Original Article

The Influence of Effective Emergency Medical Teams and Antecedents on the Smart Emergency Service System in Northern Thailand

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Abstract

OBJECTIVES: This research studies a causal relationship model of knowledge management (KM; systematic creation, sharing, and utilization of organizational knowledge), safety climate (SCL; collective perceptions of safety policies and practices), information technology capabilities (ITC; digital infrastructure and competencies), and effective emergency medical teams (EFT; coordinated performance of multidisciplinary responders) to smart emergency medical services (SEMS; technology-enhanced, data-driven emergency care systems) in Northern Thailand.

MATERIALS AND METHODS: This study employed a mixed-methods design with an explanatory sequential approach. In the quantitative phase, data were collected from 550 emergency medical services (EMS) personnel working in the public EMS system across Northern Thailand, selected through proportionate stratified random sampling to ensure representation by service type and geographic area. Eligible participants had at least one year of EMS experience, were literate in Thai, and provided informed consent; those unable to communicate in Thai or unwilling to participate were excluded. In the qualitative phase, three EMS experts with leadership roles and ≥ 5 years of professional experience were purposively recruited for in-depth interviews to contextualize and enrich the survey findings. Data analysis included descriptive and inferential statistics. Measurement model reliability and validity were assessed using confirmatory factor analysis (CFA), composite reliability (CR), and average variance extracted (AVE). Path coefficients were estimated using structural equation modeling (SEM) with maximum likelihood estimation (MLE), and statistical significance was determined through t-statistics generated by LISREL.

RESULTS: KM showed strong positive effects on ITC ($\beta = 0.818, p < 0.001$) and SCL ($\beta = 0.883, p < 0.001$), but no statistically significant direct effect on EFT ($\beta = 0.056$, not significant). SCL positively influenced EFT ($\beta = 0.401, p < 0.05$), ITC positively influenced SEMS ($\beta = 0.125, p < 0.05$), and EFT had the strongest effect on SEMS ($\beta = 0.882, p < 0.001$). KM exerted a significant indirect effect on SEMS through SCL and EFT (β_indirect = 0.312).

CONCLUSION: The study underscores the critical role of KM in enhancing EMS, SCL and EFT, demonstrating a transformative approach to improving healthcare response in Northern Thailand's challenging geographical context.

Keywords: knowledge management, KM, safety climate, SCL, information technology capabilities, ITC, effective emergency medical teams, EFT, smart emergency medical services, SEMS

Emergency Medical Services (EMS) in Northern Thailand are undergoing substantial structural transition, driven by technological innovation, strategic policy initiatives, and responses to multifaceted healthcare challenges. This study examines systemic factors that influence the effectiveness of EFT and their role as key mechanisms in advancing a smart emergency service system tailored to the region's geographical, socio-medical, and digital health contexts.

Within the broader framework of science and information technology advancement, particularly the Smart Healthcare Concept initiated by IBM in 2009,[1] EMS systems in Thailand have restructured both organizational design and operational processes. National development strategies emphasize the creation of comprehensive, accessible, rapid, safe, and holistic EMS systems that prioritize human resource capacity, academic knowledge development, medical technology assessment, and applied research to elevate service quality. Digital innovations have further improved rapid and secure communication and coordination across EMS networks, from incident sites to healthcare facilities. These reforms align with the 20-year National Strategy (2017–2037), which aims to achieve international standards in service efficiency and safety.[2–5]

Since its inception in 1976, EMS in Thailand has evolved alongside emergency logistics and humanitarian supply chain management, producing diverse operational models depending on service providers. A continuing challenge lies in developing guidelines and planning methods that address diverse patient care needs. Nevertheless, the universal goal of EMS remains the same: to deliver timely and effective assistance, leveraging logistics and information technology to mitigate the impact of emergencies. At the global level, the World Health Organization (WHO) seeks to halve road traffic deaths and injuries by 2030, advocating the integration of technology and innovation to strengthen safety across all stages of emergency care.[7,8]

A fundamental concept in EMS development is the *Stars of Life* model,[9] which remains embedded within Thailand's EMS framework and aligns with both the National Emergency Medical System Development Plan (2023–2027) and the United Nations Sustainable Development Goals (SDGs). System development also prioritizes proactive personnel training with international certification under the 3P (patient, people, and public safety) Safety Strategy aiming to establish a high-quality and safe healthcare system.[10] Among the most critical aspects of EMS improvement is the development of EFT. These teams, composed of skilled and well-coordinated professionals, are essential for the timely delivery of emergency care. Their performance directly affects patient survival, response speed, and overall system safety. Strengthening EFT through continuous training, effective communication, and collaborative practice is therefore crucial to improving both service quality and patient outcomes.[11]

Information technology development further enhances EMS performance by enabling seamless data integration, real-time communication between field responders and hospitals, and informed decision-making in critical situations. This approach is consistent with the Ministry of Public Health's Smart Healthcare policy, which emphasizes the use of digital technologies to manage health data and drive innovation. Despite these advances, EMS in Northern Thailand still faces challenges, particularly in remote areas where mountainous terrain, cultural and linguistic diversity, and limited infrastructure restrict access to timely care. Poor coordination between services and hospitals, coupled with gaps in KM and insufficient IT infrastructure, further constrains service delivery.[12–14]

Digital health innovations, particularly electronic medical records (EMR) and interoperable health information systems, have become increasingly central to EMS modernization. EMR enables real-time access to patient histories, improves continuity of care, and supports clinical decision-making during emergencies. In Thailand, the Ministry of Public Health has promoted EMR adoption as part of the national Smart Health policy; however, implementation in Northern regions remains uneven due to infrastructure gaps, lack of interoperability between hospital systems, and workforce limitations in digital competency. These barriers delay information transfer, reduce inter-agency coordination, and directly hinder EMS effectiveness. Integrating EMR within SEMS is therefore essential for enabling timely, data-driven responses and ensuring equitable access to high-quality emergency care.

Previous studies, particularly in the private sector, have highlighted the importance of KM, SCL, and ITC in advancing SEMS.[15] However, EFT have received limited attention, especially within the public sector and rural contexts. EFT are critical to ensuring that emergency responses are rapid, accurate, and well-coordinated, serving as the backbone of effective EMS networks. The National EMS Institute's 2023–2027 Master Plan emphasizes the development of high-performing EMS teams to ensure equitable access to quality medical services nationwide. It also underscores the importance of strengthening inter-agency teamwork, coordination, and continuous professional training.[16,17] Nonetheless, research examining the comprehensive relationships among the key determinants of EMS effectiveness remains scarce.

To address this gap, the present study investigates five core constructs: KM, the systematic processes of creating, sharing, and knowledge utilization; SCL, the collective perceptions of safety-related policies and practices; ITC, the digital infrastructure and competencies that support communication and emergency response; EFT, the coordinated performance of multidisciplinary emergency teams; and SEMS, technology-enhanced, data-driven emergency systems that integrate these constructs to optimize efficiency and patient outcomes. This study examines how KM, SCL, and ITC contribute to EFT and how these factors collectively influence SEMS performance in Northern Thailand. Structural equation modeling (SEM) was employed to analyze these relationships and generate evidence-based recommendations for strengthening EMS delivery. The conceptual framework is presented in Figure 1.

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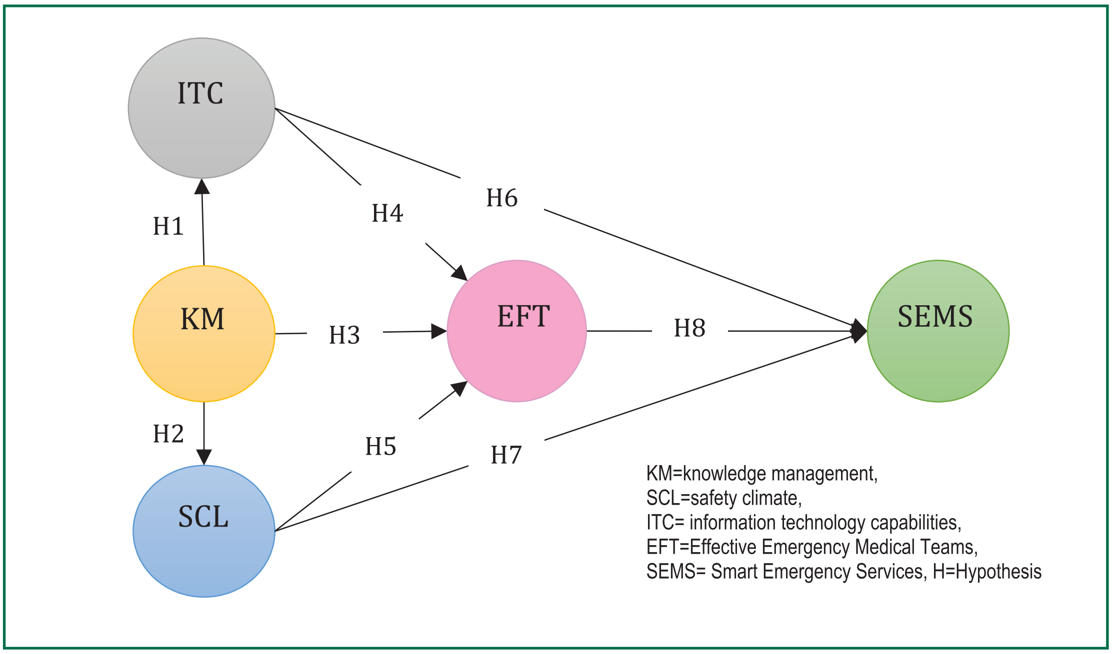

Figure 1: A research framework

All hypothesized relationships were specified as unidirectional, moving from KM, SCL, and ITC toward EFT and SEMS. This specification follows the logic of SEM, in which causal paths are defined a priori based on theory. Prior SEMS studies (Patchetphokin et al.[15]) examined the direct effects of KM, SCL, and ITC on SEMS without incorporating team effectiveness. The present study extended this framework by introducing EFT as a mediating construct, while retaining a unidirectional specification to maintain parsimony and ensure proper model identification. Although reciprocal effects between constructs are theoretically plausible, they were not included to avoid model over-specification and to preserve statistical validity of the SEM analysis.

Materials and Methods

This study employed a mixed-methods research design, specifically an explanatory sequential design. **In the first phase** (quantitative), data were collected from 550 EMS personnel working in the public EMS system of Northern Thailand. Participants were selected through proportionate stratified random sampling to ensure representativeness across different service types and geographic areas.

In the second phase (qualitative), three EMS experts were recruited using purposive sampling based on their professional expertise, leadership roles, and ≥ 5 years of work experience. A threshold of at least five years was considered sufficient to ensure professional maturity and leadership experience in EMS practice. In-depth interviews were conducted to explain and contextualize the quantitative findings.

This sequential design enabled the integration of statistical results with expert perspectives, thereby enhancing the robustness and validity of the study's conclusions.

Hypotheses

Drawing upon the conceptual framework and prior empirical evidence, the following hypotheses were tested:

H1: KM has a positive influence on ITC.
H2: KM has a positive influence on SCL.
H3: KM has a positive influence on EFT.
H4: ITC has a positive influence on EFT.
H5: SCL has a positive influence on EFT.
H6: ITC has a positive influence on SEMS.
H7: SCL has a positive influence on SEMS.
H8: EFT has a positive influence on SEMS.

Inclusion and Exclusion Criteria

Quantitative phase (survey) — Inclusion: (i) employment in the public EMS system of Northern Thailand; (ii) ≥ 1 year of EMS work experience; (iii) proficiency in Thai (speaking, reading, and writing); and (iv) provision of written informed consent.

Qualitative phase (expert interviews) — Inclusion: recognized EMS expertise with leadership responsibilities and ≥ 5 years of professional EMS experience; relevance to the study objectives; and provision of written informed consent.

Exclusion criteria (both phases) included: inability to communicate in Thai (speaking/reading/writing) or refusal to participate.

Eligible participants were approached by EMS supervisors during duty schedules; information sheets were provided, questions were answered, and written informed consent was obtained prior to questionnaire completion or interviews. Individuals who declined participation did so at the invitation stage, before data collection commenced. All procedures adhered to institutional IRB approval (NTU 1-059-2567).

Sample size determination and data analysis

In SEM, Hair JF, et al.,[21] recommend a minimum ratio of 10 participants per observed variable when using maximum likelihood estimation to ensure statistical power and model stability. With 31 observed indicators in this study, the minimum required sample size was 310. Furthermore, Comrey and Lee[20] suggested that a sample size of 500 is considered very good for multivariate analysis. Based on these standards, the final sample of 550 EMS personnel exceeded the minimum requirement and was deemed adequate for SEM analysis.

Descriptive statistics (frequency, percentage, mean, standard deviation, and coefficient of variation) were used to summarize participant characteristics and construct scores. Inferential analyses were conducted using SEM with maximum likelihood estimation to test the hypothesized relationships among KM, SCL, ITC, EFT, and SEMS. Measurement reliability and validity were assessed through CFA, CR, and AVE. All analyses were performed with LISREL (Scientific Software International, IL, USA). Path coefficients were estimated as standardized values, and their statistical significance was evaluated using t-statistics provided by LISREL.

Measurement instrument

The questionnaire comprised five sections, corresponding to the core constructs of the research model: KM, SCL, ITC, EFT, and SEMS. All construct items were rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). A demographic section captured background characteristics, including gender, age, education, years of EMS experience, and professional role. Operational definitions and measurement items were adapted from established literature.

Content validity was evaluated by five experts (associate professors, physicians, and EMS specialists) using the Item-Objective Congruence (IOC) method, with IOC values exceeding 0.80, indicating satisfactory content validity. Construct validity was assessed using CFA. Internal consistency reliability was confirmed with Cronbach's alpha coefficients ranging from 0.912 to 0.978, all surpassing the recommended threshold of 0.70,[18] thereby demonstrating strong psychometric properties.

All participants provided written informed consent. Data were de-identified, stored securely with restricted access, and retained for three years before secure disposal. The study protocol was approved by the Institutional Review Board of Nation University (Approval No. NTU 1-059-2567).

Results

A total of 550 participants completed the questionnaire. Most were female (67.8%), aged 31–40 years (47.3%), held a bachelor's degree (79.3%), and had 5–10 years of work experience (54.5%). The majority were advanced life support providers (73.1%), and all participants (100%) were employed in the Northern region.

The highest mean scores for each component were: SCL (4.555 ± 0.653), ITC (4.460 ± 0.750), KM, (4.356 ± 0.727), SEMS (4.349 ± 1.079), and EFT (3.960 ± 0.940). These results indicate strong agreement regarding SCL and organizational goal clarity, recognition of the importance of information technology in EMS operations, and the influence of KM, SCL, ITC, EFT, and SEMS. The relatively lower mean score for EFT suggests potential areas for improvement in team effectiveness and collaborative performance.

Prior to SEM, data were screened for normality and multicollinearity. Frequency distribution analysis showed that all observed variables met criteria for normality, with skewness and kurtosis values within ± 2. Correlation coefficients ranged from 0.245 to 0.762, below the multicollinearity threshold ($r < 0.85$), indicating no multicollinearity issues.

The measurement model was assessed via CFA. Factor loadings ranged from 0.726 to 0.981, AVE values from 0.500 to 0.937, and CR values from 0.833 to 0.989, exceeding recommended thresholds (CR ≥ 0.70, AVE ≥ 0.50), confirming satisfactory construct reliability and convergent validity. Model fit indices indicated an excellent fit (Chi-square = 0, df = 0, p = 1.00, RMSEA = 0.000). As the measurement model was just-identified (saturated), perfect fit indices were expected and reflect model specification rather than overfitting.

The structural model showed an excellent fit between the hypothesized framework and observed data (Chi-square = 381.05, df = 422, Chi-square/df = 0.902, P = 0.924, CFI = 1.000, GFI = 0.957, AGFI = 0.950, RMSEA = 0.000). Estimates of causal paths with corresponding t-statistics are summarized in Table 1 and illustrated in Figure 2.

As shown in Table 1 and Figure 2, eight causal relationships were identified. KM had significant positive effects on ITC ($\beta = 0.818$, $p < 0.001$) and SCL ($\beta = 0.883$, $p < 0.001$), but no statistically significant direct effect on EFT ($\beta = 0.056$, ns). Among the internal constructs, SCL significantly influenced EFT ($\beta = 0.401$, $p < 0.05$) but showed no significant effect on SEMS ($\beta = -0.118$, ns). ITC had no significant effect on EFT ($\beta = 0.013$, ns), yet demonstrated a positive effect on SEMS ($\beta = 0.125$, $p < 0.05$). EFT exerted the strongest influence on SEMS ($\beta = 0.882$, $p < 0.001$). Mediation analysis further revealed that KM indirectly affected SEMS through SCL and EFT (β_indirect = 0.312).

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Mediation analysis further revealed that KM indirectly affected SEMS through SCL and EFT, with a meaningful indirect effect (β = 0.312). This indicates that although KM did not directly enhance EFT, its influence was transmitted via a safety-oriented organizational climate, which subsequently improved team performance and, in turn, the overall efficiency of SEMS.

Collectively, these findings position KM as the upstream driver of organizational improvement, SCL as a contextual mediator, and EFT as the operational mechanism most critical for achieving effective and resilient SEMS in Northern Thailand.

Table 1: Estimation of direct (DE), indirect (IE), and total (TE) effects of the causal components influencing smart emergency medical services (SEMS) (n = 550)

Causes	Effects											
	ITC			SCL			EET			SEMS		
	DE	IE	TE	DE	IE	TE	DE	IE	TE	DE	IE	TE
KM	0.818***	-	0.818***	0.883***	-	0.883***	0.056	0.365***	0.421***	-	0.369***	0.369***
SCL							0.401*	-	0.401*	-0.118	0.354***	0.236***
ITC							0.013	-	0.013	0.125*	0.011*	0.136*
EFT										0.882***	-	0.882***
SEMS												-
R-Square		0.658			0.553			0.245			0.762	

Note: Direct (DE), indirect (IE), and total (TE) effects of hypothesized paths on SEMS (n = 550).
*DE = Direct effect; IE = Indirect effect; TE = Total effect. *$p < 0.05$; ***$p < 0.001$. KM = Knowledge management; SCL = Safety climate; ITC = Information technology capabilities; EFT = Effective emergency medical teams; SEMS = Smart emergency medical services

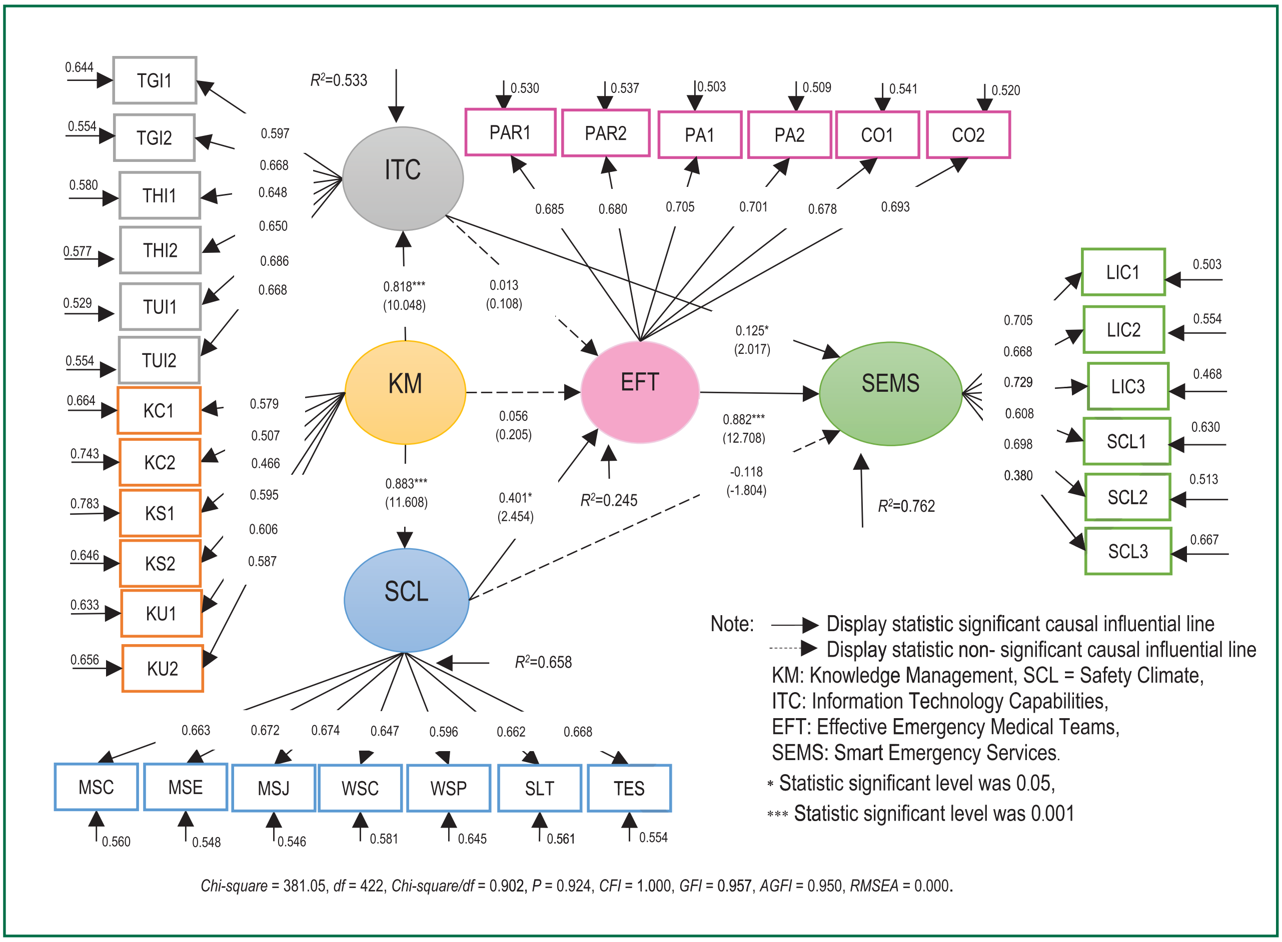

Figure 2: The structural equation model of the structural relationships which influences smart emergency medical services.

Discussion

This study developed and empirically validated a causal influence path coefficient model aimed at enhancing the performance of EMS in Northern Thailand. The model integrates five key constructs KM, ITC, SCL, EFT, and SEMS within a unified structural framework, thereby offering a comprehensive approach to EMS improvement. A mixed-methods research design was adopted, combining SEMS with in-depth qualitative interviews. This methodological integration facilitated rigorous statistical validation alongside context-specific interpretation, ensuring both the academic rigor and practical applicability of the findings.

KM had a positive influence on ITC, with a standardized path coefficient of 0.818 and a critical ratio of 10.048 ($p < 0.001$), indicating a strong and statistically significant effect. This finding is consistent with prior theoretical assumptions and empirical studies.[15,21] Complementary qualitative evidence from EMS experts highlighted the complex operational context of Northern Thailand, where geographical barriers, cultural diversity, and limited resources pose persistent challenges. Despite these constraints, KM was consistently identified as a critical enabler of ITC. Its integration into EMS operational protocols—through systematic data management, analytical processes, and effective knowledge dissemination—was viewed as essential for improving decision-making and enhancing patient outcomes. By facilitating the structured storage, transfer, and application of mission-critical knowledge, KM supports the development of robust, secure, and context-specific IT systems. This alignment enables EMS teams to deliver emergency responses with greater efficiency, precision, and resilience, while ensuring the safety of both patients and personnel.

KM had a positive influence on SCL, with a standardized path coefficient of 0.883 and a critical ratio of 11.068 ($p < 0.001$), indicating a strong and statistically significant effect. This result aligns with established theoretical perspectives and prior research.[15,23,24] Qualitative insights from EMS experts further emphasized that KM is central to shaping a positive SCL within SEMS in Northern Thailand. By facilitating systematic knowledge sharing, continual updating of best practices, and effective dissemination of safety protocols, KM enhances communication and collaboration among personnel and supports timely decision-making during emergencies. These processes promote continuous learning and active staff participation in safety-related decisions, thereby reinforcing both individual accountability and collective responsibility. Embedding KM practices into daily EMS operations ensures that safety remains an organizational priority, which in turn strengthens system resilience, improves response efficiency, and safeguards both patients and staff.

KM had a negative influence on EFT, with a standardized path coefficient of 0.056 and a critical ratio of 0.250, which was not statistically significant. This outcome is consistent with prior research suggesting that contextual barriers can weaken the KM–EFT link.[25-27] Qualitative interviews with EMS experts revealed multiple constraints that undermine this relationship, including decentralized governance, limited budgets, and high costs of specialized training, all of which restrict systematic knowledge development. Workforce heterogeneity, resource scarcity, and operational pressures further compel personnel to prioritize rapid decision-making over structured knowledge exchange. Heavy workloads, insufficient staffing, and high turnover erode institutional memory, while uneven technological infrastructure impedes effective KM. In combination with organizational challenges such as weak leadership and ineffective decentralization, these factors substantially diminish EFT performance. The findings highlight the urgent need for context-specific KM strategies tailored to the realities of EMS in Northern Thailand, where sustainable knowledge transfer and team effectiveness remain critical yet underdeveloped.

ITC had a negative influence on EFT, with a standardized path coefficient of 0.013 and a critical ratio of 0.108, which was not statistically significant. This finding aligns with previous studies[28,29], which highlighted challenges and limitations in applying information technology within EMS that may undermine team effectiveness. Insights from EMS experts revealed that unstable infrastructure in rural areas, fragmented communication, and limited resources impede IT system integration. Despite substantial investments, the lack of standardized platforms and technical support in remote settings restricts the benefits of ITC and contributes to reduced EFT performance. Time pressures in emergency situations further prevent personnel from fully utilizing IT tools, leading to inefficient data sharing and decision-making, while insufficient training and preparedness in advanced IT use exacerbate these problems. Collectively, these barriers explain the non-significant relationship between ITC and EFT in Northern Thailand, underscoring the need for context-specific strategies that strengthen infrastructure, standardization, and training to enhance technology-supported team performance.

SCL had a positive influence on EFT, with a standardized path coefficient of 0.401 and a critical ratio of 2.424 ($p < 0.05$), indicating a statistically significant effect. This finding is consistent with prior theoretical perspectives and empirical studies[30,31], which demonstrated that a strong SCL promotes positive safety behaviors and well-being among emergency responders. Expert interviews confirmed that fostering a positive SCL at both leadership and organizational levels is essential for enhancing patient transfer safety. In Northern Thailand, EMS organizations emphasize structured safety management, continuous communication, and collaborative decision-making to reduce operational stress and improve team performance. Such practices not only mitigate risks and potential injury severity but also reinforce system resilience by embedding psychological safety, standardized protocols, and collective accountability into daily operations. These mechanisms strengthen emergency response capacity and ensure high-quality medical interventions while sustaining organizational effectiveness.

ITC had a positive influence on SEMS, with a standardized path coefficient of 0.125 and a critical ratio of 2.017 ($p < 0.05$), indicating a statistically significant effect. This finding is consistent with prior theoretical perspectives and empirical evidence[15,32], which demonstrate that information and communication technology enhances SEMS through real-time communication, advanced data management, and predictive analytics. Technological infrastructure such as lobal Positioning System (GPS), mapping tools, and multi-agency communication systems enables rapid decision-making and efficient resource allocation, while artificial intelligence and automation improve triage accuracy, facilitate remote consultations, and optimize emergency protocols. Expert interviews confirmed that ITC integration effectively supports EMS operations in Northern Thailand by strengthening cross-agency coordination, ensuring timely access to critical patient data, and enabling informed clinical decision-making. Collectively, these capabilities enhance responsiveness, operational efficiency, and patient-centered care, underscoring the transformative role of ITC in advancing SEMS.

SCL had a negative influence on SEMS, with a standardized path coefficient of –0.118 and a critical ratio of –1.804, which was not statistically significant. This result contrasts with the findings of Patchetphokin and teams[15], who reported a positive relationship between SCL and SEMS. The discrepancy can be explained by contextual factors specific to Northern Thailand, including unstable infrastructure in rural areas, limited training for EMS personnel, and resource constraints that restrict the integration of safety practices with ICT systems. Cultural and linguistic diversity also complicates inter-agency communication, undermining the establishment of a strong SCL, while insufficient technical support and inadequate data management systems further limit the translation of SCL into effective SEMS. Expert interviews reinforced these observations, emphasizing that unstable infrastructure, workforce shortages, and lack of targeted training are major barriers to leveraging SCL for system development. Collectively, these challenges indicate that Northern Thailand requires tailored strategies to strengthen SCL and ensure its effective integration into SEMS, particularly through investments in infrastructure, workforce training, and sustainable technical support.

EFT had a positive influence on SEMS, with a standardized path coefficient of 0.882 and a critical ratio of 12.708 ($p < 0.001$), indicating a strong and statistically significant effect. This finding demonstrates that EFT substantially enhance the performance of SEMS and is consistent with previous research[33,34] showing that team effectiveness, supported by technology and innovation, improves system efficiency. Expert interviews confirmed that in Northern Thailand, EFT integration with SEMS is particularly critical given the region's complex geography and resource limitations. High-performing teams leverage digital technologies, real-time data connectivity, and advanced communication systems to strengthen disaster response and facilitate timely transmission of patient information to healthcare facilities. Access to diagnostic tools and systematic deployment of technological infrastructure were highlighted as mechanisms enabling rapid, precise, and coordinated responses. These findings underscore that embedding EFT within SEMS not only enhances operational efficiency but also contributes to resilient and context-sensitive emergency medical care capable of addressing the unique challenges of the region.

The analysis of path coefficients provides important practical implications for EMS development. The strong influence of KM on SCL ($\beta = 0.883$) suggests that structured knowledge-sharing mechanisms and systematic learning platforms are critical for reinforcing safety behaviors and cultivating a sustainable safety culture among EMS personnel. Likewise, the substantial effect of EFT on SEMS ($\beta = 0.882$) emphasizes the value of targeted investments in team-based simulation training and technology-enabled coordination, both of which enhance collective performance under high-pressure conditions. Together, these findings demonstrate how empirical evidence can be translated into programmatic interventions aimed at improving EMS efficiency, organizational resilience, and ultimately patient outcomes.

Limitations

This study has several limitations. First, the findings are geographically constrained to Northern Thailand and may not fully represent the complexities of EMS systems in other regional contexts. Second, the cross-sectional design restricts causal inference, as relationships were examined at a single point in time. Third, the reliance on self-reported data may introduce response bias. Fourth, the model specification was limited to unidirectional causal paths, excluding potential reciprocal relationships. Finally, while the study highlights the importance of digital health tools such as EMR, uneven adoption in Northern Thailand limits the generalizability of findings to regions with more advanced infrastructures.

Conclusion

This study presents a comprehensive framework for strengthening EMS in Northern Thailand, developed through causal path coefficient modeling. The findings highlight KM as a pivotal determinant, exerting significant effects on SCL, EFT, and SEMS, with an indirect effect of 0.312 mediated through SCL and EFT. Theoretically, the study contributes to healthcare system optimization by integrating KM, ITC, SCL, and EFT into a unified framework, thereby extending existing SEMS research. Practically, the findings provide evidence-based recommendations for policymakers, emphasizing the strategic importance of KM infrastructure, digital health adoption (e.g., EMR integration), and team-based simulation training as context-specific strategies to improve service quality and patient outcomes. This research also offers a foundation for comparative regional studies and longitudinal assessments of EMS reform, and it motivates further inquiry into digital health and inter-agency collaboration to enhance resilience and responsiveness in resource-constrained settings.

Recommendations

Policymakers should prioritize the development of an advanced information technology–based KM system for Northern Thailand's EMS, focusing on personnel training, infrastructure strengthening, and cross-agency communication. In addition, further studies should extend the current SEM framework by examining alternative model specifications and incorporating mediator variables beyond EFT to improve understanding of EMS operations and optimize resource management.

Disclosure statement

The authors declare that artificial intelligence tools (ChatGPT-5.0) were used solely for minor grammar refinement. No AI tools were involved in data collection, statistical analysis, or interpretation.

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References

1. Martin JL, Varilly H, Cohn J, Wightwick GR. Preface: Technologies for a Smarter Planet. *IBM Journal of Research and Development*. 2010;54(4):1-2. doi: 10.1147/JRD.2010.2051498
2. Jittamai P. Supply chain planning for emergency service management in regional level. National Institute for Emergency Medicine.2014:11-15. (Accessed March 1,2025, at https://www.niems.go.th/1/upload/migrate/file/255907041830181834_kqymARLsVzKmKsMN.pdf.)
3. National Institute for Emergency Medicine. [Internet] The 4th National Emergency Medical Principal Plan, B.E. 2566-2570, 2022. Available from: https://www.niems.go.th/1/Ebook/Detail/11182?group=3
4. Ministry of Public Health. *20-Year National Strategic Plan on Public Health* (2017–2037), 2nd revised edition [Thai]. Nonthaburi: Ministry of Public Health,2025 (Accessed March 1,2025, https://spd.moph.go.th/wp-content/uploads/2022/09/Ebook-MOPH-20-yrs-plan-2017-Final-Eng-120961.pdf)
5. Rudklao Wongchaisuriya, Kriengsak Pintatham, Yuttana Kowjiriyaphan and Pornthira Phromyaung. Factors related to mortality of accidental patients delivered with the advanced emergency kit of Chiang Rai Prajanukroh Hospital. Journal of Emergency Medical Services of Thailand, 2021;1(1), 14-22. doi:10.14456/jemst.2021.2
6. National Institute for Emergency Medicine. 20-Year Strategic Plan of the National Institute for Emergency Medicine (2018–2037) [Thai]. Nonthaburi: National Institute for Emergency Medicine,2019 (Accessed March 1,2025, https://www.niems.go.th/1/upload/migrate/file/256206251325543945_1015dxGgteyAeCQl.pdf)
7. National Institute for Emergency Medicine.The 4th Emergency Medical Principle Plan, 2023-2027.2025.(Accessed March 1,2025, https://online.fliphtml5.com/auukz/koew/#p=18)
8. World Health Organization. [Internet]. Global status report on road safety 2018. [cited 2025 Mar 24]. Available from: https://www.who.int/publications/i/item/9789241565684
9. National Institute for Emergency Medicine. Master plan for emergency medical communication and information technology, 3rd edition, B.E. 2563–2570 (2020–2027) [Internet]. Nonthaburi: National Institute for Emergency Medicine; 2020 [cited 2025 Apr 20]. Available from: https://www.niems.go.th/1/Ebook/Detail/11182?group=3
10. Sonvanee Tanuchit, Danai Chinnacom, Natthida Malathong, Suradech Doungthipsirikul, and Sripen Tantivess. The situations of emergency medical services associated with elderly falls in Thailand: policy recommendation. *J Prof Routine Res.* 2019;6:57–68 Available from: https://so03.tci-thaijo.org/index.php/jpr2r/article/view/136411
11. Healthcare Accreditation Institute (Public Organization). *Driving public participation from 2P to 3P Safety (people)* [Internet]. Nonthaburi: Healthcare Accreditation Institute (Public Organization); 2021 [cited 2022 Aug 25]. Available from: https://www.ha.or.th/EN/Posts/people/Details/176
12. Reuter-Oppermann M, van den Berg PL, Vile JL. Logistics for emergency medical service systems. Health Systems. 2017;6(3):187-208. doi: 10.1057/s41306-017-0023-x
13. Shatpattananunt B, Petpichetchian W, Pinsuwan S, Chaloempong T, Waraphok S, Wongwatkit C. Development and evaluation of a virtual reality basic life support for undergraduate students in Thailand: a project by Mae Fah Luang University (MFU BLiS VR). BMC Medical Education. 2023;23(1):782. doi:10.1186/s12909-023-04764-6
14. Sungbun S, Tangkawanich T, Thanakumma O, Sukrueangkul A. Perceived barrier in accessing emergency medical services of ethnic groups in the highlands of Chiang Rai Province, Thailand. *J Health Sci Med Res*. 2020;38(2):125–33. DOI: 10.31584/jhsmr.2020731
15. Patchetphokin K, Meechaisue P, Chinuntdej N, Chaimongkol D. The influence of knowledge management, safety climate, and information technology capabilities on a smart emergency logistics system: a study of BDMS emergency services. *Bangkok Med J*. 2023;19(2):74. doi: 10.31524/bkkmedj.2023.21.002
16. Rattiyakorn Thuewan & Somkid Prabpai. Accidents Experiences and Safety Behavior among Emergency Medical Personnel with Ambulance: Qualitative Research. Journal of Health and Nursing Research, 2020; 37(1), 142-155. Available from: https://he01.tci-thaijo.org/index.php/bcnbangkok/article/view/248863
17. Sittichanbuncha Y, Prachanukool T, Sarathep P, Sawanyawisuth K. An emergency medical service system in Thailand: providers' perspectives. Journal of the Medical Association of Thailand. Chotmaihet Thangphaet. 2014;97(10):1016-21 Available from: https://pubmed.ncbi.nlm.nih.gov/25632616/

18. Creswell J. Research Design: Qualitative, Quantitative and Mixed Methods Approaches. Pearson Education Inc.; 2015 (Accessed March 1,2025, at https://www.ucg.ac.me/skladiste/blog_609332/objava_105202/fajlovi/Creswell.pdf)
19. Miles MB, Huberman AM. Qualitative data analysis: An expanded sourcebook. 2nd ed. Sage Publications, Inc.; 1994.
20. Comrey AL, Lee HB. A first course in factor analysis, 2nd ed. Hillsdale, NJ, US: Lawrence Erlbaum Associates, Inc; 1992. xii, 430-xii, 125 doi:10.4324/9781315827506
21. Hair JF, Black WC, Babin BJ, Anderson RE. Multivariate data analysis: Pearson Prentice Hall; 2018. (Accessed March 1,2025, at https://eli.johogo.com/Class/CCU/SEM/_Multivariate%20Data%20Analysis_Hair.pdf)
22. Sitawati R, Manaf S, Permana RY. Impact of knowledge management and information technology capability on performance. *Int J Eng Bus Soc Sci*. 2019;3(3):219. doi: 10.58451/ijebss.v3i3.219
23. Deepak MD, Gangadhar M, Kumar MN. Knowledge management influence on safety management practices: evidence from construction industry. In: Research Anthology on Changing Dynamics of Diversity and Safety in the Workforce. IGI Global; 2022. p. 996-1020 doi: 10.4018/978-1-6684-2405-6.ch050
24. Sun K, Lan T, Goh YM, Safiena S, Huang YH, Lytle B, He Y. An interpretable clustering approach to safety climate analysis: Examining driver group distinctions. *Accid Anal Prev.* 2024; 196:107420. doi: 10.1016/j.aap.2023.107420
25. Bjorvatn T, Wald A. The impact of time pressure on knowledge transfer effectiveness in teams: trust as a critical but fragile mediator. *J Knowl Manag*. 2020;24(10):2357–2372. doi: 10.1108/JKM-05-2020-0379
26. Unahalekhaka A. Obstacles and needs of first responders in the northern region: a mixed methods study. *J Emerg Med Serv* Thailand. 2022;2(1):3-16. doi: 10.14456/jemst.2022.1
27. Ouriques R, Wnuk K, Berntsson Svensson R, Gorschek T. Thinking strategically about knowledge management in agile software development. In: Springer; 2018. p. 389–395. doi: 10.1007/978-3-030-03673-7_30.
28. Lee J, Kong SY, Kim BW, Kim SY, Park GJ, Chai HS, Kim YM, Lee SW, Kim SC. Assessment of novel ICT-EMS systems to improve emergency patient transportation during the COVID-19 pandemic. *Am J Emerg Med*. 2022; 56:107–112 doi: 10.1016/j.ajem.2022.03.035
29. Rinkinen T, Kinnula M, Nordquist H. Technological development roles and needs in pre-hospital emergency care from the advanced level paramedics' perspective. International Emergency Nursing. 2024; 73:101406 doi: 10.1016/j.ienj.2024.101406
30. Lee J, Resick CJ, Allen JA, et al. Interplay between safety climate and emotional exhaustion: effects on first responders' safety behavior and wellbeing over time. *J Bus Psychol.* 2024; 39:209–231. doi: 10.1007/s10869-022-09869-1
31. Sørskår LIK, Olsen E, Abrahamsen EB, Bondevik GT, Abrahamsen HB. Assessing safety climate in prehospital settings: testing psychometric properties of a common structural model in a cross-sectional and prospective study. *BMC Health Serv Res.* 2019;19(1):674. doi: 10.1186/s12913-019-4459-5.
32. Kim SC. Integration of information and communication technology in emergency medical services: The Chungbuk Smart Emergency Service Project. *J Korean Med Assoc.* 2023;66(7):450–457.doi: 10.5124/jkma.2023.66.7.450
33. Apiratwarakul K, Cheung LW, Pearkao C, Gaysonsiri D, Ienghong K. "Smart Emergency Call Point" Enhancing Emergency Medical Services on University Campuses. *Prehosp Disaster Med*. 2024;39(1):32–36. doi: 10.1017/S1049023X23006647
34. Usher K, Park J, Son C. Artificial Intelligence for Emergency Medical Service. In: Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care. 2024;13(1):1-6. doi: 10.1177/2327857924131049