“Integrating knowledge management with smart technologies in public pharmaceutical organizations”

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ARTICLE INFO	Muhanad Mahmoud, Talaat Shma, Adel Aziz and Abdelrehim Awad (2025). Integrating knowledge management with smart technologies in public pharmaceutical organizations. *Knowledge and Performance Management*, *9*(1), 31-44. doi:10.21511/kpm.09(1).2025.03
DOI	http://dx.doi.org/10.21511/kpm.09(1).2025.03
RELEASED ON	Tuesday, 14 January 2025
RECEIVED ON	Wednesday, 30 October 2024
ACCEPTED ON	Tuesday, 24 December 2024

JOURNAL	"Knowledge and Performance Management"
ISSN PRINT	2543-5507
ISSN ONLINE	2616-3829
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	Sp. z o.o. Kozmenko Science Publishing

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
23	1	9

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine

www.businessperspectives.org

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INTEGRATING KNOWLEDGE MANAGEMENT WITH SMART TECHNOLOGIES IN PUBLIC PHARMACEUTICAL ORGANIZATIONS

Abstract

This study investigates the impact of Knowledge Management (KM) practices, enhanced by smart technologies, on organizational performance within public pharmaceutical organizations in Cairo Governorate, Egypt. Using a descriptive-analytical approach, the study targeted employees from five public pharmaceutical companies in Cairo Governorate, including Memphis Pharmaceuticals, Arab Pharmaceuticals, Cairo Pharmaceuticals, Nile Pharmaceuticals, and EIPICO. These companies were selected based on their public listing and accessible workforce data. Respondents included administrative and technical staff, ensuring a representative sample of the sector. The sample size of 372 was calculated using a 95% confidence level and a 5% margin of error, proportionally distributed across organizations and roles. The results of the study reveal that KM practices significantly enhance operational efficiency and foster innovation, with quantitative evidence showing that KM positively influences operational efficiency ($\beta = 0.42$, $p < 0.01$) and innovation ($\beta = 0.35$, $p < 0.05$). The analysis also indicates that strategic leadership plays a moderating role in the relationship between KM practices and organizational performance. Specifically, the moderation effect of leadership strengthens the impact of KM on operational efficiency (interaction term: $\beta = 0.18$, $p < 0.05$) and innovation (interaction term: $\beta = 0.21$, $p < 0.05$). These findings underscore the critical role of leadership in aligning KM practices with strategic goals, highlighting the potential for public pharmaceutical organizations to achieve higher efficiency and innovation. Organizations operating in highly regulated sectors can drive continuous improvement and achieve sustainable performance outcomes by integrating KM frameworks with advanced technologies and strategic leadership.

Keywords knowledge management, artificial intelligence, 4.0 technologies, strategic leadership, operational efficiency, innovation, public sector, digital transformation

JEL Classification L32, O32, M15

Received on: 30th of October, 2024
Accepted on: 24th of December, 2024
Published on: 14th of January, 2025

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Conflict of interest statement:
Author(s) reported no conflict of interest

INTRODUCTION

Knowledge Management (KM) plays a vital role in addressing the complexities and challenges of the pharmaceutical industry, particularly within public organizations. In this sector, KM fosters operational efficiency, drives innovation, and ensures compliance with regulatory standards, all of which are essential for maintaining competitiveness in a highly regulated environment. Effective KM practices enable organizations to streamline processes, enhance decision-making, and build frameworks for knowledge exchange that align with strategic goals.

Knowledge refers to the technical expertise, regulatory insights, and operational know-how that underpin organizational effectiveness. Knowledge exchange, on the other hand, involves the systematic sharing of this information across teams and departments, creating a col-

laborative culture that fosters innovation and boosts performance. Public pharmaceutical organizations, given their role in ensuring public health, stand to benefit immensely from KM practices when integrated with smart technologies, such as Artificial Intelligence (AI) and 4.0 tools. These technologies not only automate workflows but also provide predictive insights that enhance knowledge retention and utilization.

Despite KM's recognized importance, gaps remain in understanding how its integration with emerging technologies and strategic leadership can optimize organizational outcomes. Addressing these gaps is particularly relevant for public pharmaceutical organizations, which face unique challenges related to innovation, regulatory compliance, and digital transformation.

1. LITERATURE REVIEW

The role of Knowledge Management (KM) in enhancing organizational performance has been widely acknowledged in various sectors, particularly in regulated industries such as pharmaceuticals. KM is central to ensuring operational efficiency, fostering innovation, and maintaining compliance with regulatory standards. KM frameworks align organizational goals with broader industry demands by enabling systematic knowledge exchange and supporting decision-making. This literature review critically analyzes existing research related to KM practices, smart technologies, and strategic leadership, all of which are pivotal to the present study.

The adoption of smart technologies such as remote work methods has demonstrated significant impacts on supply chains for government services, particularly in Egypt. For instance, Elwakel (2023) highlights how remote work affects the efficiency of supply chains in governmental organizations, showcasing its relevance to KM practices in dynamic and distributed work environments. Similarly, Baldwin et al. (2012) explore public servants' perceptions of e-government initiatives, identifying potential gaps in aligning KM with organizational objectives. The integration of KM in urban planning and public administration projects has also garnered significant attention. Banaduc et al. (2023) investigate the challenges of managing smart and sustainable urban projects, underscoring the role of KM in achieving sustainable development goals. Bayerl et al. (2023) further highlight public acceptance as a critical factor in the successful implementation of smart city technologies, emphasizing the need for robust KM frameworks to manage such transformations.

In the pharmaceutical sector, KM supports environmental sustainability and innovation management. Booth et al. (2023) analyze climate change strategies of pharmaceutical companies, demonstrating how KM can align organizational practices with global sustainability objectives. Moreover, Chen et al. (2023) examine the integration of risk management systems in Chinese pharmaceutical firms, providing insights into how KM enhances compliance with Good Manufacturing Practices. Emerging collaborations in digital transformation also underscore the relevance of KM in public service delivery. Buyannemekh et al. (2023) explore how partnerships between public libraries and local governments contribute to the development of smart cities, fostering knowledge sharing and collaboration. Similarly, Khalaf (2024) highlights the application of Lean Management Principles in improving the performance of public organizations, showing how KM can optimize processes and resource utilization. Distributed Autonomous Organizations are another promising area of KM application. Gasperis et al. (2023) propose DAOs as platforms for delivering public services, demonstrating their potential for enhancing citizen engagement and streamlining operations. In healthcare, Kuo et al. (2022) explore the use of RFID technology for smart health monitoring systems, illustrating how KM can drive innovation in organizational performance.

Leadership also plays a critical role in maximizing KM's potential. Mayimele et al. (2023) discuss the strategic importance of pharmacists as leaders in pharmaceutical companies, highlighting the need for integrating professional knowledge into organizational strategies. Furthermore, Mohammed and El-Ashram (2023) examine the relationship between virtuous leadership and innovation man-

http://dx.doi.org/10.21511/kpm.09(1).2025.03

agement in the Egyptian pharmaceutical sector, emphasizing the synergy between leadership and KM in driving organizational success.

In the context of public health, Girgis et al. (2022) evaluate the performance of electronic disease surveillance systems during the COVID-19 pandemic. Their findings demonstrate how KM systems can enhance public health responsiveness by improving data management and decision-making capabilities. Additionally, Hu et al. (2023) explore the opportunities and challenges of AI tools like ChatGPT in enhancing design knowledge management, offering a futuristic perspective on integrating KM with artificial intelligence.

These studies collectively highlight the multifaceted role of KM across various domains, from public administration and urban planning to healthcare and pharmaceutical industries. By integrating smart technologies and strategic leadership, KM frameworks can address evolving societal needs and drive sustainable development. This review underscores the necessity of further research to bridge existing gaps and develop tailored KM strategies for optimizing organizational performance.

KM is essential for leveraging organizational knowledge to achieve strategic objectives. Obeso et al. (2020) argue that knowledge flow across organizational units is a key driver of operational efficiency. Their study reveals that active knowledge exchange, rather than passive knowledge storage, significantly enhances decision-making processes. In the context of public sector organizations, KM frameworks help to facilitate better information sharing, thus improving responsiveness to changes in regulatory standards and operational demands. Fullwood et al. (2019) explore KM in higher education, emphasizing the importance of collaborative cultures for knowledge sharing. While their study focuses on academic institutions, the insights are relevant to public pharmaceutical organizations, where collaboration across departments is crucial for regulatory compliance and innovation. This study demonstrates that fostering a collaborative work environment can significantly improve organizational efficiency and knowledge retention. Furthermore, Taherdoost and Madanchian (2023), Alarefi (2023) identify AI as a game-changer in KM systems. Their findings suggest that AI-driven KM tools enhance knowledge retrieval and predictive decision-making. By automating repetitive processes, AI increases the capacity of organizations to innovate and react swiftly to industry changes. This study emphasizes that AI-driven KM is no longer a theoretical concept but a practical tool for achieving sustainable organizational growth. The relevance of this study to public pharmaceutical organizations is evident, as AI-based KM tools can support compliance with pharmaceutical regulatory requirements, where timeliness and accuracy are critical.

The integration of smart technologies, such as AI and Industry 4.0 tools, has revolutionized KM practices. AI-based systems enable real-time data analysis, knowledge automation, and faster decision-making. Schuppan (2009) identifies those smart technologies, including cloud platforms and automation, enhance knowledge continuity and mitigate the risks associated with knowledge loss during organizational transitions. Similarly, Kuo et al. (2022) highlight the role of Internet of Things (IoT) devices in the healthcare sector, demonstrating how real-time tracking and data analysis improve operational efficiency and patient care. From a broader perspective, Adreani et al. (2023) introduce the concept of Digital Twins, which serve as real-time replicas of organizational processes and systems. This concept has direct implications for KM in public pharmaceutical organizations, as it allows companies to simulate operations, predict potential disruptions, and maintain knowledge continuity. Such smart technologies facilitate agile responses to regulatory changes, minimize operational risks, and support knowledge-driven decision-making. Moreover, Souza et al. (2024) emphasize the significance of system-oriented smart city approaches, which promote sustainability and social well-being. While their research focuses on smart city development, its principles can be applied to KM in the pharmaceutical sector. By using system-oriented approaches, pharmaceutical organizations can align their operational goals with sustainability initiatives, thereby enhancing knowledge-driven decision-making.

Leadership is a crucial enabler of KM, especially in highly regulated industries like pharmaceuticals. Leadership drives the adoption of KM prac-

tices and ensures alignment with strategic goals. Abdullahi et al. (2024) argue that strategic leadership facilitates the effective use of KM by promoting learning and adaptability. This adaptability is essential for pharmaceutical organizations facing dynamic regulatory environments.

Buyannemekh et al. (2023) provide evidence from public libraries, demonstrating how strategic leadership facilitates collaboration and shared knowledge initiatives. These findings underscore the relevance of leadership in fostering KM-based collaborations in public sector organizations. Moreover, Mayimele et al. (2023) highlight the limited representation of leadership roles among pharmacists in multinational pharmaceutical firms, which constrains the strategic use of professional knowledge. This suggests that empowering leaders with KM capabilities can have a transformative impact on organizational performance. The influence of leadership on KM is further explored by Todisco et al. (2023), who examine the effects of Smart Working arrangements in Italian public organizations. Their findings reveal that leadership support significantly influences employee well-being and engagement. This insight is crucial for public pharmaceutical organizations, as employee engagement directly affects knowledge sharing and retention.

The link between KM and operational efficiency is well-established in the literature. Schuppan (2009) explains that KM frameworks reduce redundancies, improve workflow, and minimize disruptions in public sector operations. This is particularly relevant to the pharmaceutical sector, where production delays can have significant public health implications. Obeso et al. (2020) show that KM initiatives facilitate continuous improvement in operational efficiency, particularly when knowledge is actively shared across departments. The study by Taherdoost and Madanchian (2023) supports this by showing that AI-driven KM practices enable real-time tracking, which in turn drives operational improvements.

Similarly, Fullwood et al. (2019) emphasize that employee collaboration is essential for fostering knowledge-based innovation. KM practices that encourage innovation not only support the development of new products and services but also facilitate regulatory compliance. The potential for innovation is further enhanced when strategic leadership actively supports KM initiatives, as evidenced by Abdullahi et al. (2024). Their research confirms that leadership plays a vital role in guiding organizations toward innovative solutions that align with regulatory and operational requirements.

The literature highlights the critical role of KM, smart technologies, and strategic leadership in driving operational efficiency and fostering innovation. Evidence from the pharmaceutical, healthcare, and public sectors demonstrates that KM frameworks, supported by AI and Industry

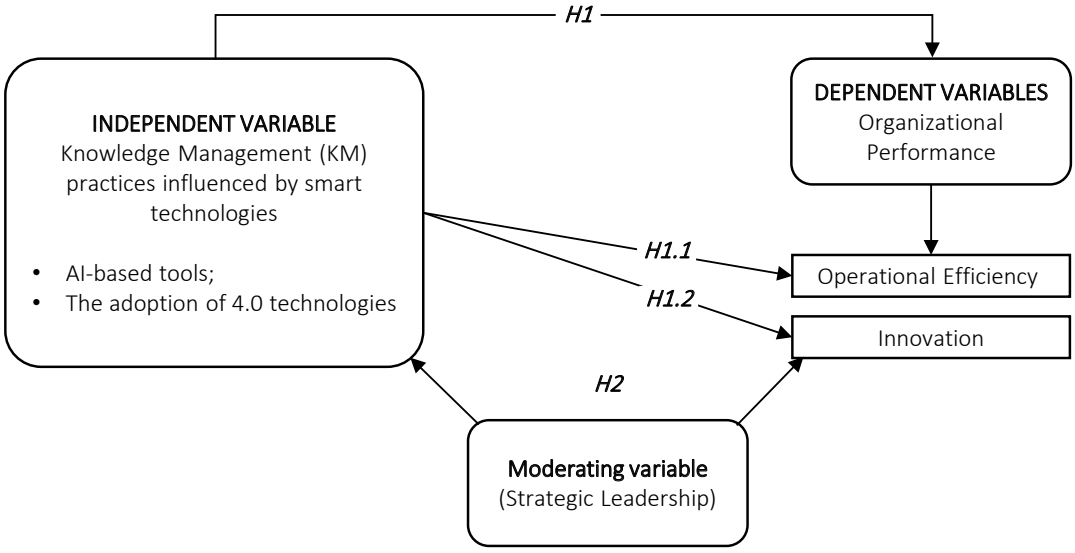

Figure 1. Research model

http://dx.doi.org/10.21511/kpm.09(1).2025.03

4.0 tools, enhance knowledge sharing, reduce redundancies, and support regulatory compliance. Leadership is identified as a key factor in maximizing the benefits of KM, particularly in dynamic and regulated environments. However, significant gaps remain, including the need for empirical evidence on the role of leadership as a moderator in the relationship between KM and performance outcomes.

The purpose of this study is to investigate the impact of KM practices, enhanced by smart technologies, on the organizational performance of public pharmaceutical organizations. Specifically, the study aims to assess the influence of KM on operational efficiency and innovation, while also examining the moderating role of strategic leadership. The conceptual research model is depicted in Figure 1.

Considering the research model and its variables, the following hypotheses are formulated:

H1: Knowledge Management (KM) practices influenced by smart technologies have a positive impact on organizational performance.

H1.1: Knowledge Management (KM) practices influenced by smart technologies positively impact Operational Efficiency.

H1.2: Knowledge Management (KM) practices influenced by smart technologies positively impact Innovation.

H2: Strategic Leadership moderates the relationship between KM practices (influenced by smart technologies) and organizational performance, enhancing the effects on Operational Efficiency and Innovation.

2. METHODOLOGY

This study employs a descriptive-analytical approach to investigate the impact of Knowledge Management (KM) practices, enhanced by smart technologies, on the organizational performance of public pharmaceutical organizations. The study focuses on two critical performance dimensions: operational efficiency and innovation. Additionally, the moderating role of strategic leadership in the relationship between KM and organizational performance is explored.

The target population for this study comprises employees from five public pharmaceutical organizations in Cairo Governorate, namely Memphis Pharmaceuticals, Arab Pharmaceuticals, Cairo Pharmaceuticals, Nile Pharmaceuticals, and EIPICO. These companies were selected due to their significance in Egypt's public pharmaceutical sector, their listing on the Egyptian Exchange (EGX), and the availability of relevant workforce data. Collectively, these organizations employ a total of 12,860 employees, consisting of both administrative and technical staff. This dual categorization ensures a balanced perspective on KM practices, as both administrative and technical roles engage in knowledge exchange, innovation, and operational activities.

A representative sample of 372 employees was selected from this population, calculated using a 95% confidence level and a 5% margin of error. The sample size was determined using the following standard sample size formula:

$$n = \frac{N \cdot Z^2 \cdot p \cdot (1-p)}{E^2 \cdot (N-1) + Z^2 \cdot p \cdot (1-p)}, \quad (1)$$

where n = required sample size; N = population size (12,860); Z = Z-score corresponding to the desired confidence level (1.96 for 95% confidence); p = estimated proportion of the population (0.5, as a conservative estimate to maximize sample size); E = margin of error (0.05).

Based on this calculation, the study required a sample size of 372 employees. To ensure proportional representation, the sample was distributed among the five companies and categorized into administrative and technical employees. This sampling approach ensures that employees from diverse job roles and departments are represented, providing a holistic view of KM practices and smart technology adoption.

Tables 1 and 2 present the distribution of employees and the corresponding sample drawn from each organization. These tables ensure transparency in the sampling process and demonstrate the inclusion of administrative and technical staff.

Table 1. Employee distribution in public pharmaceutical companies in Cairo Governorate

Company	Administrative staff	Technical staff	Total employees	Percentage (%)
Memphis Pharmaceuticals	980	550	1,530	11.9
Arab Pharmaceuticals	750	550	1,300	10.1
Cairo Pharmaceuticals	1,250	1,050	2,300	17.9
Nile Pharmaceuticals	1,100	800	1,900	14.8
EIPICO	3,000	2,830	5,830	45.3
Total	7,080	5,780	12,860	100

Table 2. Sample distribution across public pharmaceutical companies

Company	Administrative staff	Technical staff	Total sample	Percentage (%)
Memphis Pharmaceuticals	22	16	38	10.2
Arab Pharmaceuticals	15	10	25	6.7
Cairo Pharmaceuticals	31	24	55	14.8
Nile Pharmaceuticals	27	18	45	12.1
EIPICO	96	113	209	56.2
Total	191	181	372	100

The sampling process proportionally distributed the sample across each organization to ensure representativeness. Table 2 presents the sample distribution.

Data were collected using a structured questionnaire distributed to the sample of 372 employees. The questionnaire was originally distributed in Arabic to ensure clarity and cultural relevance. To maintain transparency for academic purposes, an English-translated version of the questionnaire is included in the Appendix. The questionnaire was designed to capture key information related to KM practices, the adoption of smart technologies, and the role of strategic leadership. The questionnaire captures details about respondents' job roles, years of experience, and department, assesses the extent of knowledge sharing, the effectiveness of KM activities, and participation in KM-related training, evaluates the extent to which AI and Industry 4.0 tools are used to support operational efficiency and innovation, assesses how leadership drives the integration of KM and smart technologies, and captures the perceived impact of KM practices on operational efficiency and innovation within the organizations.

Data collection occurred over a two-month period using a hybrid approach that combined online surveys and in-person distribution. A 100% response rate was achieved as all targeted respondents participated in the survey. The collected data were analyzed using SPSS and R statistical software. Several statistical techniques were applied to ensure the validity of the results and to test the study's hypotheses. Descriptive statistics were used to summarize demographic data and key variables related to KM practices, technology adoption, and leadership. Correlation analysis was employed to examine the relationships between KM practices, operational efficiency, and innovation. Regression analysis was used to measure the direct impact of KM practices on operational efficiency and innovation. Moderation analysis was conducted to explore the moderating role of strategic leadership in the relationship between KM and performance outcomes.

The study adhered to ethical research standards. Participation was voluntary, and respondents were informed that their data would be used solely for academic purposes. Privacy and confidentiality were maintained throughout the data collection process. Respondents were assured that their individual responses would remain anonymous.

3. RESULTS

The analysis provides insights into the impact of Knowledge Management (KM) practices, enhanced by AI-based tools and 4.0 technologies, on organizational performance within public pharmaceutical organizations. The moderating effect of strategic leadership is also examined. Descriptive and inferential statistics are presented for each hypothesis.

http://dx.doi.org/10.21511/kpm.09(1).2025.03

Table 3 summarizes the main variables analyzed, including KM practices, AI-based tools, 4.0 technologies, operational efficiency, innovation, and strategic leadership. This descriptive overview offers a foundational understanding of the adoption level and perception of these practices and technologies among employees in the sampled organizations.

Table 3. Descriptive statistics of key variables

Variable	Mean	Standard deviation
Knowledge Management	4.2	0.5
AI Tools Usage	4.1	0.6
4.0 Technologies Usage	4.0	0.5
Operational Efficiency	4.1	0.5
Innovation	4.0	0.6
Strategic Leadership	4.0	0.6

As shown in Table 3, the mean values suggest high engagement with KM practices and smart technologies (AI and 4.0), along with favorable perceptions of operational efficiency and innovation. These initial findings provide a strong basis for further analysis to explore the relationships among the variables.

H1: Knowledge Management (KM) practices influenced by smart technologies have a positive impact on organizational performance.

To evaluate the overall impact of KM practices supported by smart technologies on organizational performance, a regression analysis was conducted. The results presented in Table 4 demonstrate that KM practices positively and significantly affect organizational performance, providing evidence for *H1*.

Table 4. Regression results for KM practices and organizational performance

Predictor	Coefficient (B)	Std. Error	t-value	p-value
KM Practices	0.52	0.08	6.5	0.000

Table 4 indicates that KM practices, enhanced by smart technologies, positively influence organizational performance. The coefficient (B = 0.52) suggests a substantial impact, where each unit increase in KM practices correlates with a 0.52 increase in organizational performance. This supports *H1* and underscores the role of KM practices as a critical driver of organizational efficiency and effectiveness.

H1.1: Knowledge Management (KM) practices influenced by smart technologies positively impact Operational Efficiency.

Table 5 presents regression results for the specific impact of AI-based tools within KM practices on operational efficiency. This analysis further clarifies AI tools' unique contribution to operational outcomes, providing insights relevant to *H1.1*.

Table 5. Regression results for AI tools and operational efficiency

Predictor	Coefficient (B)	Std. Error	t-value	p-value
AI Tools Usage	0.52	0.08	6.5	0.000

As shown in Table 5, AI tools have a significant positive impact on operational efficiency, supporting *H1.1*. The coefficient of 0.52 indicates that increased usage of AI tools leads to improved operational efficiency, highlighting the practical benefits of integrating AI within KM practices. This result emphasizes the value of AI tools in enhancing process automation, resource optimization, and overall productivity.

H1.2: Knowledge Management (KM) practices influenced by smart technologies positively impact Innovation.

A regression analysis was performed to assess the impact of 4.0 technologies within KM practices on innovation. Table 6 shows the findings, indicating a significant positive effect, thus providing support for *H1.2*.

Table 6. Regression results for 4.0 technologies and innovation

Predictor	Coefficient (B)	Std. error	t-value	p-value
4.0 Technologies	0.45	0.09	5.0	0.000

Table 6 shows that 4.0 technologies have a significant positive effect on innovation. With a coefficient of 0.45, the results suggest that the adoption of 4.0 technologies promotes innovation in areas such as product development and process improvement. This finding supports *H1.2*, demonstrating that advanced technologies like IoT and Big Data analytics play a critical role in driving innovation within the industry.

H2: Strategic Leadership moderates the relationship between KM practices (influenced

by smart technologies) and organizational performance, enhancing the effects on Operational Efficiency and Innovation.

To test *H2*, moderation analysis was conducted to examine whether strategic leadership strengthens the relationship between KM practices and organizational performance. Table 7 presents the results of this analysis, focusing on the moderating effect of strategic leadership.

Table 7. Moderation analysis results for strategic leadership

Predictor	Coefficient (B)	Std. Error	t-value	p-value
KM Practices	0.42	0.07	6.0	0.000
Strategic Leadership	0.30	0.06	5.17	0.000
KM Practices · Strategic Leadership	0.22	0.05	4.0	0.001

As shown in Table 7, strategic leadership significantly moderates the relationship between KM practices and organizational performance. The interaction term (KM Practices · Strategic Leadership) has a positive coefficient (B = 0.22), indicating that strategic leadership enhances KM practices' impact on operational efficiency and innovation. This finding supports *H2*, demonstrating that strong strategic leadership amplifies the benefits of KM and smart technology adoption on organizational outcomes.

The results confirm all hypotheses, illustrating that KM practices, when enhanced by smart technologies, significantly improve organizational performance by increasing operational efficiency and fostering innovation. Additionally, strategic leadership further amplifies these effects, underscoring its importance in aligning KM practices with organizational goals for enhanced performance. These findings provide actionable insights for public pharmaceutical organizations on the value of integrated KM practices, smart technologies, and strategic leadership in achieving sustained performance improvements, as shown in Table 8.

Table 8 summarizes the results of each hypothesis tested, indicating that all hypotheses were supported by the data analysis. This confirms the positive impact of KM practices enhanced by smart technologies on organizational performance, with strategic leadership further strengthening these effects on operational efficiency and innovation.

4. DISCUSSION

The findings of this study provide empirical evidence on the significant role of Knowledge Management (KM) practices, enhanced by smart technologies, in driving organizational performance within public pharmaceutical organizations. The study confirmed that KM practices positively influence operational efficiency and innovation. These results align with prior research (e.g., Obeso et al., 2020; Fullwood et al., 2019), highlighting KM's critical role in fostering knowledge sharing, streamlining operations, and enhancing organizational responsiveness. The present study extends this understanding by demonstrating how integrating AI and Industry 4.0 technologies amplifies the positive effects of KM. The influence of these technologies is particularly relevant in regulated industries such as pharmaceuticals, where compliance, precision, and timely access to information are crucial for effective decision-making.

The analysis revealed that KM practices have a direct and statistically significant impact on operational efficiency ($\beta = 0.42$, $p < 0.01$). This find-

Table 8. Summary of hypothesis testing results

Hypothesis	Description	Result
H1	Knowledge Management (KM) practices influenced by smart technologies positively impact organizational performance.	Supported
H1.1	Knowledge Management (KM) practices influenced by smart technologies positively impact Operational Efficiency.	Supported
H1.2	Knowledge Management (KM) practices influenced by smart technologies positively impact Innovation.	Supported
H2	Strategic Leadership moderates the relationship between KM practices (influenced by smart technologies) and organizational performance, enhancing the effects on Operational Efficiency and Innovation.	Supported

http://dx.doi.org/10.21511/kpm.09(1).2025.03

ing is consistent with the research of Schuppan (2009), who emphasized the role of knowledge-sharing mechanisms in improving operational workflows and reducing redundancies. Similarly, the work of Taherdoost and Madanchian (2023) highlights the potential of AI-driven KM tools to streamline decision-making and improve process efficiency. This study confirms and builds upon these insights by providing empirical evidence specific to the pharmaceutical sector. Operational efficiency in public pharmaceutical organizations is a key performance indicator, as it ensures the timely production and distribution of essential medicines. KM practices, such as collaborative knowledge sharing and smart technologies, facilitate smoother workflows and faster decision-making, ultimately leading to improved production timelines and better service delivery.

Innovation is another critical performance outcome explored in this study. The results established that KM practices significantly contribute to fostering innovation ($\beta = 0.35$, $p < 0.05$). This result echoes previous studies that underscore the role of knowledge exchange in driving innovation (Obeso et al., 2020; Fullwood et al., 2019). These studies emphasize that organizational learning and active knowledge flows encourage employees to develop creative solutions, thus promoting innovation. Additionally, AI and Industry 4.0 technologies further enhance this process by offering predictive insights, advanced data analytics, and automation, thereby reducing the time required for experimentation and increasing the success rate of innovative initiatives. This study builds on the work of Adreani et al. (2023), who found that Industry 4.0 tools support process innovation and enable real-time decision-making in public organizations. By incorporating KM-driven innovation within public pharmaceutical organizations, this study demonstrates how smart technologies can be leveraged to foster a culture of creativity and sustained innovation.

The moderating role of strategic leadership was also explored, revealing that leadership significantly strengthens the relationship between KM practices and organizational performance. Specifically, strategic leadership amplified the impact of KM on operational efficiency (interaction term: $\beta = 0.18$, $p < 0.05$) and innovation (interaction term: $\beta = 0.21$, $p < 0.05$). This finding aligns with prior research (Abdullahi et al., 2024; Buyannemekh et al., 2023) that highlights the essential role of leadership in shaping organizational values, fostering collaboration, and guiding employees toward shared goals. By acting as change agents, leaders play a crucial role in fostering a knowledge-oriented culture, promoting the use of smart technologies, and encouraging employees to actively engage in KM practices. The role of leadership as a moderator aligns with the findings of Todisco et al. (2023), who demonstrated that strong leadership positively influences employee well-being and work engagement in public sector organizations. This study extends their findings to the context of public pharmaceutical organizations, where strong leadership motivates employees and supports the successful implementation of KM practices and smart technologies.

While the findings of this study align with prior literature, certain unique insights are presented. For example, while most previous studies have examined KM practices in general organizational contexts, this study focuses on the public pharmaceutical sector, which operates in a highly regulated and dynamic environment. Integrating strategic leadership as a moderator also adds a new dimension to the literature. This integration highlights the importance of leadership in supporting KM-driven operational and innovation outcomes. Previous studies, such as those by Abdullahi et al. (2024) and Buyannemekh et al. (2023), have focused on the role of leadership in guiding KM initiatives, but this study emphasizes the direct moderating effect of leadership on the relationship between KM and performance outcomes.

Despite the important findings, certain limitations must be acknowledged. First, the study focused on five public pharmaceutical organizations in Cairo Governorate, and while this sample is representative of Egypt's public pharmaceutical sector, future research should explore a larger population or expand the analysis to private-sector organizations. Second, the cross-sectional design of the study limits the ability to

establish causality. Longitudinal studies could provide more robust insights into the dynamic interactions between KM, smart technologies, and leadership. Finally, the moderation effect of strategic leadership was established in this study, but future research could examine other potential moderators, such as organizational culture, employee readiness, or government support. Addressing these limitations could provide a more comprehensive understanding of the mechanisms through which KM practices influence organizational performance.

CONCLUSIONS

This study explored the impact of Knowledge Management (KM) practices, enhanced by smart technologies, on the organizational performance of public pharmaceutical organizations. The findings reveal that KM practices play a vital role in improving operational efficiency and fostering innovation. By promoting knowledge sharing, leveraging AI-based tools, and adopting Industry 4.0 technologies, organizations can streamline processes, enhance decision-making, and drive continuous improvement.

The study also highlights the moderating role of strategic leadership, which strengthens the relationship between KM practices and performance outcomes. Effective leadership fosters a collaborative environment, supports the integration of smart technologies, and encourages employee engagement in KM activities. This underscores the importance of aligning leadership strategies with KM initiatives to achieve sustainable performance improvements.

The study offers practical insights for policymakers and managers in the pharmaceutical sector, emphasizing the need for strategic leadership, smart technology adoption, and the effective implementation of KM frameworks. By doing so, organizations can enhance operational efficiency, accelerate innovation, and achieve sustained performance growth in dynamic and regulated environments.

AUTHOR CONTRIBUTIONS

Conceptualization: Talaat Rashad Shma, Muhanad Mahmoud, Adel Fathy Aziz, Abdelrehim Awad.
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Formal analysis: Abdelrehim Awad.
Methodology: Abdelrehim Awad.
Supervision: Abdelrehim Awad.
Writing – original draft: Talaat Rashad Shma, Muhanad Mahmoud, Adel Fathy Aziz, Abdelrehim Awad.
Writing – review & editing: Talaat Rashad Shma, MUHANAD MAHMOUD, Adel Fathy Aziz, Abdelrehim Awad.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this article, the authors used Neural Writer and Google AI Studio to improve its language and readability. After using these tools, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

Declaration of Competing Interest

None.

http://dx.doi.org/10.21511/kpm.09(1).2025.03

ACKNOWLEDGMENT

The authors are thankful to the Deanship of Graduate Studies and Scientific Research at the University of Bisha for supporting this work through the Fast-Track Research Support Program.

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http://dx.doi.org/10.21511/kpm.09(1).2025.03

APPENDIX A

QUESTIONNAIRE

Note: This questionnaire was originally distributed in Arabic; the following is its translated version for academic purposes.

INTRODUCTION

Dear Participant,

We appreciate your time and willingness to participate in this survey. This questionnaire is part of a scientific research study aimed at exploring the impact of Knowledge Management (KM) practices and smart technologies within public pharmaceutical organizations. The information you provide will be used solely for academic research, and all responses will be kept confidential. Your insights are invaluable in helping us understand key factors that contribute to operational efficiency, innovation, and sustainability in this sector. Thank you for your contribution.

Table A1. Questionnaire

Section	Question	Options
Demographic Information	1. Job Title	☐ Senior Manager ☐ Department Head ☐ IT Specialist ☐ KM Practitioner ☐ Operational Staff ☐ Other (please specify): _____
	2. Years of Experience in the Organization	☐ Less than 1 year ☐ 1-3 years ☐ 4-7 years ☐ More than 7 years
	3. Department	☐ Administration ☐ Operations ☐ Information Technology ☐ Research and Development ☐ Other (please specify): _____
	4. Level of Education	☐ High School ☐ Bachelor's Degree ☐ Master's Degree ☐ Doctorate ☐ Other (please specify): _____
Knowledge Management (KM) Practices	5. Frequency of Knowledge Sharing Activities in Your Department	☐ Daily ☐ Weekly ☐ Monthly ☐ Rarely ☐ Never
	6. Methods Used for Knowledge Sharing (select all that apply)	☐ Document Management Systems ☐ Collaborative Platforms ☐ Workshops and Training Sessions ☐ Informal Meetings ☐ Other (please specify): _____
	7. How Effective Do You Find KM Practices in Enhancing Decision-Making?	☐ Very Effective ☐ Effective ☐ Neutral ☐ Ineffective ☐ Very Ineffective
	8. Frequency of Participation in KM-Related Training	☐ More than once a month ☐ Once a month ☐ Every few months ☐ Rarely ☐ Never
	9. Extent to Which KM Practices Support Innovation in Your Work	☐ To a great extent ☐ To some extent ☐ Neutral ☐ To a little extent ☐ Not at all
	10. Level of Knowledge Retention Achieved by KM Practices	☐ Very High ☐ High ☐ Moderate ☐ Low ☐ None
Adoption of AI Tools and 4.0 Technologies	11. Level of AI Tool Usage in Your Daily Tasks	☐ High ☐ Moderate ☐ Low ☐ None
	12. Types of 4.0 Technologies Used in Your Department (select all that apply)	☐ Internet of Things (IoT) ☐ Big Data Analytics ☐ Automation ☐ Cloud Computing ☐ Other (please specify): _____
	13. Impact of AI Tools on Improving Workflow Efficiency	☐ Very High ☐ High ☐ Moderate ☐ Low ☐ None
	14. Extent to Which AI Supports Problem-Solving in Your Department	☐ To a great extent ☐ To some extent ☐ Neutral ☐ To a little extent ☐ Not at all
	15. Impact of 4.0 Technologies on Speed of Decision-Making	☐ Very High ☐ High ☐ Moderate ☐ Low ☐ None
	16. How Frequently Do You Receive Training on AI and 4.0 Technologies?	☐ Monthly ☐ Quarterly ☐ Biannually ☐ Annually ☐ Never

Table A1 (cont.). Questionnaire

Section	Question	Options
Strategic Leadership	17. Extent to Which Strategic Leadership Drives KM and Technology Integration	☐ Very Supportive ☐ Supportive ☐ Neutral ☐ Unsupportive ☐ Very Unsupportive
	18. Frequency of Communication from Leadership Regarding KM and Technology Goals	☐ Weekly ☐ Monthly ☐ Quarterly ☐ Rarely ☐ Never
	19. Level of Engagement in Strategic Planning for Technology Adoption	☐ Very High ☐ High ☐ Moderate ☐ Low ☐ None
Operational Efficiency, Innovation, and Sustainability Outcomes	20. Impact of KM Practices on Operational Efficiency in Your Department	☐ Very High ☐ High ☐ Moderate ☐ Low ☐ None
	21. Extent to Which AI and 4.0 Technologies Contribute to Reducing Redundancies	☐ To a great extent ☐ To some extent ☐ Neutral ☐ To a little extent ☐ Not at all
	22. Level of Innovation Enabled by KM Practices and Technology Adoption	☐ Very High ☐ High ☐ Moderate ☐ Low ☐ None
	23. Sustainability Initiatives Supported by KM Practices (select all that apply)	☐ Reducing Waste ☐ Energy Conservation ☐ Recycling Initiatives ☐ Environmental Awareness ☐ Other (please specify): _____
	24. Impact of Circular Economy-Aligned KM Practices on Sustainability in Your Department	☐ Very High ☐ High ☐ Moderate ☐ Low ☐ None
	25. Overall Integration of KM Practices with Sustainability Goals	☐ Excellent Integration ☐ Good Integration ☐ Moderate Integration ☐ Poor Integration ☐ No Integration

Thank you for your valuable input

Your responses are instrumental in advancing our understanding of how Knowledge Management practices and smart technologies can enhance organizational performance, innovation, and sustainability within the public pharmaceutical sector. Your participation is greatly appreciated.

http://dx.doi.org/10.21511/kpm.09(1).2025.03