to be addressed. Stoltz et al. (2017) discuss the environmental impacts of new technologies and emphasize the need for sustainable implementation practices.

Legal barriers encompass regulatory compliance, intellectual property issues, data privacy regulations, and liability concerns. Navigating the complex regulatory landscape for AR technology can be time-consuming and costly. Intellectual property issues related to AR technologies and their applications can also pose significant challenges. Conroy (2017) explore the legal complexities associated with deploying AR in commercial settings and the regulatory hurdles that companies must overcome.

Social barriers, such as user acceptance, cultural differences, ethical concerns, and the impact on employment, further complicate AR adoption. Achieving widespread user acceptance and comfort with AR technology requires addressing cultural and ethical considerations. Additionally, concerns about job displacement due to automation need to be carefully managed. Martínez et al. (2014) highlight the social implications of adopting new technologies and the importance of addressing workforce concerns.

To systematically address these barriers, this study employs the BWM (Rezaei, 2015; Rezaei, 2016) to identify and rank the most significant obstacles. The BWM technique involves selecting the most and least critical barriers from a list and comparing all others against these extremes to derive a ranking. This approach provides a structured way to prioritize the barriers based on their relative importance, offering valuable insights for decision-makers.

The methodology for this study involves a comprehensive literature review and expert consultations to identify potential barriers to AR adoption. These barriers are then categorized into technological, organizational, financial, environmental, legal, and social factors. Experts rate the significance of each barrier, and the data collected from these ratings are analyzed using the BWM technique to calculate the weights of each barrier, resulting in a prioritized list.

The findings of this study have significant implications for both research and practice. Understanding the key barriers to AR adoption in inventory management can help organizations develop targeted strategies to overcome them. For instance, addressing high implementation costs might involve exploring cost-sharing models or phased implementation approaches. Enhancing technical expertise could be achieved through specialized training programs and collaborations with technology providers.

To overcome organizational resistance, change management initiatives and strong leadership support are essential. Financial concerns can be mitigated by conducting detailed cost-benefit analyses and securing funding for pilot projects. Addressing environmental barriers requires

integrating AR solutions with sustainable practices, such as energy-efficient technologies and e-waste recycling programs. Legal barriers can be navigated by staying informed about regulatory developments and seeking legal counsel. Social barriers can be addressed through user-centered design, cultural sensitivity, and ethical considerations.

Table 1: Detail of Categories and sub-categories of barriers identified in LR

Category	Sub-Category	Description	Sources
Technological	High Implementation Costs	The initial costs of purchasing and integrating AR technology can be prohibitively high.	Zhmud et al. (2021); Masood and Egger (2019)
	Lack of Technical Expertise	Insufficient technical knowledge and skills among staff to operate and maintain AR systems.	Osuna et al. (2019); Alqahtani and AlNajdi (2023)
	Data Security Concerns	Concerns about the security and privacy of data collected and used by AR systems.	Syed et al. (2022), Oke and Arowoia (2022)
	Compatibility Issues	Compatibility issues between AR hardware and existing inventory systems.	Martínez et al. (2014), Kumari and Polke (2020)
	Reliability and Performance	Concerns about the reliability and performance of AR systems in various operating conditions.	Palmarini et al. (2018), Schein and Rauschnabel (2021)
	Rapid Technological Changes	Rapid changes in AR technology can make it difficult to keep systems up-to-date.	Schein and Rauschnabel (2021), Mendoza-Ramírez et al. (2023)
	Resistance to Change	Employees and managers may resist adopting new technologies due to comfort with existing processes.	Schein and Rauschnabel (2021); Konopka et al. (2024)
Organizational	Lack of Top Management Support	Insufficient support from top management can hinder the implementation of AR technology.	de Macêdo Brito et al. (2024)
	Integration with Existing Systems	Difficulty in integrating AR systems with existing inventory management software and processes.	Berkemeier et al. (2019), Viljakainen (2020)
	Training Requirements	Significant training is required to ensure employees are proficient in using AR technology.	Thompson & Richards (2018), Zhang et al. (2019)
	Workforce	Variability in the ability of the	Schein and

Financial	Adaptability	workforce to adapt to new AR technologies.	Rauschnabel (2021), Sidani et al. (2021)
	High Maintenance Costs	Ongoing maintenance and upgrade costs for AR systems can be substantial.	Oesterreich and Teuteberg(2017), Nassereddine et al. (2022)
	Uncertain ROI	Uncertainty about the return on investment for AR technology can deter companies from adopting it.	Berman and Pollack (2021)
	Cost of Training	Financial burden associated with training employees to use AR technology effectively.	Zhmud et al. (2021), Oke and Arowoiya (2022)
	Initial Capital Expenditure	The significant upfront investment required to implement AR technology.	Oesterreich and Teuteberg(2017), Nassereddine et al. (2022)
Environmental	Energy Consumption	AR systems may increase energy consumption, offsetting some sustainability benefits.	Bekaroo et al. (2018), An et al. (2024)
	E-Waste Generation	The introduction of AR technology can lead to increased electronic waste.	Sureshkumar et al. (2023)
	Carbon Footprint	Lower carbon emissions resulting from reduced need for physical audits and transportation.	Isley et al. (2017), Shevchenko et al. (2021)
	Resource Efficiency	Improved utilization of storage space and reduction in overstock/understock situations.	Isley et al. (2017), Thiede et al. (2022)
Legal	Regulatory Compliance	Navigating the regulatory landscape for AR technology can be complex and time-consuming.	Wassom (2014), Gromova et al. (2022)
	Intellectual Property Issues	Issues related to the intellectual property of AR technologies and their applications.	Hallevy et al. (2018), Gromova et al. (2022)
	Data Privacy Regulations	Compliance with data privacy laws and regulations.	Gromova et al. (2022), Volkov (2023)
	Liability Concerns	Concerns regarding liability and insurance related to the use of AR technology.	Hallevy et al. (2018), Mostert (2020)
Social	User Acceptance	Achieving widespread user acceptance and comfort with AR	Wintersberger et al. (2018), Schein

		technology can be challenging.	and Rauschnabel (2021)
	Cultural Barriers	Cultural differences can affect the acceptance and use of AR technology in global supply chains.	Oke and Arowoiya (2022)
	Ethical Concerns	Ethical issues related to surveillance and privacy in using AR.	Schein and Rauschnabel (2021), Mendoza-Ramírez et al. (2023)
	Impact on Employment	Concerns about the impact of AR on employment and job displacement.	Billinghurst (2021)
Operational	Complexity of Operations	The complexity of implementing AR in diverse and dynamic inventory management environments.	Hall et al. (2015), Alqahtani and AlNajdi (2023)
	Supply Chain Disruptions	Potential disruptions in supply chain operations during the transition to AR.	Stoltz et al. (2017), Rejeb et al. (2020)
	Maintenance and Support	Challenges in maintaining and supporting AR systems in operational environments.	Osuna et al. (2019); Alqahtani and AlNajdi (2023)
	Scalability Issues	Difficulties in scaling AR solutions across different locations and operations.	Palmarini et al. (2018), Schein and Rauschnabel (2021)

METHODOLOGY

Data Collection and Expert Selection

The methodology of this study is structured to systematically identify and rank the barriers to adopting AR in inventory management using the BWM. For this study we have approached 75 experts following snowball sampling technique. The high technicality of our questionnaire was a restriction in having a large sample size. Out of 75, only 53 responses were having consistency index within the acceptable range (Rezaei, 2016). The experts approached in this study were from various fields including Logistics Coordinators, Warehouse Managers, IT Managers, Operations Managers, and AR Technology Providers. These experts provided a comprehensive understanding of the barriers faced in implementing AR technology in inventory management.

Best-worst Method (BWM) Overview

The BWM is a multi-criteria decision-making method that involves selecting the most important (best) and least important (worst) factors from a set of criteria and comparing all others against

these extremes to derive a ranking. This method provides a structured approach to prioritize barriers based on their relative importance, offering valuable insights for decision-makers.

Steps in Applying BWM

1. Selection of Factors:

Identify the factors influencing the adoption of AR in inventory management. These factors were categorized into six broad categories: technological, organizational, financial, environmental, legal, and social. Each category encompassed several sub-categories capturing the multifaceted challenges faced by organizations.

2. Determining Best and Worst Factors:

The decision-makers (DMs) selected the most important (best) and least important (worst) factors from among the identified set of factors $(F_1, F_2, \dots, F_n)$.

3. Pairwise Comparisons:

The DMs provided preference scores for all factors with respect to the best factor using a scale from 1 to 9, where 1 indicates equal importance and 9 indicates absolute importance of the best factor over the other factors. This resulted in the best-to-others vector (A_B) :

$$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$$

Where a_{Bi} represents the preference score of the best factor over factor i .

Similarly, the DMs provided preference scores for all factors with respect to the worst factor, forming the others-to-worst vector (A_W) :

$$A_W = (a_{1W}, a_{2W}, \dots, a_{nW})$$

Where a_{1W} represents the preference score of factors i over the worst factor.

4. Determining Optimal Weights:

The optimal weight for the factors were determined by solving the following linear programming model:

$$\begin{aligned} & \text{MIN } \varepsilon \\ & \text{Subject to:} \\ & \omega_B - a_{Bi}\omega_i \leq \varepsilon, \quad \forall i = 1, 2, \dots, n \\ & \omega_i - a_{iW}\omega_W \leq \varepsilon, \quad \forall i = 1, 2, \dots, n \\ & \sum_{i=1}^n \omega_i = 1 \\ & \omega_i \geq 0 \end{aligned}$$

Where ω_B , ω_W , and ω_i are the optimal weights for the best, worst, and i -th factor respectively.

5. Aggregating Weights:

The aggregated weight ω_i^* for each factor was obtained using the geometric mean of the weights calculated for each DM:

$$\omega_i^* = \left(\prod_{k=1}^K \omega_{ik} \right)^{\frac{1}{K}}$$

Where ω_{ik} is the weight of factor i given by the k -th DM, and K is the total number of DMs.

6. Consistency Ratio Calculation:

The consistency ratio (CR) was calculated to measure the inconsistency in the pairwise comparisons. The CR is given by:

$$CR = \frac{\varepsilon^*}{\varepsilon_{max}}$$

where ε^* is the optimal value of the objective function and ε_{max} is the maximum possible value of ε . The CR ranges from 0 to 1, with values closer to 0 indicating more consistent judgments.

RESULT AND ANALYSIS

The results of this study are derived from an analysis using the BWM to evaluate the barriers to adopting AR in inventory management. The study gathered data from 53 respondents with varied expertise, including Logistics Coordinators, Warehouse Managers, IT Managers, Operations Managers, AR Technology Providers, and others (Table 2). This diverse group provided a comprehensive perspective on the challenges faced in implementing AR technology.

Table 2: Area of Expertise of Respondents

Area of expertise of respondents	Frequency
Logistics Coordinators	16
Warehouse Managers	12
IT Managers	5
Operations Managers	5
AR Technology Providers	3
Others	12
Total	53

The BWM analysis identified and ranked the barriers based on their significance. The analysis revealed that financial barriers were the most critical, followed by operational, technological, organizational, environmental, legal, and social barriers. Each barrier category was further broken down into sub-categories, which were weighted and ranked to provide a detailed understanding of the specific challenges within each category.

Table 3, represents how many respondents selected each category as the best or worst barrier to the adoption of AR in inventory management. This table provides insight into the perceived

significance of each barrier category from the respondents' viewpoints, highlighting the most critical areas that need to be addressed for successful AR implementation. For instance, 17 respondents identified financial barriers as the most critical, while 19 respondents identified legal barriers as the least significant. Technological barriers were identified as the best by 14 respondents and not considered the worst by any, indicating their high perceived importance but lower perceived difficulty compared to legal and social barriers.

Table 3: Selection of Best and Worst Categories by Respondents

Categories	Best	Worst
Technological	14	0
Organizational	7	8
Financial	17	2
Environmental	2	10
Legal	0	19
Social	0	12
Operational	13	2

The Weights for each category and sub-categories as well as their rankings as per significance is presented in Table 4. Higher weights reflect higher importance for the category or sub-category. The financial barriers emerged as the most significant, with an overall weight of 0.28531. Within this category, the sub-category of initial capital expenditure was identified as the most critical barrier, with a local weight of 0.29364 and a global weight of 0.083778, ranking first among all barriers. This finding underscores the substantial upfront investment required to implement AR technology, which can be prohibitive for many organizations. Uncertain ROI was also a significant financial barrier, ranking second overall with a global weight of 0.074312. High maintenance costs and the cost of training further contributed to the financial challenges, ranking fourth and fifth, respectively. These findings highlight the financial risks and ongoing costs associated with AR adoption, which can deter companies from investing in this technology.

Operational barriers were the second most significant category, with a weight of 0.20173. The complexity of operations was the most critical operational barrier, ranking third overall with a global weight of 0.065038. This barrier reflects the challenges in integrating AR into diverse and dynamic inventory management environments. Maintenance and support also emerged as a significant operational barrier, ranking seventh with a global weight of 0.055665. Supply chain disruptions and scalability issues were other notable operational barriers, emphasizing the potential disruptions and challenges in scaling AR solutions across different locations and operations.

Technological barriers were identified as the third most significant category, with a weight of 0.25084. High implementation costs were the most critical technological barrier within this category, ranking sixth overall with a global weight of 0.057896. This barrier highlights the substantial initial costs associated with purchasing and integrating AR technology. Rapid

technological changes were another significant technological barrier, ranking eighth with a global weight of 0.050256. This finding indicates the challenges in keeping AR systems up-to-date amidst rapid advancements in technology. Compatibility issues, lack of technical expertise, and concerns about data security and reliability were also significant technological barriers, reflecting the technical complexities and risks associated with AR implementation.

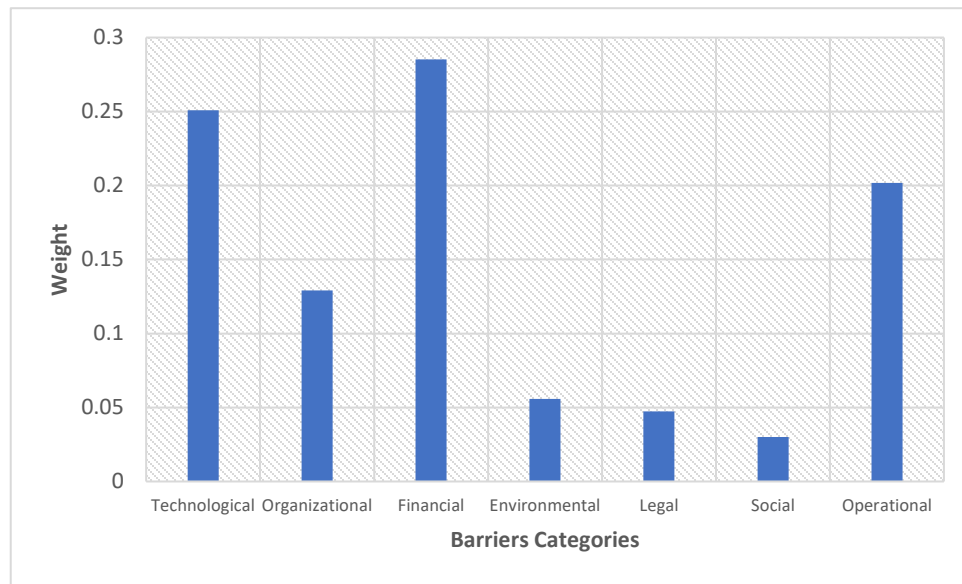


Figure 1: Relative weights for each barrier categories

Organizational barriers, with a weight of 0.12912, were the fourth most significant category. Workforce adaptability was the most critical organizational barrier, ranking twelfth overall with a global weight of 0.035369. This barrier underscores the variability in the ability of the workforce to adapt to new AR technologies. Integration with existing systems and training requirements were other notable organizational barriers, highlighting the challenges in integrating AR with current inventory management systems and the need for extensive training to ensure employees are proficient in using the technology. Resistance to change and lack of top management support further contributed to the organizational challenges, reflecting the importance of organizational culture and leadership in facilitating AR adoption.

Environmental barriers, with a weight of 0.05571, were identified as the fifth most significant category. Within this category, resource efficiency was the most critical barrier, ranking nineteenth overall with a global weight of 0.017637. This finding highlights the challenges in optimizing resource use and reducing waste through AR implementation. Carbon footprint, energy consumption, and e-waste generation were other notable environmental barriers, emphasizing the need for sustainable practices in deploying AR technology.

Legal barriers were the sixth most significant category, with a weight of 0.04728. Regulatory compliance was the most critical legal barrier, ranking twentieth overall with a global weight of 0.015605. This barrier reflects the complexities and costs associated with navigating the regulatory landscape for AR technology. Liability concerns, data privacy regulations, and

intellectual property issues were other notable legal barriers, highlighting the legal risks and challenges in deploying AR.

Social barriers, with a weight of 0.03001, were the least significant category. User acceptance was the most critical social barrier, ranking twenty-ninth overall with a global weight of 0.007804. This barrier underscores the challenges in achieving widespread acceptance and comfort with AR technology among users. Cultural barriers, ethical concerns, and the impact on employment were other notable social barriers, reflecting the social and ethical considerations in AR adoption.

Table 4: Weights and Rankings of Barrier Categories and Sub-Categories

Category	Weight	Sub-Category	Local Weight	Global Weights	Global Rank
Technological	0.25084	High Implementation Costs	0.23081	0.057896	6
		Lack of Technical Expertise	0.16926	0.042457	10
		Data Security Concerns	0.11826	0.029664	16
		Compatibility Issues	0.15849	0.039756	11
		Reliability and Performance	0.12283	0.030811	15
		Rapid Technological Changes	0.20035	0.050256	8
		Resistance to Change	0.14745	0.019039	18
Organizational	0.12912	Lack of Top Management Support	0.12045	0.015553	21
		Integration with Existing Systems	0.25817	0.033335	14
		Training Requirements	0.20001	0.025825	17
		Workforce Adaptability	0.27392	0.035369	12
		High Maintenance Costs	0.22784	0.065005	4
Financial	0.28531	Uncertain ROI	0.26046	0.074312	2
		Cost of Training	0.21806	0.062215	5
		Initial Capital Expenditure	0.29364	0.083778	1
		Energy Consumption	0.22549	0.012562	24
Environmental	0.05571	E-Waste Generation	0.19792	0.011026	25
		Carbon Footprint	0.26	0.014485	22
		Resource Efficiency	0.31659	0.017637	19
		Regulatory Compliance	0.33006	0.015605	20
Legal	0.04728	Intellectual Property Issues	0.18008	0.008514	27
		Data Privacy Regulations	0.20831	0.009849	26
		Liability Concerns	0.28155	0.013312	23
		User Acceptance	0.26004	0.007804	29
Social	0.03001	Cultural Barriers	0.23074	0.006925	30
		Ethical Concerns	0.22959	0.00689	31
		Impact on Employment	0.27963	0.008392	28
		Complexity of Operations	0.3224	0.065038	3
Operational	0.20173	Supply Chain Disruptions	0.17458	0.035218	13
		Maintenance and Support	0.27594	0.055665	7
		Scalability Issues	0.22708	0.045809	9

The comprehensive analysis using the BWM approach provided a detailed understanding of the barriers to AR adoption in inventory management. The findings highlight the need for targeted strategies to address the most significant barriers, particularly financial and operational challenges. Addressing high implementation costs and uncertain ROI through cost-sharing models, phased implementation approaches, and detailed cost-benefit analyses can help mitigate financial risks. Enhancing technical expertise through specialized training programs and collaborations with technology providers can address technological barriers. Organizational resistance can be overcome through change management initiatives and strong leadership support.

Furthermore, integrating AR solutions with sustainable practices, such as energy-efficient technologies and e-waste recycling programs, can address environmental barriers. Staying informed about regulatory developments and seeking legal counsel can help navigate legal challenges. User-centered design, cultural sensitivity, and ethical considerations can address social barriers, ensuring widespread acceptance and comfort with AR technology.

MANAGERIAL IMPLICATIONS

The findings of this study have significant implications for managers aiming to adopt AR in inventory management. By addressing identified barriers, managers can facilitate smoother implementation and integration of AR technology, enhancing operational efficiency and sustainability.

Financial barriers are the most critical, with substantial initial capital expenditure being a major concern. Managers can explore cost-sharing models or phased implementation approaches to spread out expenses. Conducting thorough cost-benefit analyses can justify investments by highlighting long-term savings and efficiency gains. To address uncertain ROI, clear metrics and performance indicators should be developed to measure AR's impact, helping secure stakeholder support. Managing high maintenance costs and training expenses through comprehensive training programs and maintenance schedules ensures workforce proficiency and system reliability.

Operational challenges, particularly the complexity of integrating AR into diverse environments, require careful planning. Pilot studies can provide valuable feedback and identify potential issues before a full-scale rollout. Detailed implementation roadmaps help manage complexity and ensure structured integration. Robust support systems, including dedicated teams or partnerships with AR providers, can minimize downtime and ensure continuous functionality. Addressing scalability issues from the planning stages ensures effective expansion across different locations. Technological barriers such as high implementation costs, rapid technological changes, compatibility issues, lack of technical expertise, and data security concerns need strategic solutions. Prioritizing investments in scalable AR technology and staying updated on advancements can mitigate technological challenges. Close collaboration with IT departments ensures seamless integration with existing

systems. Continuous learning programs enhance technical expertise, while stringent data security protocols protect sensitive information.

Organizational barriers like resistance to change, lack of top management support, integration challenges, training requirements, and workforce adaptability require effective change management. Fostering a culture of innovation and clearly communicating AR benefits can alleviate resistance. Securing top management support through compelling business cases aligns AR technology with organizational goals. Detailed integration plans and comprehensive training programs ensure smooth adoption. Supporting workforce adaptability through continuous development programs is crucial.

Environmental barriers such as energy consumption, e-waste generation, carbon footprint, and resource efficiency must be addressed with sustainable practices. Prioritizing energy-efficient AR solutions and implementing e-waste recycling programs minimize environmental impact. Optimizing resource use through accurate inventory tracking enhances sustainability. Legal barriers including regulatory compliance, intellectual property issues, data privacy regulations, and liability concerns require careful navigation. Staying informed about regulations and consulting legal experts help address these challenges. Ensuring compliance and protecting the organization against legal risks are essential. Social barriers like user acceptance, cultural differences, ethical concerns, and the impact on employment require thoughtful management. Engaging employees and stakeholders to understand and address their concerns enhances acceptance. Cultural sensitivity and ethical considerations ensure responsible AR use. Managing employment impact through upskilling and reskilling opportunities helps employees transition to new roles.

Addressing these barriers strategically enables successful AR implementation in inventory management, driving efficiency and sustainability. The insights from this study provide a roadmap for overcoming AR adoption challenges, allowing organizations to leverage the full potential of this transformative technology.

CONCLUSIONS

This study identified and ranked the barriers to adopting AR in inventory management using the BWM. Financial barriers, particularly initial capital expenditure and uncertain return on investment, were the most significant, followed by operational and technological barriers. Addressing these barriers through strategic financial planning, detailed implementation roadmaps, continuous learning programs, and robust data security protocols can facilitate smoother AR integration. The findings provide a roadmap for overcoming these challenges, enabling organizations to leverage AR for improved efficiency and sustainability in inventory management. In future research can be done focusing on longitudinal studies to track AR adoption over time and detailed case studies of successful implementations. Assessing the long-term impact of AR on efficiency and sustainability, exploring new technological advancements, and understanding user experiences are crucial. Additionally, examining regulatory and ethical considerations, scalability, cost-effectiveness, and integration with sustainable practices will

provide deeper insights and practical solutions to facilitate broader AR adoption in inventory management.

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