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ENHANCING HOSPITAL MANAGEMENT THROUGH OPEN INNOVATION AND SMART TECHNOLOGIES DURING CRISES: MODERATION BY OPERATIONAL EFFICIENCY

Baraa Mustafa Hammoudi[1*]

[1]Ph. D Student, Public Health Ph. D. Program, Faculty of Public Health, Al-Quds University, Chief Operating Officer, Policlinico San Donato Spa, Milan, Italy.

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Corresponding Author: Baraa Mustafa Hammoudi ()

ABSTRACT

During a crisis, healthcare organizations have to overcome very tough difficulties, especially considering that, besides the uncertainty, they also have to cope with the disruption of their operations and the lack of resources. The research reveals that the combination of open innovation and smart technologies can be a major support for hospitals during emergencies; meanwhile, the moderating impact of operational efficiency, which contributes to the negative side, is also highlighted. The quantitativeness cross-sectional approach is used for collecting data from both public and private health institutions in Jenin, Palestine. The Partial Least Squares Structural Equation Modeling (PLS-SEM) technique was used to analyze the data. Open innovation and smart technologies hold unique opportunities enabling hospitals to greatly improve their systems for crisis intervention. In addition, operational efficiency is a strong factor that influences the inter-relationship, and the hospitals with the highest success rates are the ones that manage to create highly efficient processes to transform innovation and digital technology into effective crisis management results. The findings indicate that without the backing of excellent operation, new concepts and innovations in technology will not be able to generate good results all by themselves. The study positions itself as a big step forward in the treatment of healthcare literature because it provides a comprehensive model that connects hospital crisis management with novelties, smart technologies, and operational efficiency based on empirical data from a war-stricken region. Moreover, the findings present an opportunity for governmental policy-makers and healthcare system top executives to create strong and flexible systems that would be able to function well even under the toughest conditions.

KEYWORDS: Hospital Management During Crises; Open Innovation; Smart Technologies; Operational Efficiency; Healthcare Resilience.

1. INTRODUCTION

Healthcare systems all over the world are getting more and more vulnerable to very complicated crises such as pandemics, natural disasters, economic downturns, and political conflicts. These crises are putting hospitals under enormous stress, making it difficult for them to continue providing safe and high-quality care to patients, in addition to dealing with limitations of resources and disruptions to their operations. Healthcare organizations have gradually adopted open innovation along with intelligent technologies as a means for developing their strengths, flexibility, and operating efficiently (Pesqueira et al., 2025). To this effect, open innovation allows institutions to make use of the external knowledge, collaborations, and tech advancements that are outside of the organization, while the Smart Technologies (ST), such as Artificial Intelligence (AI), Internet of Things (IoT), and Big Data Analytics (BDA), will make the decision process data-based, automated, and responsive in real-time (Chesbrough, 2003; Liu et al., 2022).

Globally, the use of ST in hospital management has progressed quickly over the last ten years. AI applications were used in a variety of ways, from supporting clinical decision-making and optimizing resource allocation to automating administrative processes and increasing diagnostic accuracy (Khalifa et al., 2024). The real-time monitoring of patients, medical equipment, and hospital infrastructure has been made possible by IoT technologies, leading to better operational coordination and patient safety. On the other hand, BDA has made it possible for healthcare management to do an extensive analysis of huge data sets (clinical and operational) to improve forecasting, gain efficiency, and formulate better strategies (Al Teneiji et al., 2024; Sun et al., 2013). In crises like the COVID-19 pandemic, which were public health emergencies, hospitals that accepted the use of digital health technologies showed greater adaptability, preserved care uninterrupted, and demonstrated their strength, thereby highlighting the overall impact of tech innovation in extreme situations (Liu et al., 2022).

A long-existing industry in the old world, the necessity for the old concept of 'health' has brought big changes to every nook and cranny of healthcare in the wake of the outbreak of COVID-19. OI stresses partnerships with the outside world, like tech partners, universities, NGOs, and even government agencies, to speed up innovations and get rid of the restrictions of internal capacity (Chesbrough, 2003). During crises, healthcare organizations very often do not have the time, resources, or skills to come up with solutions on their own, which is why OI is very important for quick problem-solving and adaptive responses. Recent research has shown that OI practices greatly improve organizational flexibility and crisis responsiveness in the case of healthcare (Elia et al., 2022).

In developing regions and regions affected by conflicts, ST pose more challenges to the healthcare systems at the regional level. The process of digital transformation is often marred by a lack of proper infrastructure, limited funds, uncertainty with regulations, and untrained/under-skilled professionals. However, there is proof that when smart technologies are used in a proper manner and supported by good governance and operational capabilities, they can provide considerable benefits even in such difficult situations (Pereira et al., 2018). In the Middle East and other places with limited resources, there has been a growing interest in the use of digital health innovations as a way to reduce the impact of systemic weaknesses and enhance healthcare delivery during times of instability (Ali et al., 2025).

The Palestinian healthcare system is a very complicated and a very delicate situation. Along with these factors, the population's access to healthcare in Palestine faces most of the above-mentioned limitations, that is, the lack of proper infrastructure, an insufficient number of medical staff, and la ack of proper and timely supply of medicines and other medical supplies. Hospitals in Palestine are often in a state of emergency, facing shortages of medical supplies, interruptions of electricity, and damage to infrastructure, and they also have sudden increases in patients during times of conflict (WHO, 2024). The situation in the West Bank and Gaza Strip was already difficult because of these challenges, but the conflict that escalated after the events of October 2023 made it worse, putting hospital management and service delivery under a lot of pressure for the first time (HumanRightsWatch, 2002).

Palestinian hospitals, which are functioning in this difficult situation, have begun to increasingly rely on digital tools and informal innovations to continue their services. Studies that have focused on the healthcare delivery system during the wars in Gaza and the West Bank have shown doctors and medical staff's massive reliance on electronic medical records, teleconsultation, mobile communication platforms, and data sharing practices to reduce the problems of limited access and fewer staff (Haimi, 2024). Nevertheless, the healthcare IT projects of this nature are often, in the end, disjointed, poorly supported, and disconnected from the hospital information systems, which has the effect of lessening their impact over the years.

The healthcare institutions in the northern West Bank, especially the hospitals in Jenin, have shown the problems the Palestinian healthcare sectors have to face at the time of political turmoil. The hospital, situated in a conflict zone, has to simultaneously provide emergency care, regular medical services, and deal with the consequences of the crisis. The war in October 2023, along with the later changes in stability, highlights the necessity of strong hospital management systems that would do exceptionally well even in the least predictable environments (UNRWA, 2025). Under such conditions, it is the strategic incorporation of smart technologies together with OI practices that may serve as a means to improve hospital performance, responsiveness, and sustainability.

Even though there are more and more people who are interested in digital health and innovation in Palestine, the joint impact of smart technologies and OI on hospital management during political crises has not been widely researched through empirical means. Additionally, the understanding of Operational Efficiency (OE) as a moderating factor in the translation of technological adoption into better management outcomes has not been given enough scholarly attention. OE is of utmost importance in crisis situations since the unavailability of resources makes the effects of inefficiency and poor coordination worse. Hence, it is necessary both for theory and practice to know the extent of the impact of smart technologies when the locus is efficiency.

2. LITERATURE REVIEW

Crisis hospital management is the ability of hospitals to go through extreme and unpredictable situations like wars, pandemics, or major disasters and still operate effectively, provide services, and give quality care. The normal operation of the hospitals is changed and disturbed by crises, which result in huge numbers of patients, destruction of facilities, scarcity of supplies, and reduction in the number of available workers (WHO, 2024). It is thus a prerequisite that the hospital in crisis management has quick decision-making, inter-departmental coordination, flexible resource allocation, and leadership with a resilience focus.

Conflicting situations in the territories where hospitals operate lead to constant instability and poor operations in the hospitals due to reasons like political insecurity, restrictions on movements, and uncertain funding (Abuzerr et al., 2025). In Palestine, hospitals frequently function as if they are under emergencies, even outside the peak conflict times, making crisis management a constant and not a temporary challenge (MSF, 2025). Improvisation, informal coordination, and the adaptive use of limited technological resources are among the main methods hospitals in Palestine employ to deal with the severe shortage of resources (Sabateen et al., 2022; WHO, 2024). The conclusion of this study further authenticates these claims of innovative approaches along with IT-enabled administration.

Chesbrough (2003) Open Innovation theory postulates that using external specialists and collaborative efforts can be a purposeful approach to hasten innovation cycles and boost organizational effectiveness. Open innovation is coming up in the healthcare sector, which allows hospitals to collaborate and share research, technology, and solutions with academic institutions, tech companies, startups, NGOs, and international players, among others, that they would have otherwise been unable to access (Secundo et al., 2019). At times when time, resources, and internal capacities are limited, such an approach might really help.

Research and thorough investigations assert that the open innovation process indeed enhances the resilience and adaptability of the healthcare system. In the same year, Scotti et al. (2022) indicated that hospitals applying open innovation in the course of the COVID-19 pandemic have been not only more flexible but also quicker to adopting digital solutions. In the same way, innovative collaboration, like public-private partnerships and cross-sector data sharing, improved crisis response capabilities significantly. Open innovation additionally leads to knowledge spread, lower innovation risk, and faster solving of problems characterized by uncertainty (Lazarenko, 2019).

Open Innovation is necessary in fragile and conflict-affected contexts even more (Ghossein & Rana, 2022). The case of the Palestinian healthcare providers is a good example where they relied on external collaborations to implement telemedicine platforms, digital record systems, and emergency coordination tools during times of increased conflict. Nevertheless, the study by Dolcini et al. (2025) pointed out that most of these initiatives were not even officially integrated into hospitals' management systems, which is a factor that curtailed their sustainability. Thus, the need arises for the role of open innovation to be empirically explored in terms of the strengthening of hospital management during crises.

ST is regarded as the main factor behind the change that hospitals have undergone during the present time. They allow the hospitals to operate with real-time data, thus characterizing the decision-making process based on evidence and the efficient performance of the whole organization (Kwon et al., 2022). The study is centered around three basic smart technologies: AI, IoT, and BDA.

AI is the term used for the technologies that can carry out activities like learning, prediction, recognition of patterns, and support in decision-making, which are usually performed by humans. In the management of hospitals, the areas of AI application are predictive patient flow modeling, automated scheduling, clinical decision support, and risk stratification. AI has been proven to be more accurate, less labor-intensive, and to have a positive impact on the quality of managerial decisions (Falebita & Kok, 2024b).

Recent studies in healthcare demonstrated the same, that in the case of AI, all the positive effects on operational performance happen when users have the perception that it is useful and easy to use, which corresponds with the Technology Acceptance Model (TAM). In their study, Ayed et al. (2025) found that nurses in Palestine accepted AI to a moderate extent but raised questions concerning training, trust, and ethical issues. These results imply that the potential of AI in crisis hospital management is significant but still highly dependent on the context for its effectiveness.

The IoT is a network made up of devices and sensors that are interconnected, allowing the continuous gathering and sharing of data throughout the hospital system. The application of IoT in hospitals includes the following: monitoring patients remotely, intelligent medical equipment, tracking of assets, and monitoring of the environment. Besides, IoT enhances crisis management with better situational awareness, faster response, and support coordination (Horita et al., 2023).

Sun et al. (2013) put forward a very detailed framework and recognized the previously mentioned factors of technology, security, interoperability, and user skills as the primary determinants in the area of IoT adoption in healthcare. During emergencies, IoT systems are supposed to be a blessing for hospitals by allowing them to carry out remote monitoring when no one is there to do it physically. Nevertheless, unstable infrastructure, the risk of cybercrime, and a lack of technical support remain the major challenges in war-torn areas (Kunju, 2024).

BDA is a precise method that primarily employs advanced computational resources and methods to uncover and highlight useful information in very big and complicated data sets. In hospital management, BDA is a great help in forecasting demand, optimizing the supply chain, monitoring performance, and strategic planning, etc. Also, during difficult times, BDA still acts as a hospital's partner in resource prediction, patient flow management, and response effectiveness evaluation (Al Teneiji et al., 2024).

A systematic review by Al Teneiji et al. (2024) has recently pointed out that such elements as technology infrastructure, management support, analytical capabilities, and the environment greatly influenced the BDA adoption in healthcare (Alzaabi et al., 2023). Political and regulatory conditions were among the recognized constraints and were considered very significant external barriers, especially in the unstable regions. Sohail Khan and Siddiqui (2023) confirmed that a lack of organizational readiness could result in BDA investments being completely transformed into performance losses instead.

OE signifies the hospital's capacity to enhance its internal procedures, reduce waste to the bare minimum, and make good use of resources (Yaduvanshi & Sharma, 2017). In a crisis, efficiency is not only a performance result but rather a crucial factor that decides if innovations and technologies can be of any value. Efficient hospitals have a better chance of accepting new technologies, unifying different departments, and quickly reacting to accidents or disasters. Less efficient operations in hospitals with conflict are made worse by outside limitations like a lack of manpower, destruction of facilities, and interruption of supplies (Lowe et al., 2021). It indicates that OE might be a significant intermediary that either strengthens or diminishes the role of open innovation and smart technologies in crisis hospital management.

2.1. Open Innovation (OI) And Hospital Management During Crises

OI extends beyond internal technological capability by emphasizing the strategic use of external knowledge, partnerships, and collaboration to drive innovation (Chesbrough, 2003). The importance of OI in the context of the health sector crisis management can be, as a whole, explained by the Dynamic Capabilities Theory, which states that organizations can combine, create, and redeploy internal and external resources to adapt smoothly to change in the environment (Teece et al., 1997). During crises, hospitals have to keep on making changes anew to their processes, technologies, and service delivery models; thus, the existence of dynamic capabilities becomes vital for survival and the gaining of efficacy.

Through OI, hospitals receive access to outside know-how, technologies, and resources, and thus the dynamic capabilities of OI are further strengthened. It helps very much in the case of Palestine, which is suffering from conflicts and where hospitals have to face the problems of poor funding, damaged infrastructure, and a lack of staff. Collaboration with NGOs, technology suppliers, universities, and international organizations makes it possible for the hospitals to overcome their internal limitations and to speed up innovation in times of emergency.

According to the Resource-Based View (RBV), open innovation is still a great asset for hospital management. The RBV theory argues that companies can maintain their competitive edge by managing their resources in a way that makes them valuable, rare, inimitable, and non-substitutable (Barney, 1991). In times of crises, organizations would mainly depend on knowledge, technology, and collaboration as their major resources. Open innovation not only helps hospitals access more resources but also makes them capable of better management and more resilient. Previous research has made it clear that those health care organizations that have adopted open innovation are continually adaptable, have quicker crisis resolution, and have enhanced operational coordination (Liu et al., 2022).

H1: Open Innovation has a positive and significant effect on Hospital Management during Crises.

2.2. Smart Technologies (ST) And Hospital Management During Crises (HMC)

The barriers of technological adoption and the circumstances in which they could be overcome have been the subject of a great amount of research. One such theory that focuses on the pace of new technology diffusion is the Innovation Diffusion Theory (IDT), which categorizes the main determinants of the adoption process into five groups: perceived relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2003). During a crisis, the adoption of smart technologies like AI, IoT, and BDA in hospital management has an evident advantage with regard to faster decision-making, real-time monitoring, predictive analytics, and automating operational processes. Further, unlike technologies that are used internally in the hospital, networks have sidewalk, organizational, or empirical impact.

The underpinnings of the IDT, the Technology-Organization-Environment (TOE) framework, explicate in detail the factors affecting the adoption of new technology. One of the major advantages of the framework is that it illustrates the different aspects of the technology, the organization, and the environment by emphasizing the organization's competencies, the environmental impact, and the technological maturity (Tornatzky et al., 1990). During a crisis, hospitals will be dealing with powerful environmental forces like political unrest, an increase in patients, and problems with supplies, making it essential to have digital solutions. The digital business solutions would therefore provide relief to the existing systems for the patient flow and treatment. The TOE model indicates that hospitals endowed with excellent technology infrastructure, skilled personnel, and sound management will successfully embrace smart technologies. A similar situation can be seen in Palestine, where the conflict has affected the adoption of smart technologies negatively due to insufficient organizational readiness and environmental constraints (Baker, 2011; Yee-Loong Chong et al., 2009).

Theories based on observation continually show that introducing intelligent technologies to hospitals brings about a change in performance for the better by improving coordination, cutting response times, resource allocation, balancing, and making evidence-based decisions easier (Al Teneiji et al., 2024; Sun et al., 2013). In a crisis these advantages are doubled as hospitals will be dealing with uncertainty and at the same time having very limited resources. So, the present research suggests that smart technology uptake has a favorable impact on hospital management in crises.

H2: Smart Technologies (Artificial Intelligence, Internet of Things, and Big Data Analytics) have a positive and significant effect on Hospital Management during Crises.

2.3. Operational Efficiency (OE) As A Moderating Variable

OE is a key capability of an organization that affects the extent to which hospitals, especially in crisis, convert innovative projects and technological investments into better management outcomes. In the healthcare industry, operational efficiency means the most effective utilization of resources, human resources, machines, time, and money, so that the services rendered are of the highest value and have the least waste. During crises like armed conflicts and human emergencies, hospitals still have to become even more efficient since they suddenly face increased patient numbers, interruptions in their infrastructure, and drastic reductions in their resources (Sameri et al., 2025).

Lean Management Theory, when viewed from a theoretical point of view, gives a solid foundation for recognizing the importance of operational efficiency in the health care industry. Central to lean management are the concepts of waste removal, process enhancement, constant improvement, and patient value delivery. Research in healthcare environments confirms that lean practices lead to better patient movement, shorter waiting times, improved collaboration, and stronger organizational adaptation to crises (D'Andreamatteo et al., 2015). The hospitals whose workflows are efficient can absorb shocks better and respond to rapid changes in operational processes during crises, thus making them get more and faster the benefits of innovative practices and use of new technologies.

In addition, Dynamic Capabilities Theory considers operational efficiency as a way that increases an organization's ability to reorganize both internal and external resources in fast-changing environments (Teece et al., 1997). OI and ST, although they grant access to a plethora of new knowledge, tools, and capabilities, are reliant on the internal efficiency of the healthcare organization. Inefficient processes, fragmented workflows, and poor interaction can cause the integration of external innovations and digital systems to be slow or even ineffective, thus minimizing their potential to positively affect the performance of hospital management.

The moderating influence of OE on ST outcomes is supported by empirical evidence. Wang et al. (2019) revealed that healthcare firms practicing BDA and having process efficiency levels that are higher than average fetched significantly more benefits out of the analytics, as efficient workflows were the main facilitators of data usage and decision-making. Likewise, research on digital transformation in the healthcare sector proposes that operational efficiency makes the smart technologies even more effective by allowing easier adoption, more user engagement, and better integration of systems, thus leading to reliability (Kitsios & Kapetaneas, 2022).

In cases of crisis and conflict, like the situation with Palestine, the operational inefficiencies are usually worsened externally by factors like the shortage of staff, infrastructure destruction, power outages, and interruption of supply chains. Such a scenario may hinder the hospitals from reaping the benefits of open innovation partnerships or smart technology investments. Nevertheless, hospitals that have managed to keep their operations fairly efficient through well-defined processes, good communication, and resource optimization are more ready to use outside partnerships and digital tools to maintain management performance even in crises (Ali et al., 2025).

Therefore, OE has been theorized as a moderating variable in this research that affects the intensity of the link between OI, ST, and hospital management in times of crisis. The hospitals with high OE are anticipated to have a smooth and effective integration of external innovations and ST, thereby resulting in the best possible management outcomes. On the contrary, the hospitals with low operational efficiency may weaken these relationships by restricting the implementation and utilization capacity.

H3: Operational Efficiency moderates the relationship between Open Innovation and Hospital Management during Crises, such that the relationship is stronger when Operational Efficiency is high.

H4: Operational Efficiency moderates the relationship between Smart Technologies and Hospital Management during Crises, such that the relationship is stronger when Operational Efficiency is high.

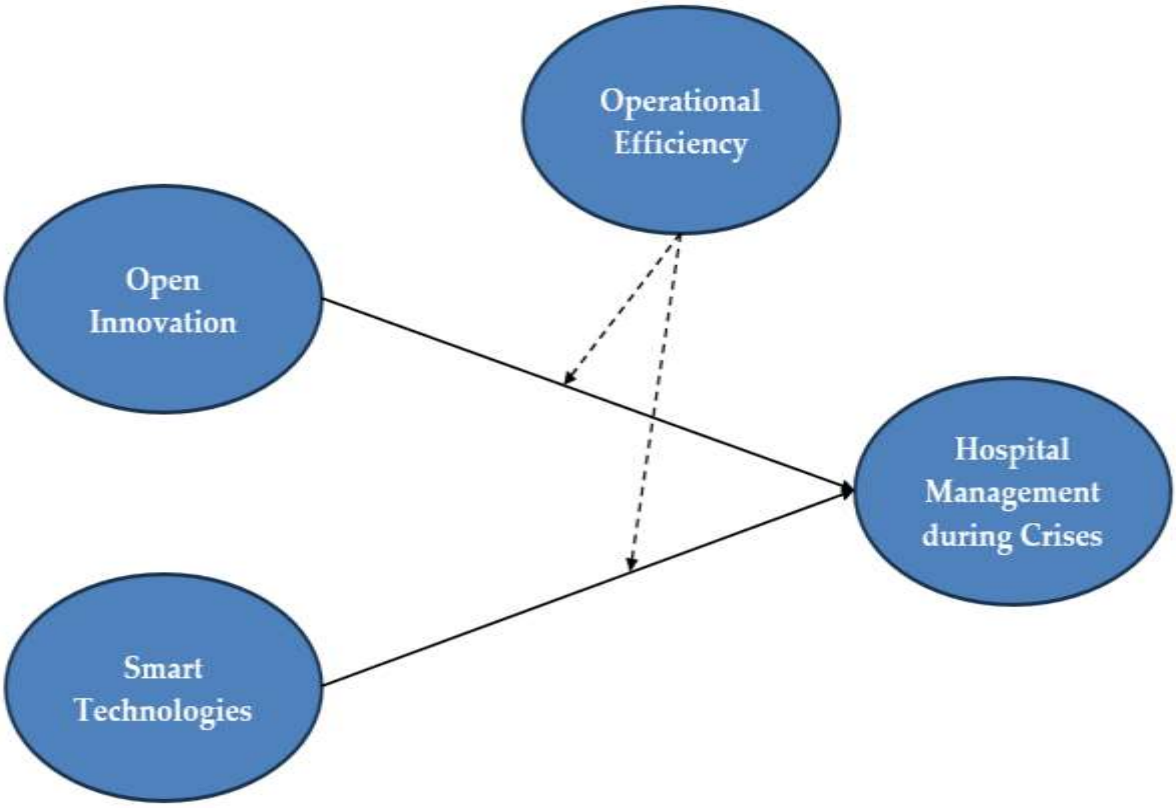

Figure 1: Study Framework.

3. METHODOLOGY

3.1. Method

This research has taken a quantitative, cross-sectional design to investigate the interrelationships of open innovation, smart technologies, operational efficiency, and hospital management during crises empirically. A cross-sectional design was considered fitting as it provides the chance to gather the data from a big sample at one specific time, thus making it possible to conduct statistical tests on the hypothesized relationships between the variables. This design is very common among studies of healthcare management and innovation for its effectiveness and convenience in understanding the organizational perception and practices. The research was carried out in two hospitals in Jenin, Palestine. These hospitals are a representation of the two sectors of healthcare: Ibn Sina Specialized Hospital (private) and Jenin Governmental Hospital (public). The combination of different hospital types increases the applicability of the results to the general public and provides a better understanding of the management practices in hospitals during times of crises.

3.2. Population And Sample Size

The focus of the study was on the entire personnel working in the chosen hospitals. The overall size of the population was around 900 workers. The Raosoft® sample size calculator was used to obtain the minimum number of subjects necessary for conducting a research study that would be both representative and statistically significant. The computation was performed with a 95 percent confidence interval, a 5 percent margin of error, and a 50 percent response distribution, which is recommended for populations with unknown variability. Together, these factors indicated a minimum sample size of 270 respondents. However, the sample size is still considered to be a good compromise between reliability and statistical validation, and it also gives a fairly high degree of precision for the research.

3.3. Measurement Of Study Variables

A complete instrument made up of 57 items extracted from previously validated methods applied in empirical research has been utilized to assess all variables involved in the study. The use of reliable measurement scales not only boosts the acceptability of the research model but also its reliability. A five-point Likert scale, from (1) Strongly Disagree to (5) Strongly Agree, was applied to assess each item in the survey. This approach is widespread in quantitative health management and innovation research, thus allowing for a trustworthy statistical analysis and a comparison between constructs.

ST obtained their measurement via three dimensions comprising 23 indicators: AI, IoT, and BDA. The AI dimension was measured with five indicators adapted by Falebita and Kok (2024a). The IoT dimension was made up of nine indicators developed by Sun et al. (2021). For the BDA dimension, 9 indicators were adapted from Sohail Khan and Siddiqui (2023). 8 indicators from Popa et al. (2017) were used to scale up OI strategies and were divided into two dimensions, Inbound Open Innovation (IOI) and Outbound Open Innovation (OOI). OE was evaluated using five indicators based on Ugwu and Ugwu (2024). Hospital Management during Crises (HMC) was evaluated through 21 indicators that were modified and translated into English from Touati (2021). The scale comprises three dimensions: Crisis Management Planning (CMP), Availability of Data and Information (ADI), and Effectiveness of Decision-making (EDM).

3.4. Data Analysis Techniques

Initially, the research employed several quantitative methods to perform data analysis. Subsequently, the validity and reliability of the measures were confirmed to corroborate the proposed hypotheses. Different methods were applied by the researchers to calculate and compute various measures of central tendency and dispersion, such as means, standard deviations, frequencies, and percentages, which gave a very clear picture of the main research variables and the demographic distribution of the participants. Besides creating a main profile of the sample, this procedure also pointed out some common behavioral patterns among the participants (Altukhi & Aljohani, 2024).

Second, a reliability analysis using Cronbach's alpha was conducted to assess each construct's internal consistency. Hair Jr et al. (2021) stated that reliability was acceptable when the Cronbach's alpha values reached 0.70 or above. Subsequently, Confirmatory Factor Analysis (CFA) was utilized for the treatment of the measurement model. CFA ascertains construct validity by confirming that the observed indicators precisely reflect the related latent variables. This technique not only gives the measurement model more credibility but also provides evidence for convergent and discriminant validity as well (Sujati & Akhyar, 2020).

Finally, a structural equation modeling (SEM) and SmartPLS software, which was preferred because of its ability to handle intricate models and medium-sized samples, were drawn upon for testing the hypothesis (Kline, 2023). To appraise the significance of the direct relationships, standardized path coefficients (β) and p-values were utilized. Furthermore, SEM was applied to determine the moderating influences (Preacher & Hayes, 2008).

4. RESULT

4.1. Descriptive And Model Assessment

The necessary measurement model assessment and descriptive statistics for one-dimensional and two-dimensional constructs are presented in Table 1. The summarizing outcomes confirm the model's aptness for the subsequent PLS-SEM analysis of the structural model, as they provide a solid empirical basis for the proposed measurement model's strength and sufficiency (Hair Jr et al., 2021).

Outer loadings functioned as the measure for the indicators' reliability. The indicator variables were proper enough to bring out the corresponding latent variables, as most of the indicators recorded loadings that were above the minimum limit of 0.70. Few items, however, had their loadings recorded at lower values than this threshold (for example, AI4, BDA5, CMP6, and ADI1). Nonetheless, the decision was made to keep these indicators in the model based on their theoretical importance and their role in ensuring content validity since their presence did not affect the overall reliability or AVE.

To conduct internal consistency-based reliability analysis, two methods were used: Cronbach's alpha (α) and Composite reliability (CR). The obtained values of α and CR for every construct were higher than the minimum permissible limits set at 0.70, and the CR values varied from 0.718 to 0.953, indicating that the internal consistency across constructs was very good. Collinearity was evaluated through the use of the variance inflation factor (VIF) values. All the VIF values remained underneath the strict threshold of 5.0, thus confirming that there are no serious multicollinearity problems among the indicators.

The application of descriptive statistics uncovers the fact that the average of different constructs is between moderate and high levels, which implies that ST, OI, OE, and HMC were perceived positively as a whole. The variability of standard deviation values is a measure of how much the respondents' perceptions vary, and it is a variability that can be considered acceptable.

Table 1: Descriptive And Model Assessment Results.

Construct	Item	Loadings	VIF	Mean	STD	α	CR	AVE
Smart Technologies (ST)								
Artificial Intelligence (AI)	AI1	0.839	2.97	2.452	1.181	0.885	0.917	0.691
	AI2	0.899	3.28	2.504	1.144			
	AI3	0.868	3.382	2.404	1.137			
	AI4	0.657	1.713	2.637	0.997			
	AI5	0.803	3.978	2.589	1.141			
Internet of Things (IoT)	IoT1	0.817	2.635	2.659	1.136	0.944	0.953	0.692
	IoT2	0.854	3.019	2.589	1.128			
	IoT3	0.825	2.678	2.581	1.132			
	IoT4	0.836	2.888	2.648	1.135			
	IoT5	0.836	3.205	2.73	1.147			
	IoT6	0.887	4.757	2.615	1.125			
	IoT7	0.748	2.099	2.856	1.067			
	IoT8	0.819	2.683	2.537	1.063			
	IoT9	0.855	3.644	2.596	1.104			
Big Data Analytics (BDA)	BDA1	0.859	3.049	2.548	1.076	0.823	0.844	0.614
	BDA2	0.838	3.295	2.4	1.066			
	BDA3	0.798	2.776	2.626	1.056			
	BDA4	0.811	2.515	2.726	1.115			
	BDA5	0.647	1.828	3.344	1.027			
	BDA6	0.613	2.453	3.256	1.01			
	BDA7	0.666	3.298	3.578	0.915			
	BDA8	0.656	2.97	3.704	0.87			
	BDA9	0.67	1.641	3.941	0.876			
Open Innovation (OI)								
Inbound Open Innovation (IOI)	IOI1	0.792	1.683	3.641	0.943	0.792	0.866	0.62
	IOI2	0.856	2.353	3.789	0.796			
	IOI3	0.815	2.152	3.822	0.824			
	IOI4	0.765	1.215	3.452	1.059			
Outbound Open Innovation (OOI)	OOI1	0.836	2.61	3.367	1.062	0.823	0.888	0.673
	OOI2	0.722	4.273	3.419	1.039			
	OOI3	0.866	2.117	3.237	1.073			
	OOI4	0.886	1.148	3.744	0.988			
Hospital Management during Crises (HMC)								
Crisis Management Planning (CMP)	CMP1	0.655	1.569	3.341	1.052	0.629	0.718	0.555
	CMP2	0.758	2.612	3.53	1.134			
	CMP3	0.777	2.681	3.63	1.137			
	CMP4	0.755	1.805	3.767	1.051			
	CMP5	0.837	2.178	3.685	1.068			
	CMP6	0.621	1.755	3.33	1.021			
	CMP7	0.659	1.426	3.233	0.974			
Availability of Data and Information (ADI)	ADI1	0.615	1.472	3.111	1.045	0.794	0.851	0.643
	ADI2	0.783	2.131	3.581	1.003			
	ADI3	0.722	2.025	3.326	1.128			
	ADI4	0.669	1.759	3.344	1.031			
	ADI5	0.196	1.414	3.441	1.093			
	ADI6	0.612	1.269	3.026	1.133			
	ADI7	0.807	3.936	3.878	0.937			
	ADI8	0.809	4.196	3.981	0.832			
Effectiveness of Decision-making (EDM)	EDM1	0.849	3.749	4.037	0.954	0.916	0.935	0.705
	EDM2	0.805	2.753	3.922	0.876			
	EDM3	0.9	4.654	3.933	0.854			
	EDM4	0.867	3.516	3.9	0.822			
	EDM5	0.822	2.731	3.981	0.836			
	EDM6	0.789	2.588	4.063	0.807			
Operational Efficiency (OE)	OE1	0.85	2.313	3.6	0.921	0.898	0.924	0.709
	OE2	0.853	2.293	3.511	1.057			
	OE3	0.855	3.022	3.633	0.875			
	OE4	0.812	2.948	3.815	0.883			
	OE5	0.884	3.023	3.652	0.941			

4.2. Discriminant Validity

Discriminant validity concerns the degree to which a certain construct is objectively different from the measurement model's other constructs. It is thereby very important to achieve discriminant validity, which enables one to identify clearly the theoretical concepts corresponding to each latent variable, besides making sure that the indicators do not have a high correlation with the constructs they are not meant to measure. Discriminant validity was evaluated in this research using two very popular and accepted methods: the Fornell–Larcker and the Heterotrait–Monotrait (HTMT) ratio. The implementation of both methods offers an inclusive and solid judgment of the uniqueness of the constructs (Fornell & Larcker, 1981).

According to the Fornell–Larcker criterion, the discriminant validity is determined if the square root of the AVE of every construct (presented on the diagonal) is greater than all its correlations with other constructs. Table 2 presents that the diagonal values of all constructs are greater than the corresponding inter-construct correlations in their respective rows and columns, so the discriminant validity is confirmed to be very good. This result reinforces the notion that every construct has more variance in common with its indicators than with the other models.

Moreover, the HTMT ratio, which is deemed a stricter and more reliable criterion, was employed to probe into the discriminant validity even deeper. The HTMT ratios for each duo of constructs are not only below the suggested limit of 0.85 but also significantly lower than the less strict cutoff level of 0.90. This points out that there are no significant problems with the constructs being mixed up, and all the latent variables are, in fact, completely distinct from one another.

Table 2: Discriminant Validity Results.

Fornell & HTMT	ADI	AI	BDA	CMP	EDM	IOI	IoT	OOI
ADI	0.665	0.265	0.28	0.661	0.683	0.425	0.23	0.478
AI	0.347	0.831	0.763	0.248	0.097	0.102	0.852	0.48
BDA	0.437	0.75	0.644	0.277	0.031	0.176	0.838	0.592
CMP	0.909	0.355	0.422	0.596	0.422	0.222	0.203	0.467
EDM	0.745	0.122	0.274	0.517	0.839	0.524	0.002	0.268
IOI	0.513	0.207	0.562	0.331	0.616	0.788	0.102	0.505
IoT	0.315	0.926	0.791	0.28	0.094	0.205	0.832	0.541
OOI	0.629	0.554	0.742	0.657	0.321	0.614	0.608	0.82

4.3. Structural Model Assessment

The evaluation of the structural model was directed towards the understanding of the inferred relationships between the hidden variables. The researchers applied four basic criteria for a thorough analysis: multicollinearity assessment, coefficient of determination (R^2), predictive relevance (Q^2), and effect size (f^2). These together, these tests provide comprehensive insight into the model’s explanatory power, predictive accuracy, and the relative importance of the structural paths (Chin, 1998; Hair Jr et al., 2021).

The values of VIF were employed at the structural level to detect the presence of multicollinearity. Since all the VIF values were under the threshold, it could be inferred that collinearity will not influence the estimation of path coefficients and that the correlations between predictors are trustworthy from a statistical viewpoint.

The R^2 was the indicator that determined the amount of variance in the model that could be explained. The R^2 values shown in the table 3 confirm a strong explanatory power for the majority of the endogenous variables. HMC's R^2 value was 0.415, meaning that 41.5% of the variance in the performance of crisis management is explained in a moderate to substantial way by open innovation, smart technologies, operational efficiency, and their interaction effects in total. Moreover, ADI, CMP, and EDM achieved R^2 values of 0.797, 0.517, and 0.814 that were quite high, respectively. This seems to suggest that HMC is a very good predictor of these crisis management layers. OI has shown an unbelievably high R^2 value of 0.993, which demonstrates the outstanding explanatory power of IOI and OOI practices.

The prediction accuracy of the model was indicated by the low RMSE and MAE values that were found for all the endogenous constructs, which were interpreted as a good fit between the predicted and observed values and as a confirmation of the model's stability.

The examination of Q^2 was done through the Stone-Geisser Q^2 value derived from the blindfolding method. The Q^2 values reported for all the endogenous constructs were greater than zero, thus confirming the model's predictive relevance. Specifically, HMC (Q^2 = 0.377), ADI (Q^2 = 0.344), CMP (Q^2 = 0.242), and EDM (Q^2 = 0.265) represent the medium to strong range of predictive capacity. The extremely high Q^2 value for OI (0.992) serves as a further indication of the strong predictive power of its antecedents.

Finally, the f^2 value was computed to assess the influence of the exogenous variables on the endogenous ones in relative terms. The connections from HMC to ADI (f^2 = 3.925), CMP (f^2 = 1.071), and EDM (f^2 = 4.367) exhibited extraordinarily large effect sizes. The critical role of effective hospital crisis management in increasing data availability, planning capabilities, and decision-making effectiveness is thus clearly pointed out. If we talk about the antecedents of HMC, OI (f^2 = 0.209) and OE (f^2 = 0.146) show medium effect sizes, while ST has a small direct effect (f^2 = 0.023). The interaction effects of OE with ST (f^2 = 0.048) and with OI (f^2 = 0.032) indicate small but significant moderating influences. Besides, both IOI and OOI impact OI with extremely large effects, having f^2 values of 48.96 and 18.903, respectively.

Table 3: Fit Model Results.

Construct	R2	R2 adjusted	Q²	RMSE	MAE	F2 Path	F2 Result
ADI	0.797	0.796	0.344	0.817	0.58	HMC → ADI	3.925
CMP	0.517	0.515	0.242	0.869	0.702	HMC → CMP	1.071
EDM	0.814	0.813	0.265	0.867	0.627	HMC → EDM	4.367
HMC	0.415	0.404	0.377	0.793	0.568	OI → HMC	0.209
						OE → HMC	0.146
						OE × ST → HMC	0.048
						OE × OI → HMC	0.032
						ST → HMC	0.023
OI	0.993	0.992	0.992	0.088	0.067	IOI → OI	48.96
						OOI → OI	18.903

4.4. Hypotheses Testing

Testing the proposed connections using the path coefficient test is the last stage in the structural model evaluation. Hair Jr et al. (2021) state that bootstrapping methods using 5,000 subsamples were used to evaluate the proposed hypotheses. Figure 2 presents the findings of the study's hypotheses and demonstrates how the inner model values represent the outcomes of the hypothesized relationships in the path analysis.

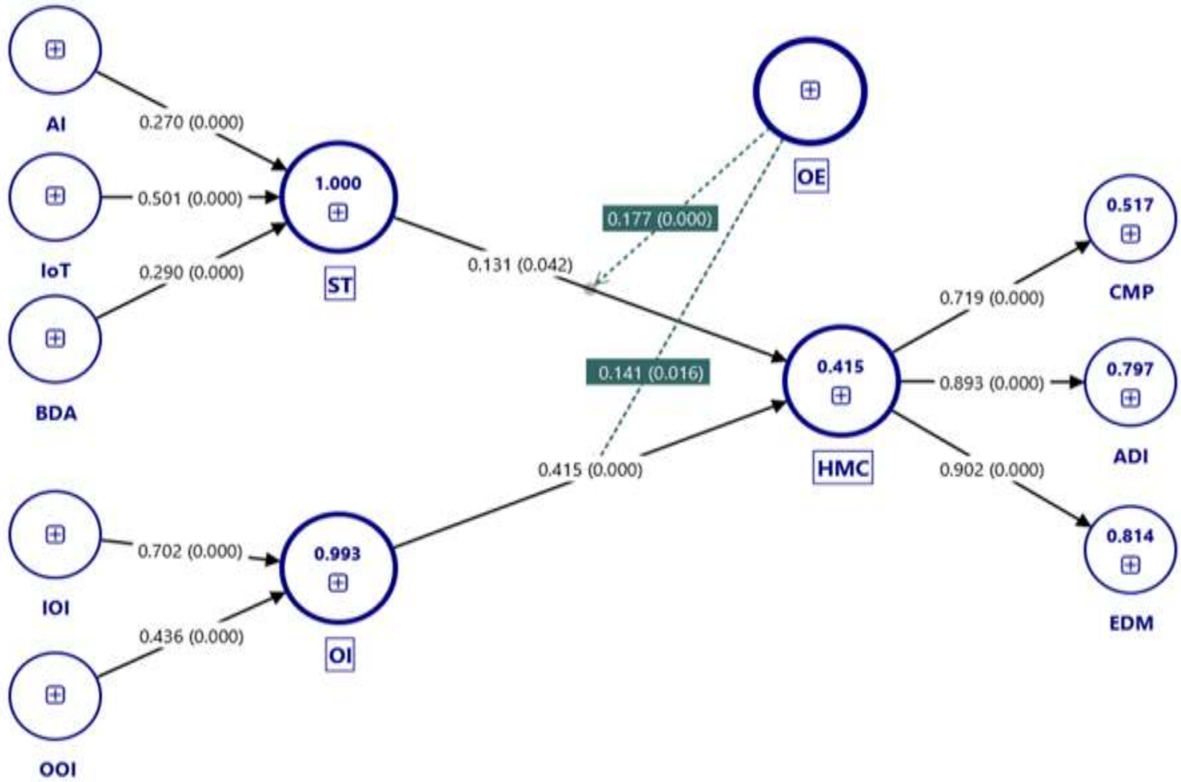

Figure 2: Results of Path Analysis

4.5. Results Of the Hypothesis

The hypotheses were examined using the PLS-SEM bootstrapping procedure to test both the direct and moderating (interaction) effects among the study constructs. The results of the hypothesis testing are presented in Table 4 and provide strong empirical support for the proposed theoretical framework.

With respect to the primary impacts, the findings show that Open Innovation (OI) considerably supports and statistically confirms Hospital Management during Crises (HMC) (β = 0.415, t = 6.156, $p < 0.001$), thus providing evidence for H1. The result affirms the pivotal importance of open innovation practices in the effective crisis management of hospitals.

Furthermore, the disaggregated evaluation of the smart technologies (ST) shows that Artificial Intelligence (AI) (β = 0.035, t = 1.754, p = 0.040), Internet of Things (IoT) (β = 0.065, t = 1.719, p = 0.043), and Big Data Analytics (BDA) (β = 0.038, t = 1.709, p = 0.044) all positively and significantly influence Hospital Management during Crises (HMC) individually. H1a, H1b, and H1c receive empirical support from these findings correspondingly. Smart Technologies, when considered together, demonstrate a positive and significant impact on Hospital Management during Crises (β = 0.131, t = 1.730, p = 0.042), thereby verifying H2.

Furthermore, both dimensions of OI have considerable direct impacts on Hospital Management during Crises (HMC). Inbound Open Innovation (IOI) is the strongest among the three factors with its huge positive impact (β = 0.291, t = 5.965, $p < 0.001$), while Outbound Open Innovation (OOI) still points out in the same manner as a positive aspect of the situation (β = 0.181, t = 5.526, $p < 0.001$). Thus, this is the case for the support of hypotheses H2a and H2b as they draw attention to external knowledge acquisition and knowledge exploitation, both of which are significantly important in crisis management situations.

Concerning the moderating effects, the interaction between Operational Efficiency (OE) and Open Innovation (OI) has a positive and statistically significant effect on Hospital Management during Crises (HMC) (β = 0.141, t = 2.164, p = 0.016), supporting H3. This result indicates that the positive impact of open innovation on crisis management becomes stronger when hospitals operate at higher levels of operational efficiency.

In the same way, the connection between Operational Efficiency (OE) and Smart Technologies (ST) is positive and extremely significant (β = 0.177, t = 3.621, $p < 0.001$), thus giving firm evidence for H4. The result indicates that the OE makes the ST more effective in improving the HMC.

Overall, the results of hypothesis testing support the assertion that open innovation and smart technologies are necessary for crisis management in hospitals, both by means of operational efficiency and directly. The moderating impacts that were observed to be significant also validate the role of operational efficiency as the premier organizational capability, which not only supports the innovation and digital technologies during the downturns but also increases their impact.

Table 4: Hypothesis Results.

Hypothesis	Direction	β	STD	T test	P values	Result
Direct						
H1	OI -> HMC	0.415	0.067	6.156	0.000	Supported
H1a	AI -> HMC	0.035	0.020	1.754	0.040	Supported
H1b	IoT -> HMC	0.065	0.038	1.719	0.043	Supported
H1c	BDA -> HMC	0.038	0.022	1.709	0.044	Supported
H2	ST -> HMC	0.131	0.076	1.730	0.042	Supported
H2a	IOI -> HMC	0.291	0.049	5.965	0.000	Supported
H2b	OOI -> HMC	0.181	0.033	5.526	0.000	Supported
Indirect						
H3	OE x OI -> HMC	0.141	0.065	2.164	0.016	Supported
H4	OE x ST -> HMC	0.177	0.049	3.621	0.000	Supported

5. DISCUSSION

The main goal of the research was to facilitate the examination of open innovation and smart technologies in the management of hospitals during a crisis, in a positive way, and at the same time, to check out the moderating effect of operational efficiency. The results of the PLS-SEM assessment not only conferred strong authentication to the proposed theoretical model but also pointed out the necessity of health management, particularly during a crisis, for the implications in theory and practice.

The findings show that Open Innovation (OE) has the most powerful and significant positive impact on Hospital Management during Crises (HMC). This is in line with the open innovation theory, which has been demonstrated by the point of using both internal and external knowledge sources as the key for organizational adaptability and responsiveness (Chesbrough, 2003; Liu et al., 2022; Secundo et al., 2019).

Moreover, time pressure and lack of resources define the hospital's situation in case of crises such as pandemics, natural disasters, or massive system failures. The OI's significant influence implies that hospitals practicing good collaboration with technology vendors, research centres, government agencies, and even other healthcare facilities will efficiently manage such crises (Lazarenko, 2019; Scotti et al., 2022). Such partnerships prove to be advantageous for the healthcare industry by providing it with faster and more efficient access to the innovations, tools, and practices that are essential for making decisions and crisis management, all through a quick and smooth process.

The open innovation review conducted in the parts reveals that the two open innovation types, Inbound Open Innovation (IOI) and Outbound Open Innovation, are significant factors in hospitals' crisis management. The considerable impact that Inbound Open Innovation has over Outbound implies that the hospitals are very much supported regarding their preparedness and capacity for dealing with the crisis when they have access to external knowledge like clinical guidelines, technological solutions, and crisis management protocols. The result corresponds with earlier research, which showed the need for obtaining outside knowledge in complicated and shifting business environments (Bogers et al., 2018; Ugwu & Ugwu, 2024). However, it is still true that the strong effect of open innovation through outbound channels gives a significant meaning to the concept of sharing not only internal knowledge and innovations but also the external stakeholders' knowledge, and that can aid the development of communication, trust, and even collaborative problem-solving during crisis times.

The research depicts, however, that Smart Technologies (ST) overall, and even through their parts of AI, IoT, and BDA, have a beneficial and sizeable effect on the management of hospitals during a crisis. The single path coefficients of AI, IoT, and BDA are quite low, but their statistical significance reveals that every technology is indeed contributing to crisis management through its own impact. This, therefore, corresponds to the literature, which is continuously getting enriched by the viewpoints of digital technologies being the chief enablers of resilience and agility in healthcare systems (Dolgui & Ivanov, 2020; Dwivedi et al., 2020).

Crisis management is made easier for hospitals, as they can predict patient influxes by the use of AI technologies, such as predictive analytics, clinical decision support, resource optimization, and better resource allocation. Real-time patient, medical supply, and even supply chain monitoring made possible by IoT devices improves the situation awareness and coordination of the operations as well. By employing BDA, healthcare institutions are capable of integrating and analyzing enormous amounts of various types of data; thus, they are able to make evidence-based decisions in uncertain situations. Furthermore, the above-mentioned outcomes, taken together, prove that the smart technologies are not only the operators' aides throughout the whole process but, in due course, the long-term strategic assets that help hospitals cope with the complex problems during emergencies (Abuzerr et al., 2025; Sabateen et al., 2022; WHO, 2024).

The results stated above, collectively, indicate that smart technologies are not only the operators' helpers in the entire process but, eventually, the strategic assets that help hospitals in the long run to deal with the complex issues during emergencies. The conclusion drawn here is in line with the crisis management and organizational capability theories, as it is mentioned that the efficient management processes and governance structures are a prerequisite for the transformation of resources and technologies into performance outcomes that are of considerable nature (Pesqueira et al., 2025; Wenzel et al., 2020).

The research provides strong proof regarding the moderating effect of Operational Efficiency (OE). The marked interaction effects reveal that OE not only enhances but also brings out the positive relationship between open innovation and hospital crisis management, alongside the case of smart technology and crisis management. The suggestion is that the combination of innovation and digital technologies would still not suffice for a proper crisis response (D'Andreamatteo et al., 2015; Kitsios & Kapetaneas, 2022; Sameri et al., 2025). Nevertheless, if the hospital has implemented extensive business processes that are effective, the benefits in hospitals can be maximized by well-trained healthcare staff, efficient planning of workflow, and complete utilization of resources.

5.1. Implications

5.1.1. Theoretical Implications

This study has brought out theoretical perspectives that significantly change the existing literature on hospital crisis management, open innovation, and digital transformation. It not only challenges the literature but also keeps the differences among these constructs by treating open innovation and smart technologies under a single roof in a crisis management framework. The empirical evidence providing support to the joint and interactive effects of innovation and digitalization confirms that these two capabilities are complementary, and their combination further improves hospitals' crisis response capability.

The study, by means of applying the open innovation theory to the health-crisis situation, which is characterized by high risk and a great need for immediate action, partially supports the theoretical open innovation development. While previous researches were almost exclusively focused on the technological and manufacturing sectors, this one has opened up the hospital domain and has proved that both inbound and outbound open innovation, albeit differently, and at the same time, are equally helpful for managing a crisis. The division of knowledge exchanges into two aspects, namely, inbound and outbound, gives a better understanding of their occurrence in a crisis.

The deductions drawn from this research are a great contribution to the existing literature on digital health and smart technologies by providing empirical evidence for the individual and combined impacts of AI, IoT, and BDA on healthcare management in a crisis. The study points out that the use of smart technologies in healthcare research is multifaceted, as it demonstrates that each technology contributes to the improvement of crisis management outcomes, thus not simply categorizing digital technologies into one class.

The hospital management during emergencies is prominent as a mediator that influences to a large degree the extent of innovations and technologies' impact on the major organizational results like data accessibility, planning efficiency, and quality of decision making. The research dares to increase the theoretical knowledge regarding the pathway through which the strategic capabilities change into successful crisis management results.

5.1.2. Practical Implications

The practical aspect of the findings points to specific recommendations that can be set up straight away in hospital administration, health care policy making, and system re-designing. First and foremost, the issue of open innovation, which necessitates hospitals to be extremely supportive in transforming the co-creation of new ideas across the health sectors into a "real" process is brought out. The aforementioned scenario is to collaborate with tech vendors, educational establishments, government health agencies, and other health organizations in a way that allows free flow of ideas and joint problem-solving, even in tough situations.

Investments in theoretical digital health at the core are as essential as ever thanks to the increasing presence of smart technologies. The hospital administrators ought to place the use of AI-assisted decision support systems, IoT-based monitoring tools, and sophisticated analytics platforms at the top of the list in order to improve the understanding of the situation, the distribution of resources, and the making of decisions in real time during emergencies.

The operational efficiency's moderating role emphasizes that the mere adoption of technology is not sufficient. Hospitals have to not only employ the latest tech but also get rid of the old and inefficient practices by working on their workflows, setting standard operating procedures, improving staff communication, and reducing processing time. In case the operations' basics are not well managed, the hospitals will miss out on the complete benefits of the innovations and the digital technologies.

Finally, the outcomes for the policy makers indicate a necessity for the healthcare sector resilience to accept the merger of policy frameworks that would be of an integrated nature, and that would enable all the aspects, i.e., the innovation, digital transformation, and the efficiency in operations, to be realized concurrently. In such a scenario, the public health approaches will have to be such that they not only support the inter-organizational cooperation but also the data sharing and the skills development, eventually all these will make the whole system more acute to crises and robust.

5.2. Contribution

Theoretical aspects and the practical side have various important contributions from this research. The empirical evidence through PLS-SEM has come out as convincing that in crises, open innovation and smart technologies significantly enhance hospital management not only directly but also through the interaction with operational efficiency through the joint effect. The complete higher-order model comprising innovation, digital technologies, and operational capabilities in a healthcare crisis context has been validated as an important methodological contribution of this paper.

Conceptually, the study virtually heralds the operational efficiency as a constraint to the eventuality of breakthroughs and digital makeover in case of emergencies. This concept provides a comprehensive, hard-to-present, and still realistic solution for hospitals to influence the results of crisis management through technology and innovation investments.

Overall, the research provides a further insight into the areas of crisis management and healthcare innovations by coming up with a model that is both integrated and backed up by empirical evidence and that shows hospitals how to achieve resilience and adaptability under conditions of increasing uncertainty and disruption of the system.

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