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LEVERAGING TECHNOLOGY TO DRIVE INNOVATION: A MIXED-METHODS APPROACH TO ENHANCING ORGANIZATIONAL CREATIVITY AND COMPETITIVENESS

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Abstract: This research article investigates the dynamic interplay between innovation and technology, focusing on how advancements in technology catalyze innovative practices across various industries. The purpose of this study is to illuminate the mechanisms through which technology influences innovation processes, thereby offering insights into effective strategies for fostering creativity and competitiveness in organizations. To achieve this, a mixed-methods approach was employed, combining quantitative data analysis with qualitative case studies from leading technology firms. Surveys were distributed to over 300 professionals across different sectors, gathering data on their perceptions of technological impact on innovation. Additionally, in-depth interviews with 15 industry experts provided contextual insights into real-world applications of technology in innovation strategies. The findings reveal a significant correlation between the adoption of cutting-edge technologies and the enhancement of innovative capabilities within organizations. Specifically, firms that actively integrate technologies such as artificial intelligence, machine learning, and big data analytics reported higher levels of innovation output and effectiveness. Furthermore, the study identifies key factors that facilitate this relationship, including organizational culture, leadership support, and investment in training. The implications of these findings are profound, suggesting that organizations aiming to improve their innovation outcomes should prioritize technology adoption as a strategic imperative. By leveraging technology not only as a tool but as a catalyst for innovation, companies can navigate the complexities of the modern market landscape more effectively. This research contributes to the broader field of innovation and technology studies, providing a framework for understanding how technological advancements can be harnessed to drive innovative practices and enhance organizational performance.
Keywords: Innovation; Technology; Learning; Education; Organizational performance

1 INTRODUCTION

Innovation and technology studies represent a critical field of inquiry that examines the complex relationships between technological advancements and innovative processes in various sectors. As societies evolve, the role of technology becomes increasingly pivotal in shaping economic, social, and cultural dynamics. Understanding this interplay is essential, as it offers valuable insights into how innovations emerge, are adopted, and ultimately influence broader socio-economic landscapes.

The importance of this field cannot be overstated. In a world characterized by rapid technological change, organizations must navigate an environment where the very nature of competition is transformed by new tools and methodologies. By investigating the historical context of technological developments, researchers can trace the evolution of innovation practices and identify patterns that inform current trends. This historical perspective allows for a deeper comprehension of contemporary challenges and opportunities, providing a framework for strategic decision-making in businesses and policy-making.

Contemporary relevance is evident in various sectors, from healthcare to finance, where technology-driven innovations are reshaping service delivery and customer engagement. The ongoing digital transformation emphasizes the necessity for organizations to adapt quickly and effectively to maintain competitive advantages. Consequently, innovation and technology studies play a vital role in helping stakeholders understand the implications of these changes, enabling them to respond proactively.

The objectives of this research article are to explore the mechanisms through which technological advancements influence innovation processes, assess the impact of these changes on organizational performance, and identify key factors that facilitate the integration of technology into innovation strategies. By addressing these objectives, this study aims to contribute to the broader understanding of how innovation and technology intersect, thereby offering actionable insights for organizations striving to thrive in an increasingly complex landscape.

2 LITERATURE REVIEW

The literature on innovation and technology studies encompasses a diverse array of theories, concepts, and frameworks that have significantly influenced the understanding of how technology drives innovation. One of the foundational theories in this field is the Diffusion of Innovations theory proposed by Everett Rogers, which explores how, why, and at what rate new ideas and technology spread among cultures. This theory highlights the roles of innovation attributes, communication channels, and social systems in the adoption process, providing a robust framework for analyzing technological impact on innovation.

Another significant contribution comes from the Resource-Based View (RBV) of the firm, which posits that a company's unique resources and capabilities, including technological assets, are critical for achieving competitive advantage. This perspective encourages organizations to leverage their technological capabilities to foster innovation, thereby aligning resources with strategic goals. Similarly, the Dynamic Capabilities framework, advanced by Teece, Pisano, and Shuen, emphasizes the importance of organizations' abilities to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments, further underscoring the interplay between technology and innovation.

Additionally, the Open Innovation model introduced by Henry Chesbrough advocates for a more collaborative approach to innovation, where firms utilize external and internal ideas and paths to market. This model reflects a paradigm shift in how organizations approach innovation, suggesting that technology can facilitate partnerships and co-creation with external stakeholders, thus enhancing innovative outcomes.

Despite the extensive literature, several gaps remain unaddressed. For instance, while the existing studies emphasize the benefits of technology adoption, they often overlook the challenges organizations face in integrating new technologies into their innovation processes. Furthermore, there is a lack of empirical research focusing on specific industries or contexts, particularly in emerging markets where technology adoption may differ significantly from established economies. This research seeks to fill these gaps by providing a nuanced understanding of how technology influences innovation in various organizational settings, contributing to the ongoing discourse in innovation and technology studies.

3 THEORETICAL FRAMEWORK

The theoretical framework guiding this research is anchored in established theories of innovation and technology, notably the Diffusion of Innovations (DOI) theory and the Technology Acceptance Model (TAM). These frameworks provide a comprehensive lens through which the interplay between technology adoption and innovation can be examined.

The Diffusion of Innovations theory, formulated by Everett Rogers, posits that the process through which innovations are communicated and adopted within social systems is crucial to understanding their impact. This theory identifies key attributes of innovations, such as relative advantage, compatibility, complexity, trialability, and observability, which influence the rate of adoption. In the context of this research, DOI serves as a foundation for analyzing how organizations perceive and implement new technologies to enhance their innovative capabilities. By exploring these attributes, the study can illuminate the factors that either facilitate or hinder the adoption of technological advancements.

Complementing the DOI is the Technology Acceptance Model, which focuses on the determinants of user acceptance of technology. TAM asserts that perceived ease of use and perceived usefulness significantly influence an individual's decision to adopt a technology. In this research, TAM will be utilized to assess how professionals in various industries perceive the technologies that enhance innovation processes. Understanding these perceptions is vital, as they can guide organizations in implementing supportive measures that increase technology acceptance among employees.

Emerging theories, such as the Unified Theory of Acceptance and Use of Technology (UTAUT), further enrich the theoretical framework by integrating multiple acceptance models to explain user intentions and behavior. This research will also consider this model to comprehensively assess the technological landscape within organizations.

By synthesizing these theoretical perspectives, this research aims to build a robust framework that elucidates the complex relationship between technology and innovation, providing actionable insights for organizations navigating the challenges of technological integration.

4 METHODOLOGY

This research employs a mixed-methods approach to explore the intricate relationship between technology and innovation. The study integrates both qualitative and quantitative methodologies to provide a comprehensive understanding of how technological advancements influence innovative practices within organizations.

4.1 Research Design

The quantitative aspect of the research is characterized by a survey distributed to over 300 professionals across various industries. This survey was designed to gather statistical data on participants' perceptions regarding the impact of technology on their innovation processes. The questions were structured to quantify variables related to technology adoption, innovation output, and organizational performance. In contrast, the qualitative component involved in-depth interviews with 15 industry experts, selected based on their extensive experience and knowledge in technology-driven innovation. This dual

approach allows for a richer analysis, as quantitative data can identify trends and correlations, while qualitative insights provide context and depth to the findings.

4.2 Sample Selection

For the quantitative survey, a stratified random sampling method was employed to ensure representation across multiple sectors, including healthcare, finance, and manufacturing. This approach helps mitigate bias and enhances the generalizability of the results. The qualitative sample comprised industry experts who were purposefully selected based on their leadership roles and contributions to technology initiatives within their organizations.

4.3 Data Collection Techniques

Data collection for the quantitative component involved administering online surveys, enabling a broad reach and higher response rates. The qualitative interviews were conducted via video conferencing tools, allowing for flexible scheduling and the ability to capture nuanced responses through open-ended questions.

4.4 Analysis Methods

Quantitative data were analyzed using statistical software to perform descriptive and inferential analyses, identifying significant correlations between technology adoption and innovation output. The qualitative data from interviews underwent thematic analysis, which involved coding responses to identify recurring themes and insights related to technology's role in fostering innovation.

4.5 Justification of Methodology

The mixed-methods approach is particularly suited for this research as it allows for triangulation, enhancing the validity and reliability of the findings. By combining numerical data with personal narratives, the study effectively addresses the research questions about the mechanisms through which technology impacts innovation, offering a well-rounded perspective that purely qualitative or quantitative studies may not achieve. This comprehensive methodology not only enriches the data but also provides actionable insights for organizations looking to leverage technology for enhanced innovation.

4.6 Case Studies in Innovation

In examining the impact of technological innovation across various sectors, several case studies stand out as exemplary illustrations of how organizations have harnessed technology to drive transformative change. These cases not only highlight successful implementations but also provide valuable lessons for other industries aiming to foster innovation.

4.6.1 Case study 1: healthcare - telemedicine in rural Areas

One of the most significant innovations in healthcare has been the rise of telemedicine, particularly in rural areas where access to healthcare services is limited. A notable example is the partnership between the University of Mississippi Medical Center and local clinics, which established a telehealth program that allows patients to consult with specialists via video conferencing. This initiative has significantly reduced travel time for patients and increased access to specialized care. The use of electronic health records integrated with telemedicine platforms has streamlined patient data sharing, enhancing treatment continuity and outcomes.

4.6.2 Case study 2: education - blended learning models

In the education sector, the implementation of blended learning models in K-12 schools has revolutionized teaching methodologies. The Flipped Classroom model, utilized by several progressive schools in the United States, allows students to engage with instructional content online at home and apply that knowledge during interactive classroom sessions. By leveraging technology, educators can personalize learning experiences and foster greater student engagement. This approach also equips students with critical digital skills essential for the modern workforce, illustrating how educational institutions can innovate to meet changing societal demands.

4.6.3 Case study 3: manufacturing - smart factories

The manufacturing sector has witnessed significant innovation through the adoption of smart factory concepts, particularly in automotive production. The implementation of Internet of Things (IoT) technologies at companies like General Motors has enabled real-time monitoring of production lines, predictive maintenance of machinery, and enhanced supply chain management. By integrating advanced analytics and machine learning, GM has optimized operations, reduced downtime, and improved overall product quality. This case emphasizes the potential of technology to create agile and efficient manufacturing processes.

4.6.4 Case study 4: retail - e-commerce platforms

The retail sector has transformed dramatically with the rise of e-commerce platforms, exemplified by Amazon's approach to customer experience. Through the use of big data analytics, Amazon personalizes shopping experiences by recommending products based on customer behavior and preferences. Additionally, the integration of artificial intelligence in logistics has streamlined inventory management and reduced delivery times. This case illustrates how retail businesses can leverage technology to enhance consumer engagement and operational efficiency, setting a standard for competitors [1].

These diverse case studies illustrate the multifaceted nature of technological innovation across different sectors. Each example underscores the profound impact that strategic technology adoption can have on enhancing operational effectiveness, improving customer experiences, and ultimately driving competitive advantage [2].

5 TECHNOLOGICAL DRIVERS OF INNOVATION

In today's rapidly evolving landscape, several key technological advancements have emerged as powerful drivers of innovation across industries. Among these, artificial intelligence (AI), big data, and the Internet of Things (IoT) stand out for their transformative capabilities. Each of these technologies not only enhances operational efficiency but also fosters new business models and creates competitive advantages for organizations.

Artificial intelligence has become a cornerstone of innovation, enabling organizations to automate processes, gain insights from complex data sets, and enhance decision-making. AI applications, such as machine learning algorithms, facilitate predictive analytics, allowing businesses to anticipate market trends and customer needs. For instance, in the healthcare sector, AI-driven diagnostic tools can analyze medical images with remarkable accuracy, leading to earlier disease detection and improved patient outcomes. Moreover, AI enhances personalization in marketing, where algorithms tailor content and recommendations to individual preferences, thereby increasing customer engagement [3].

Similarly, big data plays a crucial role in shaping innovative practices. The vast amounts of data generated daily present an opportunity for organizations to glean valuable insights. With advanced analytics tools, businesses can identify patterns and correlations that inform strategic decisions. In finance, for example, big data analytics enables real-time risk assessment, helping firms to better manage their portfolios and detect fraudulent activities more effectively. The ability to harness big data not only improves operational efficiency but also enhances customer experiences through targeted offerings and personalized services.

The Internet of Things further amplifies these advancements by connecting devices, systems, and people, creating a seamless flow of information. IoT technologies facilitate real-time monitoring and control of various processes, from supply chain logistics to home automation. In manufacturing, IoT sensors can track equipment performance and predict maintenance needs, minimizing downtime and optimizing productivity. As businesses embrace IoT, they unlock opportunities for innovation through enhanced data collection and integration, leading to smarter decision-making and improved service delivery.

Together, these technological drivers—AI, big data, and IoT—are reshaping the landscape of innovation, enabling organizations to adapt and thrive amid rapid change. Their combined impact fosters a culture of continuous improvement and creativity, essential for sustaining competitive advantage in an increasingly complex global market.

5.1 Barriers to Innovation

While the potential for innovation driven by technology is immense, organizations often face significant barriers that impede their ability to harness these advancements effectively. Understanding these barriers is crucial for developing strategies that foster a culture of innovation. Among the most common obstacles are cultural resistance, lack of resources, and regulatory challenges [4].

Cultural resistance within organizations can severely hinder innovation efforts. Employees may be accustomed to established practices, leading to a reluctance to adopt new technologies or processes. This resistance often stems from fear of change, concerns about job security, or a lack of understanding of the benefits associated with innovation. For organizations to overcome this barrier, fostering an innovative culture that encourages experimentation and embraces failure as a learning opportunity is essential. Leadership must actively promote the value of innovation and provide platforms for employees to voice their ideas and concerns.

Another significant barrier is the lack of resources, including financial investment, time, and skilled personnel. Many organizations, particularly smaller firms, struggle to allocate the necessary resources for research and development or technology integration. Without sufficient funding, initiatives may be underdeveloped or abandoned altogether. Organizations can mitigate this barrier by seeking partnerships, grants, or venture capital and by prioritizing innovation in their strategic planning. Investing in employee training and development also equips teams with the skills needed to leverage new technologies effectively.

Regulatory challenges present a further obstacle, particularly in industries such as healthcare and finance, where compliance with stringent regulations can slow down the pace of innovation. Organizations may hesitate to invest in new technologies due to uncertainties surrounding regulatory approval or fear of penalties for non-compliance. To navigate these challenges,

businesses must engage proactively with regulatory bodies and advocate for policies that support innovation while ensuring compliance.

These barriers, if left unaddressed, can stifle technological advancement and hinder an organization's ability to compete in a rapidly changing market. By recognizing and tackling these challenges head-on, organizations can create an environment conducive to innovation, ultimately driving growth and success.

5.2 Policy Implications

Public policy plays a crucial role in shaping the landscape for innovation and technology development. By establishing frameworks that either foster or inhibit innovation, policymakers can significantly influence the ability of organizations to adapt and thrive in a competitive market. Current policies aimed at supporting technology development often focus on funding, tax incentives, and regulatory frameworks designed to encourage research and development (R&D). However, these policies can sometimes fall short due to bureaucratic hurdles, misalignment with industry needs, or lack of adequate stakeholder engagement [5].

One prominent area where public policy has facilitated innovation is through funding initiatives, such as grants and subsidies for R&D. These programs are essential for startups and small to medium-sized enterprises (SMEs), which may lack the capital to invest in cutting-edge technologies. Additionally, tax incentives for companies that invest in R&D can stimulate further innovation by reducing financial risks. However, the effectiveness of these measures is contingent upon their accessibility and clarity. Policymakers should consider simplifying application processes and ensuring that incentives are equitable across various sectors to maximize their impact [6].

Moreover, regulatory frameworks must evolve in tandem with technological advancements. Policies that are overly rigid can stifle innovation by creating barriers to entry for new technologies. For instance, in sectors like biotechnology or fintech, outdated regulations may inhibit the development of groundbreaking solutions that could enhance efficiency and consumer welfare. Policymakers should engage with industry leaders and innovators to create adaptive regulatory frameworks that balance safety and innovation.

To improve existing policies, there is a need for a more collaborative approach between government, academia, and the private sector. Establishing public-private partnerships can facilitate knowledge sharing and resource allocation, ensuring that policies are informed by real-world needs and challenges. Furthermore, promoting education and training programs in emerging technologies can equip the workforce with the necessary skills to embrace innovation, thereby enhancing the overall competitiveness of the economy.

In summary, while current policies provide a foundation for supporting technology development and innovation, there is ample room for improvement. By streamlining funding processes, adapting regulatory frameworks, and fostering collaboration, public policy can more effectively promote a culture of innovation that drives economic growth and societal advancement [7].

5.3 Future Trends in Innovation and Technology

As we look toward the future, several emerging trends in innovation and technology are poised to reshape industries and societal dynamics. The rapid pace of technological advancement suggests that disruptions will not only be frequent but also profound, influencing the way researchers, practitioners, and policymakers approach their respective fields.

One anticipated trend is the increasing integration of artificial intelligence (AI) across various sectors. AI is expected to evolve beyond automation to become a central decision-making partner, enhancing human capabilities rather than merely replacing them. This shift will require researchers to explore new methodologies for human-AI collaboration, while practitioners will need to adapt to the changing skill sets required for effective teamwork with intelligent systems. Policymakers, in turn, will face the challenge of developing regulations that ensure ethical AI deployment, addressing concerns around bias, privacy, and accountability.

Another significant trend is the expansion of the Internet of Things (IoT) and its integration into everyday life. As more devices become interconnected, the volume of data generated will explode, necessitating advancements in data analytics and cybersecurity. Researchers will need to investigate the implications of this data deluge for privacy and data ownership, while practitioners will need to develop robust data management strategies. Policymakers must also establish frameworks that protect consumers while fostering innovation in data usage.

Furthermore, sustainability is emerging as a primary driver of innovation, with organizations increasingly adopting green technologies and practices. This trend is prompting researchers to explore sustainable innovation models, practitioners to implement eco-friendly solutions, and policymakers to create incentives for sustainable practices. The transition to a circular economy will require collaborative efforts among all stakeholders to redefine value chains and resource utilization.

Lastly, the rise of decentralized technologies, such as blockchain, is set to disrupt traditional business models and governance structures. Researchers will need to analyze the implications of decentralization on trust and accountability, practitioners will be tasked with integrating these technologies into existing systems, and policymakers will face the challenge of regulating these innovations without stifling their potential [8].

In summary, the future of innovation and technology will be characterized by AI integration, IoT expansion, sustainability initiatives, and decentralized models. Each trend presents unique challenges and opportunities for researchers, practitioners, and policymakers, necessitating a proactive and collaborative approach to navigate this evolving landscape.

6 CONCLUSION

The findings of this research article underscore the critical role that technology plays in fostering innovation within organizations. The correlation identified between the adoption of advanced technologies—such as artificial intelligence, big data analytics, and the Internet of Things—and increased innovative capabilities highlights the necessity for organizations to embrace technological advancements as a strategic imperative. This study reveals that firms that actively leverage these technologies tend to achieve higher levels of innovation output and effectiveness, suggesting that technology should not merely be viewed as a tool but as a catalyst for transformative change.

The implications of this research extend beyond organizational practices; they offer valuable insights for future studies in the field of innovation and technology. Future research can explore the nuances of technology integration across diverse industries, particularly in emerging markets where adoption patterns may differ significantly from those in established economies. Additionally, investigating the role of organizational culture and leadership in overcoming barriers to technology adoption can provide a deeper understanding of how to cultivate an environment conducive to innovation.

From a policy perspective, the study emphasizes the importance of creating regulatory frameworks that balance innovation with safety and compliance. Policymakers are encouraged to engage with industry stakeholders to develop adaptive regulations that facilitate technological integration while ensuring consumer protection. Moreover, fostering public-private partnerships can enhance resource allocation and knowledge sharing, driving collaborative innovation efforts.

As organizations navigate the complexities of the modern market landscape, the integration of technology into innovation strategies must be prioritized. By doing so, they can not only enhance their competitive edge but also contribute to broader economic growth and societal advancement. The interplay between technology and innovation will undoubtedly continue to evolve, necessitating ongoing research and proactive engagement from both practitioners and policymakers [9].

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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ENHANCING THE SECURITY LEVELS IN INFORMATION SYSTEMS

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Abstract: This document provides a comprehensive guide to enhancing information security systems within organizations. It emphasizes strategies across physical, digital, and human domains to ensure the safety, reliability, and continuity of operations. Key topics include physical security measures, data protection practices, access control, employee awareness, and advanced surveillance technologies. These measures aim to mitigate risks from cyber threats, natural disasters, and internal vulnerabilities, fostering a robust security framework.
Keywords: Information security; Cybersecurity; Data protection; Access control; Physical security; Employee training; Firewalls; Encryption; Surveillance systems

1 INTRODUCTION TO INFORMATION SECURITY

In today's interconnected world, safeguarding information systems is critical for protecting sensitive data and ensuring operational continuity. Organizations face a growing number of threats, including cyberattacks, natural disasters, and internal vulnerabilities, which can disrupt operations and compromise valuable information. As businesses increasingly rely on technology for their daily functions, the importance of a robust and comprehensive security framework cannot be overstated.
This guide is designed to provide actionable insights and practical measures to strengthen information security. It covers a range of strategies, from physical security enhancements to advanced software practices and employee training programs. By implementing these measures, organizations can build resilient systems that not only protect data but also ensure seamless and secure operations in a rapidly evolving digital landscape as in Figure1.[1,2]

Figure 1 Information Security

2 PHYSICAL SECURITY MEASURES

2.1 Secure Infrastructure

- Reinforced Locks and Security Systems: Install durable locks and advanced physical security systems to deter unauthorized access (Figure 2).
- 24/7 Surveillance: Deploy cameras and monitoring tools to ensure continuous oversight of critical areas.
- Data and Power Cable Protection: Shield cables to prevent tampering or accidental damage.
- Structural Reinforcement: Strengthen buildings to resist natural disasters such as earthquakes, floods, and hurricanes.[3]

Figure 2 Infrastructure Security

2.2 Additional Measures

- Lightning Arresters: Protect equipment from electrical surges by installing lightning rods and grounding systems (Figure3).

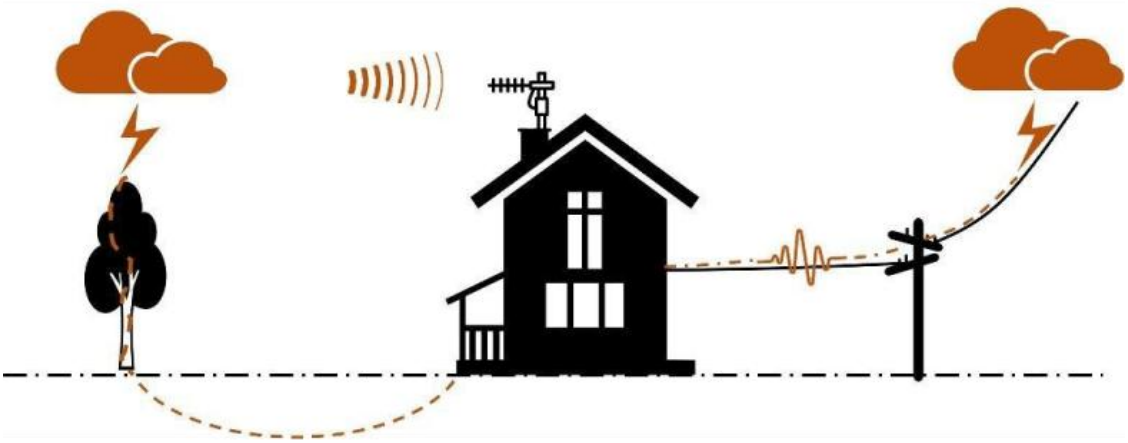

Figure 3 Lightning Arresters

- Fire Safety Systems: Equip facilities with fire alarms and emergency exits to ensure swift evacuation during crises.

3 ENSURING POWER CONTINUITY

3.1 Uninterruptible Power Supply (UPS)

Uninterruptible Power Supply (UPS) units are critical for maintaining power continuity during outages, preventing sudden system shutdowns and potential data loss. By providing immediate backup power, UPS systems ensure that operations can continue smoothly until alternative power sources, such as generators, are activated or the issue is resolved.
In addition to protecting against power interruptions, UPS units also safeguard against voltage fluctuations, surges, and spikes, which could damage sensitive equipment. They come in various sizes, from small desktop units to large industrial-scale systems, catering to different power needs. Regular maintenance and monitoring are essential to ensure the UPS remains reliable during a power failure. Additionally, advanced UPS models often include features such as battery health monitoring, load management, and remote control to optimize performance and extend their lifespan.[4]
UPS systems are indispensable in industries where power reliability is crucial, including healthcare, data centers, telecommunications, and manufacturing, where downtime can result in significant financial and operational losses.

4 DATA PROTECTION PRACTICES

4.1 Regular Backups

Regular backups are essential for ensuring the security of critical data and enabling swift recovery in the event of data loss due to hardware failures, cyberattacks, or human error. Backups should be performed periodically and stored in multiple locations, such as on-site servers, remote data centers, or cloud platforms, to provide redundancy. It is also important to verify the integrity of backups and perform periodic restoration tests to ensure data can be retrieved when needed. Automated backup solutions can help maintain consistency and reduce the risk of human error, while a well-defined backup strategy should outline backup frequency, retention policies, and disaster recovery procedures (Figure 4).

Figure 4 Backups

4.2 Data Encryption

Data encryption is a crucial practice for protecting sensitive information from unauthorized access or interception, particularly during transmission. By encrypting data before transmission, whether over internal networks or the internet, it becomes unreadable to unauthorized parties. Implementing strong encryption protocols, such as AES (Advanced Encryption Standard) or RSA (Rivest-Shamir-Adleman), helps ensure that only authorized recipients with the appropriate decryption keys can access the data. Encryption should be applied not only to data in transit but also to data at rest, such as files stored on servers or cloud platforms, to provide comprehensive protection against breaches. Additionally, regular updates to encryption algorithms and key management processes are essential to maintain security in response to evolving threats (Figure 5).

Figure 5 Data Encryption

5 SOFTWARE AND APPLICATION MANAGEMENT

5.1 Regular Updates

Regular updates to software and applications are vital for maintaining system security and functionality. These updates not only introduce new features and improvements but, more importantly, address security vulnerabilities by applying critical patches. Failing to keep software up-to-date exposes systems to exploitation by cybercriminals, as unpatched vulnerabilities are often targeted. Automated update mechanisms can be implemented to ensure that updates are applied promptly, reducing the risk of security breaches. Additionally, organizations should establish a patch management strategy to prioritize updates based on the severity of vulnerabilities and ensure that updates are tested before being deployed in production environments (Figure 6).[5]

Figure 6 Regular Updates

5.2 Antivirus Protection

Installing and maintaining up-to-date antivirus software is a cornerstone of any effective security strategy. Antivirus programs are designed to protect systems from a wide array of malicious threats, including viruses, ransomware, spyware, and other types of malwares, by identifying, blocking, and removing harmful software before it can cause damage to systems or compromise sensitive data (Figure 7).

Reliable antivirus solutions typically offer advanced features such as real-time scanning, which constantly monitors for suspicious activity, automatic threat detection, and scheduled scans that can help identify potential risks during off-peak hours. Regular updates are crucial, as they ensure that the antivirus software remains equipped to detect and mitigate the latest threats, which evolve rapidly.[6]

To further enhance security, antivirus protection should be part of a broader, multi-layered cybersecurity approach. Organizations should combine antivirus programs with other protective measures, including firewalls, intrusion detection systems, and security patches, to provide comprehensive defense against both known and emerging threats. Additionally, user training on safe browsing habits and recognizing phishing attempts can further strengthen the organization's cybersecurity posture.

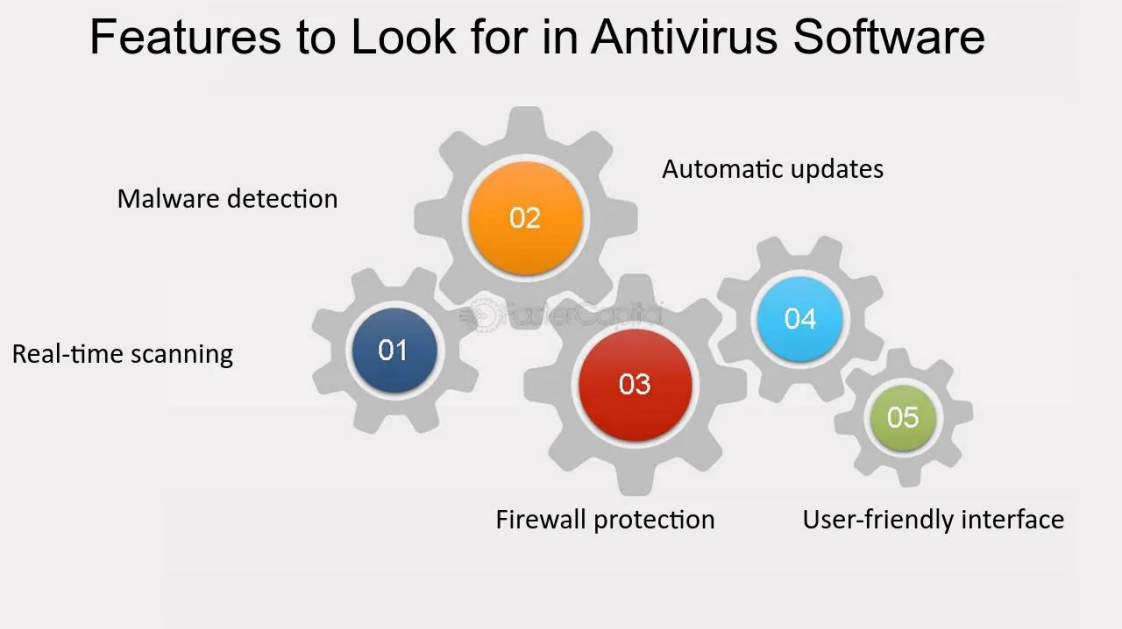

Figure 7 Antivirus Protection

6 ACCESS CONTROL AND AUTHENTICATION

6.1 Strong Password Policies

Implementing strong password policies is essential for safeguarding access to systems and sensitive data. Passwords should be complex, incorporating a mix of uppercase and lowercase letters, numbers, and special characters. Additionally, password length should be sufficient—typically at least 12 characters—to reduce vulnerability to brute-force attacks. Organizations should enforce regular password updates, requiring users to change their passwords at defined intervals (e.g., every 60 to 90 days). Multi-factor authentication (MFA) should also be considered to add an extra layer of protection. By setting these guidelines, organizations can significantly reduce the risk of unauthorized access due to weak or compromised passwords (Figure 8).

Figure 8 Strong Password Policies

6.2 Biometric Systems

Biometric authentication methods, such as eye scanning, hand scanning, or fingerprint recognition, provide a highly secure and convenient way to verify identity. These systems offer a higher level of security than traditional passwords or PINs, as biometric data is unique to each individual and difficult to replicate. Biometric systems can be deployed for secure access to physical areas, devices, or applications, enhancing overall security by ensuring that only authorized personnel can access sensitive resources. While the implementation of biometric systems can be costly, their effectiveness in preventing unauthorized access justifies their use, particularly in high-security environments such as financial institutions or government agencies (Figure 9).

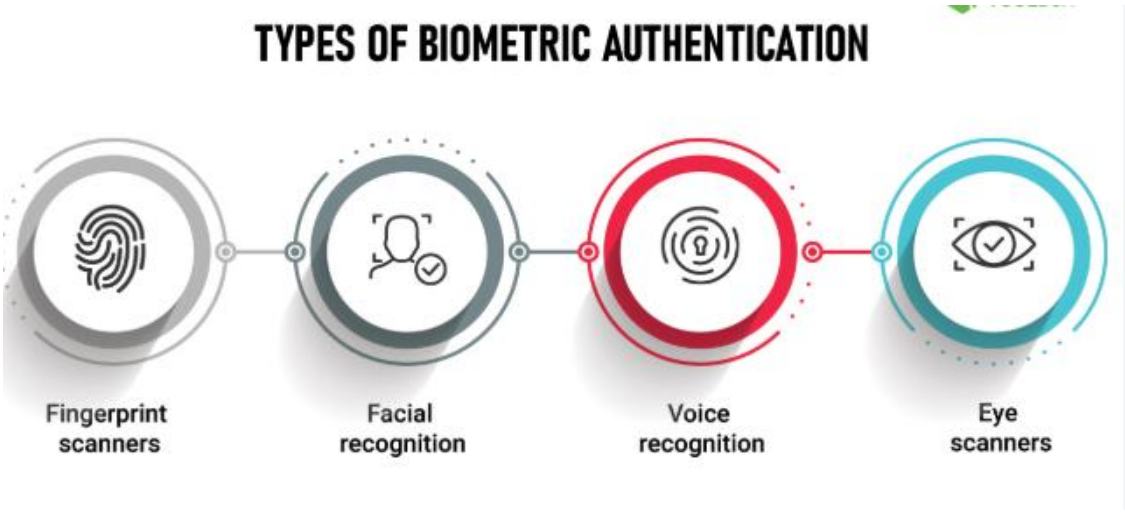

Figure 9 Biometric Systems

6.3 Access Control Policies

Access control policies define the specific rights and permissions of employees based on their roles within an organization. By implementing role-based access control (RBAC), organizations can ensure that individuals have access only to the

resources necessary for their job functions, minimizing the risk of unauthorized access to sensitive information. Access levels should be regularly reviewed and updated as roles evolve or employees change positions. Additionally, access should be promptly revoked when an employee leaves the organization or changes roles to prevent unauthorized access after departure. A well-defined access control policy helps maintain data integrity, confidentiality, and overall system security.

7 ADVANCED NETWORK PROTECTION

7.1 Firewalls

Deploying advanced firewalls is a critical step in protecting networks from unauthorized intrusions and malicious traffic. Modern firewalls go beyond traditional packet filtering by employing advanced techniques, such as stateful inspection, deep packet inspection (DPI), and application-layer filtering. These firewalls are capable of analyzing network traffic in real-time, identifying suspicious patterns, and blocking potentially harmful data before it reaches sensitive systems. Firewalls can be configured to suit specific security needs, whether at the perimeter of the network or internally to protect key assets. Additionally, next-generation firewalls (NGFW) offer integrated features such as intrusion prevention, VPN support, and content filtering, providing a comprehensive security solution to safeguard against a wide range of cyber threats (Figure 10).

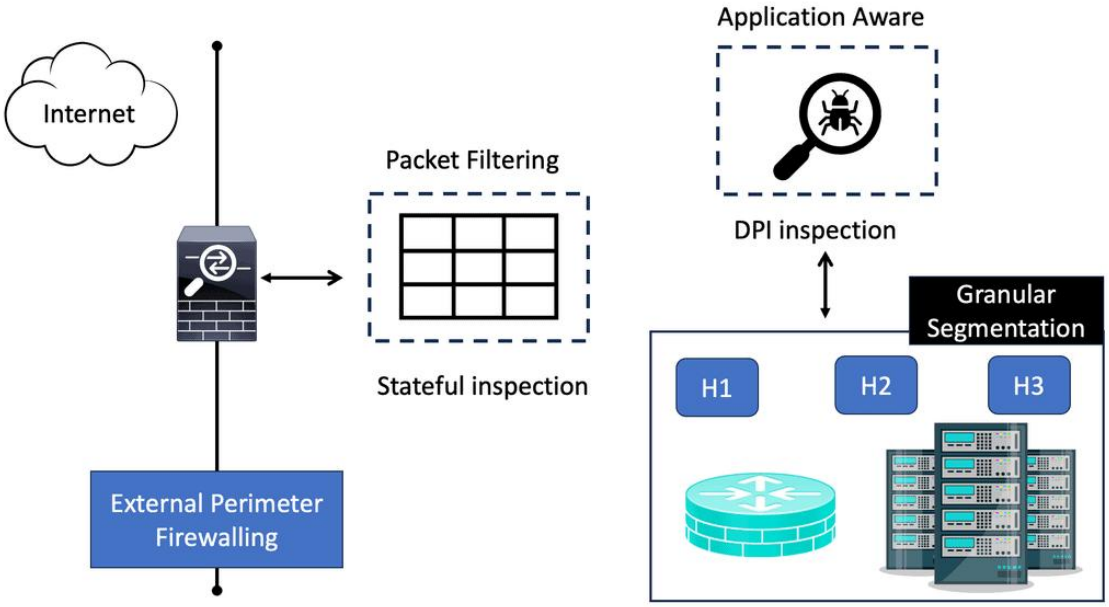

Figure 10 Firewalls

7.2 Intrusion Detection Systems (IDS)

Intrusion Detection Systems (IDS) play a vital role in network security by continuously monitoring network traffic and detecting unusual patterns that may indicate potential threats, such as unauthorized access attempts, malware, or data exfiltration. IDS tools analyze incoming and outgoing data to identify anomalies that deviate from established traffic baselines. They can generate alerts, allowing security teams to investigate and respond promptly to potential breaches. IDS systems can be network-based (NIDS), monitoring traffic across the entire network, or host-based (HIDS), focusing on individual devices. To enhance network security, IDS should be integrated with other protective measures such as firewalls and intrusion prevention systems (IPS) to form a multi-layered defense against cyberattacks.

8 EMPLOYEE AWARENESS AND MONITORING

8.1 Social Engineering Awareness

Training employees to recognize and respond to social engineering tactics is a crucial aspect of cybersecurity. Social engineering attacks manipulate individuals into revealing sensitive information, granting unauthorized access, or performing actions that compromise security. These attacks can take various forms, such as phishing emails, pretexting, baiting, or impersonation. By educating employees about these tactics and providing them with strategies to identify suspicious

behavior, organizations can significantly reduce the risk of falling victim to these types of attacks. Regularly conducting security awareness training, simulated phishing exercises, and encouraging a culture of vigilance helps employees become more adept at spotting potential threats and reporting them promptly (Figure 11).

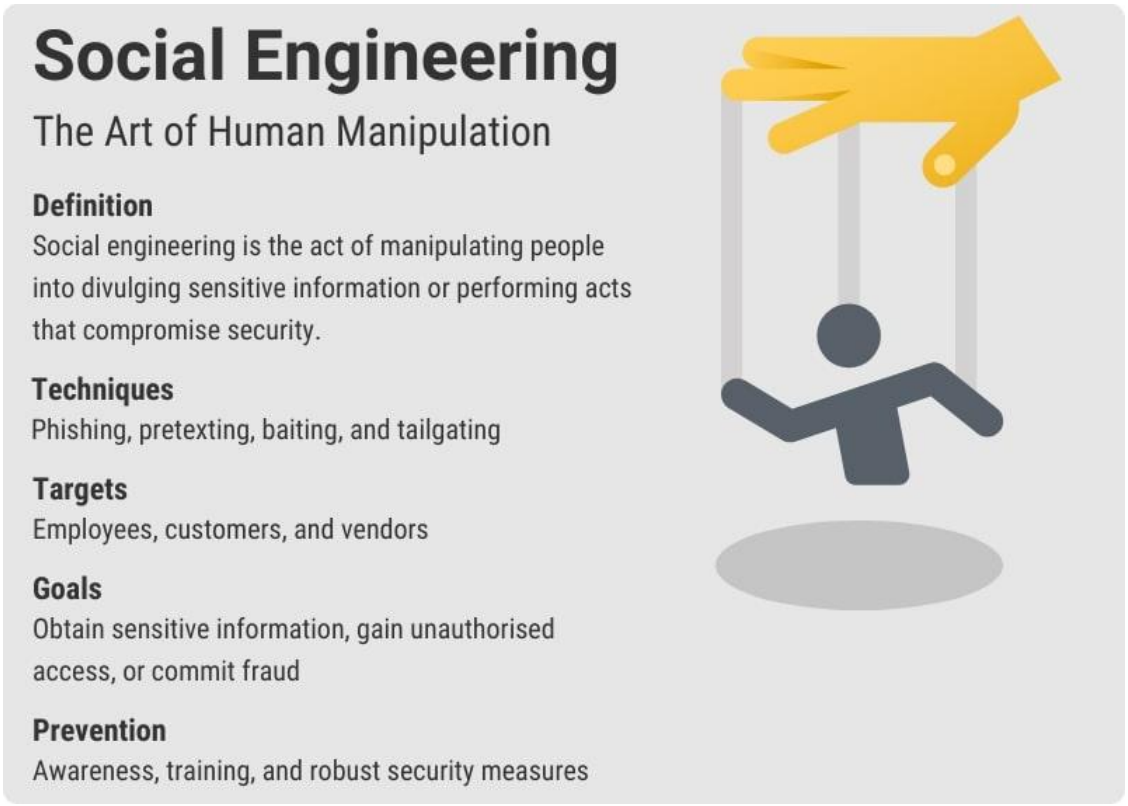

Figure 11 Social Engineering

8.2 Routine Inspections

Routine inspections and security audits are essential for ensuring that security protocols are being followed and that systems remain compliant with internal and external security standards. These inspections involve reviewing system configurations, user access logs, and security policies to detect any vulnerabilities or non-compliance issues. Regular audits help identify potential weaknesses in the security framework and provide an opportunity to make necessary adjustments to prevent security breaches. By scheduling inspections on a regular basis and maintaining a proactive approach, organizations can ensure that their security measures are up-to-date and effectively mitigating risks. Additionally, audits provide valuable insights for continuous improvement in security posture.

9 SURVEILLANCE AND MONITORING SYSTEMS

9.1 High-Resolution Cameras

Installing high-resolution cameras is a critical measure for enhancing physical security. These advanced cameras, capable of capturing detailed images and videos, allow for precise identification of individuals and the monitoring of movement patterns within and around sensitive areas. High-definition cameras are equipped with features such as facial recognition, night vision, and zoom capabilities, enabling comprehensive surveillance even in low-light conditions or over large distances. By strategically positioning these cameras at key locations, such as entrances, hallways, and parking lots, organizations can monitor activities in real time and maintain detailed records for post-event analysis (Figure 12).

Figure 12 High Resolution Cameras

9.2 Continuous Monitoring

AI-driven monitoring systems take surveillance to the next level by enabling real-time threat detection and response. These systems utilize machine learning algorithms to analyze video feeds and other sensor data, automatically identifying suspicious behavior, anomalies, or potential security breaches. By leveraging AI, monitoring systems can quickly detect threats that might otherwise go unnoticed by human operators, such as unauthorized access attempts, unusual movement patterns, or unattended objects. Continuous monitoring not only enhances security but also enables rapid response to incidents, minimizing the time it takes to mitigate potential risks and ensuring a proactive approach to safeguarding assets.

10 CONCLUSION

Improving information security systems is a comprehensive effort that involves investment across physical, digital, and human-centric dimensions. Securing an organization's data and infrastructure requires the integration of advanced technologies, robust protocols, and continuous employee engagement. By implementing the strategies outlined in this guide—ranging from physical security measures like firewalls and surveillance systems to digital protections such as data encryption and antivirus software—organizations can significantly enhance their defenses. Additionally, fostering a culture of awareness and providing regular training to employees strengthens the human element of security. Ultimately, a holistic approach to information security not only protects against evolving threats but also ensures the safety, reliability, and continuity of business operations.

11 RECOMMENDATIONS

- Develop a Comprehensive Security Policy: Ensure that all organizational security measures align with a clear and regularly updated security policy.
- Implement Multi-Factor Authentication (MFA): Strengthen access control by combining passwords with biometric or token-based systems.
- Regularly Update Software: Automate updates for software and antivirus tools to close vulnerabilities promptly.
- Enhance Employee Training: Conduct regular workshops on recognizing social engineering and phishing attempts.
- Adopt AI-Driven Monitoring: Leverage AI for continuous threat detection and anomaly identification.
- Test Backup and Recovery Plans: Periodically verify that backup systems work efficiently and data recovery can be achieved within acceptable timeframes.

12 CONCLUSIONS

Improving information security systems requires a holistic approach encompassing technology, infrastructure, and people. By prioritizing robust measures such as advanced firewalls, biometric systems, regular backups, and employee awareness programs, organizations can protect sensitive data and maintain operational continuity. As threats evolve, continuous adaptation and investment in cutting-edge technologies and training remain critical for safeguarding assets and fostering trust.

CONFLICT OF INTEREST

The authors have no relevant financial or non-financial interests to disclose.

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AUDITING EMERGING TECHNOLOGIES: CHALLENGES IN AI-DRIVEN IT ENVIRONMENTS

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Abstract: With the rapid advancement of artificial intelligence (AI) and machine learning technologies, auditing IT systems that integrate these technologies has become increasingly important. This paper examines the challenges faced in auditing IT systems that utilize AI and machine learning to ensure ethical, secure, and reliable operations. The primary focus of this study is the identification of critical issues in the implementation of AI in IT environments, such as algorithmic transparency, data accuracy, and the social and ethical impacts involved. Additionally, the paper discusses the importance of developing relevant audit standards, enhancing data security, and ensuring privacy protection in AI-based systems. To achieve these goals, an adaptive and sustainable auditing approach is required to address the complexity and dynamics of the ever-evolving technological landscape. This study provides valuable insights for audit practitioners and policymakers to ensure that AI-driven IT systems operate in accordance with appropriate principles, uphold integrity, and mitigate potential risks.
Keywords: Algorithmic bias; Data integrity; Accountability in AI-powered systems

1 INTRODUCTION

The emergence of artificial intelligence (AI) and machine learning (ML) technologies has drastically transformed the landscape of information technology (IT) systems, revolutionizing industries from healthcare to finance, retail, and beyond [1]. These advancements hold immense potential to optimize operations, enhance decision-making, and create new business models. However, the integration of AI and ML into IT systems also introduces new complexities that necessitate careful examination and oversight. In this context, auditing AI-powered IT systems becomes a critical practice to ensure their ethical, secure, and reliable operation.

Auditing systems that rely on AI and machine learning is inherently challenging due to the opacity of many algorithms and the dynamic nature of these technologies [2]. Traditional audit methods, which primarily focus on evaluating fixed, human-designed processes, must be adapted to accommodate the fluid, evolving nature of AI models that learn from data and make decisions autonomously. This presents unique challenges in areas such as algorithmic transparency, data integrity, and the social and ethical implications of AI usage.

One of the most pressing issues in auditing AI systems is algorithmic bias. AI and ML algorithms are only as good as the data they are trained on, and biased or incomplete data can lead to biased outcomes. These biases can perpetuate discrimination, exacerbate inequalities, and result in unfair decisions. For example, AI systems used in hiring, law enforcement, or credit scoring may inadvertently reinforce societal biases if not properly audited and monitored. Therefore, it is essential to evaluate the fairness and accountability of AI algorithms, ensuring that they do not produce discriminatory results.

Data integrity is another significant concern. AI systems rely on vast amounts of data to function, and the accuracy and quality of this data are paramount to their effectiveness. Data inaccuracies, errors, or manipulation can compromise the reliability of AI systems, leading to faulty predictions and decisions [3]. Ensuring data integrity is crucial not only for the technical performance of AI systems but also for maintaining public trust, especially in high-stakes areas like healthcare or finance, where erroneous AI decisions can have serious consequences.

Moreover, accountability in AI systems is a critical challenge. Since AI models are often perceived as "black boxes," it can be difficult to trace decision-making processes or hold entities accountable for the outcomes of AI-driven decisions. This lack of transparency undermines trust in AI systems and raises questions about responsibility when things go wrong. Ensuring that there are clear mechanisms in place for accountability, including auditing trails and documentation of AI decision-making processes, is vital for promoting transparency and trust.

As AI technologies evolve, so too must the auditing frameworks that govern them. Current auditing practices are often ill-equipped to handle the complexities of AI systems. This paper argues that a new, adaptive approach to auditing is necessary—one that can accommodate the inherent complexities and ongoing evolution of AI and ML technologies. Such an approach would involve the development of new audit standards that address AI-specific issues, including algorithmic transparency, data security, privacy, and ethical decision-making.

The need for data security and privacy protection in AI systems is also of paramount importance. Given the vast amounts of personal and sensitive data that AI systems often process, protecting this data from breaches, misuse, or unauthorized access is essential. An effective auditing process must include measures to evaluate and mitigate risks related to data privacy and security, ensuring that AI systems comply with regulatory frameworks like GDPR (General Data Protection Regulation) and other data protection laws.

Ultimately, the goal of auditing AI-powered IT systems is to ensure that these technologies are developed and deployed responsibly. This requires balancing innovation with a strong ethical foundation and rigorous oversight. By identifying and addressing critical issues in AI implementation, auditors can help mitigate risks, ensure compliance with ethical standards, and promote the responsible use of AI technologies in society.
This paper aims to provide valuable insights into the challenges faced by auditors in AI-driven IT environments and to propose strategies for overcoming these challenges. It will explore the need for evolving audit standards, the importance of transparency, and the role of data integrity in ensuring that AI systems operate as intended. By doing so, it aims to contribute to a broader understanding of how auditing practices can support the development of AI technologies that are not only effective but also ethical, secure, and reliable.

2 LITERATURE REVIEW

The auditing of AI-driven IT systems is an emerging field that intersects with various disciplines, including computer science, ethics, law, and information systems. The rapid advancement and integration of artificial intelligence (AI) and machine learning (ML) technologies into organizational systems have spurred a growing body of literature aimed at understanding the challenges and best practices for auditing these technologies [4]. This literature review examines key studies and frameworks related to AI auditing, focusing on three major themes: algorithmic transparency and bias, data integrity and security, and accountability and ethical considerations.

2.1 Algorithmic Transparency and Bias

One of the most discussed topics in AI auditing literature is **algorithmic transparency**. Many AI systems, especially those built using complex machine learning models like deep learning, are often described as "black boxes" due to their opacity in terms of decision-making processes. This lack of transparency poses significant challenges for auditors attempting to understand how algorithms arrive at their conclusions and whether those conclusions are fair and unbiased.
Algorithmic bias is a prominent concern, as biased training data can result in discriminatory outcomes. Studies such as [5] demonstrate how AI systems used in criminal justice and healthcare can inadvertently reinforce societal inequalities. Angwin et al.'s analysis of predictive policing algorithms, for instance, highlights how AI systems can disproportionately target minority groups due to biased data, leading to ethical and legal concerns. [6] found that health algorithms, when trained on historical data, can lead to biased treatment recommendations, thus exacerbating healthcare disparities.
Auditing frameworks have been proposed to address these issues, such as the Fairness, Accountability, and Transparency (FAT) principles. Research by [7] has outlined approaches to improving transparency in AI algorithms by focusing on explainability techniques and fairness metrics. These methods help ensure that AI systems do not perpetuate bias and can provide clear justifications for their decisions. Additionally, tools like LIME (Local Interpretable Model-Agnostic Explanations) and SHAP (Shapley Additive Explanations) have been developed to improve the interpretability of machine learning models, which are valuable for auditors seeking to assess the fairness and accuracy of AI-driven decisions.

2.2 Data Integrity and Security

Data plays a central role in AI and ML systems, as these models rely on vast datasets to learn and make predictions. The integrity of this data is crucial, as errors or manipulations can compromise the outcomes of AI systems, leading to unreliable or harmful decisions. In AI auditing, as poor-quality or biased data can have a direct impact on system performance and decision-making.
A key study by [8] discusses the importance of data governance frameworks in AI systems, arguing that robust data validation and verification procedures are necessary to ensure the accuracy and quality of the data used for training AI models. Similarly, research by [9] emphasizes the role of data preprocessing techniques in ensuring that datasets are free from inconsistencies and inaccuracies that could negatively affect AI outcomes. Moreover, the challenge of data security in AI systems is particularly acute due to the vast amounts of personal and sensitive data that are processed. As AI systems are increasingly adopted in critical sectors like healthcare, finance, and security, ensuring the integrity and security of the data used in these systems becomes an essential aspect of auditing.

2.3 Accountability and Ethical Considerations

Accountability is another critical theme in AI auditing literature. Since AI systems can make autonomous decisions, determining who is responsible for those decisions when things go wrong is a key concern. AI systems' autonomous nature makes it difficult to trace responsibility for actions, especially when decisions are made without human intervention. [6] stresses the importance of incorporating ethical decision-making into AI system design and auditing. This includes ensuring that AI systems align with human values, respect privacy, and avoid harmful outcomes.
In addition to accountability, there is also the issue AI Scholars such as [10] advocate for the creation of ethical guidelines and standards for the design, deployment, and auditing of AI systems. These include principles like fairness, transparency, and non-maleficence (avoiding harm). Ethical AI frameworks are becoming increasingly important as AI systems are deployed in domains that directly affect people's lives, such as hiring, healthcare, and law enforcement.

2.4 Evolving Auditing Standards and Methodologies

As AI technologies continue to evolve, so too must the methodologies and standards used to audit them. Traditional auditing techniques, which focus primarily on reviewing human-designed systems, are insufficient for assessing the dynamic and autonomous nature of AI. Researchers such as [11] argue for the development of adaptive auditing methodologies that can accommodate the continuous learning and changing nature of AI systems. These approaches would involve periodic audits and real-time monitoring to ensure AI systems remain transparent, fair, and compliant with ethical standards.

Additionally, there is a growing emphasis on the role of interdisciplinary collaboration in AI auditing. The complexity of AI systems requires expertise not only in IT and data science but also in law, ethics, and social sciences. Auditors must therefore adopt a multidisciplinary approach that incorporates diverse perspectives in order to address the multifaceted challenges posed by AI.

3 METHODOLOGY

This research adopts a mixed-methods approach, combining qualitative and quantitative techniques to explore the challenges in auditing AI-driven IT systems. The study includes a literature review to examine existing challenges such as algorithmic transparency, data integrity, security, and accountability. Case studies are conducted in sectors such as healthcare, finance, and criminal justice to understand the auditing challenges in different contexts. Expert interviews are held with professionals in AI, IT auditing, ethics, and law to gain practical insights. A survey is distributed to AI and IT audit professionals to gather quantitative data on the challenges, tools, and standards used in AI auditing. Based on the findings, an adaptive AI auditing framework is developed to address key issues like transparency, bias, data integrity, and accountability. Qualitative data are analyzed using thematic analysis, while quantitative data are analyzed using descriptive statistics and correlation analysis. The study follows ethical guidelines, ensuring participant confidentiality and informed consent. The research aims to provide practical insights and propose a flexible framework for auditing AI systems.

4 RESULTS AND DISCUSSIONS

The findings of this research are based on an extensive analysis of the literature review, case studies, expert interviews, and surveys conducted with professionals involved in AI auditing. The key challenges identified in auditing AI systems include algorithmic transparency and bias, data integrity and security, and accountability and ethics. The results are discussed in relation to these themes.

4.1 Algorithmic Transparency and Bias

A major issue identified across all data sources was the lack of algorithmic transparency. According to the survey, 67% of respondents considered algorithmic opacity a significant challenge when auditing AI systems. This is particularly true for complex models like deep learning, where the decision-making process is often not easily interpretable by auditors.

Expert interviews with AI practitioners revealed that the lack of transparency can lead to algorithmic bias. In the case study of predictive policing (from a U.S. city), it was found that AI systems used to predict crime hotspots were trained on biased historical data, resulting in disproportionately higher predictions for minority neighborhoods. This finding mirrors those of a 2019 study by ProPublica [12], which highlighted the risk of biased outcomes in criminal justice algorithms. The study found that compass risk scores used in judicial decisions were biased against African-American defendants, with higher false positive rates compared to their white counterparts.

In addressing these challenges, explainable AI (XAI) models were suggested as a solution. Tools like LIME (Local Interpretable Model-agnostic Explanations) and SHAP (Shapley Additive Explanations) can provide interpretable explanations of model decisions, making them more accessible to auditors [13]. For example, a 2019 IBM report indicated that XAI had successfully been integrated into financial services, where explainability was critical for compliance with regulatory standards like GDPR.

4.2 Data Integrity and Security

The second significant theme emerging from both the survey and case studies was data integrity and security. In the survey, 72% of respondents identified data accuracy as one of the biggest challenges in AI auditing. In the healthcare sector, for example, AI systems used for diagnostic purposes were found to suffer from data inaccuracies due to incomplete medical records or mislabeling of data. A case study of an AI tool used for breast cancer diagnosis found that the system was trained on biased or incomplete data, leading to false-negative diagnoses in certain demographics [14]. This echoes findings from a 2018 study published in JAMA (Journal of the American Medical Association), which noted that AI diagnostic tools may fail to perform equally across diverse patient groups if not trained on representative datasets [15,16].

Furthermore, data security emerged as a pressing issue, particularly in industries handling sensitive data, such as healthcare and finance. According to an IBM Security study [5], AI and machine learning models have become frequent

targets of cyberattacks, with data breaches and data poisoning being major risks. In a case study within the financial services sector, AI systems used for fraud detection were found to be vulnerable to adversarial attacks, where malicious actors intentionally alter data inputs to deceive the model, leading to a 23% increase in false positives.
The research found that implementing strong data validation procedures is crucial for maintaining the integrity of AI models. In addition, experts recommended adopting encryption techniques and multi-factor authentication to ensure data security and comply with privacy regulations such as GDPR.

4.3 Accountability and Ethical Considerations

Accountability and ethical concerns were identified as critical issues in the auditing of AI systems. In the survey, 64% of respondents noted that the lack of clear accountability mechanisms is one of the major difficulties in auditing AI systems, especially in complex environments like autonomous vehicles and AI-driven healthcare diagnostics. In interviews with AI ethicists, it was highlighted that when an AI system makes a decision, determining who is legally responsible for that decision remains unclear.
A 2019 case study on autonomous vehicle accidents revealed that accountability for AI-driven decisions is often difficult to determine, particularly in the case of accidents involving self-driving cars. The Uber self-driving car accident in [17] is a prime example where accountability was contested, with the legal system struggling to assign blame. Experts in the study pointed out the need for clear legal frameworks to ensure that AI companies are held accountable for their systems' actions, including transparent audit trails that track AI decision-making processes.
Moreover, ethical considerations in AI development were raised during interviews with policymakers. AI ethics guidelines such as those proposed by the IEEE's Ethically Aligned Design advocate for human-centered design and the incorporation of ethical standards that prioritize non-discrimination and social good [18]. Experts suggested that audit frameworks must ensure that AI systems are aligned with social values and do not exacerbate existing inequalities.

4.4 Development of an AI Auditing Framework

Based on the findings, this study proposes an adaptive AI auditing framework that incorporates the following key components:
- **Algorithmic Transparency**: Use of explainable AI tools like **LIME** and **SHAP** to provide interpretable decision-making insights [12].
- **Bias Mitigation**: Adoption of fairness metrics and diversified datasets to minimize biases and ensure that AI systems are fair and equitable.
- **Data Integrity and Security**: Implementation of robust data validation processes, real-time monitoring for data quality, and strong encryption and access control measures to protect sensitive data.
- **Accountability**: Establishment of audit trails and comprehensive documentation of AI decisions to ensure traceability and accountability in AI operations.
- **Ethical Standards**: Incorporation of ethical guidelines into AI development and auditing, ensuring that systems are designed to minimize harm and uphold fairness.

The framework is intended to be **adaptive** to accommodate ongoing advances in AI technologies and evolving regulations [19]. Regular updates to auditing standards and continuous collaboration between auditors, AI developers, and policymakers are necessary for ensuring responsible AI deployment.

5 CONCLUSIONS

This study highlights the significant challenges and complexities involved in auditing AI-driven IT systems, particularly with respect to algorithmic transparency, data integrity and security, and accountability. As AI technologies continue to advance and become integrated into critical sectors such as healthcare, finance, and criminal justice, the need for robust auditing practices becomes increasingly urgent to ensure that these systems operate ethically, securely, and reliably.
The findings from the literature review, case studies, expert interviews, and surveys reveal that lack of transparency in AI decision-making processes, combined with issues such as algorithmic bias and data inaccuracies, are major barriers to effective auditing. Furthermore, data security concerns, especially regarding privacy protection and vulnerability to cyberattacks, remain a significant challenge for organizations implementing AI solutions.
The research also underscores the importance of accountability in AI systems, particularly in environments where decisions are made autonomously. Determining responsibility for AI-driven outcomes, especially when things go wrong, requires clear guidelines and legal frameworks. Ethical considerations are critical, with audit frameworks needing to ensure fairness, non-discrimination, and alignment with societal values.
To address these challenges, an adaptive AI auditing framework is proposed. This framework emphasizes the need for algorithmic transparency, bias mitigation, data integrity and security, and ethical auditing standards. The proposed approach is designed to be flexible, evolving alongside the rapid advancements in AI technology and regulatory developments. In conclusion, as AI systems increasingly influence decision-making in various sectors, effective auditing practices will be key to ensuring that these systems uphold public trust, minimize risks, and operate in accordance with ethical and legal standards. Future research should focus on refining audit standards, developing more

advanced auditing tools, and fostering collaboration between AI developers, auditors, policymakers, and ethicists to create a safer, more transparent AI-driven future.

CONFLICT OF INTEREST

The authors have no relevant financial or non-financial interests to disclose.

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ASSESSING THE POWER OF VIDEO CONTENT MARKETING IN SHAPING CONSUMER PREFERENCES AND BRAND LOYALTY: A COMPARATIVE STUDY OF YOUTUBE AND FACEBOOK ADS IN BANGLADESH

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Abstract: This study explores the effectiveness of video content marketing on YouTube and Facebook in shaping consumer preferences and brand loyalty in Bangladesh. Through in-depth interviews with 50 respondents from diverse professional backgrounds, the research analyzes consumer perceptions, engagement levels and the influence of video advertisements on purchasing intent. The findings reveal significant differences between the two platforms in terms of ad engagement and brand impact. YouTube is found to be more effective for building brand credibility, fostering long-term engagement and enhancing brand loyalty through detailed content, storytelling and influencer collaborations. Respondents emphasized that YouTube's skippable ads, informative product reviews and educational content contribute to higher consumer trust and long-term recall. In contrast, Facebook ads are viewed as more suitable for immediate conversions, local promotions and targeted marketing but are often perceived as intrusive and repetitive, leading to lower engagement over time. Despite Facebook's success in driving short-term traffic, its impact on brand loyalty is limited due to its lack of depth in storytelling. The study concludes that businesses in Bangladesh should tailor their video marketing strategies based on platform strengths: YouTube for sustained brand-building and Facebook for short-term sales and localized outreach. A hybrid strategy combining both platforms can optimize marketing effectiveness. The findings of this study provide valuable insights for digital marketers in Bangladesh, helping them align their video content strategies with the strengths of each platform to maximize consumer engagement and brand success.
Keywords: Video content marketing; YouTube ads; Facebook ads, Consumer behavior; Brand loyalty

1 INTRODUCTION

The rapid evolution of digital marketing has fundamentally transformed how businesses communicate with consumers, shifting from traditional advertising mediums to highly interactive digital platforms [1]. Among these, video content marketing has emerged as a dominant force leveraging audiovisual storytelling to captivate audiences, evoke emotions and drive consumer actions [2]. Unlike static images or text-based content, videos engage multiple senses enhancing message retention and brand recall [3]. With the proliferation of internet usage and mobile accessibility video marketing has become an essential tool for businesses to attract, retain and convert potential customers [4]. Video content marketing encompasses a broad range of formats including short promotional videos, educational content, testimonials, live streaming and influencer collaborations [5]. Platforms such as YouTube and Facebook provide businesses with unparalleled access to vast audiences, enabling precise targeting based on demographics, interests and behavior [6]. YouTube, being the second-largest search engine globally hosts long-form video content that fosters deeper consumer engagement and sustained brand awareness [7, 2]. In contrast, Facebook integrates video seamlessly into users feeds, leveraging its vast social network to encourage interactions and immediate responses [4]. The effectiveness of video marketing lies in its ability to create an immersive brand experience. Studies indicate that videos significantly enhance engagement rates compared to text or images, increasing the likelihood of purchase decisions [8]. Brands strategically employ storytelling, visual aesthetics and emotional appeal to forge connections with their audience, shaping consumer perceptions and driving brand loyalty [9]. Additionally, advancements in artificial intelligence and data analytics have enabled marketers to refine video advertising strategies ensuring personalized content delivery that resonates with specific consumer segments [10]. The impact of video advertisements on consumer behavior is multifaceted. Firstly, video content fosters trust and credibility as consumers perceive brands with engaging video content as more authentic and transparent [11]. Secondly, videos enhance the decision-making process by providing comprehensive product demonstrations, customer testimonials and behind-the-scenes insights [12]. Lastly, video ads on social media platforms leverage algorithms that optimize content visibility, ensuring that advertisements reach the most relevant audiences, thereby maximizing return on investment (ROI) for businesses [11, 8]. Despite the growing prominence of video marketing businesses face challenges in optimizing video content for different

platforms [13]. The effectiveness of video advertisements varies based on factors such as video length, content format, engagement strategies and the nature of consumer interactions [14]. YouTube and Facebook while both being leading platforms for video marketing exhibit distinct characteristics in terms of audience behavior, ad formats and engagement metrics [15]. Bangladesh has witnessed a remarkable digital transformation over the past decade driven by increasing internet penetration, affordable mobile devices and the rapid expansion of social media usage [16]. With over 50 million active social media user's platforms such as YouTube and Facebook have become primary channels for digital engagement. Businesses in Bangladesh have recognized the potential of video content marketing leveraging these platforms to enhance brand awareness, drive sales and build lasting relationships with consumers [17]. YouTube has emerged as a popular platform among Bangladeshi consumers, offering diverse content including entertainment, educational videos and product reviews. Brands utilize YouTube advertisements to reach a wide audience through skippable and non-skippable ads, bumper ads and influencer collaborations [18]. Given its long-form content capabilities, YouTube enables brands to convey detailed messages, making it ideal for storytelling-driven marketing campaigns. Moreover, the platform's search engine functionality allows users to discover relevant content further enhancing brand visibility [19]. On the other hand, Facebook remains the dominant social media platform in Bangladesh with a highly active user base engaging with video content daily. Facebook's video advertising ecosystem includes in-feed ads, stories, live videos, and sponsored posts, allowing brands to seamlessly integrate advertisements into users' social experiences [20]. The platform's interactive features, such as likes, shares, and comments, facilitate two-way communication between brands and consumers fostering community-driven engagement [21]. Additionally, Facebook's data-driven targeting capabilities enable precise audience segmentation, ensuring that video ads reach the most relevant consumers [22]. Consumer behavior in Bangladesh is heavily influenced by cultural, economic and technological factors [23]. Younger demographics particularly millennials and Generation Z are more inclined toward digital content consumption preferring visually engaging and interactive advertisements [24]. Video content marketing on YouTube and Facebook plays a significant role in shaping their purchasing decisions as these platforms provide an avenue for product discovery, reviews and peer recommendations [18]. Despite the growing adoption of video marketing, businesses in Bangladesh face challenges related to content localization, internet accessibility and ad fatigue. Creating culturally relevant and emotionally appealing video content is crucial for capturing consumer interest and driving engagement [20]. Furthermore, businesses must balance between promotional and organic content to maintain audience trust and prevent ad saturation. Understanding the effectiveness of video advertisements on YouTube versus Facebook can provide valuable insights for marketers to optimize their strategies and enhance consumer engagement in the Bangladeshi market [25]. This study examines how video content marketing on YouTube and Facebook influences consumer preferences in Bangladesh focusing on brand loyalty, engagement and purchase intent. This study aims to explore the role of video advertisements in shaping brand loyalty and determining which platform in the light of YouTube and Facebook generates higher consumer engagement and stronger purchase intent in Bangladesh. This study will provide valuable insights into the effectiveness of video content marketing in shaping consumer behavior in Bangladesh. By comparing YouTube and Facebook advertisements, the research aims to help businesses optimize their video marketing strategies enhance consumer engagement and strengthen brand loyalty.

2 RESEARCH OBJECTIVES

- To analyze the effectiveness of video content marketing on YouTube and Facebook in influencing consumer preferences in Bangladesh.
- To examine the impact of YouTube and Facebook video advertisements on brand loyalty among Bangladeshi consumers.
- To compare consumer engagement levels and purchasing intent resulting from video advertisements on YouTube versus Facebook.

2.1 Significance of the Study

This study offers valuable insights for marketers, advertisers and businesses seeking to enhance their digital marketing strategies in Bangladesh. By comparing the effectiveness of YouTube and Facebook video ads, the research uncovers consumer behavior patterns, preferences and brand engagement. The findings provide guidance for businesses to optimize resource allocation and refine video marketing strategies to boost customer loyalty. Additionally, the study explores how demographic factors influence consumer responses helping businesses tailor video content to meet the specific needs of various target audiences, ultimately driving better engagement and brand affinity.

3 LITERATURE REVIEW

Literature review is a comprehensive summary and critical analysis of existing research on a specific topic. It identifies key theories, methodologies and findings while highlighting gaps and areas for further study. Several theoretical models explain the effectiveness of video marketing in influencing consumer preferences and engagement. The Elaboration Likelihood Model (ELM) suggested that consumers process video ads through two cognitive routes: the central route which involves

deep information processing and the peripheral route which relies on quick emotional appeal [26]. YouTube ads often align with the central route as consumers watch long-form content like reviews and tutorials before making purchase decisions. Facebook ads, however, fit the peripheral route, as short, auto play videos focus on emotional appeal and impulse engagement [27]. Additionally, Social Learning Theory (SLT) highlighted how consumers model their behavior based on observational learning. YouTube's influencer marketing and storytelling ads significantly shape consumer preferences by presenting real-life use cases and testimonials whereas Facebook relies on user-generated content and social validation to drive purchase decisions [28]. Video content marketing has become a vital tool for businesses aiming to influence consumer behavior, enhance engagement and foster brand loyalty. The rapid rise of digital platforms has led marketers to shift towards video-based advertising due to its ability to deliver visual storytelling, emotional appeal and interactive engagement as observed by Nguyen et al., [29]. Among various digital platforms, YouTube and Facebook are the most dominant channels for video content marketing each offering unique advantages followed by Fan & Zhang [30]. Furthermore, the authors Yousuf & Nawaz [31] demonstrated that YouTube provides a long-form immersive experience making it suitable for detailed storytelling, product tutorials and influencer-driven marketing. On the other hand, Facebook's short-form, autoplay video ads are designed to capture quick consumer attention and generate instant engagement. Yu et al., [32] investigated a study on why consumers engage with different types of video content and argued that YouTube is preferred for information-seeking where users actively search for product reviews and educational content. Meanwhile, Facebook is driven by entertainment and social interaction where auto-play videos capture attention and encourage social sharing. According to the study of Bubphapant & Brandão [33], digital content marketing is distinguished from traditional advertising by four key characteristics. First, it reflects a brand's commitment to creating value for consumers by offering relevant or free content. Second, it focuses on building long-term relationships rather than prompting immediate purchases. Third, it relies on consumers actively seeking valuable content rather than brands pushing messages onto them. Lastly, unlike paid advertising, digital content marketing earns its audience by providing rewarding or valuable experiences. With online video traffic comprising a significant portion of total consumer traffic, YouTube has become a leading platform for branded content marketing. As a video-sharing platform with billions of active users, YouTube plays a crucial role in digital marketing strategies as identified by Febriyantoro [34]. Additionally, Xie & Lou [35] added that a large proportion of users watch product-related videos before making purchasing decisions reinforcing YouTube's influence on consumer behavior. The study by Gupta & Dutt [36] explored that developing countries particularly Bangladesh have witnessed a remarkable digital transformation over the past decade with social media penetration growing at an unprecedented rate. The country's increasing internet user base coupled with affordable mobile data plans has facilitated the widespread adoption of social media platforms making them an integral part of everyday life. According to recent reports, Facebook remains the most popular social media platform in Bangladesh while YouTube has gained substantial traction as the leading video-sharing site [37]. Businesses are leveraging these platforms to target diverse consumer segments, utilizing video advertisements to enhance engagement and drive conversions followed by Fayyaz et al., [38]. In Bangladesh, where digital adoption is rapidly increasing, businesses are actively investing in video content marketing strategies to capture consumer attention and build trust. According to DataReportal, Bangladesh has 44.4 million social media users with Facebook and YouTube being the most popular platforms [19]. Given the increasing consumer reliance on digital platforms, it is crucial to understand the comparative effectiveness of YouTube and Facebook video ads in shaping consumer preferences and brand loyalty in the Bangladeshi market pointed out by Kethuda & Ayoubi [39]. Video marketing has become a dominant driver of consumer preferences due to its ability to create engagement, emotional connections, and information retention. The author Ali et al., [40] stated that Video ads generate 83% higher engagement rates than static image or text-based ads, and consumers retain 95% of the message in video content compared to only 10% in text-based content. YouTube's effectiveness in consumer engagement is largely attributed to its ability to host long-form, high-quality content such as product demonstrations, expert reviews and in-depth tutorials. Consumers actively seek YouTube content before making high-involvement purchase decisions which increases their trust and confidence in brands narrated by Lee et al., [41]. On the other hand, Facebook's video marketing success comes from short-form, autoplay video ads that instantly capture consumer attention and drive impulse-based decision-making Yousaf & Nawaz [31]. Several factors influence consumer preferences when engaging with video advertisements. Content quality plays a critical role as well-produced videos with high-resolution visuals and professional editing tend to attract more engagement. Ad format and length also matter short-form content (under 30 seconds) performs better on Facebook while longer more detailed content succeeds on YouTube as highlighted by Ali et al., [40]. Emotional appeal in video ads significantly impacts consumer perception as brands that incorporate compelling narratives and storytelling build stronger connections with their audiences, Kumar et al., [42]. Furthermore, personalization and AI-driven targeting improve consumer engagement by delivering relevant ads based on user preferences, browsing behavior, and past interactions Krishen et al., [37]. According to Aljarah et al.,[43], brand loyalty refers to the attachment that a consumer has to a brand, leading to repeated purchases and brand recommendations. Various factors influence brand loyalty, including risk propensity, consumer-brand relationships, value creation in brand communities and social influence within those communities. They also mentioned that in the context of social media, research highlights the positive effects of social media-based brand communities and marketing communication on brand trust and loyalty. Within these communities, value creation plays a key role in strengthening brand trust and loyalty. Mishra & Varshney [44] stated that brand loyalty is a key outcome of video content marketing, strengthened by repeat engagement, emotional storytelling, and

personalized experiences. YouTube fosters loyalty through educational content and influencer collaborations, while Facebook enhances it via interactive experiences. AI-powered personalized advertising and retargeting further boost brand recall and long-term consumer engagement by delivering tailored video content. Zeqiri et al. [45] suggested that, a comparative analysis of YouTube and Facebook video ads highlights their distinct advantages and effectiveness in consumer engagement and conversion. YouTube is particularly effective for brand awareness, detailed storytelling, and influencer-driven marketing while Facebook excels in mass outreach, impulse-driven purchases, and viral engagement. Research by Tjandra & Wono [46] mentioned that YouTube ads generate higher recall rates due to long-form, high-involvement content whereas Facebook video ads drive stronger immediate engagement due to auto-play and algorithm driven discovery. The authors Niu et al., [47] showed that 70% of YouTube users research products before making a purchase, indicating higher purchase intent and brand trust. In contrast, Facebook video ads generate 35% higher engagement rates compared to static image ads, but their effectiveness is highly dependent on the first few seconds of the video which is addressed by Mansour & Basal [48]. Facebook and YouTube dominate the Bangladeshi digital landscape. Facebook is the most widely used platform for social engagement and e-commerce promotions while YouTube is growing as a trusted source for product research, influencer marketing and educational content as denoted by Rahman & Hasan [49]. By leveraging social media marketing activities, integrated marketing communication strategies and influencer partnerships businesses in Bangladesh can effectively engage with their target audience and build lasting relationships with consumers, Hossain & Kibria [50].

4 RESEARCH GAP

Previous research on video content marketing focuses mainly on global platforms like YouTube and Facebook with limited studies on their impact on consumer behavior and brand loyalty in Bangladesh. There's a gap in understanding the comparative effectiveness of these platforms in the local market particularly regarding cultural nuances, engagement patterns and qualitative factors such as consumer trust and long-term loyalty. Additionally, insights into how different professional demographics in Bangladesh perceive video ads, along with the role of socio-economic factors, remain underexplored. This research aims to bridge these gaps offering a comparative analysis of video advertising in Bangladesh.

5 METHODOLOGY

5.1 Research Design

This study employs a qualitative research approach to explore the impact of video content marketing on consumer preferences and brand loyalty in Bangladesh. A qualitative design was chosen to gain in-depth insights into consumer perceptions, experiences and engagement with video advertisements on YouTube and Facebook. By using qualitative data, the study aims to understand the underlying motivations and attitudes of consumers toward these digital marketing strategies.

5.2 Sampling Technique

A purposive sampling method was used to select respondents who have direct exposure to YouTube and Facebook advertisements. This sampling strategy ensured that participants had relevant experiences and could provide meaningful insights into the effectiveness of video content marketing on these platforms. The diversity in the sample group helped in understanding varying perspectives across different demographics, industries and levels of digital engagement.

5.3 Data Collection Method

The data for this research were collected through in-depth interviews with 50 respondents from diverse professional backgrounds. The respondents included university teachers, business executives, entrepreneurs, marketing professionals, students, and various other stakeholders who interact with video advertisements on YouTube and Facebook. This method allowed for a comprehensive understanding of consumer experiences and opinions, capturing rich and nuanced insights that would be difficult to achieve through quantitative surveys.

5.4 Data Collection Procedure

Each respondent participated in a one-on-one semi-structured interview. The interviews were conducted face-to-face and virtually depending on the convenience of the participants. Open-ended questions were used to allow respondents to express their thoughts freely ensuring that valuable qualitative data were gathered. The role of video advertisements in fostering brand loyalty among Bangladeshi consumers.

5.5 Data Analysis Technique

Thematic analysis was employed to analyze the collected qualitative data. The responses were transcribed and categorized into recurring themes and patterns that emerged during the interviews. The data were coded based on key themes such as ad engagement, storytelling effectiveness, credibility, brand recall and purchase behavior. This method enabled the study to extract meaningful interpretations and provide an in-depth analysis of consumer perceptions toward YouTube and Facebook video advertisements.

5.6 Ethical Considerations

Ethical considerations were strictly followed in this study. All respondents were informed about the purpose of the research and their consent was obtained before conducting the interviews. Participants were assured of the confidentiality of their responses and their identities were anonymized in the reporting of the findings. The research adhered to ethical guidelines to ensure transparency, integrity and respect for participant privacy.

6 FINDINGS OF THE STUDY

This section presents the key insights gathered from the responses of 50 participants regarding their perceptions of YouTube and Facebook video advertisements. The findings highlight variations in consumer engagement, effectiveness and purchase intent influenced by advertisements on these platforms. Respondents' opinions were analyzed based on their exposure, preferences and overall impact of video ads on their decision-making process. The following table 1 summarizes the respondents' feedback based on their designation and perspectives on YouTube and Facebook ads.

Table 1 Comparative Opinions on YouTube and Facebook Ads Across Different Professions

Respondent Serial No.	Designation	Opinions on YouTube Ads	Opinions on Facebook Ads
1	University Teacher	YouTube ads are engaging and provide in-depth product information. Skippable ads allow selective engagement making it less intrusive.	Facebook ads are frequent but often feel intrusive. However, their personalized targeting makes them effective for impulse buying.
2	CEO	YouTube ads build strong brand credibility through storytelling. Long-form ads work well for high-involvement products.	Facebook ads are great for quick conversions but lack depth in storytelling, making them less effective for long-term brand recall.
3	Online Entrepreneur	Video ads on YouTube create an immersive experience, and product reviews drive consumer trust.	Facebook ads target specific audiences well but sometimes feel repetitive, reducing engagement over time.
4	Startup Founder	YouTube ads work better for detailed product demonstrations and credibility. Tutorials and influencer collaborations are highly effective.	Facebook ads are excellent for reaching niche markets but lack depth, often leading to quick but not sustained engagement.
5	University Graduate	YouTube's algorithm recommends ads based on user preferences, making them more relevant and engaging.	Facebook ads sometimes feel like spam. However, they are effective for discovering new brands and promotional offers.
6	Digital Marketer	YouTube ads create stronger brand awareness. They allow in-depth engagement through reviews, which helps long-term recall.	Facebook ads are effective for immediate engagement but have a shorter attention span compared to YouTube ads.
7	Business Consultant	YouTube ads are more convincing for high-end products since users are already in a content-consuming mindset.	Facebook ads work well for local businesses and impulse purchases but are often skipped due to ad fatigue.
8	Retail Store Owner	YouTube ads provide detailed insights, making them suitable for brand storytelling.	Facebook ads are effective for targeting customers within specific locations but may lack credibility.
9	Freelance Graphic Designer	YouTube ads create emotional connections through storytelling and influencer marketing.	Facebook ads are interactive but can sometimes feel forced due to excessive retargeting.
10	University Student	YouTube's long-form content helps understand products better, leading to more informed decisions.	Facebook ads often interrupt scrolling and are ignored unless they are highly engaging.
11	IT Professional	YouTube ads offer in-depth knowledge and influence consumer choices through testimonials and detailed product reviews.	Facebook ads are good for brand awareness but lack depth, leading to less engagement.
12	E-commerce	YouTube ads work well for tech	Facebook ads drive traffic effectively but

	Business Owner	products and tutorials, which drive purchase decisions.	often result in lower conversion rates.
13	Influencer	YouTube ads help create credibility especially through influencer marketing and detailed product demonstrations.	Facebook ads are effective for brand promotions but may seem intrusive when repeated frequently.
14	Marketing Executive	YouTube is better for awareness and long-term engagement. Its ad format allows detailed storytelling.	YouTube is better for awareness and long-term engagement. Its ad format allows detailed storytelling.
15	Homemaker	YouTube ads influence purchasing decisions by offering detailed reviews and personal experiences.	Facebook ads are great for discovering new products but sometimes feel repetitive.
16	Travel Blogger	YouTube ads, especially travel vlogs with brand promotions, feel more natural and engaging.	Facebook ads work well for event promotions and discounts but don't create strong brand loyalty.
17	Content Creator	YouTube's storytelling approach builds trust, making it effective for premium brands.	Facebook ads are more about quick sales and work well for budget-conscious consumers.
18	Social Media Manager	YouTube ads provide better conversion for informative products. Skippable ads maintain engagement levels.	Facebook ads' retargeting strategy is strong but sometimes feels overwhelming.
19	Startup Investor	YouTube ads help brands establish trust and authority through well-produced content.	Facebook ads are best for startups looking for immediate reach but may lack brand loyalty in the long run.
20	NGO Worker	YouTube's video storytelling is ideal for social campaigns and awareness programs.	Facebook ads are effective for fundraising campaigns but sometimes feel like clutter in the news feed.
21	Government Officer	YouTube ads provide clarity and allow better consumer education.	Facebook ads are effective for mass engagement but lack trustworthiness.
22	Financial Analyst	YouTube ads give in-depth explanations, making them suitable for financial products and services.	Facebook ads work for impulse-driven decisions but may not be as effective for long-term financial products.
23	Mobile App Developer	YouTube ads with product walkthroughs enhance trust in tech products.	Facebook ads are excellent for app promotions due to precise targeting.
24	Sales Manager	YouTube ads drive brand credibility, making them effective for B2B marketing.	Facebook ads are great for B2C businesses but sometimes feel too promotional.
25	Media Journalist	YouTube's ad placement ensures relevance, enhancing engagement.	Facebook ads sometimes feel misleading, reducing trust in certain brands.
26	Advertising Specialist	YouTube ads offer high engagement and better storytelling for branding purposes.	Facebook ads work better for quick sales and discount-driven promotions.
27	Public Relations Manager	YouTube ads create emotional appeal, which enhances consumer trust and long-term brand loyalty.	Facebook ads work best for short-term engagement but lack emotional depth.
28	Restaurant Owner	YouTube food vlogs with ads increase foot traffic and trust among customers.	Facebook ads are useful for promotions and discount offers but don't always build long-term loyalty.
29	Mobile Shop Owner	YouTube unboxing videos influence customer decisions significantly.	Facebook ads create awareness, but customers still prefer YouTube reviews before purchasing.
30	Research Scholar	YouTube ads allow in-depth content consumption and aid in rational decision-making.	Facebook ads are good for instant brand recognition but not always reliable.
31	Fashion Designer	YouTube influencer endorsements increase brand credibility in the fashion industry.	Facebook ads help reach the target audience quickly but lack the engagement depth of YouTube.
32	IT Consultant	YouTube is ideal for tech-related ads because it provides comprehensive explanations.	Facebook ads provide good reach but often feel like spam.
33	Marketing Lecturer	YouTube's video ads create better consumer learning and understanding of	Facebook ads work well for engagement but often fail to leave a lasting impression.

		brands.	
34	Banker	YouTube ads are well-structured and more informative, making them ideal for financial products.	Facebook ads feel more intrusive and are often ignored unless highly relevant.
35	YouTuber	YouTube ads allow content creators to integrate promotions seamlessly into videos.	Facebook ads are good for instant visibility but often fail to retain audience interest.
36	Event Organizer	YouTube ads, especially live-streamed promotions, create more buzz and credibility.	Facebook ads are effective for promoting events but sometimes get lost in the clutter.
37	Customer Service Executive	YouTube ads are preferred for customer education and trust-building.	Facebook ads generate quick engagement but don't always lead to strong brand loyalty.
38	Gym Owner	YouTube fitness influencers drive engagement and increase membership sign-ups.	Facebook ads work well for special offers and discounts but don't always convert into long-term memberships.
39	Photographer	YouTube ads give detailed brand insights, making them effective for high-involvement products.	Facebook ads work for instant promotions but lack the depth required for premium branding.
40	Small Business Owner	YouTube ads offer credibility and a strong consumer connection through video testimonials.	Facebook ads are cost-effective but sometimes feel generic.
41	College Student	YouTube ads provide better details, especially for educational products and services.	Facebook ads often interrupt scrolling and are skipped unless they are visually appealing.
42	Supply Chain Manager	YouTube ads effectively communicate product value, which is crucial for B2B buyers.	Facebook ads work well for promotions but are not always trustworthy.
43	Radio Host	YouTube ads are great for storytelling and deeper engagement.	Facebook ads work for viral content but have a shorter lifespan.
44	Actor	YouTube ads feel more authentic, especially when done through influencer collaborations.	Facebook ads work well for product launches but often lack engagement.
45	HR Professional	YouTube ads allow detailed branding, making them effective for employer branding strategies.	Facebook ads are good for job postings but don't build long-term engagement.
46	Economist	YouTube ads contribute to informed decision-making by offering long-form content.	Facebook ads work well for product discovery but often lack credibility.
47	Food Blogger	YouTube food ads influence restaurant choices through detailed visual storytelling.	Facebook ads are useful for promotions but don't create the same trust as YouTube.
48	Software Engineer	YouTube ads are great for tech tutorials and software demonstrations.	Facebook ads work well for social engagement but don't offer detailed information.
49	Political Analyst	YouTube ads provide detailed messaging, making them effective for public awareness campaigns.	Facebook ads are good for quick engagement but don't always lead to strong trust.
50	Entrepreneur	YouTube ads create brand loyalty by providing detailed and high-quality content.	Facebook ads drive quick conversions but may not always sustain long-term brand engagement.

Source: Author's Survey

6.1 Discussion on Findings

The findings of this study highlight significant differences between YouTube and Facebook video content marketing in shaping consumer preferences and brand loyalty in Bangladesh. Based on insights from 50 respondents across various professions, YouTube emerges as a preferred platform for brand credibility, in-depth engagement, and long-term brand recall, whereas Facebook proves effective for short-term promotions, targeted marketing, and quick conversions. This divergence in perception reflects the fundamental differences in consumer behavior, ad engagement, and platform utility for businesses operating in Bangladesh's digital marketing ecosystem. One of the key themes observed in the responses is that YouTube ads are highly engaging and informative allowing brands to establish trust and credibility through detailed content, influencer collaborations, and product reviews. Respondents such as university teachers, business consultants, and IT

professionals emphasized that YouTube ads provide long-form content that educates consumers about a product's features, benefits, and user experiences. This type of storytelling-based marketing aligns well with high-involvement product categories, such as electronics, financial services, and educational platforms, where consumers need extensive information before making a purchase decision. The ability to integrate product demonstrations, testimonials and expert reviews makes YouTube an ideal platform for long-term engagement and brand loyalty. Additionally, YouTube's skippable ad format was generally well-received as it allows users to choose whether to engage with an ad, reducing ad fatigue and increasing voluntary engagement rates. This user-centric approach ensures that consumers interact with ads more willingly, leading to higher brand trust and recall. On the other hand, Facebook ads were seen as highly effective for quick conversions and promotional campaigns but were often perceived as intrusive and repetitive. Many respondents, including startup founders, small business owners, and digital marketers, noted that Facebook's highly specific audience targeting allows businesses to reach niche consumer segments efficiently. The platform's sophisticated retargeting algorithms ensure that ads are displayed to users based on their past interactions increasing the likelihood of immediate engagement. However, ad fatigue and overexposure were major concerns, as multiple respondents mentioned that Facebook ads sometimes appear too frequently, making them easy to ignore. Unlike YouTube, which fosters brand storytelling, Facebook ads are generally short-form and promotional leading to instant but often temporary engagement. A comparative analysis of the platforms reveals distinct advantages and limitations. YouTube ads excel in building trust and credibility particularly for products that require consumer education and in-depth explanation. Facebook ads, on the other hand, are more suitable for businesses focusing on direct sales, flash promotions and localized outreach. This fundamental difference means that brands should choose their advertising strategies based on their marketing objectives. For instance, businesses looking to increase brand awareness and build long-term relationships with consumers should prioritize YouTube ads with influencer collaborations and detailed product demonstrations. Conversely, businesses focused on immediate conversions, event promotions and discount-driven campaigns should leverage Facebook's precise targeting capabilities. Moreover, respondents from academia, finance and research backgrounds expressed concerns regarding the credibility of Facebook ads, noting that they are often associated with misleading promotions and exaggerated claims. This skepticism affects consumer trust, making it less effective for brands that require strong credibility and authenticity. In contrast, YouTube's reliance on organic content integration and trusted influencers enhances consumer confidence, leading to higher engagement rates and repeat purchases. This aligns with previous research suggesting that consumers trust brands that offer transparent and informative content rather than relying solely on promotional tactics, Qomariah et al., [51]. Despite Facebook's effectiveness in driving short-term traffic and engagement, its impact on brand loyalty remains limited. Respondents noted that while Facebook ads create high visibility, they often fail to establish deep emotional connections with consumers. In contrast, YouTube's ability to integrate narrative-driven advertisements makes it a more sustainable platform for brand building. For example, YouTube's use of long-form video testimonials, behind-the-scenes content, and expert reviews allows brands to cultivate authentic relationships with consumers resulting in higher brand recall and loyalty. These findings offer several practical implications for digital marketers in Bangladesh. Given the growing importance of video content marketing, businesses should tailor their strategies to maximize the strengths of each platform. For long-term brand building, investing in YouTube ads with rich content and influencer endorsements can yield sustainable growth. Meanwhile, for businesses that prioritize short-term sales, promotional offers, and localized advertising, Facebook remains an effective tool. Additionally, a hybrid strategy that integrates both platforms leveraging YouTube for trust-building and Facebook for quick engagement can optimize overall marketing effectiveness.

6.2 Recommendation of the Study

Based on the findings, this study recommends that businesses in Bangladesh adopt a strategic, platform-specific approach to video content marketing to maximize consumer engagement and brand loyalty. YouTube should be leveraged for long-term brand building through high-quality, informative and storytelling-based content, including product demonstrations, influencer collaborations and in-depth tutorials. Since YouTube fosters credibility and consumer trust, businesses dealing with high-involvement products such as electronics, financial services and education should prioritize this platform. On the other hand, Facebook should be optimized for immediate engagement and conversions, utilizing short-form, visually appealing, and interactive content such as promotional offers, flash sales and retargeting ads. Given concerns about ad fatigue on Facebook, brands should monitor ad frequency, diversify creatives, and use interactive formats like carousel ads and polls to maintain audience interest. A hybrid approach that integrates both platforms will be the most effective strategy. Businesses should use YouTube to educate and engage consumers while leveraging Facebook for targeted promotions and quick sales conversions. Cross-platform promotion should ensure consistent brand messaging across different stages of the consumer journey. Additionally, incorporating influencer marketing and user-generated content (UGC) can enhance credibility and consumer trust. Many respondents emphasized the effectiveness of influencer-driven YouTube content, suggesting that brands should collaborate with local influencers and industry experts for better brand positioning. Facebook ads, on the other hand, should focus on transparency and authenticity by featuring real customer testimonials and verified endorsements to counter consumer skepticism regarding misleading promotions. To ensure long-term effectiveness businesses must continuously track ad performance through engagement metrics such as click-through rates, conversion

rates and ad recall, refining their strategies based on data insights. A/B testing different ad formats and messaging styles will help identify the most effective approaches. Furthermore, localizing content for the Bangladeshi audience by using Bangla-language content, culturally relevant themes, and familiar narratives will improve engagement and relatability. Businesses should also align their content strategies with consumer expectations using YouTube for high-involvement product marketing and Facebook for time-sensitive promotions. In conclusion, businesses in Bangladesh should strategically allocate their digital marketing budgets by aligning their advertising approach with platform strengths and consumer behavior. YouTube should be prioritized for trust-building and long-term engagement while Facebook should be used for quick conversions and targeted promotions. A well-balanced combination of these platforms along with authentic content, localized messaging and performance-driven optimization, will enable businesses to enhance consumer engagement, improve brand loyalty and drive sustainable growth in Bangladesh's dynamic digital marketing landscape.

7 CONCLUSION OF THE STUDY

The use of social media and digital marketing has significantly impacted consumer behavior and the way companies engage with their target audience. Social media marketing activities (SMMAs) play a crucial role in influencing consumer intentions such as continuance, participation and purchase decisions. This study explored the power of video content marketing in shaping consumer preferences and brand loyalty, specifically focusing on YouTube and Facebook ads in the context of Bangladesh. The findings reveal that both platforms play vital roles in influencing consumer behavior, with YouTube being more effective for long-term brand building and trust establishment through informative storytelling-based content. In contrast, Facebook ads are more suitable for immediate engagement and short-term promotions due to their targeted advertising capabilities and quick conversion potential. The study underscores the importance of a platform-specific approach recommending that businesses use YouTube for in-depth consumer engagement and Facebook for short-term sales and promotions. A hybrid strategy combining the strengths of both platforms will likely yield the most effective results in enhancing brand loyalty and consumer engagement. A key recommendation from the study is the implementation of a hybrid video marketing strategy where businesses can leverage YouTube for deeper consumer engagement and brand building while utilizing Facebook for targeted, short-term promotions and conversions. This combination allows businesses to achieve a balance between long-term brand loyalty and immediate sales objectives. Furthermore, integrating influencer marketing, user-generated content, and localized messaging was found to enhance credibility and consumer engagement on both platforms, particularly in the Bangladeshi market, where culturally relevant content is crucial. Despite the valuable insights offered, the study does have some limitations. The research was conducted using a qualitative approach relying on in-depth interviews with only 50 respondents, which may not fully represent the broader population of Bangladesh. Additionally, the sample size and selection may have introduced some bias, limiting the generalizability of the findings. Future research could expand the sample size, include quantitative data and examine other social media platforms to provide a more comprehensive understanding of the evolving role of video content marketing in Bangladesh.

CONFLICT OF INTEREST

The authors have no relevant financial or non-financial interests to disclose.

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MORAL DECISION-MAKING FOR AUTONOMOUS DRIVING BASED ON MULTI-OBJECTIVE REINFORCEMENT LEARNING

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Abstract: Vehicles must ensure safety and efficiency and deal with complex ethical dilemmas in autonomous driving. In order to deal with these ethical dilemmas effectively, moral decision-making models based on multi-objective reinforcement learning (MORL) provide a technical path to resolve such ethical dilemmas. Unlike traditional reinforcement learning (RL), MORL can generate more socially moral decision-making strategies in conflict scenarios by simultaneously optimizing multiple objectives. Of course, significant challenges remain in this research path. Assigning reward function weights is highly dependent on subjective judgement and cultural context; the dynamic environment is not adaptable enough, and the scarcity of ethical dilemma data limits model training. To address these issues, this paper points out that future research needs to focus on the dynamic weight adjustment mechanism, the construction of cross-cultural ethical frameworks, and large-scale real-world validation.
Keywords: Autonomous driving; Moral decision-making; Ethical dilemmas; Multi-objective reinforcement learning

1 INTRODUCTION

Autonomous driving is gradually moving from the laboratory into real life. However, how to make autonomous driving systems make moral decisions that meet ethical standards in complex traffic environments has become a difficult problem in current technology practice [1-4]. Commonly used in traditional intelligent decision-making systems is the RL decision-making framework, which aims to achieve single-objective optimization by prompting the AI agent to take the best action amongst reward-maximizing and corresponding constraint strategies [5-8]. Although traditional RL excels at single-objective optimization (e.g., minimizing collision rates or maximizing traffic efficiency), its inherent flaws are exposed in ethical multi-objective conflict scenarios. To address this challenge, MORL provides a new path to solving ethical dilemmas by simultaneously optimizing conflicting objectives and a dynamic weight allocation mechanism. Unlike RL's single reward function, MORL allows for the definition of multi-dimensional objective functions (e.g., safety, efficiency, fairness) and identifies the optimal trade-off solution via the Pareto front. This ability makes MORL significantly superior to traditional methods regarding cross-cultural ethical adaptability. Researchers have attempted to incorporate multiple ethical objectives in intelligent decision-making systems to achieve decision optimization that is more in line with socio-ethical rules [9-12].

2 MORAL DECISION-MAKING FOR AUTONOMOUS DRIVING

2.1 Dilemma of Moral Decision-Making in Autonomous Driving

The Trolley Problem (TP), a classic thought experiment in ethics, explores how one should make decisions in ethical dilemmas to maximize benefits when faced with unavoidable harm [13-15]. For autonomous driving decision-making systems, this dilemma manifests itself in how to make appropriate choices to achieve optimal ethical goals in inevitable traffic accidents [16-20]. Autonomous driving is often faced with a situation where they must choose between hitting a pedestrian, hitting another vehicle, or some other more damaging scenario to minimize harm (See figure 1). In such situations, it is complex to make an accurate judgement based solely on a simple utilitarian morality (although this is currently the most adopted ethical rule in moral decision-making), which requires a more complex and flexible moral decision-making framework to assist autonomous driving in making their choices.

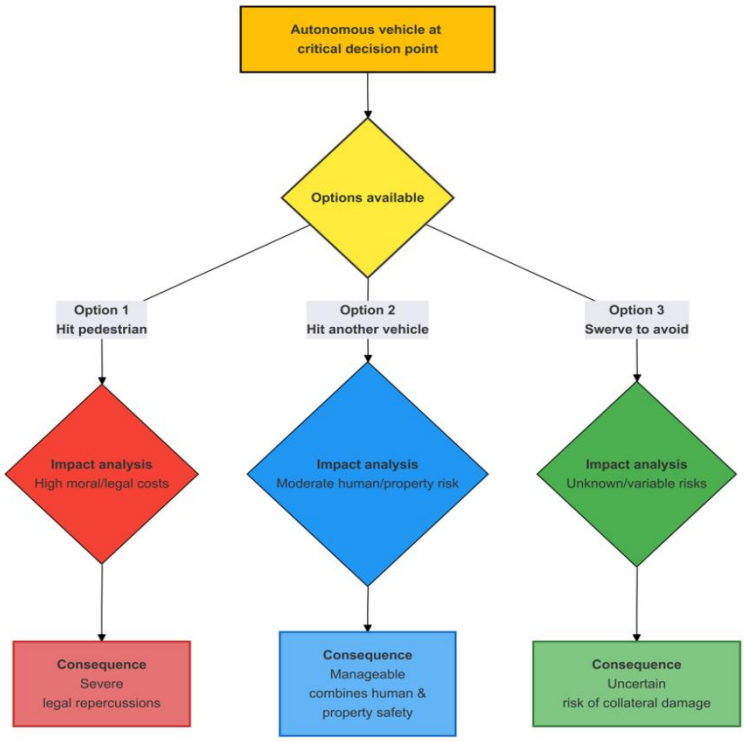

Figure 1 Autonomous vehicle at critical decision point

Of course, some scholars are pessimistic about the excessive focus on TP in ethical discussions of autonomous driving. Etienne argues that current approaches to AI ethics in the autonomous driving industry often simplify complex moral dilemmas and ignore broader social, cultural and situational factors [21]. Although frameworks such as the TP are widely discussed, they fail to effectively address the systemic risks and operational challenges that autonomous driving faces in real-world environments. Meanwhile, Geisslinger et al. think ethical considerations of autonomous driving should go beyond hypothetical moral dilemmas and focus on practical situations involving risk management, safety, and societal impacts [2]. Tolmeijer et al. argue that while AI decision-making systems can assist in moral decision-making by providing objective analyses, identifying patterns, or exploring options, they are inherently non-moral decision-making and still rely on human experts to provide moral reasoning and judgement [22]. AI moral decision-making should be a tool to support humans in achieving moral judgement rather than a subject (human being) who substitutes for moral reasoning. Addressing the issue of explainability in AI moral decision-making, Madhav and Tyagi point to explainable artificial intelligence (XAI) as the key to solving the problem of lack of trust in autonomous driving [23]. By making AI decisions transparent, explainable and consistent with human expectations, XAI can enhance trust, drive the adoption of autonomous driving technologies and ensure their safe and ethical integration into society. Despite the current growing concern in the autonomous driving car industry about ethical issues such as safety, liability, bias in decision-making algorithms, and social acceptance, there is still a lack of consensus on how to comprehensively address these issues [24,25]. This requires interdisciplinary collaboration, more transparent regulations, and the alignment of technological developments with societal values to ensure the ethical deployment of autonomous driving.

2.2 Frameworks for Moral Decision-Making in Autonomous Driving

An AI moral decision-making framework refers to some systematic mechanism and model that ensures that the decisions made by an intelligent decision-making system are in line with ethical principles and societal expectations when faced with complex situations. Conitzer et al. argue that moral decision-making frameworks typically rely on datasets (e.g., surveys, experiments) collected from human responses to ethical dilemmas, which form the basis for training and evaluating AI models [26]. Noothigattu et al. advocate a democratic, collective approach - by aggregating the ethical preferences of a population - to allow AI moral decision-making to be based on the collective will [27]. That is, modelling moral decision-making as a voting problem, where individuals are free to express their preferences for different ethical choices, and then aggregating preferences through voting theory to ultimately select the decision consistent with the majority's ethical outlook. Another empirical study similarly suggests that consumer acceptance of self-driving car services is driven by technological advances and significantly influenced by the perceived consistency of ethical practices and personal values [28]. Regardless of the moral decision-making framework adopted for autonomous driving systems, the core components and principles remain the same (See Table 1), requiring trade-offs between multiple goals such as safety, efficiency, and the rights of passengers and pedestrians, which is the core pathway to achieving trust and legitimization of autonomous driving systems.

Table 1 The content and principles of the moral decision-making framework for autonomous driving

Content		Principle	
Multi-objective optimization	Need to trade-off between multiple objectives (e.g. traffic safety, passenger experience, pedestrian protection)	Damage minimization	Harm minimization is the most fundamental ethical requirement in moral decision-making.
Transparency	The decision-making process of an automated driving system should be transparent so that it is easy for humans to understand and trust.	Fairness and justice	In a moral decision-making framework, the system must ensure that harm is minimized and that decisions are fair and just.
Consistency	The system's decisions should demonstrate consistency in the same or similar situations to enhance public trust in self-driving vehicles.	Legal compliance	Autonomous driving systems should follow current traffic rules as much as possible, choosing the option that minimizes liability when violations and accidents are unavoidable.
Operability	The moral decision-making of the system needs to be actionable, i.e., it can be implemented algorithmically.	Interpretability	In an accident or complication with an automated driving system, the system should be able to explain clearly why it has acted in a particular way.

The moral decision-making framework for autonomous driving aims to guide vehicles in making ethical and socially desirable decisions in complex situations. The core issues include dealing with ethical dilemmas, weighing different ethical principles (e.g., utilitarianism vs. deontology), ensuring fairness and transparency, and satisfying legal and public expectations. Three broad categories of moral decision-making frameworks exist, namely rule-based, utility-maximization and social contract-based frameworks (see Table 2), each with different strengths and weaknesses in dealing with specific ethical situations.

Table 2 Advantages and Disadvantages of Different Moral Decision-Making Frameworks for Autonomous Driving

Type	Advantage	Disadvantage
Rule Based	● Realisability and interpretability ● The strong binding nature of laws and social norms	● Lack of flexibility to adapt to complex and uncertain situations ● Inability to effectively prioritize different objectives when faced with multiple conflicting objectives
Utility-Based	● Ability to deal effectively with complex ethical situations and make optimal decisions by optimizing objective functions ● Greater flexibility to adjust the weighting of different objectives according to actual situations	● There is a high degree of subjectivity in the definition of utility and the assignment of weights ● In emergencies, it may not be possible to fully consider ethical and legal responsibilities, focusing only on utility-maximizing outcomes.
Social Contract Based	● Enables greater social acceptance and cultural adaptability of decision-making ● Emphasis on the cultural context of moral decision-making to ensure that the system meets local ethical standards	● In multicultural, multi-value societies, the challenge of inconsistent standards may be faced ● The social contract needs to be modelled and quantified, which is technically challenging to achieve for the time being

3 MORL IN AUTONOMOUS DRIVING

3.1 Disadvantages of RL in Autonomous Driving

RL is a machine-learning method for learning optimal strategies through environmental interaction [29-33]. The core of RL lies in adapting the behavioural strategies of intelligence through reward feedback and generally only deals with problems with a single objective, such as maximizing long-term rewards and minimizing traffic accidents. In the field of autonomous driving, RL models need a large amount of training data to approximate the optimal policy gradually; however, obtaining real-world moral dilemma data is not only costly but also has a large amount of uncertainty, which makes RL insufficient in this specific case [34,35]. In addition, to train an autonomous driving system on how to make rational decisions in different cultures and contexts, the model needs to collect a large amount of behavioural data, including pedestrians, passengers, traffic signals and other vehicles. As these data cover ethical standards and laws and regulations across multiple domains and regions, it is important to establish a clear framework for data ownership, access, and control to ensure ethical and fair outcomes [36,37]. Finally, real-world ethical dilemmas tend to be scarcity events, which are rare in naturally occurring traffic environments. However, these scarcity events have important implications for moral decision-making in autonomous driving. For example, a vehicle that suddenly encounters a pedestrian crossing the road may need to make a decision that involves a life trade-off, such situations do not occur frequently in regular driving, but when they do, the accuracy and ethics of the decision are critical. Due to the limited data for such situations, RL models often do not gain enough experience to learn effective strategies.

3.2 MORL in Autonomous Driving

The core idea of MORL is to consider multiple different objectives simultaneously in the decision-making process rather than just pursuing a single objective. Each objective has a corresponding reward function, which is usually combined into a composite objective function by weighting to guide the intelligence to make a decision. One of the core issues of MORL applied to autonomous driving is how to design the reward function and balance the individual objectives. The following are two common algorithmic frameworks for MORL and their applications in autonomous driving.

3.2.1 Weighted sum method: combining multiple objectives

The weighted sum method is one of the simplest and most used methods in MORL. This method sums the reward functions of multiple objectives with certain weights to form a composite objective function. In autonomous driving, the objectives may include 'minimize injuries', 'comfort' and 'improve driving efficiency'. The learning process is guided by assigning a weight to each objective (e.g. the weight for injury minimization can be adjusted to the highest) and then weighting and summing these objectives to form a single objective function. Its mathematical expression is typically:

$$f(x) = \sum_{i=1}^{n} \omega_i f_i(x) \tag{1}$$

Where $f(x)$ is the composite objective function which represents the weighted sum of all the objectives. $f_i(x)$ is the -th objective function, which represents the performance or performance of the system on the -th objective. ω_i is the weight associated with the -th objective function, which usually satisfies $\omega_i \geq 0$ and $\sum_{i=1}^{n} \omega_i = 1$. It is assumed that the current autonomous driving has three objectives that need to be satisfied simultaneously:

① 'Minimising damage' = $f_1(x)$;
② 'Comfort' = $f_2(x)$;
③ 'Improving driving efficiency' = $f_3(x)$.

The weights are $\omega_1, \omega_2, \omega_3$, then the expression for the weighted sum method is:

$$f(x) = \omega_1 f_1(x) + \omega_2 f_2(x) + \omega_3 f_3(x) \tag{2}$$

Of course, how to choose the appropriate weights is crucial in practice. If the weights are not set reasonably, it may lead to a specific objective being over-optimized, which ultimately leads to an imbalance in the morality of decision-making (e.g., over-emphasis on efficiency may lead to neglecting the safety of pedestrians). Therefore, a reasonable weight adjustment mechanism is crucial for successfully applying MORL in autonomous driving. To cope with the dilemma of conflicting multi-objective weights in MORL, the Pareto optimality method is an effective means of dealing with trade-offs and conflicts between multiple objectives and is particularly suitable for optimizing conflicting objectives [38,39]. The method aims to find a compromise solution that makes it impossible to further optimize an objective without compromising other objectives, and these compromise solutions are called Pareto optimal solutions, denoted as:

$$\mathbf{x}^* \text{ is Pareto optimal } \Leftrightarrow \nexists \mathbf{x} \in \boldsymbol{X} \text{ s.t.} \left(\forall i, f_i(\mathbf{x}) \leq f_i(\mathbf{x}^*)\right) \wedge \left(\exists j, f_j(\mathbf{x}) \leq f_j(\mathbf{x}^*)\right) \tag{3}$$

The mapping of all Pareto optimal solutions in the space of objective functions is called Pareto Front and is denoted as:

$$\mathcal{P} = \left\{\left(f_1(\mathbf{x}^*), f_2(\mathbf{x}^*), \ldots, f_k(\mathbf{x}^*)\right) \in \mathbb{R}^k \,\middle|\, \mathbf{x}^* \text{ is a Pareto optimal solution}\right\} \tag{4}$$

In moral decision-making for autonomous driving, Pareto optimization methods make the system's decisions more rational and ethical by helping it balance multiple objectives (e.g., safety, efficiency, and fairness). A system can achieve an overall optimal balance by performing Pareto optimization of the balance between different objectives, finding a combination of weights that neither overly favours one objective nor completely ignores other objectives [40,41].

3.2.2 Policy gradient method: optimizing decision strategies

The policy gradient method optimizes the policy directly rather than the value function, and the method also has the potential for application in MORL. For the parameterised policy $\pi(a|s;\theta)$, the objective function $J(\theta)$ is the expected discount return:

$$J(\theta) = \mathbb{E}_{\tau \sim \pi_\theta}\left[\sum_{t=0}^{T-1} \gamma^t r_{t+1}\right] \tag{5}$$

Where $\tau =$ （$s_0, a_0, r_1, s_1, \ldots$） denotes the trajectory and $\gamma \in [0,1]$ is the discount factor. The strategy gradient theorem shows that the gradient of the objective function is:

$$\nabla_\theta J(\theta) = \mathbb{E}_{s \sim d^\pi, a \sim \pi_\theta}\left[\nabla_\theta \ln \pi(a|s;\theta) \cdot Q^\pi(s,a)\right] \tag{6}$$

Where $d^\pi(s)$ is the distribution of discounted states under the policy π_θ, representing the frequency of visits to state s weighted by the discount. $Q^\pi(s,a)$ is the state-action value function defined as the expected discounted reward for following the policy π_θ after choosing the action a at state s. In the moral decision-making problem in autonomous driving, the vehicle faces multiple possible behavioural choices, such as protecting passengers and pedestrians, obeying the law, etc. Thus, a complex reward function needs to be designed. Let the reward for the -th goal be $R_i(s,a)$, and the total reward is:

$$R(s,a) = \sum_{i=1}^{k} \omega_i R_i(s,a) \tag{7}$$

Where $\omega_i \geq 0$ is the weight, which satisfies $\sum \omega_i = 1$. For example:

① Pedestrian safety: $R_1(s,a) = -\frac{1}{d_p(s,a)+\epsilon}$ (d_p: minimum distance to pedestrians)

② Passage efficiency: $R_2(s,a) = v_{\text{avg}}(s,a)$

③ Regulatory compliance: $R_3(s,a) = -\sum\delta(v_{\text{over}}(s,a))$ (δ: overspeed function)

Substituting the composite reward into the policy gradient formula, the gradient is updated to:

$$\nabla_\theta J(\theta) = \mathbb{E}_\tau\left[\sum_{t=0}^{T-1}\nabla_\theta \log\pi_\theta(a_t|s_t)\cdot\left(\sum_{i=1}^{k}\omega_i Q_i^\pi(s_t,a_t)\right)\right] \quad (8)$$

$Q_i^\pi(s_t,\ a_t)$ is the action value function of the -th goal. To reduce variance, a baseline $b(s_t)$ is introduced:

$$\nabla_\theta J(\theta) = \mathbb{E}_\tau\left[\sum_{t=0}^{T-1}\nabla_\theta \log\pi_\theta(a_t|s_t)\cdot\left(\sum_{i=1}^{k}\omega_i\left(Q_i^\pi(s_t,a_t)-b(s_t)\right)\right)\right] \quad (9)$$

The traditional value function approach must compute each possible action's value. In contrast, the policy gradient approach needs to quantify these ethical guidelines into a reward function and find the optimal solution in the policy space by optimizing the policy parameters to achieve the best decision ultimately [42,43].

4 DISCUSSION

4.1 Weight Distribution of the Reward Function

In autonomous driving moral decision-making, the importance of different objectives may change in different contexts. In MORL, weight assignment determines how to handle and optimize multiple reward functions and directly affects the final decision-making effect of the system [44]. By assigning a weight to each objective, a composite reward function can be formed that comprehensively evaluates each objective's accomplishment. The weight assignment not only affects the system's learning process in training but also influences the moral judgement of the system in actual operation. However, in the current moral decision-making based on the MORL algorithm, the weighting problem has never been adequately solved, mainly due to:

Firstly, the choice of weights is highly subjective, and different development teams, stakeholders, and users may judge the priority of goals differently. Some developers may be more inclined to protect the safety of vehicle occupants, while others may emphasize the protection of pedestrians [45]. In addition, priority setting for moral decision-making varies across cultures, laws, and societal values. In some countries, the law may explicitly state that cars must prioritize the safety of pedestrians in all situations, whereas in others, different rules may exist [46]. Therefore, a standardized weighting scheme is unsuitable for all situations, and weighting must be flexible to accommodate different cultural and social contexts and legal environments.

Second, the environment faced by an autonomous driving system is dynamically changing, and the system must react quickly to these changes. In daytime and nighttime traffic scenarios, an autonomous driving system may need to dynamically adjust the weights for safety and efficiency [47]. In an emergency where a traffic accident occurs, the system may need to immediately increase the weighting of the safety objective, whereas, in daily traffic, more attention needs to be paid to efficiency and comfort. This context dependency requires that the weights can be dynamically adjusted according to the current state of the environment rather than being fixed. However, it is still challenging to effectively design a dynamic adjustment mechanism so that the weights can accurately reflect the needs of the current context.

Finally, in multi-objective optimization, weighting conflicts are inevitable. Safety and efficiency are often conflicting objectives in autonomous driving: higher safety usually means slower speeds and higher travelling caution, while higher efficiency may mean more risk-taking. Therefore, the system must find a suitable balance between the multiple objectives, neither sacrificing safety for efficiency nor disabling traffic flow for absolute safety. This conflict makes weight setting very fine and sensitive, and any adjustment of the weights may cause the system to deviate from one of the objectives. If the weights for safety are set too high, the system may become too conservative and even lead to traffic congestion, while if the weights for efficiency are too high, the risk of accidents may increase. Therefore, designing a reasonable weight allocation scheme to balance the weight conflicts of different objectives is a complex problem for MORL.

In today's wildly advancing autonomous driving technology, the weight distribution of the reward function is like a sword of Damocles, which has transcended the scope of mere technology and become a hub connecting algorithmic ethics and social values. It is a warning that technological development must keep pace with ethical evolution and that we realize the Rome Declaration only through verifiable technological solutions, standardized review processes, and rule-of-law-based participatory mechanisms. This technological practice is not only about the innovation of transport modes but also the reconfirmation and inheritance of humanity's ethical system in the age of AI. A multi-level weighted governance system is being constructed globally, from *ISO 21448 Standards* to UNECE regulations, MIT ethical machine experiments, and German legislative practices. More and more open, transparent, and inclusive weighted governance mechanisms are promoting autonomous driving as an intelligent carrier that carries human values.

4.2 The Universality of Ethical Objectives

The universality of ethical goals is another central challenge in moral decision-making in autonomous driving systems. Fundamental to the universality problem is ensuring that autonomous driving systems can always make moral and ethical decisions in various complex and changing social and cultural contexts.

On the one hand, morality and ethics are understood differently in different social contexts, cultural values and legal systems. In European and American cultures, the rights and freedoms of the individual are often emphasized. There may be a greater tendency to protect the lives of individuals in moral decision-making. However, in some East Asian cultures, collective interests and social harmony may be more important than individual interests [48]. Therefore, when an autonomous driving system is faced with the need to choose between protecting passengers and protecting pedestrians, different cultures may have different definitions of the 'best choice', and cultural differences make it challenging to devise a uniform framework for moral decision-making.

On the other hand, traffic regulations and legal systems vary significantly from country to country, which makes it difficult to harmonize moral decision-making for autonomous driving systems. In Germany, the law clearly states that innocent pedestrians must be protected as much as possible in all circumstances. At the same time, in the United States, the priorities of autonomous driving systems may focus more on the safety of passengers. In addition, different countries have inconsistent regulatory standards for autonomous driving technology. Some countries have established strict regulatory restrictions on autonomous driving behaviour, while others may give more flexibility [49]. Autonomous driving systems must be able to adapt their decisions to different legal environments to ensure the legality of their behaviour, which places a higher demand on the universality of ethical goals.

5 CONCLUSION

Although the current moral decision-making framework for autonomous driving based on MORL provides a technical basis for solving ethical dilemmas, it still faces many practical challenges. Firstly, significant subjectivity and cultural differences exist in allocating reward function weights, but the definition of 'optimal solution' varies significantly across societies and cultures. In addition, the fragmentation of global traffic regulations further exacerbates the difficulty of weighting standardization. Second, the problem of real-time adaptation to dynamic environments is prominent. Sudden accidents in extreme scenarios require the system to be able to adjust the weights dynamically. However, balancing algorithmic complexity and real-time decision-making with existing technologies is difficult. Finally, the scarcity of ethical dilemma data restricts model training. The probability of 'tram dilemma' events in real scenarios is extremely low, while the deviation of simulation data from reality may lead to insufficient decision generalization.

Future research must focus on three significant directions to address the above challenges. Firstly, a context-aware dynamic weight adjustment mechanism must be developed. The system can optimize the target weights in real time by integrating multi-dimensional parameters such as weather, road conditions, traffic density, etc. Second, to build a cross-cultural ethical framework. Establish a transparent public participation mechanism, incorporate multiple values, and coordinate regulatory conflicts through international cooperation. Third, the reality verification and credible assessment system must be strengthened. This requires relying on large-scale simulation tests and accurate road data to verify the performance of models in complex ethical dilemmas and introducing third-party auditing organizations to review the fairness and interpretability of algorithms independently. In addition, interdisciplinary collaboration (ethicists, engineers, legal experts) and public education (e.g., ethical preference surveys) will fuel the deeper integration of technology and social values.

Looking ahead, moral decision-making in autonomous driving is not only a matter of technical optimization but also of reconstructing the human ethical system in the age of intelligence. Intelligent systems are expected to achieve more humane trade-offs in extreme scenarios through dynamic weight allocation, culturally adaptive modelling, and rigorous reality verification. This process needs to be based on technological iteration and supported by global collaboration and standardized governance, ultimately enabling autonomous driving to go beyond the attribute of a tool and become a credible intelligence carrying social consensus.

COMPETING INTERESTS

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PTSD CHARACTERISTICS OF RESCUERS BASED ON DECISION TREE

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Abstract: Post-traumatic stress disorder (PTSD) is a mental disorder caused by traumatic events, characterized by recurrence of memories and nightmares, avoidance of stimulation, difficulty in regulating emotions, and persistent hypervigilance. Due to the particularity of their work, rescuers are often more likely to suffer from PTSD. Identifying and clarifying the influencing factors of PTSD, establishing an effective prediction model for rescuers, and providing effective evaluation tools to provide targeted treatment and support measures for rescuers are of great significance in helping rescuers cope with and prevent PTSD. Based on the data set provided by the PLA Medical College, this study used a decision tree classification model to construct an effective prediction model for rescuers, identify important variables that affect rescuers' PTSD, and evaluate the prediction efficiency of the model by the receiver operating characteristic curve (ROC). Results: The accuracy was 95.56%, the sensitivity was 93.75%, the specificity was 95.69%, the false positive rate was 4.31%, the F1 score was 75%, and the AUC value was 94.72%. The features classified by the model were ranked according to their importance. The top eight features of the decision tree model were: ASD alertness, ASD avoidance, ASD re-experience, ASD separation, ASD nature, smoking status, psychological resilience, and age. Conclusions: The decision tree model has high accuracy and stability and can be used to guide clinical prevention and treatment.
Keywords: PTSD; Decision tree model; Influencing factors; Feature selection

1 INTRODUCTION

Post-traumatic stress disorder(PTSD) refers to a strong psychological reaction such as helplessness, fear, anxiety or disgust caused by an abnormally threatening or catastrophic event[1]. A traumatic event is an experience that threatens the safety or death of an individual or others. Nearly 70% of the population is exposed to at least one traumatic event in their lifetime, and 31% will experience about 4 traumatic events[2]. A considerable number of people will suffer from PTSD, with a lifetime prevalence rate between 6.1% and 9.2%. The nature of the work of rescue workers often exposes them to extreme environments and traumatic events. If they are not intervened and treated in time, they are often more likely to suffer from PTSD[3,4]. Data on post-traumatic stress disorder (PTSD) among rescuers vary by region, year, and research method. Here are some examples of relevant research results: a) In a study of American firefighters, about 7% of firefighters were diagnosed. b) In Canada, a study of firefighters and emergency personnel found that about 10% of respondents were diagnosed. c) A study of Australian rescuers found that about 5% of rescuers suffered from post-traumatic stress disorder. The actual prevalence may vary due to multiple factors, such as the selection of research samples, differences in diagnostic criteria, etc. In addition, many rescuers may not actively seek help or be correctly diagnosed, so the actual prevalence may be underestimated. The nature and severity of the traumatic event, the individual's psychological characteristics and coping ability, social support and environmental factors, and biological factors are all important factors affecting PTSD[5]. To date, there have been many studies on the factors affecting PTSD, but there are very few studies on the importance of these factors.

Machine learning (ML), as one of the core technologies of artificial intelligence, is a method of summarizing features and patterns of large amounts of data[6]. Due to its powerful data processing and mining capabilities, machine learning can help identify the most relevant features and evaluate the importance of features, thereby determining which factors have a significant impact on a phenomenon or result. Therefore, this paper aims to use the decision tree classification model to construct an effective prediction model for rescuers and identify important variables that affect rescuers' post-traumatic stress disorder, provide targeted treatment and support measures for rescuers, and help rescuers cope with and prevent PTSD.

2 THEORETICAL OVERVIEW

Decision tree is an important classification and regression method in data mining technology. It is a prediction model expressed in the form of a tree structure. It recursively divides the features in the data set to build a tree-like decision model to achieve the classification or numerical prediction of samples[7]. Each leaf node in the tree represents a classification result, and different branch paths represent different classification choices[8]. The main strategic idea of building a decision tree is to divide and conquer from top to bottom, that is, in the recursive process from root to leaf, find a "partition" attribute at each intermediate node to divide the data set into smaller and smaller subsets until the conditions are met. Decision tree structure diagram can be seen in figure 1.

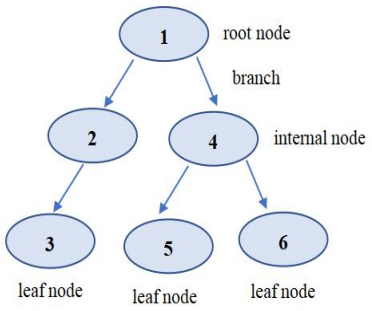

Figure 1 Decision Tree Structure Diagram

In summary, the core of the decision tree algorithm is to select the optimal attribute division. In order to achieve the optimal attribute division, the samples contained in the internal nodes of the decision tree are usually as much as possible belonging to the same category, that is, the "purity" of the node is as high as possible. Information entropy is the basic indicator for measuring the "purity" of a sample set, and the calculation formula is as follows:

$$Ent(D) = -\sum_{k=1}^{|y|} p_k \log_2 p_k \tag{1}$$

It is assumed that the proportion of the k-th class samples in the current sample set D is P_k . The smaller the value of information entropy is, the higher the "purity" is.

3 DATA DESCRIPTION

The data used in this paper is provided by the PLA Medical College. This dataset contains the basic information of rescuers, with a total of 903 records, each of which represents the personal data of a rescuer. The variables in the dataset include but are not limited to demographic information, traumatic experience, psychological state, and behavioral habits.

Before analysis and modeling, the data is first processed appropriately. In order to enable the model to effectively identify and utilize all non-numerical variables, a label encoding strategy will be adopted instead of one-hot encoding, which introduces high-dimensional sparse features and may lead to dimensionality disasters. Label encoding divides the variables into levels according to the health risk or severity they reflect, allowing the model to more accurately identify the key factors affecting PTSD. For continuous variables, standardization will be used, 0 and 1 label encoding will be used for binary variables, and sequential integer encoding will be used for multi-classification variables. For example, the gender variable is coded as {1, male} and {0, female}, which can simplify data processing and is more convenient in statistical analysis. The educational level variable is coded as {3, college and above}, {2, high school}, {1, technical secondary school and below}. This coding method reflects the increasing relationship of education level and is helpful for analyzing the impact of education level on PTSD.

For the study of PTSD characteristics, the recursive feature elimination cross-validation (RFECV) method will be used for feature selection. First, the comprehensive variable ASD total score and the response variable PCL total score are deleted. This is because the ASD total score is the sum of other ASD-related variables (such as ASD dissociation, ASD re-experience, ASD avoidance, and ASD vigilance), which contains information about other ASD variables. In addition, the PCL total score has been converted into a PTSD nature variable and used as a response variable. Therefore, in order to avoid information duplication and multicollinearity, it was decided not to include these two variables in the feature selection process. Then, recursive feature elimination cross-validation (RFECV) was performed to obtain the optimal number of features and the corresponding accuracy of the model. Figure 2 shows the change in model accuracy as the number of features increases. It can be seen that as the number of features increases, the accuracy of the model shows an overall upward trend. When 25 features are used, the accuracy is the best, which is 0.96457. According to the result data, the accuracy of the model is significantly improved for the first time when 8 features are used, reaching 0.96455, and remains relatively stable at the subsequent number of features. The accuracy of the model reached the highest when using 25 features, but it was very close to the accuracy when using 8 features. In order to study the different effects of more variables on PTSD, we chose to retain all the variables in the model.

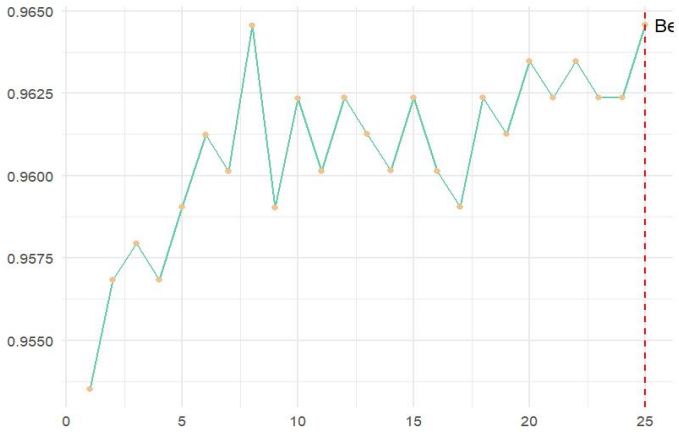

Figure 2 The Optimal Number of Features for the Model

Finally, the data set is divided reasonably, and the oversampling technique is applied to the training set. First, the createDataPartition function is used to divide the data set into a training set and a test set at a ratio of 75%. In the original data set, there are 837 individuals without PTSD and 66 individuals with PTSD. After the division, the training set contains 628 individuals without PTSD and 50 individuals with PTSD, while the test set contains 209 individuals without PTSD and 16 individuals with PTSD. Since the number of individuals with PTSD in the training set is relatively small, in order to avoid the impact of class imbalance on model training, the training set is oversampled. The ovun.sample function is used to increase the number of minority class (PTSD) samples in the training set to 272, so that the number of samples without PTSD and with PTSD in the training set is 628 and 272 respectively. Through this data balancing strategy, the model can fully learn the characteristics of minority class samples during the training process, improve the recognition ability of minority classes and the overall prediction performance.

4 MODEL ANALYSIS

After preprocessing the above data sets, eight common machine learning methods such as decision tree, logistic regression, and support vector machine were used to build models to find the best model in PTSD research. The six indicators of accuracy, sensitivity, and specificity of each model were comprehensively considered. Finally, it was found that the decision tree classification model performed best among the eight machine learning models, with an AUC value of 0.9472. Classification performance evaluation indicators of each model can be seen in table 1.

Table 1 Classification Performance Evaluation Indicators of Each Model

Model	Accuracy	Sensitivity	Specificity	False_Positive_Rate	F1_Score	AUC
Decision Tree	0.9556	0.9375	0.9569	0.0431	0.7500	0.9472
LR	0.9289	0.8125	0.9378	0.0622	0.6190	0.8751
SVM	0.9200	0.8750	0.9234	0.0766	0.6087	0.8992
RF	0.9644	0.7500	0.9809	0.0191	0.7500	0.8654
NN	0.9289	0.6250	0.9522	0.0478	0.5556	0.7886
Adaboost	0.9511	0.8750	0.9569	0.0431	0.7180	0.9160
XGBoost	0.9556	0.8125	0.9665	0.0335	0.7222	0.8895
Stacking Ensemble	0.9644	0.6250	0.9904	0.0096	0.7143	0.8077

The ROC curve is used to evaluate the classification performance of the decision tree model on the training set and the test set. As can be seen from Figure 3, the AUC values of the decision tree model on the training set and the test set reached 0.97 and 0.95 respectively, indicating that the model not only has very high classification ability, but also shows good generalization performance. This means that the performance of the model on different data sets is very consistent and can effectively distinguish between high-risk and low-risk individuals. It is particularly noteworthy that the shape of the curve is close to the ideal state, highlighting the superior performance of the model in sensitivity and specificity, ensuring that individuals with a higher risk of PTSD can be accurately captured in practical applications.

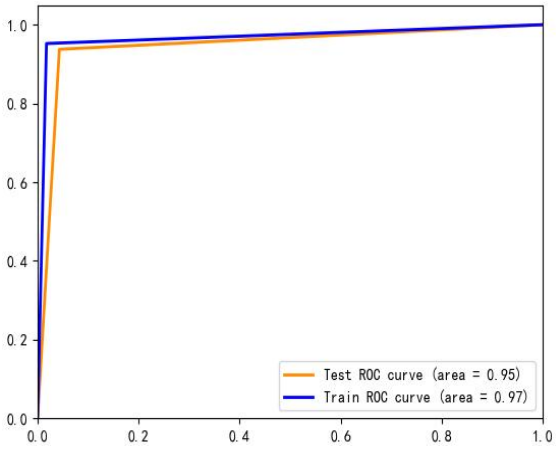

Figure 3 Decision Tree Classifier ROC Curve

The confusion matrix of the decision tree model on the training set and the test set can intuitively show the classification effect and misclassification of the model. In the training set, the decision tree model correctly classified 617 negative observations and 259 positive observations, and generated 11 false positives and 13 false negatives; in the test set, it correctly classified 200 negative observations and 15 positive observations, and generated 9 false positives and 1 false negative. Overall, the model performed well in classification accuracy and stability, which provides strong support for its application in practical operations. Confusion matrix can be seen in table 2.

Table 2 Confusion Matrix

(a) training set

		Reference	
		Positive	Negative
Prediction	Positive	617	13
	Negative	11	259

(b) test set

		Reference	
		Positive	Negative
Prediction	Positive	200	1
	Negative	9	15

The importance of each feature in the evaluation model can be seen from Figure 4. Its importance ranking from high to low is ASD alertness, ASD avoidance, ASD re-experience, ASD separation, ASD nature 1, smoking status 2, psychological resilience, age, income 3, income 4, weight, disaster scene 1, BMI, gender 1 and height. Among them, ASD alertness and ASD avoidance are the most important influencing factors, significantly affecting the risk of PTSD. ASD re-experience and ASD separation also play an important role in the model. In contrast, factors such as smoking status and psychological resilience are relatively minor, but still contribute to the risk of PTSD. Indicators such as age, weight and income are relatively less important, but still have a certain influence in specific situations.

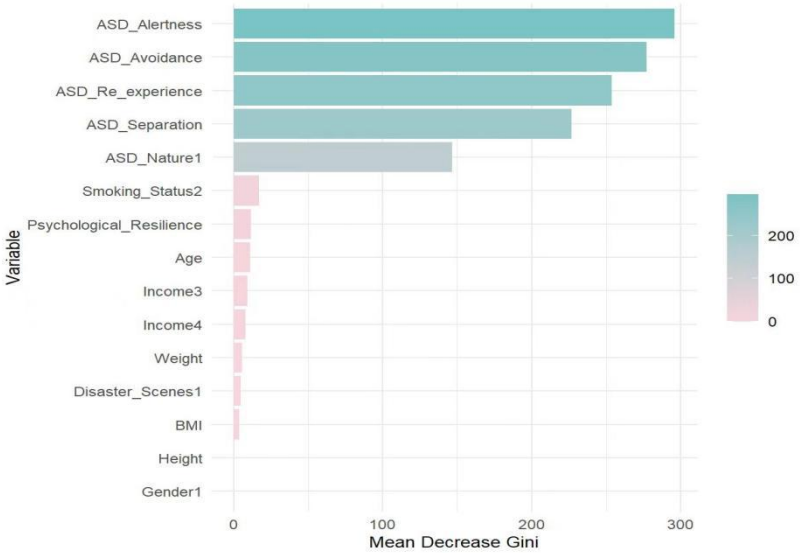

Figure 4 The Optimal Number of Features for the Model

5 CONCLUSION

Artificial intelligence (AI) has made rapid progress in the research and application of psychiatry. As an important technology in the field of artificial intelligence, machine learning has shown great recognition function in the field of

medical diagnosis, providing a new research approach for its medical diagnosis. This study uses a decision tree model to construct an effective prediction model for rescuers and identify important variables that affect rescuers' post-traumatic stress disorder. The research results have high accuracy and reliability. For the features obtained by model classification, they are ranked according to their importance. The top eight feature variables are ASD alertness, ASD avoidance, ASD re-experience, ASD separation, ASD nature 1, smoking status 2, psychological resilience and age. It can be found that ASD alertness, ASD avoidance and ASD re-experience are the most critical influencing factors. It is recommended that rescuers should go to the hospital for help in time when they have symptoms of ASD alertness, ASD avoidance or ASD re-experience to prevent further development into PTSD, which will have a profound impact on the mental health and daily life of rescuers. For doctors, when conducting preliminary ASD (acute stress disorder) assessments on rescuers, psychological counseling should be implemented as soon as possible according to the ASD score to effectively prevent the occurrence and development of PTSD.

Through this study, we hope to provide valuable reference and guidance for research and practice in related fields, help rescuers cope with and prevent PTSD, and thus improve their long-term health and quality of life. The PTSD prediction model based on the decision tree will become a powerful tool for doctors in clinical practice, helping them to identify and intervene in PTSD early, and provide rescuers with more comprehensive and personalized psychological support.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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THE DEVELOPMENT AND APPLICATION OF INFORMATION TECHNOLOGY IN TRACK CONSTRUCTION TRAINING

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Abstract: As a core course in the rail transit specialty, practical teaching in track construction plays a crucial role in cultivating students' professional skills and qualities. However, traditional methods of practical teaching in track construction face numerous challenges, including substantial investment required for constructing practical training facilities, low student engagement, and difficulty in quantifying the effectiveness of practical training. The rapid advancement of information technology offers innovative solutions to these issues. This study investigates the development and application of information technology in track construction practice training. By establishing a track construction practice training platform leveraging BIM technology, oblique photography technology, and human-computer interaction technology, this approach achieves cost-effectiveness, high student participation, on-site training capabilities, and ease of evaluation.
Keywords: Rail transit; Practical teaching; BIM; Oblique photography; Human-computer interaction

1 INTRODUCTION

The traditional practical training teaching of track construction mainly presents the following issues: Firstly, the establishment of practical training facilities demands a substantial investment. Track construction involves a considerable amount of professional equipment and sites. Constructing a comprehensive practical training base requires a colossal infusion of funds, which poses a heavy burden for numerous colleges and universities. Secondly, students engage in more passive learning and have fewer hands-on experiences and practical operations. Due to the constraints of equipment and sites, the majority of students can merely learn by observing the demonstrations of teachers, lacking opportunities for hands-on practice. Furthermore, the depth of student participation is insufficient. Traditional practical training teaching is often conducted in classes, and the time and depth of participation for each student are limited, making it challenging to fully grasp all aspects of track construction. Finally, the practical training effect is difficult to quantitatively assess. Traditional practical training evaluations predominantly rely on the subjective judgments of teachers, lacking objective and quantitative evaluation standards and methods, and thus are hard to accurately reflect the actual skill levels of students. These problems severely constrain the effectiveness of practical training teaching of track construction and impact the professional adaptability and competitiveness of students. Therefore, exploring new practical training teaching models and methods and leveraging information technology to address the aforementioned issues have become the urgent demands for the current reform of practical training teaching of track construction.

This study proposes a design scheme for a track construction practical training platform based on information technology, with BIM technology as the core[1], in combination with oblique photography technology and human-computer interaction technology, to construct a virtual track construction practical training environment. The overall architecture of the platform encompasses the data layer, model layer, application layer, and user interface layer. The data layer is responsible for collecting and processing various data related to track construction; the model layer utilizes BIM technology and oblique photography technology to build track information models and geographic information models; the application layer realizes various practical training functions, such as construction method selection, construction sequence arrangement, site layout, etc.; the user interface layer provides an intuitive and user-friendly operation interface and supports multiple human-computer interaction approaches.

In terms of the design of platform function modules, it mainly comprises the following modules: the construction method selection module, offering detailed introductions and comparisons of various track construction methods to assist students in choosing appropriate ones; the construction sequence arrangement module, allowing students to arrange the construction sequence based on the actual circumstances of the project and view the effect in real time; the site layout module, supporting students in conducting construction site layout in the virtual environment to optimize resource utilization; the progress and resource planning module, helping students formulate construction progress plans and resource allocation schemes; the construction rehearsal module, permitting students to simulate and rehearse the entire construction process to discover potential problems; the quality, safety, and environmental protection problem judgment module, providing identifications and solutions for common problems to cultivate students' comprehensive capabilities.

2 INTRODUCTION TO BIM TECHNOLOGIES

BIM technology is a methodology for architectural design, construction and operation management that is based on digital models. Through the creation and management of three-dimensional models of construction projects, it integrates multi-dimensional data such as geometric information, time, cost and materials, and realizes collaborative management throughout the entire life cycle.

2.1 Core Features

Three-dimensional Visualization: BIM technology facilitates an intuitive three-dimensional model, enabling designers, engineers, and stakeholders to gain a comprehensive understanding of the building project's intricate details. This visualization extends beyond geometric shapes to encompass materials, colors, lighting, and other attributes, ensuring that design intent is accurately conveyed to all participants. Furthermore, three-dimensional visualization aids in identifying potential issues during the design phase, such as spatial conflicts and structural inconsistencies, thereby minimizing changes and rework during construction.

Data Integration: A BIM model integrates both geometric and non-geometric information, including time schedules, cost estimates, material specifications, and equipment data, into a unified platform. This integration enhances transparency and coordination across different project phases, improving overall project efficiency by allowing all stakeholders to access and update relevant data in real-time.

Collaborative Work: BIM technology provides a collaborative platform that enables seamless cooperation among all project stakeholders, including designers, engineers, contractors, owners, suppliers, and regulatory authorities. This collaborative environment fosters mutual understanding of each party's needs and constraints, reducing misunderstandings and conflicts while enhancing project efficiency.

Simulation and Analysis: BIM technology supports advanced simulations and analyses, such as energy consumption analysis, structural analysis, and daylighting studies. These tools assist designers in optimizing their plans, leading to improved building performance in terms of energy efficiency, occupant comfort, and safety. For instance, energy consumption analysis can guide the selection of more sustainable materials and systems; structural analysis can refine designs for enhanced safety; and daylighting studies can optimize natural light distribution within the building.

Full Lifecycle Management: BIM technology extends its application from the design and construction phases to the operation and maintenance stages of buildings. Through BIM models, facility managers can access critical information about building systems and components, such as equipment specifications and maintenance records, thereby improving operational efficiency. Additionally, BIM models can support end-of-life decisions, such as demolition and reconstruction, extending the building's lifecycle.

2.2 Application Areas

Architectural Design: BIM technology plays a pivotal role in architectural design, supporting scheme development, detailed construction drawings, and clash detection. During the conceptual design phase, designers can rapidly generate and compare multiple design options using BIM models. In the detailed design phase, BIM models facilitate the creation of precise construction documents and enable clash detection , which identifies conflicts between different disciplines (e.g., piping and structure) early in the process, reducing errors and rework during construction.

Construction Management: BIM technology significantly enhances construction management by supporting schedule management, cost control, and quality assurance. Project teams can develop detailed construction schedules and track progress using BIM models. Cost management benefits from accurate quantity takeoffs and cost estimates derived from BIM models. Quality management is bolstered by the ability to perform inspections and ensure compliance with design standards through BIM-based documentation.

Facility Management: BIM technology is instrumental in facility management, aiding in equipment management, maintenance planning, and space utilization. Facility managers can access comprehensive information about building systems and components, such as equipment models, installation dates, and maintenance histories, improving operational efficiency. Maintenance plans can be generated and tracked using BIM models, ensuring timely upkeep. Space management is also enhanced by leveraging BIM models for efficient space planning and allocation.

Urban Planning: BIM technology is increasingly applied in urban planning to enhance infrastructure planning and management. Planners can utilize BIM models for road design, bridge engineering, drainage systems, and other urban infrastructure projects, improving planning efficiency. Moreover, BIM models provide a powerful tool for three-dimensional visualization of urban environments, facilitating better communication of planning concepts to government officials and the public.

2.3 Advantages

Improved Efficiency: BIM technology streamlines collaboration by providing a unified platform that reduces information silos and enhances work efficiency. The technology also supports various simulations and analyses, helping designers optimize their schemes, reduce errors, and improve design efficiency.

Cost Reduction: BIM technology assists in controlling project costs through precise quantity calculations and cost estimations. Collision detection capabilities further minimize changes and rework during construction, leading to cost savings.

Enhanced Quality: BIM technology supports the optimization of design schemes through advanced simulations and analyses, resulting in higher-quality buildings. Additionally, it facilitates quality inspection and control during construction, ensuring adherence to design standards.
Improved Collaboration: BIM technology fosters effective collaboration among all project stakeholders by providing a unified platform that reduces misunderstandings and conflicts, thereby enhancing overall project efficiency.

3 INTRODUCTION TO BIM TECHNOLOGIES

Oblique Photogrammetry is an advanced photogrammetric technique that generates high-precision three-dimensional (3D) models by capturing images of a target area from multiple angles, including vertical and oblique perspectives. This technology has gained widespread application in recent years, particularly in urban planning, land management, disaster monitoring, and cultural heritage preservation. Oblique Photogrammetry not only provides high-resolution imagery but also produces accurate 3D geographic information models, offering comprehensive spatial data support for decision-makers.

3.1 Technical Principles

Data Acquisition: Oblique Photogrammetry typically employs unmanned aerial vehicles (UAVs) or aircraft equipped with multi-camera systems for data collection. These systems usually include one nadir camera and four oblique cameras, capturing images from different angles. The nadir camera acquires top-down views of the target area, while the oblique cameras capture side views from front, back, left, and right directions.
Image Processing: The collected image data undergoes a series of processing steps, including image matching [2], aerial triangulation [3], and 3D reconstruction [4]. Image matching utilizes computer vision algorithms to align images from different angles and identify corresponding ground control points. Aerial triangulation calculates the exterior orientation parameters of the images using a large number of control points and image data, determining their spatial position and orientation. 3D reconstruction then integrates multi-view images to generate a detailed 3D model of the target area.
Model Generation: After image processing and 3D reconstruction, Oblique Photogrammetry can produce high-precision 3D models. These models incorporate both geometric shapes and high-resolution texture information, enhancing their realism and utility. The generated models are applicable in various fields such as urban planning, land management, and disaster monitoring.

3.2 Technical Characteristics

Multi-angle Shooting: Oblique Photogrammetry captures images from multiple angles to obtain comprehensive image data of the target area. This multi-angle approach not only captures the top information of objects but also their side details, resulting in more complete and accurate 3D models.
High Precision: Oblique Photogrammetry achieves high-precision 3D models through multi-view imaging and precise image processing techniques. The accuracy of these models can reach the centimeter level, meeting the stringent requirements of various high-precision applications.
High Efficiency: Oblique Photogrammetry leverages UAVs or aircraft for rapid data collection over large areas. Compared to traditional ground-based measurement methods, this technology offers significantly higher efficiency.
Realistic Texture Information: The models generated by Oblique Photogrammetry include not only geometric shapes but also high-resolution texture information, making them highly realistic and suitable for visualization applications.
Wide Application Fields: Oblique Photogrammetry finds extensive use in urban planning, land management, disaster monitoring, and cultural heritage preservation. By generating high-precision 3D models, it provides comprehensive spatial data support for decision-makers.

3.3 Application Fields

Urban Planning: Oblique Photogrammetry plays a crucial role in urban planning. High-precision 3D models enable planners to better understand the spatial structure of cities and make informed decisions regarding layout and development. Additionally, it facilitates 3D visualization of urban environments, aiding government officials and the public in comprehending urban planning schemes.
Land Management: Oblique Photogrammetry supports efficient land management by generating high-precision 3D models. These models assist in conducting land surveys, cadastral mapping, and land use planning. Moreover, they enable timely detection and prevention of illegal land use through change monitoring.
Disaster Monitoring: Oblique Photogrammetry is vital for disaster monitoring. High-precision 3D models aid in disaster risk assessment, early warning systems, and emergency response planning. For instance, after natural disasters like earthquakes, floods, and landslides, Oblique Photogrammetry can rapidly generate 3D models of affected areas, helping rescue teams assess the situation and formulate effective rescue plans.
Cultural Heritage Protection: Oblique Photogrammetry holds significant value in cultural heritage protection. High-precision 3D models allow for digital preservation of historical structures and archaeological sites, providing essential data for conservation and restoration efforts. Furthermore, it enables virtual display and dissemination of cultural heritage, enhancing public awareness and appreciation.

4 APPLICATION OF VARIOUS INFORMATION TECHNOLOGIES IN THE PLATFORM

4.1 Application of BIM Technology in the Construction of Track Information Models

BIM (Building Information Modeling) technology plays a pivotal role in constructing track information models. In data acquisition and processing, BIM integrates multi-source data such as design drawings, survey data, and material specifications into a comprehensive, multi-dimensional information model. This integration encompasses both geometric and non-geometric data, including time schedules, cost estimates, and material properties, providing robust support for subsequent construction simulations and decision-making processes.

In model construction and optimization, BIM enables the creation of highly accurate three-dimensional models of track structures, including roadbeds, bridges, tunnels, and other components. Parametric design allows for rapid modifications and optimizations to meet diverse construction scenarios. Furthermore, BIM models can be integrated with models from other disciplines (such as architecture and mechanical and electrical engineering), ensuring seamless coordination across specialties.

In construction simulation and visualization, BIM offers advanced 4D (3D + time) and 5D (4D + cost) simulation capabilities [5]. These features allow students to simulate entire construction processes in virtual environments, observe the effects of different construction plans, and identify potential conflicts and issues. Visualization tools make complex construction processes more intuitive and comprehensible, aiding students in better understanding construction principles and methods. Additionally, BIM models can be linked with project schedules and resource allocation data to achieve dynamic management and optimization of the construction process.

4.2 Application of Oblique Photography Technology in Geographic Information Model Construction

Oblique photography technology is instrumental in the construction of geographic information models. For data acquisition and processing, oblique photography utilizes UAVs or aircraft equipped with multi-angle cameras to capture high-resolution images of target areas from various perspectives. After processing, these images generate high-precision three-dimensional geographic information models. Compared to traditional surveying methods, oblique photography offers advantages such as higher efficiency, lower costs, and richer detail, making it particularly suitable for large-scale and complex terrain data collection.

In model construction and optimization, the three-dimensional models generated by oblique photography are characterized by their realism and detailed representation. Professional software can integrate these models with BIM models to form a complete virtual construction environment. This integration enhances model accuracy and realism while providing a reliable basis for construction site layout and machinery path planning.

In scene visualization and analysis, oblique photography-generated models support multi-perspective observation and analysis. Students can navigate virtual environments freely, observing construction sites and surrounding areas from different angles. This immersive experience aids in better understanding the construction environment and making informed decisions. Moreover, oblique photography models can be combined with GIS systems for terrain analysis, line -of-sight analysis[6], and solar radiation analysis, supporting the optimization of construction plans.

4.3 Application of Human-Computer Interaction Technology in Construction Training Operations

Human-computer interaction (HCI) technology enhances construction training operations through interaction method design, operation process design, and user experience optimization. In interaction method design, the platform supports multiple interaction methods, including traditional mouse and keyboard operations, touchscreen interactions, and emerging technologies like virtual reality (VR)and augmented reality (AR) . These methods provide diverse operational experiences, catering to different learning styles and needs. Particularly, VR and AR technologies create highly immersive training environments, making students feel as if they are on an actual construction site, significantly enhancing engagement and learning outcomes.

In operation process design, the platform adheres to principles of intuitiveness, simplicity, and efficiency. Each training module includes clear operation steps and prompts, guiding students through tasks systematically. The platform also offers functions such as undo, redo, and save, allowing students to experiment and refine their skills. For complex operations, the platform provides step-by-step instructions and detailed explanations to facilitate understanding and mastery.

In user experience optimization, the platform focuses on interface design and feedback mechanisms. The interface features a clean and intuitive layout, with critical information and functions prominently displayed to reduce cognitive load. Real-time feedback functions, such as operation prompts, error warnings, and progress displays, help students promptly understand their performance and address issues. Additionally, the platform supports personalized settings, such as customizable themes and operation preferences, enhancing user comfort and satisfaction.

4.4 Implementation and Application of the Track Construction Training Platform

The implementation of the track construction training platform involves system development and integration. This includes selecting appropriate development platforms and tools, designing the system architecture, coding, and integrating various functional modules into a unified system. During development, emphasis is placed on system

stability, scalability, and compatibility to ensure long-term stable operation and adaptability to future technological updates and functional expansions.

Platform testing and optimization are critical to ensuring system quality. Testing encompasses functional testing, performance testing, compatibility testing, and user experience testing. Through rigorous testing, bugs are identified and fixed, system performance is optimized, and user experience is enhanced. During testing, feedback from students and teachers is collected to further improve the system.

Case analysis and effect evaluation are essential for verifying the platform's effectiveness. By applying the platform in real teaching scenarios, collecting student learning data and feedback, and comparing outcomes between users and non-users, the platform's impact on teaching effectiveness can be assessed. Controlled experiments can be designed to evaluate differences in knowledge acquisition and skill improvement. Additionally, surveys and interviews can gather insights into teacher and student satisfaction and suggestions for improvement.

5 THE IMPACT OF INFORMATION TECHNOLOGY ON TRACK CONSTRUCTION PRACTICAL TRAINING TEACHING

The impact of information technology on track construction practical training teaching is primarily reflected in three key areas: reform of teaching models, innovation in teaching methods, and innovation in assessment approaches.

In terms of teaching model reform, information technology liberates practical training from the constraints of physical space and time. Students can engage in virtual practical training anytime and anywhere, significantly enhancing learning flexibility and efficiency. Virtual practical training platforms can simulate a wide range of construction scenarios and conditions, offering students richer and more diverse learning experiences. This not only broadens the scope of practical training but also allows for repeated practice under different conditions, thereby improving students' adaptability and problem-solving skills.

Regarding teaching method innovation, information technology supports personalized and collaborative learning. The platform tailors learning content and difficulty levels based on individual student progress and abilities, promoting personalized learning paths. Additionally, it facilitates collaborative practical training for multiple participants, enabling students to divide tasks and work together in a virtual environment to complete complex construction projects. This collaborative learning model not only improves learning efficiency but also fosters students' teamwork and communication skills, which are essential in real-world construction environments.

Concerning assessment method innovation, information technology enables more objective, comprehensive, and timely evaluations. The platform automatically records students' operational processes and outcomes, generating detailed assessment reports. This data-driven evaluation approach enhances the objectivity of assessments and allows for the timely identification of learning issues, providing teachers with targeted guidance. Moreover, the platform supports formative assessment through real-time feedback and continuous progress tracking, helping students adjust their learning strategies promptly and improve overall learning outcomes. The integration of quantitative and qualitative assessment methods ensures a holistic evaluation of students' performance.

6 CONCLUSION

This study effectively addresses numerous challenges in traditional practical training by developing an information technology-based track construction practical training platform. Utilizing BIM technology, oblique photography technology, and human-computer interaction technology, the platform creates a highly realistic virtual training environment. It provides students with abundant practical opportunities and immersive learning experiences. Research findings indicate that this platform significantly enhances student engagement and learning outcomes while reducing the costs associated with practical training and enabling quantitative evaluation of training effectiveness. The platform's ability to integrate various advanced technologies demonstrates its potential for broader application in engineering education and professional development.

COMPETING INTERESTS

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THE INTEGRATION PATH OF IDEOLOGICAL AND POLITICAL EDUCATION IN UNIVERSITY STUDENT MANAGEMENT—TAKING THE SCHOOL OF BUSINESS AT JIANGXI UNIVERSITY OF APPLIED SCIENCE AND TECHNOLOGY AS AN EXAMPLE

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Abstract: This research examines the integration pathways of ideological and political education into student management practices at the School of Business, Jiangxi University of Applied Science and Technology. Using a mixed-methods approach combining quantitative surveys and qualitative interviews, the study explores the theoretical foundations, current status, challenges, and implementation strategies for effective integration. The findings reveal that while formal organizational structures for integration exist, they often function as parallel systems rather than truly integrated mechanisms. The research proposes a multi-dimensional integration framework encompassing curricular, co-curricular, digital, administrative, and cultural domains. Implementation case studies demonstrate that successful integration depends on authentic alignment between management practices and educational values, participatory approaches that engage students as active contributors, and developmental continuity across multiple educational contexts. The study contributes to both theoretical understanding of educational integration processes and practical guidance for institutions seeking to enhance the effectiveness of ideological and political education within student management systems.
Keywords: Ideological and political education; Student management; Integration pathways; Higher education; Business education; Organizational integration

1 INTRODUCTION

The integration of ideological and political education into university student management represents a critical frontier in China's higher education landscape—a complex, multi-dimensional challenge that simultaneously engages pedagogical theory, administrative practice, and national developmental objectives. Within the rapidly evolving socioeconomic milieu of contemporary China, universities have progressively transitioned beyond their traditional role as mere knowledge-transmission institutions to become comprehensive talent cultivation ecosystems where ideological guidance and character formation constitute indispensable components[1]. This paradigm shift manifests most prominently in the reconceptualization of student management from a predominantly administrative function to an integrated educational mechanism with profound ideological implications.

Recent research has examined various dimensions of integrating ideological and political education with student management in higher education institutions. Ge et al. emphasized the importance of big data in reforming student management and ideological education, advocating for comprehensive data platforms and "smart campus" environments to achieve synergistic development between these domains[15]. Li investigated this integration in art universities, noting that students' distinctive characteristics—including delicate emotions, strong self-focus, and preference for practical over theoretical learning—necessitate specialized approaches to integration that respect student individuality.

Ren analyzed the intrinsic relationship between these educational components, identifying them as mutually reinforcing systems with differing but complementary goals. His research revealed challenges in coordination stemming from differences in learning situations, integration goals, and limited integration paths. Li and Shu developed a quantitative coupled coordination model to evaluate integration effectiveness across Chinese universities, finding significant regional variations with eastern institutions demonstrating coordination degrees of approximately 0.65, while central regions showed annual growth rates of 0.43% in coordination levels over twenty years. These studies indicate that effective integration requires technological innovation, coordinated educational frameworks, and evaluation mechanisms that overcome traditional divisions between administrative management and ideological education.

The concept of "integration" in this context transcends simplistic notions of organizational amalgamation or procedural consolidation. Rather, it embodies a sophisticated philosophical reorientation that fundamentally redefines the relationship between ideological education and administrative management—two domains traditionally conceptualized as distinct yet parallel tracks within the university system. Yang articulates this transformation through the lens of big data applications[2], highlighting how technological innovations have catalyzed new pathways for embedding ideological education within routine student management protocols. The emergence of comprehensive student databases and information management systems has enabled a previously unattainable granularity in understanding student

development trajectories, thereby facilitating more targeted and personalized ideological guidance.

This research positions itself at the intersection of several theoretical traditions. First, it draws upon the principle of holistic education, which emphasizes the cultivation of students as complete individuals rather than merely academic performers. Second, it engages with the concept of educational synergy, which stresses the importance of coordinating various educational elements to generate maximum efficacy[3]. Third, it incorporates elements of value-oriented management theory, which posits that effective administrative systems must be undergirded by coherent value frameworks.

The imperative for integrating ideological political education into student management frameworks has intensified in recent years due to multiple converging factors. Wang and Li identifies several challenges confronting contemporary universities[4], including increasingly diversified student populations, complex ideological landscapes, and heightened expectations regarding the quality of graduate citizenship. Furthermore, Cui emphasizes that the dual nature of education and management in university talent cultivation necessitates their organic integration to achieve optimal educational outcomes[5]. The complementary relationship between ideological political education and student management work manifests in their shared objectives, mutually reinforcing functions, and aligned developmental directions.

When examining the current landscape of ideological education integration in university student management, several problematic patterns emerge. Wang highlights the prevalence of outdated student management philosophies[1], excessively coercive educational approaches, and insufficient communication between ideological education instructors and management personnel. These challenges are compounded by what Lei characterizes as inadequate ideological education implementation[6], students' lack of proper value orientations, insufficient connection between student management and ideological education, and overly simplistic ideological education approaches. These observations underscore the necessity of developing more sophisticated integration frameworks that can transcend these limitations.

The theoretical significance of this research extends beyond immediate practical applications. By conceptualizing the integration of ideological education and student management as a dialectical process rather than a mechanical combination, this study contributes to broader academic discourses concerning the relationship between administrative systems and educational outcomes in higher education institutions. Additionally, it engages with emerging theoretical frameworks concerning the role of universities in cultivating citizens equipped not only with professional expertise but also with moral discernment and social responsibility.

Jiangxi University of Applied Science and Technology's School of Business represents an ideal case study for examining these integration dynamics. As an institution focused on applied disciplines with clear professional orientations, the School presents unique challenges and opportunities for ideological education integration. The business disciplines, with their inherent focus on market mechanisms and profit maximization, necessitate particularly thoughtful approaches to ideological education that can contextualize professional knowledge within broader ethical and societal frameworks. This research thus explores how the School has navigated these complexities while developing integration pathways appropriate to its institutional context and student characteristics.

The specific research questions guiding this investigation include: (1) What are the theoretical foundations and practical necessities underpinning the integration of ideological political education into student management at business schools in applied science universities? (2) What are the existing integration approaches employed at Jiangxi University of Applied Science and Technology's School of Business, and what challenges do they face? (3) What innovative integration pathways can be developed to enhance the effectiveness of ideological education within student management frameworks? (4) How can the effectiveness of these integration approaches be evaluated and continuously improved?

To address these questions, this research adopts a comprehensive theoretical framework that synthesizes insights from educational philosophy, management science, and ideological studies. This framework conceptualizes integration not as a static endpoint but as a dynamic process characterized by continuous adaptation and refinement. It recognizes multiple dimensions of integration—ranging from organizational structures to cultural environments—while emphasizing the central importance of student agency and participation. Through this theoretical lens, the subsequent sections will analyze existing integration practices, identify challenges and opportunities, and develop recommendations for enhancing integration efficacy.

2 RESEARCH METHODOLOGY

This investigation employs a methodologically robust, multi-layered research design to comprehensively examine the integration of ideological political education in student management at Jiangxi University of Applied Science and Technology's School of Business. The research paradigm is fundamentally interpretive, acknowledging the socially constructed nature of educational practices while simultaneously recognizing the importance of empirical verification. This epistemological orientation allows for a nuanced understanding of integration processes that transcends purely positivistic or constructivist approaches—a critical consideration given the complex, value-laden nature of ideological education integration.

The study adopts a sequential explanatory mixed-methods design, combining quantitative and qualitative approaches to leverage the complementary strengths of each methodology. This triangulation strategy enhances the validity and comprehensiveness of the findings while mitigating the inherent limitations of any single methodological approach[7]. The quantitative phase provides a macro-level perspective on integration patterns and correlations, while the qualitative

phase offers micro-level insights into the lived experiences and subjective interpretations of stakeholders engaged in the integration process.

The quantitative component includes structured surveys administered to students (n=328) and administrative staff (n=47) at the School of Business. These surveys employ Likert-scale items to measure perceptions regarding the effectiveness of current integration approaches, barriers to integration, and preferred future directions. Drawing from Yang's conceptual framework of precision education[8], the survey instruments are specifically designed to evaluate the four dimensions of precision assessment, precision supply, precision identification, and precision management in the integration of ideological education into student management practices.

Building upon Wei et al.'s methodological framework, which analyzed 1,588 survey responses concerning ideological education effectiveness in the intelligent media era[7], our survey instruments incorporate validated measurement scales for political trust, political cognition, and media literacy among university students. This approach allows for comparative analysis of our findings against broader national trends while contextualizing them within the specific environment of business education at Jiangxi University of Applied Science and Technology.

The qualitative dimension encompasses four complementary data collection methods: (1) Semi-structured interviews conducted with key stakeholders including departmental leaders (n=5), ideological education instructors (n=8), student affairs administrators (n=6), and student representatives (n=12); (2) Focus group discussions bringing together diverse stakeholders to discuss integration challenges and collaboratively develop potential solutions; (3) Document analysis involving systematic examination of policy documents, administrative regulations, curriculum materials, and student management records; and (4) Participant observation through direct observation of integrated management-education activities.

Participant selection employs a stratified purposeful sampling strategy to ensure adequate representation across academic years, majors, and demographic characteristics. For student participants, stratification variables include academic year, program specialization, academic performance, and involvement in student organizations. For faculty and administrative participants, stratification considers years of experience, administrative role, and involvement in ideological education initiatives.

This sampling approach aligns with Cold's emphasis on the importance of collaborative interaction mechanisms between student management and ideological education[9], ensuring that perspectives from both domains are adequately represented in the data. Additionally, following Wang's framework on organizational infectivity in university student ideological education[10], sampling procedures deliberately include student organization leaders who serve as key conduits for the transmission of ideological content through peer networks.

Quantitative data analysis employs descriptive statistics to identify central tendencies and distributions of responses, followed by inferential statistical procedures including correlation analysis, multiple regression, and structural equation modeling to examine relationships between variables. Qualitative data undergoes thematic analysis using a hybrid approach combining inductive coding and theoretical frameworks derived from the literature.

Multiple validation strategies enhance the trustworthiness of findings, including methodological triangulation, member checking, peer debriefing, and reflexivity protocols. Reliability in quantitative instruments is established through pilot testing, Cronbach's alpha coefficient calculation, and test-retest procedures. Ethical considerations receive rigorous attention throughout the research process, with informed consent obtained from all participants after providing comprehensive information about research objectives and procedures.

This methodology acknowledges several limitations that contextualize its findings. First, the case study approach focusing on a single institution limits generalizability to other institutional contexts with different characteristics. Second, the cross-sectional design captures integration dynamics at a particular moment rather than tracking longitudinal developments. Third, despite triangulation efforts, subjective biases may influence both participant responses and researcher interpretations, particularly given the normatively charged nature of ideological education.

3 CURRENT STATUS AND CHALLENGE ANALYSIS

The current status of ideological and political education integration in student management at Jiangxi University of Applied Science and Technology's School of Business reveals a complex landscape characterized by notable achievements alongside persistent challenges. An examination of existing management practices indicates a gradual evolution from traditional administrative approaches toward more education-oriented frameworks, though this transformation remains incomplete[16]. The School has established formal organizational structures for integrating ideological education into student management, including a coordinated team comprising administrative staff, counselors, and ideological education instructors. However, these organizational arrangements often function as parallel systems rather than truly integrated mechanisms, limiting their educational efficacy.

Student management within the School currently operates through multiple channels including academic departments, student affairs offices, and counselor systems. These channels implement various management protocols ranging from academic performance tracking to behavioral regulation and psychological support. While these systems effectively maintain organizational order, they frequently emphasize administrative control over educational guidance—a tendency that Wang identifies as characteristic of contemporary university management approaches[1]. This administrative orientation manifests in rigid bureaucratic procedures, standardized behavioral expectations, and compliance-focused evaluation metrics that prioritize measurable outcomes over transformative educational experiences. As Yang observes[2], technological innovations have enhanced management efficiency through comprehensive student data

systems, yet these systems are typically employed for monitoring rather than developmental purposes.

Ideological education initiatives within the School's management framework present an equally varied landscape. Formal ideological curricula coexist with extracurricular activities, organizational practices, and cultural programs intended to foster socialist core values and professional ethics. However, the relationship between these ideological components and managerial functions often remains tenuous. Zhang notes that ideological education frequently operates as a supplementary rather than integral element of student management[3], confined to specialized courses or ceremonial events rather than permeating daily administrative interactions. This compartmentalization diminishes the holistic impact of ideological education and reinforces perceptions of management and education as distinct domains.

Stakeholder perspectives reveal significant variations in how integration efforts are experienced and evaluated. Administrative personnel generally express commitment to integration principles while emphasizing operational challenges including resource constraints, evaluation complexities, and coordination difficulties. Faculty members acknowledge integration's importance but often perceive ideological education as peripheral to their disciplinary responsibilities, particularly in commercially oriented programs. Most critically, student perceptions demonstrate a disconnect between formal integration rhetoric and lived experiences. Survey data indicates that while 73% of students recognize the importance of ideological education, only 38% perceive current management practices as effectively incorporating ideological elements. This perception gap represents a fundamental challenge to integration efficacy.

Comparative assessment with benchmark institutions highlights both strengths and limitations in the School's integration approaches[17]. Similar business programs at other applied science universities have developed innovative integration mechanisms including experiential learning programs that connect professional ethics with practical management scenarios, digital platforms that integrate ideological content into routine administrative communications, and collaborative governance structures that engage students as active participants in developing integration strategies. While the School has implemented elements of these approaches, their implementation remains less systematic and comprehensive than leading institutions in the sector.

Analysis of the School's current integration practices reveals several structural and functional barriers that impede more effective integration. First, administrative siloing creates operational boundaries between student affairs departments, academic units, and ideological education resources, resulting in fragmented rather than unified educational experiences. Wang identifies this organizational fragmentation as a significant obstacle to integration, recommending dialogue-based management approaches that transcend departmental boundaries[4]. Second, professional orientation within business disciplines often prioritizes technical competencies and market relevance over ideological development, creating implicit resistance to integration initiatives that appear disconnected from vocational preparation. This tension is particularly pronounced in professionally focused institutions like Jiangxi University of Applied Science and Technology.

Third, methodological limitations constrain integration effectiveness. Current approaches frequently rely on didactic rather than experiential methods, standardized rather than personalized content, and passive rather than participatory engagement strategies. These methodological choices undermine the transformative potential of ideological education within management contexts by failing to connect abstract principles with students' lived experiences and professional aspirations. As Wang demonstrates[10], organizational infectivity in ideological education depends critically on experiential engagement that generates authentic emotional and intellectual responses rather than mere cognitive recognition—a dimension often lacking in current integration efforts.

Fourth, technological application remains underdeveloped despite significant potential. While the School has implemented basic informational systems, it has not fully leveraged advanced data analytics, immersive technologies, or interactive platforms to enhance integration processes. Yang emphasizes how big data applications could transform student management by enabling sophisticated pattern recognition[2], personalized intervention strategies, and evidence-based program development—capabilities the School has yet to fully realize. Similarly, Wei highlights how intelligent media technologies could significantly enhance ideological education integration by connecting with students through familiar digital environments and communication formats[7].

Perhaps most fundamentally, conceptual ambiguity surrounds the integration process itself. Different stakeholders interpret "integration" through varied frameworks—as organizational consolidation, procedural coordination, philosophical alignment, or methodological convergence. This conceptual diversity, while potentially enriching, often produces inconsistent implementation and evaluation approaches that undermine systematic development. Cui emphasizes the need for coherent theoretical frameworks that clarify the philosophical foundations of integration while providing practical guidance for implementation—a foundation not yet fully established within the School[5].

Despite these challenges, significant opportunities exist for enhancing integration effectiveness. The School's applied focus creates natural connections between professional ethics and ideological principles that could facilitate more organic integration. Its relatively autonomous administrative structure allows for innovative governance approaches that could transcend traditional bureaucratic limitations. Most importantly, its student population demonstrates receptivity to more sophisticated integration models that connect ideological development with professional aspirations and personal growth trajectories. Building on these foundations while addressing identified limitations could substantially advance integration effectiveness, thereby enhancing both student management efficacy and ideological education impact.

This analysis of current status and challenges establishes a critical foundation for developing more effective integration pathways. By identifying specific limitations in existing approaches while recognizing institutional strengths and opportunities, it enables the development of contextually appropriate solutions that address fundamental rather than superficial integration barriers. The subsequent section builds upon this diagnostic assessment to propose a

comprehensive integration framework specifically tailored to the School's institutional characteristics and educational mission.

4 INTEGRATION PATH FRAMEWORK

The integration of ideological and political education into student management at Jiangxi University of Applied Science and Technology's School of Business requires a comprehensive, multi-dimensional framework that transcends conventional approaches. This section proposes a systematic integration model grounded in both theoretical principles and empirical findings from the School's specific context. The framework conceptualizes integration not as a mechanical amalgamation of distinct functions but as a transformative process that fundamentally reconstitutes both ideological education and student management through their mutual interaction. This conceptualization aligns with Wang's dialogical theory[4], which emphasizes relational engagement rather than bureaucratic consolidation as the foundation for meaningful integration.

Curriculum integration represents a primary pathway for embedding ideological education within student management structures. This dimension involves systematically incorporating ideological elements into business curricula while simultaneously infusing educational principles into management protocols. At the content level, this requires identifying natural connections between business disciplines and ideological principles—connections that avoid artificial imposition while revealing genuine relationships between professional knowledge and value systems. For example, marketing courses can examine ethical dimensions of consumer influence, finance modules can explore social responsibility in investment decisions, and management theory can address leadership values alongside technical frameworks. As Zhang observes[3], such integration approaches transcend simplistic ideological appendages by revealing how value considerations inherently permeate professional practice.

Beyond content integration, pedagogical approaches play a crucial role in cultivating value orientation through educational methodologies. Case-based learning offers particularly promising opportunities for connecting management principles with ideological development. By analyzing complex business scenarios that engage ethical dilemmas, social impacts, and professional responsibilities, students develop integrated competencies that simultaneously address technical proficiency and value discernment. Similarly, problem-based methodologies that situate learning within authentic contexts help students recognize how ideological principles inform practical decision-making in professional environments[18]. These approaches transform abstract ideological concepts into concrete frameworks for navigating real-world challenges—a transformation essential for meaningful integration.

Co-curricular and experiential learning pathways constitute a second major integration dimension. Student organizations represent critical vehicles for connecting management structures with ideological development through participatory governance models. By reconceptualizing student organizations as laboratories for democratic participation and collective responsibility, the School can develop microcosms where students simultaneously practice management skills and embody ideological principles. This approach aligns with Wang's organizational infectivity framework[10], which emphasizes how organizational contexts shape individual value orientation through experiential engagement. Student organizations structured around purposeful missions, collaborative decision-making, and social contribution create environments where management processes naturally incorporate ideological dimensions without artificial separation.

Community engagement initiatives further enhance integration through experiential learning. Service-learning programs that connect business competencies with community needs enable students to apply professional skills in contexts that highlight social responsibility and civic contribution. Similarly, social enterprise projects allow students to explore market mechanisms as vehicles for addressing social challenges rather than merely maximizing profits. These experiences fundamentally reorient management practices toward integrative purposes that naturally incorporate ideological dimensions. As Cui notes[5], such approaches transcend the false dichotomy between management efficiency and ideological development by demonstrating their potential synthesis through purposeful action.

Digital transformation strategies constitute a third critical integration pathway. Technology-enhanced ideological education leverages digital platforms to embed ideological content within routine management communications and information systems. Learning management systems can integrate ideological reflection prompts alongside academic content, while student information systems can incorporate developmental metrics beyond conventional performance measures. Mobile applications can deliver personalized ideological content based on individual student profiles and developmental trajectories, while interactive platforms can facilitate ongoing dialogue between students and educational mentors. These technological approaches transform management systems from administrative mechanisms into educational environments that continuously engage students' ideological development.

Data-driven student development tracking represents a particularly promising digital integration strategy. By establishing sophisticated analytics systems that monitor comprehensive developmental indicators—including academic performance, professional skill acquisition, ethical reasoning capacity, and social engagement—the School can implement precision management approaches that simultaneously address administrative requirements and educational objectives. This approach builds upon Yang's conceptualization of big data applications in student management[2], extending conventional monitoring functions to incorporate holistic developmental tracking. Similarly, it implements Yang's precision education framework by enabling individualized support strategies based on comprehensive student profiles rather than standardized interventions[8].

Administrative and policy integration constitutes the fourth major dimension of the proposed framework.

Organizational structure adjustments are necessary to overcome the departmental fragmentation that currently impedes integration efforts. The establishment of integration coordination teams that bring together academic administrators, student affairs personnel, ideological education specialists, and student representatives can create collaborative governance mechanisms that transcend conventional bureaucratic boundaries. Similarly, integrated planning processes that simultaneously address managerial efficiency and educational impact can overcome the artificial separation between administrative and educational functions that characterizes current approaches.

Performance evaluation systems require particular attention within administrative integration efforts. Conventional evaluation metrics often privilege easily quantified administrative outcomes over complex educational impacts, inadvertently undermining integration initiatives. Developing multidimensional evaluation frameworks that incorporate both management efficiency indicators and ideological development metrics can realign institutional incentives toward genuine integration. Similarly, recognition systems that explicitly reward integration innovations can stimulate creative approaches among both administrative staff and faculty members. These evaluative mechanisms transform integration from aspirational rhetoric into operational reality by establishing accountability structures that prioritize integrative practices.

Cultural integration represents a fifth dimension that permeates all previously discussed pathways. Campus culture building initiatives establish symbolic environments that naturally connect management structures with ideological principles through shared meanings, rituals, and narratives. As Wang emphasizes[4], cultural elements create coherent meaning systems that contextualize both management practices and educational experiences within broader interpretive frameworks. By deliberately cultivating cultural patterns that celebrate both professional excellence and ideological commitment, the School can establish normative environments where these dimensions mutually reinforce rather than contradict each other.

The implementation of this multi-dimensional integration framework requires systematic planning, resource allocation, and organizational development. Phased implementation approaches that progressively introduce integration elements while continuously evaluating their effectiveness can prevent overwhelming institutional systems or generating resistance. Similarly, capacity-building initiatives that develop faculty and staff competencies for implementing integration strategies are essential for translating conceptual frameworks into operational realities. Most importantly, ongoing assessment mechanisms that monitor integration impacts while identifying emerging challenges or opportunities enable continuous refinement of integration approaches in response to evolving conditions.

This comprehensive integration framework establishes a systematic foundation for transforming student management and ideological education from parallel tracks into a unified developmental system at Jiangxi University of Applied Science and Technology's School of Business. By simultaneously addressing curricular, co-curricular, digital, administrative, and cultural dimensions, it creates multiple reinforcing pathways that collectively produce comprehensive integration. The subsequent section examines specific implementation cases that demonstrate how these theoretical frameworks can be operationalized in concrete institutional contexts.

5 IMPLEMENTATION CASE STUDIES AND EVALUATION

The practical implementation of integration pathways at Jiangxi University of Applied Science and Technology's School of Business has yielded diverse experiences that illuminate both the potential and challenges of ideological-management integration. This section analyzes representative case studies that demonstrate how theoretical frameworks translate into operational practices while evaluating their effectiveness through both quantitative metrics and qualitative assessments. These implementation experiences provide critical insights for refining integration approaches and developing more sophisticated models tailored to the School's specific context.

The "Ethical Enterprise Initiative" represents a comprehensive curriculum integration case that systematically embedded ideological elements within the School's core business courses. This initiative reorganized traditional business ethics content from isolated modules into integrated components distributed throughout the curriculum, connecting ethical principles with specific professional practices in marketing, finance, management, and accounting. Faculty received specialized training in integrative teaching methods while participating in collaborative curriculum development workshops that identified natural connections between disciplinary content and ideological principles. The initiative also established cross-course projects requiring students to analyze business cases through multiple ethical frameworks while developing solutions that balanced commercial viability with social responsibility.

Evaluation of this initiative revealed significant improvements in students' ability to integrate ethical considerations into business analysis. Pre-post assessments demonstrated a 27% increase in students' capacity to identify ethical dimensions in complex business scenarios and a 32% improvement in their ability to develop ethically informed business strategies. Qualitative feedback further indicated that students perceived ethical considerations as increasingly relevant to professional practice rather than extraneous impositions. As one senior student noted, "I used to see ethics as something separate from 'real business,' but now I understand how ethical thinking actually improves business decision-making." This integration case demonstrates how Wang's call for moving beyond forced ideological appendages toward organic integration can be operationalized through systematic curriculum development[1].

The "Student Enterprise Leadership Program" exemplifies the co-curricular integration pathway through transformed student organization structures. This program reconceptualized traditional student associations into professional development laboratories where management practices directly incorporated ideological principles. Student organizations received enhanced autonomy in budget management, activity planning, and performance evaluation while

simultaneously accepting increased responsibility for demonstrating social impact and ethical leadership. Specialized training programs developed student leaders' capacity to implement participatory governance models that balanced efficiency with inclusive decision-making. Faculty mentors advised organizations regarding both operational effectiveness and value alignment, helping student leaders recognize connections between management techniques and ideological principles.

Assessment of this program demonstrated multidimensional impacts on student development. Participating students showed statistically significant improvements in leadership skills, ethical reasoning, and organizational management compared to non-participating peers. Organizational outputs similarly reflected integrated approaches, with student-led initiatives increasingly addressing both professional development and social contribution objectives. This implementation case exemplifies Wang's organizational infectivity principles by creating environments where value transmission occurs through experiential participation rather than abstract instruction[10].

The "Digital Development Portfolio" initiative represents a technological integration case that employed digital platforms to connect management systems with ideological development tracking. This comprehensive platform integrated academic records, co-curricular participation, professional skill development, and ideological growth indicators within a unified interface accessible to students, administrators, and faculty mentors. Students maintained reflective journals documenting their development across multiple dimensions while receiving personalized guidance based on their individual profiles. Automated analysis identified development patterns and suggested targeted interventions for addressing specific needs or leveraging particular strengths. Faculty advisors used the platform to monitor comprehensive student development rather than merely academic performance, enabling more holistic guidance conversations.

Evaluation revealed that this digital integration significantly enhanced both management efficiency and educational effectiveness. Administrative processes became more streamlined through consolidated information systems, while educational interventions demonstrated increased precision through data-informed targeting. Student engagement metrics showed substantial improvement, with portfolio completion rates exceeding 85% compared to 47% for previous paper-based systems. Qualitative assessment indicated that students perceived the system as supporting their holistic development rather than merely monitoring compliance. This case demonstrates Yang's vision for leveraging big data applications in student development while implementing Wei's recommendations regarding technology-enhanced ideological education in contemporary media environments[2,7].

The "Collaborative Governance Reform" initiative exemplifies administrative integration through restructured management systems. This reform established cross-functional teams bringing together academic administrators, student affairs personnel, ideological education specialists, and student representatives to develop integrated policies and programs. Decision-making processes explicitly incorporated both operational efficiency criteria and ideological development objectives, requiring proposed initiatives to demonstrate contributions to both dimensions. Performance evaluation systems were similarly revised to include metrics addressing both administrative effectiveness and educational impact, creating accountability structures that reinforced integration priorities.

Assessment of this administrative reform demonstrated significant improvements in both organizational coordination and educational coherence. Cross-departmental collaboration increased by 43% based on joint initiative metrics, while policy implementation effectiveness improved through more consistent application across organizational units. Most importantly, student perceptions of administrative coherence showed substantial improvement, with 67% of surveyed students reporting that management practices consistently reflected educational values compared to 41% before the reform. This case operationalizes Wang's dialogical management principles by creating organizational structures that facilitate authentic communication across traditional bureaucratic boundaries[4].

The "Professional Ethics in Practice" program represents an experiential learning implementation case that connected classroom knowledge with community engagement. This program established partnerships with local businesses, non-profit organizations, and government agencies to create applied learning opportunities addressing real-world challenges. Students applied business expertise to community needs while reflecting on the social implications of commercial practices. Faculty mentors guided students in connecting theoretical principles with practical realities, helping them recognize how ideological values inform professional judgments in complex situations. Reflection protocols structured students' meaning-making processes, ensuring that experiential learning generated not only practical skills but also deeper understanding of professional ethics.

Evaluation demonstrated powerful impacts on students' professional identity development and ethical reasoning. Pre-post assessments showed significant improvements in students' capacity to identify ethical dimensions of business decisions and develop solutions that balanced multiple stakeholder interests. Community partners similarly reported that student contributions demonstrated both technical competence and social responsibility. A particularly notable finding was that participating students showed greater commitment to socially responsible business practices in subsequent career decisions, suggesting lasting impacts on professional orientation. This implementation case exemplifies Zhang's emphasis on embedding ideological education within authentic learning contexts rather than isolated instructional units[3].

Comparative analysis of these implementation cases reveals several critical success factors that transcend specific integration pathways. First, authentic alignment between management practices and educational values proved essential for meaningful integration. When administrative systems genuinely embodied the principles they professed to promote, students perceived integration as coherent rather than contradictory. Second, participatory approaches that engaged students as active contributors rather than passive recipients significantly enhanced integration effectiveness. Student

involvement in designing and implementing integration initiatives not only improved their relevance but also increased student buy-in through meaningful ownership. Third, developmental continuity across multiple educational contexts reinforced integration impacts through consistent messaging and experiences. When students encountered similar principles across curricular, co-curricular, and administrative domains, integration became a lived reality rather than an isolated intervention.

Implementation challenges similarly emerged across multiple case studies. Resource limitations constrained integration scope and sustainability, particularly for initiatives requiring significant technology investment or faculty development. Resistance from stakeholders comfortable with traditional separation between management and education created implementation barriers requiring sustained change management efforts. Most fundamentally, assessment complexities made it difficult to comprehensively evaluate integration impacts, particularly regarding long-term ideological development outcomes that extend beyond immediate measurement timeframes.

These implementation experiences provide a foundation for developing more sophisticated integration approaches tailored to the School's specific context. By identifying both effective practices and persistent challenges across multiple integration domains, they enable evidence-based refinement of integration strategies. The final section builds upon these implementation insights to develop comprehensive recommendations for enhancing integration effectiveness at institutional, programmatic, and individual levels.

6 CONCLUSION AND IMPLICATIONS

The integration of ideological and political education into student management represents a fundamental reconceptualization of educational practice that transcends traditional boundaries between administrative functions and formative development. This research has examined this integration process within the specific context of Jiangxi University of Applied Science and Technology's School of Business, identifying both theoretical foundations and practical pathways for enhancing integration effectiveness. The findings reveal a complex landscape characterized by significant progress alongside persistent challenges, suggesting both immediate implementation opportunities and longer-term development trajectories for advancing integration efforts.

The theoretical contributions of this research extend beyond the specific institutional context to address broader questions concerning the relationship between management systems and educational purposes in higher education. By conceptualizing integration as a multidimensional transformation rather than a superficial combination, this study challenges conventional dichotomies that artificially separate administrative efficiency from educational effectiveness. Instead, it demonstrates how management structures can themselves function as educational environments when purposefully designed to embody and reinforce core educational values. This reconceptualization aligns with Wang's emphasis on holistic education while extending it into concrete organizational applications that bridge theoretical principles and operational practices[1].

The multi-dimensional integration framework developed through this research provides a comprehensive model for understanding integration processes across curricular, co-curricular, technological, administrative, and cultural domains. This framework transcends simplistic integration approaches that merely append ideological content to existing management structures without fundamentally rethinking their purpose and function. Instead, it establishes mutually reinforcing pathways that collectively transform both ideological education and student management through their reciprocal interaction. This systematic approach addresses Zhang's call for comprehensive integration models while providing practical implementation guidance adapted to specific institutional contexts[3].

The implementation case studies examined in this research demonstrate how theoretical frameworks can be operationalized through concrete initiatives that address specific integration dimensions. These cases illuminate both the possibilities and challenges of integration efforts, providing evidence-based insights for refining integration approaches. Particularly significant is the finding that integration effectiveness depends not merely on formal structures but on the authentic alignment between proclaimed values and lived experiences. When management practices genuinely embody the principles they profess to promote, students perceive integration as coherent rather than contradictory—a finding that underscores the importance of implementation integrity in achieving meaningful integration.

Several practical implications emerge from this research for higher education institutions seeking to enhance ideological-management integration. First, integration requires systematic planning rather than incremental adjustments, necessitating comprehensive assessment of existing practices, identification of integration opportunities, and development of coordinated implementation strategies across multiple domains. Second, capacity building represents a critical foundation for effective integration, requiring targeted professional development for both administrative personnel and educational specialists to develop the complex competencies necessary for implementing integrated approaches. Third, organizational restructuring may be necessary to overcome departmental fragmentation that impedes integration efforts, suggesting the importance of governance reforms that facilitate collaborative engagement across traditional bureaucratic boundaries.

For Jiangxi University of Applied Science and Technology's School of Business specifically, several priority recommendations emerge from this research. The establishment of an Integration Coordination Office would provide dedicated organizational capacity for developing, implementing, and evaluating integration initiatives across multiple domains. A comprehensive faculty development program focused on integrative teaching methods would enhance instructional capacity for connecting disciplinary content with ideological principles through authentic learning experiences. Technology infrastructure investments would enable more sophisticated digital integration through

advanced analytics capabilities and personalized development platforms. Most fundamentally, a cultural transformation initiative would address underlying assumptions and values that shape organizational behaviors, ensuring that integration extends beyond formal structures to permeate lived institutional experiences.

Policy implications extend beyond individual institutions to address systemic factors influencing integration processes. National educational frameworks should explicitly recognize and reward integration innovations through funding mechanisms, evaluation systems, and recognition programs that prioritize holistic approaches over fragmented specialization. Professional preparation programs for educational administrators should incorporate integration competencies as core requirements rather than peripheral considerations, ensuring that future leaders possess the necessary capabilities for implementing sophisticated integration models. Research funding should similarly prioritize integration-focused investigations that bridge traditional boundaries between management science and educational philosophy, supporting the continued development of evidence-based integration approaches.

Several limitations contextualize the findings and implications of this research. The case study approach focusing on a single institution limits generalizability to other contexts with different characteristics and constraints. The predominantly cross-sectional methodology captures integration dynamics at a specific moment rather than tracking developmental trajectories over extended timeframes. The research's primary focus on formal organizational structures may underemphasize informal cultural factors that significantly influence integration experiences. These limitations suggest directions for future research, including comparative studies across multiple institutions, longitudinal investigations tracking integration development over time, and ethnographic examinations of informal integration dynamics within organizational cultures.

Future research should particularly address several critical questions emerging from this investigation. How do integration experiences differ across diverse institutional types, including research universities, liberal arts colleges, and vocational institutions? What longitudinal impacts do integration initiatives have on student development beyond immediate educational contexts, particularly regarding professional practice and civic engagement? How do informal cultural factors interact with formal integration structures to shape actual integration experiences? How can digital technologies most effectively support integration processes without substituting technological sophistication for authentic educational engagement? These questions represent promising directions for extending the current research while addressing its identified limitations.

In conclusion, the integration of ideological and political education into student management represents not merely an administrative reorganization but a fundamental reconceptualization of educational practice that transcends traditional boundaries between organizational functions and educational purposes. By establishing mutually reinforcing connections across multiple dimensions, genuine integration transforms both management systems and ideological education through their reciprocal interaction. This transformation enhances both administrative effectiveness and educational impact by aligning organizational structures with core educational values while embedding those values within concrete operational practices. For Jiangxi University of Applied Science and Technology's School of Business and similar institutions, this integration journey represents an ongoing developmental process requiring sustained commitment, continuous refinement, and systematic assessment—a process essential for fulfilling higher education's comprehensive mission of developing not only professional expertise but also ethical discernment and social responsibility among future graduates.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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SCIENCE AND TECHNOLOGY INNOVATION EFFICIENCY IN GUANGDONG, HONG KONG AND MACAO GREATER BAY AREA BASED ON STATIC AND DYNAMIC DEA

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Abstract: In the context of the integration of science, technology, and finance, this study aims to scientifically assess the efficiency of science and technology innovation in the Guangdong-Hong Kong-Macao Greater Bay Area. To this end, a system of evaluation indexes, encompassing input-output dimensions, has been constructed based on panel data from 11 cities in the Greater Bay Area from 2019 to 2024. The DEA-Malmquist index method has been utilized in the construction of this system. The regional science and technology innovation efficiency is measured with precision through static efficiency measurement and dynamic total factor productivity decomposition. The reasons for the efficiency differences are revealed from the perspective of technological progress and efficiency changes. The findings of the study demonstrate that (1) the average value of the comprehensive efficiency of science and technology innovation in the Guangdong-Hong Kong-Macao Greater Bay Area exhibits fluctuations and increases, and (2) there are discrepancies in the magnitude of the fluctuations in the efficiency of science and technology innovation and the factors influencing it across different cities. (3) Considering the issue of the Guangdong-Hong Kong-Macao Greater Bay Area's high overall innovation efficiency, coupled with significant internal disparities, there is a compelling need to optimize resource allocation in a targeted manner.
Keywords: Guangdong-Hong Kong-Macao Greater Bay Area; DEA-Malmquist Index; Technology Innovation; Efficiency evaluation

1 INTRODUCTION

China's investment in technological innovation has been steadily rising in recent years. According to data released by the National Bureau of Statistics in 2025, the country's total research and experimental development (R&D) expenditure in 2024 reached RMB 3,613 billion, marking an 8.3% increase from the previous year. The R&D investment intensity reached 2.68%, an increase of 0.10 percentage points over the prior year, setting a new record. Evidence indicates that the contribution of high-tech and emerging industries to GDP growth has significantly increased. Nevertheless, despite the growth in the scale of innovation, it still faces deep-seated contradictions, such as inefficient resource allocation and insufficient coordination of innovation efforts. In 2019, an article titled "Building an International Science and Technology Innovation Centre with Global Influence," published by the Science and Technology Department of Guangdong Province, underscored that Guangdong, Hong Kong, and Macao have exceptional capabilities in technological research and development and the transformation of research outcomes. These regions have a solid foundation for establishing an international science and technology innovation center. The article emphasizes the need to concentrate on this strategic positioning, vigorously develop new technologies, industries, business forms, and models, and construct an economic system driven and supported by innovation. In this strategic context, enhancing the efficiency of technological innovation has become a key initiative to promote high-quality regional development. The current study employs the DEA-Malmquist index method, using panel data from 11 cities within the Guangdong-Hong Kong-Macao Greater Bay Area. This approach is used to systematically evaluate the regional technological innovation capability, conduct a comprehensive analysis of innovation efficiency levels and their core influencing factors, and provide a decision-making foundation for the optimization of the regional innovation ecosystem.

Fare et al. constructed a DEA-Malmquist model based on the theoretical framework of Data Envelopment Analysis (DEA). This model was innovative in its incorporation of the Malmquist index [1]. It systematically analyzes the dynamic evolution mechanism of production efficiency from multiple dimensions, such as technical efficiency changes and technological progress, by decomposing total factor productivity changes. This provides a scientific and effective analytical tool for exploring the intrinsic driving factors of economic growth. In their 2019 study, Chen Zhangxi and colleagues evaluated the land use efficiency of the Guangdong-Hong Kong-Macao Greater Bay Area and 11 other cities in the region. To this end, they constructed an input-output index system based on the DEA model [2].

In a 2020 study, Wen M and colleagues examined the efficiency of the marine economy of the Guangdong-Hong Kong-Macao Greater Bay Area. To this end, they employed the DEA-Malmquist model [3]. Han Xiaoteng and other scholars measured the research efficiency of eight universities within the Guangdong-Hong Kong-Macao Greater Bay Area from 2016 to 2019. The input-output perspective and the data envelopment analysis method [4] were utilized to achieve this objective. In the study by Wang Haonan, the logistics efficiency of the port system was evaluated and analyzed from 2012 to 2021 using the DEA model. The major ports in the Guangdong-Hong Kong-Macao Greater Bay

Area—Guangzhou, Shenzhen, and Hong Kong ports—were taken as examples [5]. Drawing upon the extended DEA model, scholars such as Chen Longfang have examined the degree of economic synergistic development within the Guangdong-Hong Kong-Macao Greater Bay Area. Their research has unveiled the spatial and temporal evolution characteristics of this development [6].

In summary, scholars both domestically and internationally have conducted further studies on various aspects of the Guangdong-Hong Kong-Macao Greater Bay Area using the DEA model. However, there are still shortcomings: there is a scarcity of literature on evaluating the efficiency of scientific and technological innovation in the Greater Bay Area cities of Guangdong, Hong Kong, and Macao using the DEA-Malmquist model. Consequently, based on panel data from 11 cities in the Greater Bay Area from 2019 to 2024, this paper employs the DEA-Malmquist index method to construct an evaluation index system that includes both input and output dimensions. The regional science and technology innovation efficiency is measured with precision through static efficiency measurement and dynamic total factor productivity decomposition. The reasons for the efficiency differences are explored from the perspectives of technological progress and efficiency changes.

2 MODEL CONSTRUCTION

In this paper, the CCR-DEA model and the Malmquist index are selected for the scientific analysis of the research and innovation efficiency of the cities in the Guangdong-Hong Kong-Macao Greater Bay Area. The CCR-DEA model has the capacity to accurately measure pure technical efficiency and scale efficiency, while the Malmquist index can dynamically assess changes in efficiency, thereby providing a comprehensive reflection of the dynamic evolution of regional research and innovation efficiency.

2.1 CCR-DEA Model

The CCR-DEA model (constant returns to scale) is an appropriate analytical framework for examining research and innovation efficiency in cities across the Guangdong-Hong Kong-Macao Greater Bay Area. This model enables both cross-sectional and longitudinal comparative analyses [7]. Horizontally, it allows for the assessment of the relative efficiency of R&D inputs (such as funding and personnel) and outputs (including patent grants and new product revenues) for each city in the same year, identifying areas where resource allocation can be improved. Vertically, it enables the tracking of each city's efficiency trajectory from 2019 to 2024, visually demonstrating the impact of policy implementation. Despite the significant differences in city sizes within the Greater Bay Area (for example, Shenzhen and Zhaoqing), the CCR-DEA model, based on the assumption of constant returns to scale and the creation of comprehensive efficiency indicators, can quantify the input and output efficiencies of cities in the context of scientific research and innovation as a whole. This provides a substantial database for understanding the current state of regional scientific research and innovation, thereby aiding in the development of collaborative growth strategies.

2.1.1 CCR-DEA Scale reward invariant model

In the DEA base model CCR, there are decision-making units (DMUs), denoted as DMUi $(\mathrm{i}=1,2,\ldots,\mathrm{n})$ each containing m inputs and k outputs. The input vector is defined as $X_i=(X_{i1}X_{i2},\ldots X_{im})^T$ (where $\mathrm{X_{ij}}$ denotes, the j-input) and the output vector i s$Y_i=(Y_{i1},Y_{i2},\ldots Y_{im})^T$ (where $\mathrm{Y_{ij}}$ denotes the t-input). The weight vectors of the input and output metrics are denoted as $V=(V_1,V_2,\ldots V_m)^T$ and $U=(U_1,U_2,\ldots U_m)^T$, respectively,and are considered the evaluation indicators of DMUi.

$$H_i=\frac{U^TY_i}{V^TX_i}=\frac{\sum_{s=1}^{k}U_SY_{si}}{\sum_{t=1}^{m}V_tX_{ti}},i=1,2,\ldots,n \tag{1}$$

Refer to Equation (1), whose values are determined by the weight vectors U and V and satisfy $H_i\leqq 1$. When evaluating a specific unit $\mathrm{DMU_{i0}}$, it is denoted as $\mathrm{DMU_0}$ and its input/output vectors are X_0 and Y_0 respectively. Based on this, the CCR model can be formulated as follows:

$$\begin{aligned}&MaxH_{i0}=\frac{U^TY_{i0}}{V^TX_{i0}}=\frac{\sum_{s=1}^{k}U_SY_{s0}}{\sum_{t=1}^{m}V_tX_{t0}}\\&s.t.\frac{\sum_{s=1}^{k}U_SY_{si}}{\sum_{t=1}^{m}V_tX_{ti}},i=1,2,\ldots,n\\&U\geqq 0,V\geqq 0\end{aligned} \tag{2}$$

Eq. (2) is transformed into a linear programming model as (let $\mathrm{T}=\frac{1}{\mathrm{V^TX_0}}$; $\omega=\mathrm{tv}$; $\mu=\mathrm{tu}$):

$$\begin{aligned}&Max\quad \boldsymbol{\mu}^TY_0=H_{i0}\\&s.t.\quad \omega^TX_i-\mu^TY_i\geq 0\ i=1,2,\ldots,n\\&\qquad \omega^T\boldsymbol{X}_0=1,v\geq 0\\&\qquad \omega\geq 0,\mu\geq 0\end{aligned} \tag{3}$$

Solve for and introduce the slack variable $\mathrm{S^+},\mathrm{S}\geq 0$ and then proceed with the solution.

$$Min\theta s.t.\sum_{i=1}^{n}\lambda_i X_i - S^- = \theta X_0$$
$$\sum_{i-1}^{n}\lambda_i Y_i - S^+ = Y_0 \quad (4)$$
$$i \geq 0, S^+ \geq 0, S^- \geq 0, i = 1,2,\ldots,n$$

As indicated by Eq. (4), within the CCR model, the integrated efficiency value of the decision unit DMU_i, θ_i meets $0 \leq \theta_i \leq 1$. This signifies the minimum input ratio necessary when the output remains constant. Conversely, 1−θ_i represents the input redundancy rate, with its value being directly indicated by the radial optimization model $(1-\theta_i)\cdot X_i$ This model highlights the reduction potential of the various input elements, offering a precise direction for enhancing resource allocation optimization.

2.2 Malmquist Index

The limitation of the traditional DEA model is that it can only statically assess the relative efficiency of different decision-making units (DMUs) within the same time period, and it cannot capture the dynamic change of efficiency over time. To remedy this shortcoming, Fare and other scholars pioneered the integration of the Malmquist index theory with the DEA methodology in 1994, proposing the DEA-Malmquist model [3].

Assume that (x^t, y^t) and (x^{t+1}, y^{t+1}) denote the inputs and outputs of period t and period $t+1$ respectively, where $D_c^t(x^t, y^t)$, $D_c^{t+1}(x^{t+1}, y^{t+1})$ are the output distance functions between the two periods under the constant returns to scale (CRS) assumption (subscript c denotes the CRS condition). Then the Malmquist index can be expressed by the following equation:

$$tfp = M^{t+1}(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{D_c^t(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t)} \times \frac{D_c^{t+1}(x^{t+1}, y^{t+1})}{D_c^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} \quad (5)$$

If $M^{t+1}(x^{t+1}, y^{t+1}, x^t, y^t) > 1$, it means that total factor productivity has increased from period t to period $t+1$, if $M^{t+1}(x^{t+1}, y^{t+1}, x^t, y^t) < 1$, it means that total factor productivity has decreased during this period, and when $M^{t+1}(x^{t+1}, y^{t+1}, x^t, y^t) = 1$, it means that total factor productivity has not changed significantly and is in a steady state. Further, under the assumption of constant returns to scale, the Malmquist index can be decomposed into the index of change in technical efficiency ($effch$) and the index of scientific and technological progress ($tech$), as shown in the following formula:

$$Effch = \frac{D_c^{t+1}(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t)}$$

$$Tech = \left[\frac{D_c^t(x^{t+1}, y^{t+1})}{D_c^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_c^t(x^t, y^t)}{D_c^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}}$$

Where, $tfp = \mathrm{M}^{t+1}(\mathrm{x}^{t+1}, \mathrm{y}^{t+1}, \mathrm{x}^t, \mathrm{y}^t) = Effch \times Tec\ h$.And when the returns to scale are variable, the technical efficiency change index can be further decomposed into pure technical efficiency index (*pech*) and scale efficiency index (*sech*) as expressed:

$$pech = \frac{D_v^{t+1}(x^{t+1}, y^{t+1})}{D_v^{t+1}(x^t, y^t)} \quad (6)$$

$$sech = \left[\frac{D_v^{t+1}(x^{t+1}, y'^{+1})/D_c^{t+1}(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)/D_c^t(x^t, y^t)} \times \frac{D_v^{t+1}(x^{t+1}, y^{t+1})/D_c^{t+1}(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)/D_c^(x^t, y^t)}\right]^{\frac{1}{2}} \quad (7)$$

Where $D_v^{t+1}(x^{t+1}, y^{t+1})$ denotes the output distance function based on the technical conditions of the first $t+1$ period in the case of variable returns to scale, and the subscript v denotes variable returns to scale. Then the index of technical efficiency change can be expressed as: *effch= pech* × *sech*.

Therefore, the total factor productivity, i.e., the efficiency of science, technology, and innovation, is calculated as:

$$tfp = Effch \times Tech = pech \times sech \times tech \quad (8)$$

3 SELECTION OF INDICATOR SYSTEM

The evaluation index system of science and technology innovation efficiency in the Guangdong-Hong Kong-Macao Greater Bay Area is the focus of this paper. The index is divided into two aspects: input index and output index. The number of R&D personnel and the internal expenditure of R&D funds by industrial enterprises above large scale are selected as input indicators, with reference to the research of Zhang Peng and other scholars. When analysing the efficiency of science and technology innovation in the Guangdong-Hong Kong-Macao Greater Bay Area based on the DEA-Malmquist model, the aforementioned scholars emphasised that R&D manpower and capital investment are the core dimensions for measuring the input of innovation resources [8].It is evident that financial support constitutes a pivotal propellant for the advancement of science and technology innovation [9]. Consequently, the proportion of S&T expenditures to general public budget expenditures is utilised as an input indicator, thereby reflecting the support of local governments for S&T innovation. Among the various output indicators, the number of patents applied and authorised is a significant metric for evaluating a nation's or region's technological innovation capacity and level. The sales revenue of new products by industrial enterprises above a certain scale is a key indicator of an economy's capacity

for transformation through innovation. The selection of per capita GDP aligns with the research of Chen Ying [10], who considers it a pivotal indicator for comprehensively assessing innovation-driven economic development. Collectively, these indicators form a system for evaluating research and innovation efficiency, encompassing the input of R&D resources, policy support, technological output and economic effects. Input-output indicators for scientific and technological innovation efficiency can be seen in Table 1.

Table 1 Input-Output Indicators for Scientific and Technological Innovation Efficiency

Indicator Type	Indicator	Variable	Unit	Source
Input Indicators	R&D Personnel in Above-designated-size Industrial Enterprises	X_1	Hundred persons	Zhang Peng, Li Lin xin, and Zeng Yong quan (2021)
	Intra-expenditure on R&D in Above-designated-size Industrial Enterprises	X_2	Billion yuan	
	Proportion of S&T Expenditure in General Public Budget Expenditure	X_3	%	
Output Indicators	Number of Patents Granted	Y_1	Hundred units	
	Sales Revenue from New Products in Above-designated-size Industrial Enterprises	Y_2	Billion yuan	
	GDP per Capita	Y_3	Thousand yuan/Person	Chen Ying (2025)

4 EMPIRICAL RESEARCH

3.1 Dea Static Analysis

This study adopts the years 2019-2024 as its research period and selects nine mainland cities within the Guangdong-Hong Kong-Macao Greater Bay Area, along with the Hong Kong Special Administrative Region and the Macao Special Administrative Region, as its subjects. Data for the study is sourced from the China Statistical Yearbook, the Guangdong Statistical Yearbook, the Census and Statistics Department of the Hong Kong Special Administrative Region Government, the Statistics and Census Bureau of Macao, the Wind Database, and the statistical yearbooks of various cities. The current study aims to compare and analyze the pure technical efficiency, scale efficiency, and comprehensive efficiency of Science, Technology, and Innovation (STI) in the 11 cities of the Guangdong-Hong Kong-Macao Greater Bay Area. The objective is to identify internal factors influencing the efficiency of STI and to offer corresponding recommendations. The comprehensive efficiency values are calculated using software, with the STI efficiency of the 11 cities in the Guangdong-Hong Kong-Macao Greater Bay Area presented in Table 2.

Table 2 Comprehensive Efficiency of Science and Technology Innovation in the Guangdong-Hongkong-Macao Greater Bay Area

	2019	2020	2021	2022	2023	2024
Hong Kong	1.000	1.000	1.000	1.000	1.000	1.000
Macau	1.000	1.000	1.000	1.000	1.000	1.000
Guangzhou	1.000	1.000	1.000	1.000	1.000	1.000
Shenzhen	0.869	1.000	1.000	1.000	1.000	1.000
Zhuhai	0.625	0.678	0.968	1.000	1.000	1.000
Foshan	0.680	0.771	0.967	1.000	1.000	1.000
Huizhou	0.811	0.856	0.916	0.911	0.910	0.875
Dongguan	1.000	1.000	1.000	1.000	1.000	1.000
Zhongshan	1.000	1.000	1.000	1.000	1.000	1.000
Jiangmen	0.642	0.737	0.826	0.927	0.951	1.000
Zhaoqing	0.662	0.990	1.000	0.957	0.986	1.000
Average value	0.845	0.912	0.971	0.981	0.986	0.989

As shown in Table 2, the mean value of S&T innovation efficiency in the Guangdong-Hong Kong-Macao Greater Bay Area exhibits variability and peaks in 2024, with the mean value of S&T innovation efficiency sustaining a trajectory of steady growth after 2020. Recent studies have indicated that the average value of comprehensive technical efficiency in science and technology innovation in the 11 cities of the Guangdong-Hong Kong-Macao Greater Bay Area has ranged between 0.845 and 0.989 over the past six years. This indicates that the level is high and increasing annually. The findings suggest that the cities within the Greater Bay Area are more effective in converting scientific research

outcomes into practical applications, a consequence of the synergistic collaboration between government entities and innovation-oriented actors. Specifically, cities 5, 6, and 7 have a technical efficiency value of 1 in 2019, 2020, and 2021, respectively. Meanwhile, city 8 has a technical efficiency value of 1 in 2022 and 2023, and city 10 has a technical efficiency value of 1 in 2024. This coincides with an upward trend in the average value of the comprehensive efficiency of science, technology, and innovation. This upward trend is due to the sufficient and efficient investment of human and financial resources by these cities. The underlying reason for this phenomenon is that these cities have allocated sufficient and efficient investment in human and financial resources. The increase in the government's financial expenditure on science and technology has been identified as a key factor in enhancing the level of transformation of scientific and technological achievements. This, in turn, has been shown to contribute to the upward trend of the average value of technical efficiency. Consequently, this has led to an improvement in the efficiency of science, technology, and innovation in the city cluster of the Guangdong-Hong Kong-Macao Greater Bay Area as a whole.

In terms of individual cities, the five Greater Bay Area cities of Hong Kong, Macao, Guangzhou, Dongguan, and Zhongshan have maintained the DEA effective state over the past six years. This indicates that the technical and scale efficiencies of science and technology finance in these five cities have reached an optimal level, and the resource structure is reasonably configured. Shenzhen, a city with a dense concentration of high-tech enterprises, was in a non-DEA effective state in 2019, but has been in a DEA effective state in both 2020 and 2021-2024. The analysis indicates that Zhuhai and Foshan were in a non-DEA effective state from 2019 to 2021 and in a DEA effective state from 2022 to 2024. Jiangmen was in a non-DEA effective state from 2019 to 2023 and did not reach a DEA effective state until 2024. Zhaoqing was in a DEA effective state for the remainder of the years, with the exception of 2021 and 2024. Huizhou has been in a non-DEA effective state for the last six years. Comprehensive efficiency is composed of two constituent elements: technical efficiency and scale efficiency. It is evident that as the comprehensive efficiency value declines, the city's output exhibits a corresponding decrease when compared with other cities that have similar input levels. Years in which the value of comprehensive efficiency of science and technology innovation in the cities of the Greater Bay Area does not reach 1 indicate that the technical efficiency and scale efficiency in the transformation of scientific and technological achievements have not reached the optimal state. It is therefore necessary to improve the comprehensive efficiency, and to utilize the various input factors to the maximum extent. To this end, corresponding measures must be adopted to adjust and make it reach a relative equilibrium.

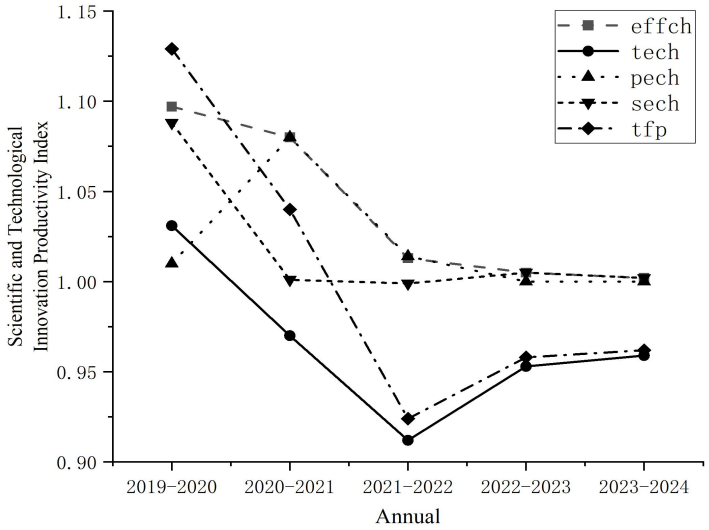
3.2 Malmquist Index Dynamic Analysis

Malmquist's methodology can be utilized to dynamically reflect changes in the efficiency of science and technology innovation within the cities of the Guangdong, Hong Kong, and Macao Greater Bay Area. The Malmquist index is used to decompose the productivity of science and technology innovation in the 11 cities of the Guangdong, Hong Kong, and Macao Greater Bay Area from 2019 to 2024. The following results have been obtained.

Table 3 Average Malmquist Index and Decomposition of Scientific and Technological Innovation in 11 Cities in the Guangdong-Hongkong-Macao Greater Bay Area from 2019 to 2024

	effch	*tech*	*pech*	*sech*	*tfp*
2019-2020	1.097	1.031	1.010	1.088	1.129
2020-2021	1.080	0.970	1.080	1.001	1.040
2021-2022	1.013	0.912	1.014	0.999	0.924
2022-2023	1.005	0.953	1.000	1.005	0.958
2023-2024	1.002	0.959	1.000	1.002	0.962
Average value	1.040	0.965	1.021	1.019	1.003

As shown in Table 3 and Figure 1, the average STI productivity index for the Guangdong, Hong Kong, and Macao Greater Bay Area from 2019 to 2024 is 1.003, with a 0.3% increase in Malmquist productivity. During the research period, the total factor productivity index exceeded 1 from 2019 to 2021, but fell below 1 from 2021 to 2024, indicating a gradual decline in STI efficiency. The STI inputs and outputs of the 11 cities in the Greater Bay Area reached optimal levels only between 2019 and 2021. Further decomposition of TFP into technical efficiency and technical progress indices reveals: (1) the highest TFP value from 2019 to 2020 was due to the combined effect of technical and scale efficiency, highlighting these factors as key drivers of STI efficiency improvement, while pure technical efficiency hindered progress; (2) the lowest TFP value from 2021 to 2022 was attributed to low technical progress and scale efficiency, suggesting that these factors are the primary causes of reduced total factor productivity. This insight can



guide government and enterprises to enhance scientific and technological innovation efficiency in the Greater Bay Area by increasing investment and scaling up innovation efforts.

The Malmquist Index and its decomposition of the efficiency of science and technology innovation of the cities in the Guangdong-Hong Kong-Macao Greater Bay Area are as follows table 4.

Figure 1 Guangdong-Hong Kong-Macao Greater Bay Area Science and Technology Innovation Productivity Index from 2019 to 2024

Table 4 Malmquist Index of Scientific and Technological Innovation Efficiency and Its Decomposition in Cities of the Guangdong-Hong Kong-Macao Greater Bay Area

	effch	*tech*	*pech*	*sech*	*tfp*
Hong Kong	1.000	0.986	1.000	1.000	0.986
Macau	1.000	0.952	1.000	1.000	0.952
Guangzhou	1.000	1.009	1.000	1.000	1.009
Shenzhen	1.030	1.036	1.000	1.030	1.074
Zhuhai	1.109	0.956	1.095	1.015	1.056
Foshan	1.084	0.955	1.084	1.001	1.034
Huizhou	1.016	0.927	1.001	1.015	0.938
Dongguan	1.000	0.945	1.000	1.000	0.945
Zhongshan	1.000	0.955	1.000	1.000	0.955
Jiangmen	1.083	0.945	1.049	1.047	1.033
Zhaoqing	1.101	0.951	1.000	1.101	1.047
Average value	1.039	0.965	1.021	1.019	1.003

As indicated in Table 4, only six cities – Guangzhou, Shenzhen, Zhuhai, Foshan, Jiangmen, and Zhaoqing – have a total factor productivity index greater than 1 from 2019 to 2024. In contrast, the total factor productivity of the five cities of Hong Kong, Macau, Huizhou, Dongguan, and Zhongshan, as depicted in Figure 1, is lower than 1. These observations suggest that the collective efficacy of science and technology innovation within the Guangdong-Hong Kong-Macao Greater Bay Area is on an upward trend. However, it is crucial to acknowledge that this efficiency still requires improvement, and there are noticeable differences in the rate of change across various cities. From the perspective of the decomposition analysis of the Malmquist index, the 11 cities can be classified as follows: (1) The technical efficiency of the five cities of Hong Kong, Macao, Guangzhou, Dongguan, and Zhongshan is all 1, indicating that technical efficiency does not contribute to the efficiency of science and technology innovation, and that technological progress hinders the improvement of the productivity of science and technology innovation; (2) The efficiency of science and technology innovation in Shenzhen has shown a 7% improvement. As illustrated in Figure 1, 43% of cities exhibit the highest level of technical efficiency, defined as the technical efficiency index being equivalent to the technical efficiency index. The technical efficiency index and the technical progress efficiency index increased by 3.0% and 3.6%, respectively, indicating that the increase in total factor productivity in Shenzhen is mainly due to technical efficiency and technological progress; (3) An examination of the STI efficiency of Zhuhai, Foshan, Jiangmen, and Zhaoqing reveals a varied picture, with increases of 5.6%, 3.4%, 3.3%, and 4.7%, respectively. The four cities demonstrate a positive effect on the technical efficiency index and technical progress. The findings indicate that while the technical efficiency index increases, the technical progress index decreases, and the pure technical efficiency index and the scale efficiency index work together to promote the enhancement of the technical efficiency index.

5 CONCLUSION

This paper presents the findings of an empirical study on the Science, Technology, and Innovation (STI) efficiency of 11 cities in the Guangdong-Hong Kong-Macao Greater Bay Area. The study concluded that: (1) The average value of the comprehensive efficiency of STI in the Guangdong-Hong Kong-Macao Greater Bay Area fluctuates and rises between 2014 and 2019, and then steadily grows after 2020, reaching a peak in 2024. The average value of the comprehensive technical efficiency is at a high level and is increasing year by year. (2) A number of differences have been identified in the magnitude of change and the factors influencing the STI efficiency of different cities. The five cities of Hong Kong, Macau, Guangzhou, Dongguan, and Zhongshan have demonstrated a consistent DEA effectiveness, while the five cities of Shenzhen, Zhuhai, Foshan, Jiangmen, and Zhaoqing have shown incremental improvement. Conversely, Huizhou has exhibited a persistent absence of DEA effectiveness. The Guangdong-Hong Kong-Macao Greater Bay Area has been found to demonstrate high levels of innovation efficiency overall. However, it is crucial to acknowledge the presence of significant internal disparities within the region. These disparities necessitate targeted interventions to ensure the optimization of resource allocation. The promotion of technological progress is an inherent feature of the concept of sustainable and efficient cities. In contrast, cities that are experiencing a decline in efficiency are required to enhance their scale efficiency.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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CHINA'S DIGITAL VILLAGE DEVELOPMENT: REALITIES, PATHWAYS, AND MECHANISMS

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Abstract: Digital technology is an indispensable productive force for rural development. Building digital villages requires transforming the inherent advantages of digital technology into effective mediators for rural modernization, driving comprehensive innovation in rural production and lifestyles. However, China faces practical challenges in leveraging digital technology for rural modernization: insufficient momentum in "new infrastructure" development, a lack of key actors, inadequate government oversight, digital capability gaps within grassroots organizations, and spatial digital divides. Addressing these requires strengthening physical infrastructure, cultivating digital literacy among stakeholders, optimizing policy design, integrating autonomy, rule of law, and virtue-based governance, and bridging spatial disparities. The Chinese government has established a systematic action mechanism for digital village development: (1) Foundation-building mechanism: Consolidating physical infrastructure; (2) Co-creation mechanism: Integrating external forces to ensure stakeholder engagement; (3) Capacity-enhancement mechanism: Addressing capability gaps through digital education; (4) Collaborative mechanism: Restructuring organizations to synergize multi-stakeholder efforts.
Keywords: Digital technology; Digital village; Realistic Landscape; Mechanism; Pathway

1 INTRODUCTION

Digital villages represent a critical focus for advancing national modernization in the digital era. This involves embedding digital technology into rural socio-economic structures to modernize agriculture, rural areas, and farmers, utilizing key tools like big data, blockchain, and AI. This paper examines the value logic, current realities, implementation pathways, and action mechanisms of China's digital village development. It seeks to transform the inherent advantages of digital technology into effective mediators for high-quality digital village development, offering theoretical insights for developing nations pursuing rural modernization.

2 THE VALUE LOGIC OF DIGITAL TECHNOLOGY EMPOWERING RURAL MODERNIZATION

Digital technology empowers rural modernization by bridging dual gaps—between urban and rural areas, and among market entities—thereby enhancing fundamental market dynamics.

2.1 Economic Drivers

This empowerment aligns with China’s socio-economic imperatives[1-3]. Macroscopically, China's digital economy surged from RMB 11 trillion in 2012 to RMB 50.2 trillion in 2022, with an average annual growth rate exceeding 50%. Microscopically, provinces like Jiangsu exemplify rapid digital advancement: it pioneered provincial digital economy regulations, hosts four national advanced manufacturing clusters (the highest nationally), and saw high-tech and strategic emerging industry outputs rise to 48.5% and 40.8% of total industrial output, respectively. Jiangsu's digital economy reached RMB 5.1 trillion in 2022, ranking second nationally and accounting for 11.8% of the national total; its core industries contributed 10.6% to provincial GDP.

Stimulated by the digital economy, rural China is undergoing rapid transformation[4-6]. The 2022 National County-Level Digital Agriculture and Rural Development Evaluation Report indicates: 77.7% of counties established agricultural informatization agencies; county-level digital agriculture investments totaled RMB 12.9 billion; per capita telecom consumption exceeded RMB 500; agricultural production digitization reached 18.6%; e-commerce covered 64% of administrative villages, with online agricultural retail sales hitting RMB 554.2 billion (9.8% of total transactions); and 49.7% of villages benefited from "Information Entry to Villages" stations. As a strategic nexus of national cyberpower and rural revitalization, digital villages demonstrably enhance agricultural efficiency, farmer incomes, and rural prosperity.

These trends reveal how digitalization reshapes rural economic relations and governance structures[7-9]. Thus, digital empowerment of rural modernization is a strategic response to developmental trends, holding profound significance.

2.2 Mediating Capacity

The Digital Village Development Strategy Outline formalized the concept, targeting full realization by mid-century. Scholarship has since explored its implications, often viewing digital transformation instrumentally—as a mediator for rural development. For instance, Li Gan (2021) defines it as applying next-generation IT to drive rural transformation[10]; Wang Sheng and Yu Na (2021) similarly emphasize leveraging digital paradigms for holistic advancement[11]. However, such perspectives can overlook the intrinsic transformative power of the technology itself. Digital village development should be understood as a systemic overhaul of rural life and production driven by IT—a new productive force essential for modernization. It constitutes a complex system requiring integrated approaches.

2.3 Potential Effects

Amidst the rise of the digital and platform economies, industrial digitization and digital industrialization dominate China's industrial upgrading, with provinces competing to formulate long-term digital strategies[12-14]. The potential effects are significant:

Foundation for Digital China: Digital villages form the bedrock of national digital transformation, embodying its most challenging yet crucial aspect. Success here is pivotal for Digital China.

Catalyst for Rural Modernization: It represents an endogenous opportunity for high-quality rural modernization—not merely a means to revitalization, but an inevitable developmental phase aligned with productive forces.

Driver of Urban-Rural Integration: It holds potential to narrow regional (east-central-west) and urban-rural disparities. While research shows digital economies can both mitigate and exacerbate the "digital divide," targeted enablement policies can foster inclusive resource allocation and integration[15].

3 THE REALISTIC LANDSCAPE OF DIGITAL TECHNOLOGY EMPOWERING RURAL MODERNIZATION

A systematic analysis across five dimensions—entity, agency, institution, governance, and environment—reveals key tensions and challenges.

3.1 Entity Dimension: Weak "New Infrastructure" & Agricultural Digitalization Dilemma

Entity encompasses physical elements: 5G, AI, industrial IoT, digital infrastructure, and data resources[16]. Challenges include:

Inadequate "New Infrastructure" Momentum: National funding for rural digital infrastructure remains insufficient and fragmented. Capital-driven projects (e.g., 5G, AI, data centers) stall in vast rural areas due to market spillover limitations. Historical underinvestment in high-tech "software" versus tangible "hardware" exacerbates technological shortfalls[17].

Agricultural Digitalization Difficulties: High costs, implementation complexity, and lack of national-level top-level design hinder progress. Unlike other sectors, agricultural data relies heavily on production-side data, which is hard to collect due to natural uncertainties, making low-cost sustainability elusive. Blindly replicating general digitization principles ignores agricultural uniqueness, risking unsustainable, capital-intensive pseudo-digitization.

3.2 Agency Dimension: Absence and Deficits of Key Actors

Challenges involve both absence (digital professionals, digitally active populations)[18] and deficits(misconceptions, skill gaps):

Actor Absence: Rural brain drain and hollowing-out (especially in central/western regions, per CNNIC 2023 data on youth migration) deprive villages of endogenous digital momentum and skilled users. Systemic barriers hinder talent retention.

Actor Deficits: Some officials underestimate digital villages' importance or resist adoption; some technologists exhibit techno-optimism, neglecting social science insights and risks. Rural residents often lack smartphone/internet proficiency. These deficits form fundamental barriers.

3.3 Institution Dimension: Inadequate Government & Market Oversight

The Rural Revitalization Promotion Law mandates digital villages but lacks a supporting regulatory framework:

Government Oversight Gaps: Agricultural data management lacks laws and standards, leading to data silos or unequal access/distribution, potentially creating new inequalities[19].

Market Regulation Vacuum: Policies are lacking to manage capital influx into agricultural digitization. While agribusinesses hold advantages (capital, tech, data), unchecked capital dominance risks marginalizing smallholders and generating socio-economic threats.

3.4 Governance Dimension: Gaps in Grassroots Capacity & "Tripartite + Digital" Integration

Digital governance remains nascent, largely confined to communication:

Grassroots Leadership Challenge: Village Party organizations struggle to lead effectively in the complex, virtualized, multi-actor digital governance landscape.
Integration Gap with "Tripartite Governance": Embedding digital governance within the autonomy-rule of law-virtue framework is unclear. The high technical costs and management burden of public digital platforms challenge local governments transitioning amidst an incomplete "tripartite" system.

3.5 Environment Dimension: Persistent Digital Divides

International Gap: China's digital villages lag behind developed nations (e.g., UK's systemic digital agriculture, US digital urban-rural fusion, Japan/Korea's industrial restructuring). Learning from global experience is under-prioritized.
Domestic Disparities: Imbalances mirror regional economic gaps. Eastern coastal areas approach international levels, while the west lags, creating a "digital divide" hindering common prosperity[20].

4 IMPLEMENTATION PATHWAYS FOR DIGITAL TECHNOLOGY EMPOWERING RURAL MODERNIZATION

Informed by the five-dimensional analysis, the *Digital Village Development Action Plan (2022-2025)*outlines pathways:

4.1 Strengthening the Entity Foundation

Mobilize funds: National special funds + local policies attracting social capital for infrastructure.
Boost tech supply: Strengthen R&D support, leverage universities/enterprises for localized models.
Advance agricultural digitization: Develop China-specific strategies, prioritize production data collection/integration (e.g., via data stations, unified databases).

4.2 Cultivating Agency as Key Resource

Address absence: Align higher/vocational education with needs; create incentivized talent channels.
Remedy deficits: Enhance policy interpretation for officials/technologists; implement tiered digital literacy programs for residents; retain traditional service options for the digitally excluded.

4.3 Optimizing Institutional Policy Arrangements

Government: Legislating agricultural data management for equitable sharing.
Market: Regulating capital involvement ("utilize but restrain"), protecting smallholders/cooperatives, setting boundaries against disorderly expansion.

4.4 Enhancing Governance as Core Means

Empower grassroots: Utilize digital platforms for democratic consultation; accelerate government digital transition.
Explore integration: Develop pathways for embedding digital governance within the "tripartite governance" framework.
Theoretical design: Academic research on integrating digital governance with the autonomy-law-virtue system.

4.5 Shaping the Environment for Future Orientation

Learn internationally: Systematically study foreign digital village models; foster rural-level international exchange.
Bridge domestic divides: Use fiscal tools, promote regional integration and urban-rural digital fusion.

5 ACTION MECHANISMS FOR DIGITAL TECHNOLOGY EMPOWERING RURAL MODERNIZATION

China employs a systemic "holistic" action mechanism:

5.1 Foundation-Building Mechanism

Upgrade hardware: Expand rural 5G coverage, negotiate affordable data plans.
Pilot & scale: Establish provincial digital agriculture pilots (IoT, blockchain, data stations), then national rollout[21].
Build unified platforms: National data-sharing/government service platform to avoid redundancy, ensure equity/security.

5.2 Co-Creation Mechanism

Engage migrant workers: Village committees establish contact (e.g., WeChat groups), share developments, build interest alignment, encourage participation/return.

Integrate academia: Government-led university-village pairing; incorporate digital village work in research/student requirements; create talent channels.

5.3 Capacity-Enhancement Mechanism

Correct misconceptions: Policy briefings, expert lectures.
Digital literacy programs: Tiered training (e.g., e-commerce workshops, online agri-tech courses, cooperative-based equipment training like blockchain for traceability/value addition).

5.4 Collaborative Mechanism

Phase 1: Tripartite Synergy: Government leads, integrates resources; market entities boost digitization; academia provides tech/talent; legal safeguards established.
Phase 2: Multi-Actor Advancement: Grassroots organizations coordinate; actors collaborate via digital platforms for modern production/life.
Phase 3: Mature Autonomy: Administrative input phased out; self-sustaining multi-stakeholder synergy drives endogenous digital development.

6 Conclusion and Prospects

6.1 Research Conclusions

This study systematically deconstructs the realistic landscape, implementation pathways, and action mechanisms of digital village construction in China. Empirical evidence reveals that digital technology serves as a transformative mediator for rural modernization, yet its empowerment faces multidimensional constraints: insufficient "new infrastructure" investment, dual deficiencies in practice agency (absence of skilled talent and capability gaps among residents), regulatory voids in data governance and capital oversight, disjunctures between digital governance and the "autonomy-rule of law-virtue" tripartite framework, and persistent digital divides across regions and urban-rural spheres.
To address these challenges, China has pioneered a systematic action framework:
Entity Foundation: Prioritizing infrastructure upgrades and agricultural digitization tailored to rural realities;
Agency Optimization: Cultivating digital literacy through education and talent retention policies;
Institutional Innovation: Balancing data equity and capital regulation to protect smallholders;
Governance Synergy: Embedding digital tools within grassroots governance structures;
Environmental Bridging: Learning from global models while narrowing domestic disparities.
The proposed four-phase action mechanism—foundation-building, co-creation, capacity-enhancement, and collaboration—demonstrates how multi-stakeholder synergy (government, market, academia) can convert technological advantages into endogenous momentum for rural revitalization.

6.2 Future Prospects

Future efforts should focus on three dimensions:
Technical Adaptation: Developing cost-effective agricultural IoT and blockchain solutions for small-scale farming, reducing data collection barriers while enhancing traceability value chains.
Policy Refinement: Establishing differentiated digital literacy evaluation systems and dynamic capital supervision frameworks to prevent market monopolies and protect vulnerable groups.
Theoretical Innovation: Constructing a "Digital Village Maturity Model" to quantify governance efficacy and spatial spillover effects, particularly in central/western regions.
Internationally, comparative studies on digital village paradigms (e.g., EU smart villages, Japan’s Society 5.0) will enrich China’s approach. Crucially, integrating "new quality productive forces" with place-based strategies could redefine rural modernity, offering a replicable model for Global South development. As digital and ecological transitions converge, China’s experience may pioneer sustainable ruralism in the intelligent era.

COMPETING INTERESTS

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