SCIENTIFIC OASIS

Decision Making: Applications in Management and Engineering

Journal homepage: www.dmame-journal.org
ISSN: 2560-6018, eISSN: 2620-0104

The Impact of Smart Wards Construction on Nursing Efficiency and Patient Safety: An Empirical Study Based on SEM

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ARTICLE INFO

Article history:
Received 23 November 2025
Received in revised form 20 May 2026
Accepted 19 June 2026
Available online 30 June 2026

Keywords:
Smart Wards, SEM, Nursing Efficiency, Patient Safety, Technology Acceptance

ABSTRACT

Amid the ongoing digital transformation of healthcare, the emergence of smart wards is reshaping conventional approaches to nursing practice through the integration of technologies including the Internet of Things, big data analytics, and artificial intelligence. Against this backdrop, this study investigates whether the development of smart wards contributes to greater nursing work efficiency and improved patient safety, while examining healthcare professionals' technology acceptance and interaction with these systems as a mediating mechanism from a Human-Computer Interaction (HCI) perspective. Data were collected from 669 healthcare professionals working across several large tertiary hospitals in China. Structural equation modelling (SEM) was subsequently employed to assess the relationships between smart ward development (SW), perceived nursing work efficiency (EFF), perceived patient safety (SAFE), and technology acceptance (TAPV). The empirical results demonstrate that SW has a significant positive influence on EFF and contributes substantially to improved perceptions of patient safety. The analysis further establishes a significant positive association between EFF and SAFE, suggesting that more efficient nursing practices are closely linked with enhanced patient safety. In addition, TAPV fully mediates the association between SW and EFF, whereas its mediating effect on the relationship between SW and SAFE is partial. These findings emphasise that healthcare professionals' willingness to accept and engage with emerging technologies is a critical determinant of the benefits achieved through smart ward implementation. The study therefore offers theoretical and empirical evidence supporting the advancement and practical deployment of smart wards, particularly in relation to improving nursing performance and strengthening patient safety. On the basis of these findings, practical recommendations are developed to support the effective adoption and broader implementation of smart ward technologies across healthcare environments worldwide.

1. Introduction

The global healthcare sector is presently experiencing a major transition towards digitally enabled and intelligent governance [1]. Within this broader transformation, smart wards have been developed as a means of improving the utilisation of resources and streamlining medical operations

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https://doi.org/10.5281/zenodo.22710869

[2]. Rather than representing a simple combination of technological hardware, smart wards constitute integrated intelligent decision-support environments in which multiple technological components operate in coordination [3].

Technologies such as intelligent bedside interaction, automated infusion supervision, and non-invasive vital-sign monitoring enable substantial modifications to conventional nursing procedures. Through such integration, smart wards seek to improve nursing efficiency substantially while addressing the constraints associated with limited human resources [4]. The relevance of these systems is particularly pronounced in developing economies. China provides an illustrative case, where statistics reported by the National Health Commission indicate that tertiary hospitals constitute only 0.3% of all medical institutions, despite providing more than 55% of inpatient services [5].

The combination of a highly concentrated medical infrastructure and a large population places considerable pressure on these institutions, encouraging hospital administrators to adopt intelligent technologies to address operational constraints and potential safety risks during wartime. Assessing the efficiency of smart ward systems within such circumstances can therefore provide valuable international insights for emerging economies and for developed countries experiencing comparable pressures while seeking more effective approaches to healthcare operations.

Despite the widespread expectation that digital healthcare technologies will generate substantial operational benefits, their practical outcomes at the organisational level are far from uniform. Differences in return on investment and realised effectiveness remain evident across healthcare institutions. Although considerable resources have been devoted by many hospitals to IoT sensors, intelligent alert mechanisms, and related technologies, implementation can produce what has been described as a technology paradox. In some circumstances, sophisticated technological solutions introduce additional operational complexity or disrupt established patterns of work.

Such changes can increase the cognitive demands placed upon healthcare professionals and, consequently, undermine rather than improve overall system efficiency. This situation creates a fundamental resource-allocation dilemma for hospital administrators. In environments characterised by financial constraints, it remains unclear whether greater priority should be assigned to strengthening underlying technological infrastructure or to developing employees' digital capabilities and improving human-computer interaction. The absence of sufficiently robust quantitative evidence makes this strategic decision particularly challenging.

Existing research on smart hospital effectiveness has frequently assessed outcomes through narrowly defined technical indicators, particularly within nursing informatics, or through relatively straightforward economic and cost-based evaluations. Such approaches provide limited insight into the human factors that influence technology performance within complex organisational settings. To address this limitation, the present study adopts Sociotechnical Systems Theory (SST) as its principal theoretical foundation. SST proposes that superior organisational outcomes emerge through the coordinated adaptation of technological and social subsystems. Within healthcare environments, the technological subsystem encompasses elements such as hardware and algorithms, whereas the social subsystem incorporates users' cognition, perceptions, behaviour, and acceptance of technology.

Consequently, technological systems should not be regarded as isolated black boxes when evaluating their contribution to operational performance. Instead, attention must be directed towards the mechanisms through which technology acceptance influences the transmission of technological capabilities into organisational outcomes. In particular, understanding the mediating function of technology acceptance within the decision-making structures of complex intelligent healthcare systems is essential. Nevertheless, relatively few studies have applied rigorous SEM to quantify these interconnected pathways across large and organisationally diverse healthcare settings.

In response to these identified gaps, this study employs SEM to empirically assess whether the level of SW construction influences two fundamental operational outcomes, namely nursing efficiency and patient safety. It further examines the extent to which technology acceptance functions as a mediating mechanism within these relationships. The results are expected to provide implications for several groups of stakeholders. First, hospital administrators and decision-makers can obtain empirical evidence to support decisions concerning technological investment and the strategic distribution of organisational resources. Second, medical system engineers can gain clearer guidance regarding areas requiring optimisation in intelligent system governance as well as UI/UX design. Third, health policymakers can draw upon the findings as a globally relevant reference when formulating and implementing digital health strategies across healthcare systems with differing levels of infrastructure and technological development.

The remainder of this article is structured as follows. Section 2 examines the relevant literature and develops the research hypotheses. Section 3 describes the research methodology, including the measurement instruments and procedures adopted for data collection. Section 4 reports the outcomes of the reliability and validity assessments and presents the structural model analysis. Section 5 interprets the principal findings and discusses their theoretical contributions and practical implications. Finally, Section 6 provides an overall conclusion, identifies the principal limitations of the study, and outlines potential directions for future research.

2. Literature Review and Research Hypotheses

2.1. Literature Review

Modern smart wards can be understood as highly integrated intelligent decision-support environments rather than as isolated technological installations. Through IoT, these systems enable non-intrusive data acquisition and closed-loop verification, while warning algorithms facilitate the dynamic restructuring of resource scheduling networks. A smart hospital collaboration system integrating BCI and IoT has been shown to substantially improve the quality of communication transmission, thereby strengthening the reliability of information exchange within intelligent hospital environments [6].

Other empirical evidence based on ubiquitous computing has demonstrated the value of this technology in streamlining medical service processes and increasing the overall intelligence of hospital operations [7]. The integration of digital health technologies with 5G, big data cloud storage, and HIS has also been examined in the context of elderly diabetic patient management. The resulting model was found to improve patient health management outcomes while contributing to higher-quality medical services within smart hospital environments [8].

Within the development of smart wards, nursing efficiency and patient safety represent two important dimensions for evaluating healthcare quality and the operational performance of medical systems. Evidence indicates that nurses generally demonstrate favourable attitudes towards intelligent technologies and recognise their potential to improve the quality and efficiency of nursing practice [9]. Intelligent patient care systems can further support nurses in establishing more appropriate priorities when responding to alarm information and managing continuous nursing activities, thereby improving both the timeliness and effectiveness of nursing interventions [10]. In addition, empirical assessment of IoT applications within hospital wards has indicated that smart hospital technologies can produce significant improvements in patient safety [11].

Although digital intelligent systems are commonly expected to accelerate task completion and minimise human error, the assumption that technological advancement alone will generate superior organisational outcomes may not hold in complex and high-risk healthcare environments. SST provides an appropriate theoretical perspective for understanding this limitation. According to SST, organisational performance emerges from the compatibility and interaction between the technical and social subsystems. The technical subsystem encompasses hardware, algorithms, and operational procedures, whereas the social subsystem incorporates users' skills, cognition, attitudes, and behavioural responses. Accordingly, within smart ward environments, the benefits associated with automated processes and closed-loop management cannot be realised fully through technological capabilities alone. Their effective operation also depends upon users' active adoption and acceptance of the technologies involved [12].

Despite the growing body of empirical research concerning smart hospital development, important shortcomings remain in the way its effectiveness is evaluated. Existing studies have predominantly concentrated on direct relationships between smart hospital implementation and outcome measures, including nursing efficiency, patient safety, and healthcare quality. Comparatively limited attention has been devoted to explaining the mechanisms through which these effects arise. Furthermore, technology acceptance has rarely been incorporated explicitly into the analytical frameworks used to assess smart hospital effectiveness. Consequently, the role and transmission mechanism of technology acceptance in converting smart hospital development into measurable operational benefits remain insufficiently established.

To address these limitations, this study applies SEM following systematic assessment of the model's reliability, validity, and discriminant validity. The proposed framework establishes and empirically evaluates the relationships among smart ward development, technology acceptance, and nursing operational efficiency. Particular attention is given to the mediating function of technology acceptance in these relationships. Through this approach, the study seeks to clarify the underlying mechanism through which smart ward development contributes to improvements in nursing operational efficiency.

2.2. Research Hypotheses

The progressive adoption of smart wards has emerged as an important approach to strengthening both the quality of healthcare delivery and the efficiency of hospital operations. Within the broader framework of smart hospital development, nursing informatics constitutes a fundamental element of the "trinity" model. Its contribution extends beyond the introduction of novel concepts into nursing practice, as it also promotes greater scientific standardisation and responsiveness in clinical activities. These improvements can contribute to safer nursing practices, enhanced clinical care quality, and more effective management. Empirical evidence further indicates that intelligent information management platforms can improve the operational efficiency of healthcare personnel [13]. On the basis of these findings, the following hypothesis is proposed:

H1: The level of smart wards development has a positive impact on nursing work efficiency.

Ensuring patient safety constitutes a fundamental priority within nursing management. The implementation of smart wards can contribute to this objective by incorporating digital closed-loop verification, automated alarm mechanisms, and systematic risk assessment tools that help minimise errors arising from human factors. In addition, IoT-supported real-time monitoring enables nursing personnel to detect emerging risks at an earlier stage and respond through appropriate interventions without unnecessary delay. Such capabilities can reduce the occurrence of adverse clinical events and consequently strengthen the level of patient safety achieved in healthcare settings [14]. Accordingly, the following hypothesis is formulated:

H2: The level of smart wards development has a positive impact on patient safety.

The relationship between patient safety and SW extends beyond a direct technological effect, as the efficiency of nursing activities also represents an important factor in determining safety outcomes. Higher nursing efficiency should not be interpreted merely as the ability to perform routine duties within a shorter period. Its greater significance lies in enabling available nursing resources to be redistributed towards patients and situations requiring closer attention, particularly those involving elevated levels of clinical risk. When nursing processes are organised and executed more efficiently, healthcare professionals can respond more rapidly to patient requirements. Such timely responses help minimise safety threats associated with delayed care and, consequently, provide an important operational basis for improving patient safety [15]. Accordingly, the following hypothesis is proposed:

H3: Nursing work efficiency has a positive impact on patient safety.

Within information systems research, users' perceptions of a system's usability and practical value are widely recognised as important factors shaping their subsequent behaviour towards that system. In the setting of smart wards, nurses are more inclined to adopt the available technologies and incorporate them into their routine activities when the systems are perceived as straightforward to operate and capable of improving the quality of their work. Such positive perceptions can facilitate sustained system use and, in turn, contribute to greater nursing efficiency. In contrast, limited acceptance or inadequate recognition of the value of SW among nursing personnel may restrict the extent to which its technological capabilities can be translated into practical benefits [16]. On this basis, the following hypothesis is proposed:

H4: Technology acceptance mediates the relationship between smart wards construction and nursing efficiency.

Although SW incorporates capabilities such as automated risk alerts and closed-loop management that can contribute directly to safer patient care, the practical value of these functions is strongly dependent on how actively nursing personnel engage with the system. Technological capabilities alone cannot guarantee the expected safety outcomes when users do not consistently adopt and apply them in clinical practice. Previous evidence indicates that greater satisfaction with and willingness to use smart nursing information systems is associated with a lower occurrence of adverse clinical events [17]. This relationship suggests that TAPV extends beyond its contribution to nursing efficiency, as greater acceptance can encourage more effective utilisation of SW and thereby provide an indirect pathway through which patient safety may be improved. On this basis, the following hypothesis is proposed:

H5: Technology acceptance mediates the relationship between smart wards construction and patient safety.

3. Research methodology

3.1. Questionnaire Design

The measurement instruments adopted in this study were primarily derived from scales that had been previously developed and empirically validated, with contextual adjustments introduced where necessary to ensure their suitability for the present research setting [18]. All measurement items were evaluated on a five-point Likert scale extending from "strongly disagree" to "strongly agree". Nursing staff were instructed to provide responses according to their own experiences and perceptions of the relevant clinical practices.

The measurement framework comprised four principal dimensions, with four items assigned to each dimension, resulting in 16 items in total. The items were formulated around observable indicators of clinical operations to minimise potential bias arising from purely subjective assessments. Prior to commencement of the main survey, the instrument underwent both expert consultation and preliminary pilot testing. Feedback obtained from the experts and participating respondents was subsequently used to identify and revise items that were considered ambiguous, unsuitable, or insufficiently clear. The final measurement items are presented in Table 1.

Table 1
Measurement Items of Variables

Variable	Item Code	Item Statement
SW	SW1	In your opinion, your ward extensively uses connected smart devices (e.g., vital signs monitors, infusion pumps) to automatically collect important patient data.
	SW2	The ward information system can automatically send you reminders or alarms based on pre-set rules (e.g., abnormal vital signs, medication time).
	SW3	You believe that with mobile terminals (e.g., PDA or tablet), you can conveniently enter or access all required nursing information and execute medical orders at the bedside.
	SW4	You believe that the ward has achieved digital closed-loop verification and management of key processes such as patient identification, medication, and specimen handling (e.g., using barcode/RFID scanning).
EFF	EFF1	You believe that using smart devices (e.g., automatic vital signs monitoring) significantly reduces the time you spend on manually measuring and recording routine data.
	EFF2	You believe that digital systems (e.g., electronic medical records, mobile devices) make the execution of medical orders (medication, examinations, etc.) faster and more direct.
	EFF3	You believe that intelligent reminders and call-location functions help you respond to patient needs more promptly, prioritize critical tasks, and reduce unnecessary walking and searching time.
	EFF4	You believe that the application of smart wards technologies (e.g., automated documentation, centralized information) significantly improves your efficiency in paperwork and information retrieval.
SAFE	SAFE1	You believe that digital closed-loop verification (e.g., barcode scanning for patient identification and medication) effectively reduces the risk of errors in medication or treatment targets.
	SAFE2	You believe that intelligent monitoring and alarm systems (e.g., abnormal vital signs, infusion completion, bed exit) help in the early detection and management of potential safety risks.
	SAFE3	You believe that standardized operation prompts and risk assessment tools within the electronic system help you perform nursing operations more consistently and safely, reducing safety hazards caused by negligence.
	SAFE4	You believe that in an environment applying smart wards technologies, the risk of patients under your care experiencing nursing-related adverse events (e.g., falls, medication errors, pressure ulcers) is reduced.
TAPV	TAPV1	You believe that the smart wards technologies applied in your ward are relatively easy to learn and use.
	TAPV2	You believe that using smart wards technologies can clearly help you perform nursing work better (e.g., improve efficiency, ensure safety, enhance quality).
	TAPV3	Overall, I am satisfied with the smart wards technologies applied in my ward.
	TAPV4	I am willing to recommend working in a smart wards environment to my colleagues because it brings value to both nurses and patients.

To establish semantic equivalence of the measurement instrument within the Chinese healthcare context, a systematic translation and back-translation procedure was adopted. Initially, two bilingual scholars specialising in nursing management independently translated the original instrument into Chinese. The resulting Chinese version was then independently translated back into English by two native English-speaking researchers with extensive experience in medical management research. The back-translated version was subsequently compared with the original instrument to identify discrepancies in meaning or wording.

A five-member expert panel, comprising three nursing department directors from leading hospitals and two specialists in medical information systems, reviewed the identified ambiguities and jointly determined the necessary revisions. Before the main survey was initiated, a pilot study was conducted with 30 nurses who satisfied the predefined inclusion criteria. Feedback obtained during the expert review and evidence from the pilot study were used to refine unclear or unsuitable items, resulting in the final questionnaire used for the formal investigation.

The investigation was designed primarily to assess the effects of SW construction on nursing work efficiency and patient safety. For the main data collection stage, healthcare professionals employed in several large tertiary hospitals in China were invited to complete the questionnaire. Given the demanding working schedules of medical personnel, an online distribution approach was adopted as the principal means of questionnaire administration, thereby facilitating participation and completion. In total, 682 questionnaires were returned.

After responses deemed invalid were removed, 669 questionnaires remained for analysis, corresponding to an effective response rate of 98.1%. The demographic characteristics presented in Table 2 indicate a relatively even distribution between male and female participants. A substantial proportion of the respondents reported more than 10 years of nursing experience and possessed a bachelor's degree. In addition, 72.65% of participants had previously used smart ward technologies. This level of prior exposure provides the sample with a meaningful degree of clinical representativeness for examining the research relationships. Overall, the characteristics of the respondents were considered appropriate for the objectives and requirements of the study.

Table 2
Descriptive Statistics of the Sample

Variable	Category	Frequency	%
Gender	Male	310	46.3
	Female	359	53.7
Nursing Experience	＜3 Years	145	21.67
	3-6 Years	164	24.51
	6-10 Years	110	16.44
	＞10 Years	250	37.37
Education Level	Associate Degree	98	14.65
	Bachelor's Degree	519	77.58
	Master's Degree	46	6.88
	Doctoral or Above	6	0.9
Duration of Smart Wards Use	＜1 Year	183	27.35
	1-3 Years	236	35.28
	3-5 Years	118	17.64
	＞ 5 Years	132	19.73

3.2. Sampling Strategy and Sample Size Criteria

The adequacy of the obtained sample can be established against commonly applied criteria for SEM. Previous methodological research suggests that approximately 200 observations are generally adequate for conducting standard SEM analyses, whereas increasing the sample to around 500 observations can provide greater parameter stability and improve statistical efficiency. In the present study, 669 valid responses were available for analysis, substantially exceeding these commonly recommended levels.

A further empirical guideline proposes that the required number of observations should be approximately five to ten times the total number of measurement items. As the measurement instrument used in this study comprises 16 items, this criterion would yield a minimum sample requirement of 80 to 160 observations. The final sample of 669 respondents therefore provides a considerable margin above the minimum threshold, supporting stable estimation of model parameters, dependable model-fitting results, and greater confidence in the robustness of the study's empirical conclusions.

3.3. Sampling Strategy and Sample Size Criteria

As the study employed an anonymous questionnaire-based approach, the information collected from participants was not associated with personally identifiable information, thereby minimising concerns regarding privacy or disclosure of participant identities. The research also involved neither physical procedures nor psychological interventions, and was therefore considered to involve only minimal risk to participants. In accordance with the applicable ethical requirements, the study did not require written informed consent. Prior to questionnaire administration, the investigators informed all participants about the purpose of the research, the nature and content of the survey, the measures adopted to maintain anonymity, and their rights to participate voluntarily and discontinue their participation at any stage. Data collection proceeded only after participants had provided verbal informed consent.

3.4. Data Analysis

The measurement instrument was first subjected to systematic reliability and validity assessment to establish the quality of the scale. Discriminant validity was examined further using the heterotrait-monotrait ratio (HTMT), which provides a more stringent assessment than several conventional approaches and is particularly appropriate when substantial correlations exist between constructs. A conservative HTMT criterion of 0.85 was adopted, with values below this level indicating satisfactory discriminant validity.

Given that the study relied on cross-sectional data collected through self-reported responses, the possibility of CMB was also considered. To assess this potential source of bias, the Harman single-factor procedure was applied. All measurement items were entered into an unrotated exploratory factor analysis, and the proportion of variance attributable to the first factor was examined. A value below 50% was treated as evidence that CMB was unlikely to exert a substantial influence on the empirical findings.

The proposed hypotheses and the mediating effects were subsequently evaluated using the bias-corrected non-parametric percentile Bootstrap procedure. To obtain robust estimates of the indirect effects, 5,000 Bootstrap replications were performed, from which 95% bias-corrected CI were generated. Compared with the conventional Sobel test, this procedure provides more reliable interval estimation for indirect effects and is widely regarded as an appropriate approach for assessing mediation within SEM. Statistical significance was evaluated at $\alpha = 0.05$. A mediating effect was considered statistically significant when the corresponding 95% CI for the indirect effect did not contain zero.

4. Result Analysis

4.1. Reliability and Validity Test

The reliability and validity of the collected survey responses were evaluated using SPSS 23.0 and AMOS 24.0, with the corresponding results reported in Table 3. For every construct, both Cronbach's α and CR exceeded 0.80, providing evidence of satisfactory internal consistency and composite reliability. The assessment of factorability also produced favourable results. Specifically, the KMO statistic was 0.89, exceeding the recommended value of 0.80, while Bartlett's test of sphericity confirmed the suitability of the dataset for factor analysis. Following Varimax rotation, each measurement item produced a factor loading above 0.70, supporting the adequacy of the measurement instrument.

Table 3
Reliability and Validity Test Results

Variable	Observed Items	Factor Loadings	Reliability		
			Cronbach's a	CR	AVE
SW	SW1	0.79	0.86	0.89	0.68
	SW2	0.83			
	SW3	0.85			
	SW4	0.82			
EFF	EFF1	0.82	0.90	0.91	0.74
	EFF2	0.84			
	EFF3	0.86			
	EFF4	0.87			
SAFE	SAFE1	0.77	0.88	0.90	0.67
	SAFE2	0.79			
	SAFE3	0.80			
	SAFE4	0.83			
TAPV	TAPV1	0.84	0.92	0.93	0.81
	TAPV2	0.86			
	TAPV3	0.89			
	TAPV4	0.90			

Further evidence of construct validity was obtained from the AVE results. The AVE values ranged between 0.67 and 0.81, with every value exceeding the 0.50 criterion. Thus, each latent construct accounted for more than half of the variance associated with its observed indicators, demonstrating satisfactory convergent validity. Discriminant validity was subsequently assessed, with the results provided in Table 4. The square root of the AVE for each construct was greater than its correlations with the remaining constructs. This pattern confirms that the constructs demonstrated satisfactory discriminant validity and that the measurement scale adequately distinguished between the respective concepts.

Table 4
Discriminant Validity Test Results

	AVE	SW	EFF	SAFE	TAPV
SW	0.68	0.87			
EFF	0.74	0.71	0.85		
SAFE	0.67	0.65	0.53	0.82	
TAPV	0.81	0.49	0.58	0.46	0.90

4.2. Discriminant Validity Test

A further assessment of discriminant validity was performed using the HTMT ratio, with the corresponding results reported in Table 5. The analysis demonstrated that every HTMT coefficient remained below the conservative threshold of 0.85. For the relationships involving SW, the HTMT coefficients with EFF, SAFE, and TAPV were 0.782, 0.654, and 0.721, respectively. The coefficients observed for the remaining construct pairs likewise remained within acceptable limits, with the highest value reaching 0.809. Collectively, these findings provide additional evidence that the constructs are empirically distinguishable from one another and confirm the satisfactory discriminant validity of the measurement model.

Table 5
HTMT Results

	SW	EFF	SAFE	TAPV
SW	1			
EFF	0.782	1		
SAFE	0.654	0.698	1	
TAPV	0.721	0.753	0.809	1

4.3. CMB Test

Because the data were collected through a questionnaire and relied entirely on respondents' self-reported assessments, the possibility of CMB required empirical examination. Accordingly, the Harman single-factor procedure was applied to evaluate whether a substantial portion of the observed variance could be attributed to a common measurement source. As reported in Table 6, all questionnaire items were entered into an unrotated factor analysis, and the first principal component accounted for 31.2% of the total variance. This proportion remained well below the 50% criterion, indicating that CMB did not represent a serious threat to the validity of the dataset. The results, together with the preceding reliability and validity assessments, demonstrate that the measurement data possess adequate psychometric quality and are therefore suitable for subsequent model analysis.

Table 6
Harman's Single-Factor Test

Indicators	Result	Standard	Conclusion
Unrotated Factor Analysis of the Variance Explained by the First Principal Component	31.2	<50%	No Serious Common Method Bias

4.4. Analysis of the Results of the SEM

AMOS was employed to estimate the SEM and examine the relationships between SW construction, EFF, and SAFE. Statistical significance was assessed at $P = 0.05$, and the structural model results are presented in Figure 1. The analysis provided empirical support for all five proposed hypotheses. SW demonstrated a strong and statistically significant positive association with EFF ($\beta = 0.72$, $p < 0.001$), thereby supporting H1. A similarly significant positive relationship was identified between SW and SAFE ($\beta = 0.68$, $p < 0.001$), providing support for H2. In addition, EFF exerted a significant positive effect on SAFE ($\beta = 0.48$, $p < 0.001$), confirming H3.

The results further showed that TAPV was positively associated with both EFF ($\beta = 0.34$, $p < 0.01$) and SAFE ($\beta = 0.29$, $p < 0.05$), with the corresponding indirect effects reaching statistical significance. For the SW → EFF relationship, the indirect effect through TAPV was 0.28 ($p < 0.05$), indicating a complete mediating effect and supporting H4. In contrast, TAPV accounted for only part of the effect of SW on SAFE, with an indirect effect of 0.23 ($p < 0.05$). This finding demonstrates partial mediation in the SW → SAFE relationship and provides support for H5. Overall, the structural model confirms the proposed direct relationships and demonstrates that TAPV constitutes an important mechanism through which SW influences EFF and SAFE.

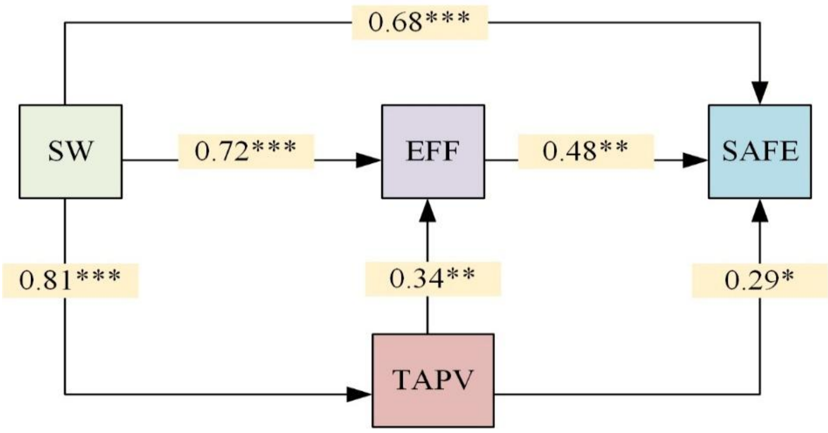

Fig.1: Path Analysis Results

The regression coefficients were estimated using the maximum likelihood approach, and the resulting weighted regression estimates were found to be statistically significant across all specified paths, as reported in Table 7. Within the SEM results, C.R. denotes the Critical Ratio and is obtained by dividing the parameter estimate (Estimate) by its corresponding standard error (S.E.). This statistic is equivalent in interpretation to a t-test value and is used to assess the statistical significance of individual parameter estimates. In general, results falling within the range of $0.01 < P < 0.05$ are regarded as statistically significant. The findings presented in Table 7 show that every hypothesised path satisfied the required significance criterion. Accordingly, the observed structural relationships receive empirical support from the sample data.

Table 7
Path Coefficient Test Results

Path	Standardized Estimate	Unstandardized Estimate	S.E.	C.R.	P	Result
SW→EFF	0.72	0.80	0.06	12.01	***	Supported
SW→SAFE	0.68	0.73	0.07	9.71	***	Supported
EF→SAFE	0.48	0.52	0.09	5.33	**	Supported
SW→TAPV	0.81	0.88	0.05	16.20	***	Supported
TAPV→EFF	0.34	0.39	0.09	3.78	**	Supported
TAPV→SAFE	0.29	0.32	0.10	2.91	*	Supported

The findings of the model fit assessment are presented in Table 8. Evaluation of the principal goodness-of-fit indices shows that each reported indicator satisfies the corresponding recommended criterion. These results demonstrate that the proposed model provides an adequate representation of the observed data, with the overall model fit reaching a satisfactory level.

Table 8
Model Fit Test Results

Model Fit Index	Value	Recommended Standard	Fit Evaluation
CMIN/DF	2.41	<3	Good
RMSEA	0.04	<0.08	Good
GFI	0.93	>0.9	Excellent
CFI	0.95	>0.9	Excellent
IFI	0.95	>0.9	Excellent

The mediating function of TAPV in the relationships between SW, EFF, and SAFE was further examined using the Bootstrap procedure, with the corresponding findings reported in Table 9. For the SW → EFF relationship, the indirect pathway through TAPV (SW → TAPV → EFF) produced an estimated effect of 0.215, accompanied by a 95% CI ranging from 0.142 to 0.318. As zero was not contained within this interval, the indirect effect was statistically significant, demonstrating that TAPV significantly mediates the association between SW and EFF.

A comparable result was obtained for the relationship between SW and SAFE. The indirect effect transmitted through TAPV (SW → TAPV → SAFE) was estimated at 0.128, with a corresponding 95% CI of [0.072, 0.218]. Since this interval likewise excluded zero, the mediation effect of TAPV was statistically significant for the SW → SAFE relationship. Taken together, the Bootstrap results provide empirical evidence that TAPV constitutes a significant mediating mechanism linking SW with both EFF and SAFE.

Table 9
Bootstrap Test

Effect	Effect Size	95% CI	
		Lower Limit	Upper Limit
SW→TAPV→EFF	0.215	0.142	0.318
SW→TAPV→SAFE	0.128	0.072	0.218

5. Discussion and Management Insights

5.1. Discussion

Using empirical evidence obtained from 669 medical professionals, this study applied SEM to examine the structural associations among SW, TAPV, EFF, and SAFE. The findings demonstrate substantial positive effects of SW on both EFF ($\beta = 0.72$) and SAFE ($\beta = 0.68$). These relationships are particularly relevant in the context of tertiary hospitals in China, where high bed-to-nurse ratios and considerable operational demands place substantial pressure on nursing personnel. Under such conditions, the integration of intelligent decision-support capabilities into ward operations may provide an effective means of reducing operational constraints. Automated acquisition of vital-sign information, together with the establishment of a closed-loop monitoring system, can reduce the amount of nursing time devoted to repetitive documentation and routine administrative activities. The time and resources released through such automation can subsequently be redirected towards clinical assessment and the delivery of more timely and appropriate interventions.

The mediating analysis further identified distinct mechanisms through which TAPV operates across the two outcome pathways. Specifically, TAPV completely mediates the relationship between SW and EFF, with an indirect effect of 0.215, whereas its mediating influence on the relationship between SW and SAFE is partial, with an indirect effect of 0.128. This distinction has important implications for both theoretical interpretation and practical implementation. The conversion of technological capabilities into improvements in operational efficiency appears to depend strongly on users' behavioural engagement and cognitive alignment with the implemented systems. When nurses perceive a technology as difficult to operate, poorly aligned with established workflows, or disruptive to their routine practices, resistance to adoption may arise.

Under such circumstances, nurses may resort to inefficient dual-recording practices involving both paper and electronic systems, thereby diminishing or even eliminating the efficiency gains expected from digitalisation. This finding reinforces the importance of the social subsystem in the SST perspective: technological infrastructure alone cannot be translated into improved operational efficiency unless users accept the system and incorporate it into their working practices. The complete mediation observed in the SW → EFF pathway therefore indicates that TAPV represents a critical mechanism through which technological investment is converted into measurable efficiency gains.

The partial mediation identified for SAFE reflects a different underlying mechanism. Certain intelligent safety-management functions incorporate rigid engineering constraints that can prevent inappropriate actions irrespective of the user's subjective willingness to engage with the technology. A representative example is the BCMA system, which can prevent the execution of incorrect medication orders through automated or programmed restrictions. Such safeguards operate as mandatory system-level controls and therefore do not rely entirely on users' attitudes or acceptance. By constraining potentially unsafe actions at the technical level, these mechanisms can reduce the likelihood of medical errors even when user acceptance remains incomplete. Consequently, SW can retain a direct relationship with SAFE in addition to the indirect pathway operating through TAPV. The observed partial mediation therefore suggests that intelligent ward technologies can enhance patient safety through both user-dependent mechanisms and technology-enforced safety controls.

5.2. Theoretical Contribution

This study extends the existing body of research by introducing perspectives from management engineering and decision science into the analysis of digital healthcare transformation. Whereas prior studies have predominantly employed the technology acceptance model to explain or predict individuals' intentions to use technological systems, the present research assigns TAPV a broader theoretical function.

Specifically, TAPV is positioned as a mediating mechanism through which the development of smart hospital infrastructure can be translated into improvements in operational performance. This conceptualisation extends the conventional application of the technology acceptance model beyond its predominant individual-level orientation towards the organisational and operational context. In doing so, the study offers an alternative theoretical explanation of how investments in digital medical infrastructure can generate tangible improvements in operational outcomes.

The study also advances the conceptualisation of smart hospitals beyond their conventional treatment as isolated clinical-care technologies. Rather than viewing smart hospital infrastructure solely as a collection of tools for supporting individual healthcare activities, this research considers it as an integrated intelligent decision-support environment encompassing information perception, analytical processing, and decision-making support. Drawing upon SST theory, the findings further emphasise the importance of HCI and TAPV in determining whether the technological capabilities introduced through smart ward construction can produce improvements in EFF and SAFE. This perspective strengthens the theoretical understanding of value realisation within medical operations management by clarifying how digital healthcare technologies interact with human and organisational factors.

Consequently, the study proposes an integrated analytical perspective for explaining the pathway through which technological deployment is converted into enhanced operational performance within smart medical environments.

5.3. Management Insights

The findings of this study offer practical guidance for hospital administrators, system engineers, and health policy makers concerning resource optimisation, allocation decisions, and the management of healthcare operations.

1) Strategic Resource Allocation by Hospital Managers

The prominent mediating role of TAPV demonstrates that relying exclusively on technological solutions is insufficient for achieving successful digital transformation. When developing budgets for digital healthcare initiatives, hospital managers should therefore avoid concentrating resources disproportionately on hardware acquisition while underinvesting in software, organisational adaptation, and personnel development. A more balanced allocation strategy should reserve adequate resources for organisational change management, sustained digital literacy development, and the redesign of established clinical workflows.

Strengthening the social subsystem should consequently be regarded as an essential component of technology investment rather than as an optional supplementary activity, since effective user adoption is fundamental to obtaining the anticipated returns from digital healthcare technologies. In addition, employee technology acceptance can be incorporated as a forward-looking management indicator. Continuous monitoring of this indicator, together with the operational condition of intelligent healthcare systems, would enable hospital managers to identify emerging problems proactively and progressively shift from reactive risk management towards preventive and data-driven governance.

2) The Optimisation Framework for System Engineers

The findings also indicate a need for medical information system engineers and developers to reconsider the principles guiding system design. Rather than continually increasing the number of technological functions, development efforts should place greater emphasis on decision-support capability and the practical requirements of clinical users. Particular attention should be given to ergonomics and the cognitive demands imposed on healthcare personnel. To limit cognitive overload and reduce alarm fatigue, intelligent systems should present structured, clinically meaningful decision prompts rather than overwhelming users with disconnected streams of information.

Effective UI/UX design can further improve perceived usability by making system functions more intuitive and easier to incorporate into routine clinical activities. From an engineering perspective, such user-centred design is essential for addressing resistance among front-line healthcare personnel and for ensuring that the technical capabilities of SW are translated into the expected improvements in operational efficiency.

3) Discussion on International Universality and Digital Health Strategies

Although the empirical investigation was conducted within the highly centralised tertiary hospital environment of China, the management implications derived from the findings may extend to healthcare systems experiencing comparable resource constraints and workforce pressures. In developing economies characterised by large populations and unevenly distributed medical infrastructure, the deployment of SW as an intelligent decision-support system may provide a strategic means of improving the utilisation of limited healthcare resources.

Nevertheless, transferring these findings to developed healthcare systems requires careful consideration of differences in organisational preparedness and healthcare delivery structures. Many developed countries possess more established primary healthcare networks and clearer levels of healthcare provision, while simultaneously experiencing substantial shortages of nursing personnel. Their digital health strategies should therefore extend beyond improving efficiency within individual hospital wards. Greater emphasis should also be placed on interoperability between intelligent hospital systems and external health information exchange platforms. Such integration is necessary to support continuous information sharing and coordinated decision-making across institutions, thereby facilitating more seamless management throughout the broader healthcare pathway.

6. Conclusion

Drawing on 669 valid questionnaire responses, this study empirically examined how SW construction influences EFF and SAFE. The findings demonstrate that the development of SW produces significant direct improvements in both nursing efficiency and patient safety. In addition to these direct effects, the analysis confirms an indirect pathway through TAPV, indicating that greater acceptance of newly introduced technologies among healthcare personnel contributes to the realisation of the operational and safety benefits associated with SW.

Despite these findings, several limitations should be acknowledged. First, the research adopted a cross-sectional design, meaning that the temporal sequence required to establish causal relationships could not be determined conclusively. Future investigations should therefore employ longitudinal research designs to examine how the relationships among SW, TAPV, EFF, and SAFE develop over time and to provide stronger evidence concerning causality.

Second, the empirical sample was drawn primarily from large tertiary hospitals in China. Although this sampling context is appropriate for examining SW within highly developed hospital environments, it may constrain the generalisability of the findings to healthcare institutions with different organisational characteristics, resource conditions, or geographical settings. Subsequent research could address this limitation by increasing the sample size and incorporating hospitals of varying scales and from different geographical locations, thereby providing a broader basis for evaluating the robustness and generalisability of the conclusions.

Finally, further research could investigate whether the effects of intelligent ward technologies vary across clinical departments and hospital settings. Such comparative analysis would provide greater insight into the contextual conditions under which SW generates different levels of benefit. Future models could also incorporate additional organisational and employee-related variables, including nurse burnout, organisational culture, and workflow integration. Incorporating these factors may enable the development of a more comprehensive framework for explaining the mechanisms through which intelligent healthcare technologies influence operational and patient-related outcomes.

7. Funding

This study was funded for key technologies of disease-specific mechanism modeling and intelligent intervention based on multimodal medical data (262102521094) and for energy management and efficiency innovation in a hospital dual-carbon environment (2025JYQS1079).

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