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Research Article

Air Transport Innovation for Enhancing Medical Evacuation of Army Aviators

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ABSTRACT

The objectives of this research are (1) to study the patterns, roles, and approaches for applying air transport innovations to enhance the efficiency of aeromedical evacuation missions conducted by Army pilots; (2) to analyze the technological, human, and systemic management factors that influence the success or pose obstacles to the application of air transport innovations in aeromedical evacuation missions; and (3) to synthesize guidelines for developing a more efficient aeromedical evacuation system through the integration of air transport innovations, linking with the dimensions of medical logistics, time management, and appropriate resource allocation in accordance with international standards. This research is a qualitative study employing in-depth interviews as the primary research instrument. The key informants are divided into three groups: the group of aeromedical evacuation operators, the group of administrators and stakeholders involved in policy and management, and the group of emergency medicine experts, with a total of ten participants. The collected data were then analyzed descriptively and systematically synthesized to draw conclusions. The findings revealed that air transport innovations play a crucial role in improving the safety and efficiency of patient evacuation missions by reducing risks, enhancing decision-making accuracy, and supporting operations in challenging environments. Training and simulation were identified as critical factors in strengthening personnel readiness and minimizing operational errors. Key supporting factors included the reliability and readiness of aircraft and medical equipment, the skills and expertise of pilots and medical teams, continuous training, and policy as well as budgetary support. The obstacles identified were geographical and weather limitations, technological complexity, and communication and information constraints in remote areas. Development guidelines suggested by experts emphasized the adaptation of equipment and aviation systems to mission requirements, enhancement of training and simulation programs, and the establishment of international-standard operating procedures to ensure maximum safety and efficiency in medical evacuation.

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1. Introduction

Aviation has become an essential tool in the advancement of humankind, particularly in emergency medical missions where speed, precision, and maximum safety are vital to saving lives. The concept of Aeromedical Evacuation (AE) originated in the 19th century and has continued to evolve over time. In 1916, the French Army modified an aircraft to install a stretcher for transporting injured Serbian soldiers from the battlefield, marking the beginning of a systematic use of aircraft for medical purposes. Later, during World War II, aeromedical evacuation was further developed through the establishment of dedicated units such as the U.S. Armys 38 th Medical Air Ambulance Squadron, which transported over one million casualties within just three years [1].These advancements laid the foundation for the widespread use of helicopters in MEDEVAC missions during the Korean and Vietnam Wars, particularly the Bell 47 and Bell UH-1(Huey), which reduced evacuation time by more than 50% and significantly increased survival rates compared to earlier battlefield medical tactics [2]. Their success later inspired the development of Helicopter Emergency Medical Services (HEMS) in the civilian sector in many countries, such as REGA (Switzerland, established in 1952) and ADAC Luftrettung [3].

Medical innovation and aviation technology have become key drivers in enhancing the medical logistics chain, especially in terms of reducing lead time in patient transport, optimizing resource allocation including personnel, equipment, and vehicles–and minimizing losses during patient movement. The integration of advanced aviation technologies such as modern avionics systems, GNSS, RNP and SBAS navigation, night vision goggles (NVG), and weather radar has significantly improved operational efficiency in terms of speed, accuracy, and safety.

In Thailand, the development of the national air medical emergency system began in earnest in 2009 under the leadership of the National Institute for Emergency Medicine (NIEM) [4], in collaboration with security agencies such as the Royal Thai Army, Royal Thai Air Force, Royal Thai Navy, as well as private hospitals. The goal is to ensure equitable access to emergency medical services, particularly for patients in remote areas [4]. However, when compared with countries such as Germany which operates over 80 dedicated emergency helicopters nationwide with an average response time of under 10 minutes [3] Thailand still faces limitations in the number of aircraft, specialized personnel, and infrastructure, particularly the helipad network that supports patient transport. These constraints affect the overall efficiency of the national medical logistics system.

Within the context of the Royal Thai Army, although Army Aviation units play a significant role in supporting aeromedical evacuation missions especially in remote areas or during disasters there remains a lack of empirical research exploring in depth the technical, human, and managerial factors in aviation innovation that influence mission safety and effectiveness. Previous studies in Thailand have mostly focused on policy aspects or civilian emergency services, while field-based data from military operations remain limited.

Therefore, studying aviation innovation through the lens of real operational experience, incorporating the perspectives of Army pilots and related personnel, is essential for understanding the capabilities, challenges, and appropriate development pathways for improving aeromedical evacuation missions. The findings of this research are expected to contribute to the advancement of the military emergency medical system, ensuring that it aligns with international standards and remains capable of responding effectively to complex and rapidly changing situations.

1.1. Objectives of the research

1. To examine the patterns, roles, and approaches in applying aviation innovations to enhance the efficiency of aeromedical evacuation missions carried out by Army pilots.

2. To analyze the technological, human, and systems-management factors that contribute to the success or present obstacles in the implementation of aviation innovations in aeromedical evacuation operations.

3. To synthesize development strategies for improving aeromedical evacuation systems through aviation innovation, with an emphasis on medical logistics, time management, and optimal resource allocation in accordance with international standards.

1.2. Research Conceptual Framework

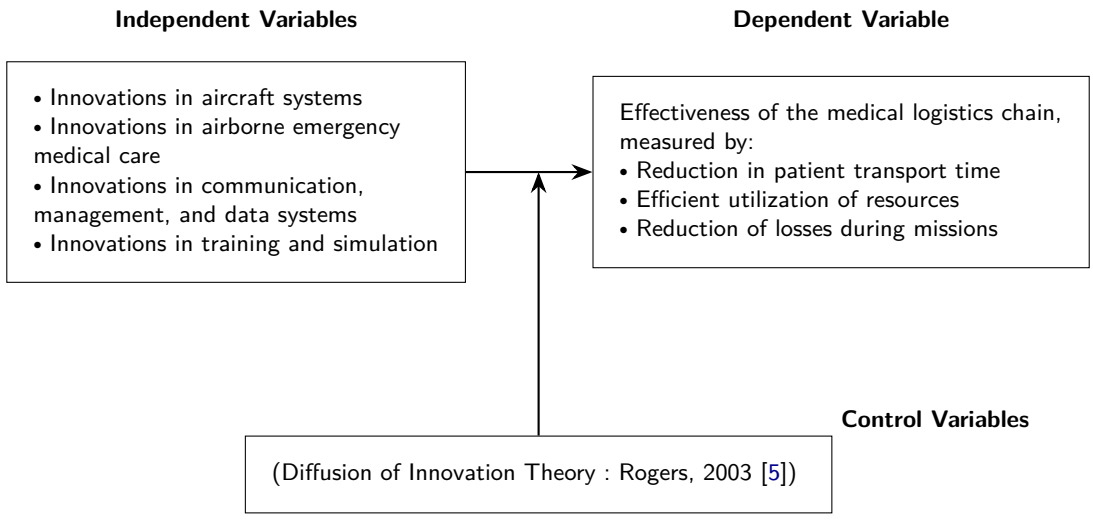


Figure 1: Conceptual Framework.

2. Literature Review

The study of aviation innovations for Aeromedical Evacuation (AE) or MEDEVAC is essential for strengthening the operational capabilities of Army Aviation units, as such missions directly involve saving lives and providing humanitarian support during emergencies. Numerous studies, both domestic and international, have identified key factors that influence the success of aeromedical evacuation operations.

2.1. Diffusion of Innovation

Innovation refers to the process or outcome of creating new and valuable solutions that meet needs or improve upon existing systems [5]. In the context of aeromedical transport, innovation is a critical factor that enhances speed, safety, and the quality of patient care during emergency evacuation missions. Innovations can emerge across multiple dimensions, including technology, management systems, personnel development, and operational standards. Rogers (2003) [5] defines innovation as an idea, tool, or process perceived as new by individuals who adopt it to create value. In aeromedical operations, innovation encompasses the development of specialized aircraft, installation of medical equipment, and utilization of digital technologies to support communication and patient data management, thus improving the effectiveness and safety of mission execution.

2.2. Diffusion of Innovation Theory

Rogers Diffusion of Innovation Theory (2003) [5] emphasizes that the adoption of new technologies or concepts is influenced by several factors. These include the observability and perceived advantages of the innovation compared to existing methods, the ease of use meaning the innovation should not be overly complex and the level of organizational and societal support. Policy support and adequate personnel resources significantly influence the successful adoption of innovations.

2.3. Aviation System Innovations

Aviation system innovations play a critical role in enhancing the safety and efficiency of aeromedical evacuation missions conducted by Army pilots. One key technology is the Helicopter Terrain Awareness and Warning System (HTAWS), which reduces the risk of Controlled Flight Into Terrain (CFIT) accidents one of the leading causes of helicopter mishaps in complex terrain or low-visibility environments. Research by the UK Civil Aviation Authority [6] indicates that enhanced HTAWS Classic Modes effectively reduce such accidents and are suitable for HEMS and offshore operations [7].

Meanwhile, GPS-based navigation and the concept of Performance-Based Navigation (PBN) improve accuracy and reduce the limitations of traditional navigation methods, particularly in remote areas or airfields without ground-based navigation aids [8]. The application of RNAV and RNP procedures has increased the safety and rapid accessibility of emergency helicopter missions, directly contributing to improved patient survival outcomes [9].



Figure 2: Helicopter Emergency Medical Services (HEMS) equipped with aeromedical transport medical equipment [10].

2.4. Medical Innovations in Airborne Emergency Care

Rotary-wing aircraft used in Helicopter Emergency Medical Services (HEMS) are designed with spacious cabins and modular interior systems to accommodate essential medical equipment for in-flight patient care. Key innovations include wireless vital-sign monitoring systems, transport ventilators, smart infusion pumps, defibrillators/AEDs, and modular medical mounting systems. These technologies enhance precision, safety, and flexibility in caring for critically ill patients in the challenging environment of flight [7, 11]. According to the Air Medical Transport Innovation Model [11], the integration of aviation technologies and medical equipment supports immediate patient care, reduces transfer time, and improves survival rates.

2.5. Medical Innovations in Airborne Emergency Care

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2.6. Innovations in Communication and Information Management

Communication and data management are central to aeromedical missions. VHF/UHF communication systems enable coordination among aircraft, control units, and rescue teams, enhancing safety and operational continuity [12]. Airbuss Helionix system is a notable example of Integrated Modular Avionics (IMA) [13], combining communication, navigation, flight management, and warning systems into one platform. Its key functions such as HTAWS, Synthetic

Vision, four-axis autopilot, and SAR Mode reduce pilot workload, enhance situational awareness, and support MEDEVAC missions effectively [13]. These advancements significantly improve safety, speed, and the accuracy of information management during aeromedical evacuations.

2.7. Innovations in Training and Simulation

Training and simulation innovations, particularly flight simulators, play a vital role in enhancing pilot training by reducing costs, strengthening decision-making skills, and improving mission safety. Simulators can replicate real flight environments, emergency scenarios, and communication procedures with high fidelity [14]. Systems such as Full-Flight Simulators (FFS), Flight Training Devices (FTD), and VR simulators allow pilots to train under high-risk conditions such as severe weather or technical malfunctions that would be unsafe to replicate in real aircraft [15].

Research suggests that the adoption of flight simulation in the aviation industry since the 1970s has reduced aviation accident rates by up to 50%, despite a fourfold increase in flight volume [16]. Recent reports also indicate that AI and VR-based simulators reduce pilot errors during emergency scenarios by more than 20% compared to traditional classroom-based training [18].

3. Research Methodology

Step 1: Review of Documents, Concepts, Theories, and Related Research The researcher conducted a comprehensive review, analysis, and synthesis of documents, books, research reports, and theoretical frameworks related to medical logistics, aviation innovation, and aeromedical evacuation. This review served as the basis for developing the research framework, guided by Everett Rogers (2003) [5] Diffusion of Innovation Theory, particularly in the dimensions of innovation adoption and the diffusion of aviation and medical technologies within military units.

Step 2: Selection of Key Informants A purposive sampling method was used to select key informants who possess knowledge, expertise, and direct experience in aeromedical evacuation missions. A total of 10 informants were selected and categorized into three groups:1. Army pilots with experience in aeromedical evacuation (6 informants) : 2 Army Aviation instructors 2 unit-level flight instructors 2 senior aircraft commanders 2. Medical personnel involved in aeromedical missions (2 informants) Physicians, nurses, and emergency medical rescue staff 3. Administrators and policy-related personnel (2 informants) Mission planners, aviation safety officers, and support personnel The selection ensured representation across aviation, medical, and management perspectives, providing sufficiently diverse and in-depth qualitative data. Data collection was conducted between July and September 2025

Step 3: Research Instruments The research employed three sets of semi-structured interview guides, tailored to each informant group :

1. Army pilots (instructors and aircraft commanders) Interviews focused on the role and significance of aviation system innovations in enhancing flight safety during aeromedical evacuation missions, operational limitations, and impacts on pilot decision-making.

2. Medical personnel (HEMS physicians and nurses) Interviews explored the use and management of medical equipment onboard aircraft, innovations supporting critical patient care, and the suitability of cabin layout for safety and operational efficiency.

3. Administrators, policymakers, and aviation safety officers Interviews emphasized resource management, policy and organizational support, communication and information systems, and development approaches that promote the use of aviation and medical innovations aligned with safety and operational standards.

Step 4: Instrument Validation The interview guides were reviewed by academic advisors and subject matter experts to assess content validity, language clarity, and appropriateness. Revisions were made prior to data collection.

Step 5: Data Collection Procedures

1. The researcher obtained permission from relevant authorities to contact key informants and explained the purpose of the study.

2. In-depth, semi-structured interviews were conducted, lasting 12 hours each. Audio recording and notetaking were used with prior consent.

3. When necessary, follow-up interviews were conducted to verify incomplete or unclear information.

4. After each interview, the researcher transcribed the recordings and verified accuracy with informants.

Step 6: Data Validation

To ensure the credibility and trustworthiness of the data, the researcher employed several validation techniques:

1 . Member Checking: Summaries of key information were sent back to the informants for verification of accuracy.

2. Peer Debriefing: Experts in qualitative research and aviation were consulted to review and validate the data analysis process.

Step 7: Data Analysis

Content analysis was employed, using categorization and narrative interpretation within the framework of Rogers [5] Diffusion of Innovation Theory to explain the patterns of innovation adoption and application in aeromedical evacuation operations.

Step 8: Conclusion and Presentation

The researcher synthesized key findings related to aeromedical transport innovations that enhance the effectiveness of air medical evacuation operations, including operational, medical, and managerial aspects. Policy recommendations and practical suggestions were also proposed to support future development within the Royal Thai Army.

4. Research Findings

1. Roles and Applications of Aeromedical Transportation Innovations in Aeromedical Evacuation Missions Interviews with subject-matter experts revealed that innovations in aviation systems, medical equipment, and communication technologies are key factors enhancing the safety and effectiveness of aeromedical evacuation missions.

1.1 Innovations in Aircraft Systems

Flight instructors and aircraft commanders indicated that systems such as Helionix Avionics, HTAWS, TCAS, and Synthetic Vision significantly reduce operational risks in highly complex environments particularly during flights over mountainous terrain, low-visibility conditions, and night operations. These systems support faster decision-making, reduce the likelihood of CFIT (Controlled Flight Into Terrain), and increase pilot confidence. Furthermore, GPS and PBN (Performance-Based Navigation) improve navigational accuracy, decrease route complexity, and enable the selection of safer routes for patients and medical crews.

1.2 Innovations in Aeromedical Emergency Care

HEMS physicians and nurses emphasized that medical equipment such as transport ventilators, wireless patient monitoring systems, infusion pumps, and defibrillators/AEDs enhances continuity of care, reduces errors, and increases mission success particularly for critically ill patients requiring precise and continuous monitoring. Additionally, the use of modular cabin interiors and medical mounting systems improves flexibility, safety, and mission-specific adaptability of equipment placement.

1.3 Innovations in Communication and Data Management

Aviation safety officers and medical teams highlighted that Real-time Data Link and Telemedicine systems allow patient information to be transmitted directly to hospitals. These systems enable ground-based medical teams to provide timely consultation, improve decision-making accuracy, reduce risks during operations, and strengthen confidence among pilots and medical crews.

1.4 Innovations in Training and Simulation

Experts across all groups agreed that simulation training and blended training play a crucial role in preparing pilots and medical teams. Simulation-based practice reduces human error, especially in scenarios that are difficult to train for in real flight environments such as night operations, critical patient management, and emergency response. These training methods contribute significantly to safer and more efficient mission execution.

2. Supporting Factors and Challenges in Implementing Innovations Interviews revealed several key supporting factors:

2 .1 Reliability and Readiness of Aircraft and Medical Equipment Stable aircraft systems and dependable medical devices form the foundation of mission safety.

2.2 Skills and Competence of Pilots and Medical Teams Knowledge and proficiency in using new technologies directly affect decision-making and patient safety.

2.3 Simulation and Blended Training These training methods enhance confidence and reduce human error, particularly for emergency situations that cannot be practiced in real flight environments.

2.4 Policy Support and Efficient Resource Management Effective policy support and resource allocation strengthen maintenance capabilities and ensure ongoing technological improvements for aeromedical operations. Key challenges identified include: 1. Geographical and weather-related constraints such as mountainous terrain,

low visibility, and thunderstorms 2. Complexity of new technologies requiring time for training and adaptation 3. Communication and data-transmission limitations, particularly in remote areas

3. Development Strategies for Enhancing Aeromedical Evacuation Through Innovation Experts proposed several key strategies to improve aeromedical evacuation efficiency:

3.1 Upgrade aircraft systems and medical equipment to match mission demands and environmental conditions.

3.2 Expand simulation and blended training programs to strengthen the skills and confidence of pilots and medical teams.

3.3 Enhance communication systems and real-time data links to ensure reliable functionality even in remote areas.

3.4 Promote systematic resource management and policy support to ensure continuous maintenance and improvement of equipment and technologies.

3.5 Develop international-standard operating procedures (SOPs) to ensure high-quality and safe aeromedical evacuation aligned with global standards.

5. Discussion

The findings of the study on Aviation Innovations for Enhancing the Efficiency of Aeromedical Evacuation Missions in the Royal Thai Army can be discussed as follows:

1. Roles and Applications of Aeromedical Transportation Innovations

1.1 Aviation System Innovations for Enhancing Safety

The results indicate that aviation system innovations such as Helionix Avionics, HTAWS, TCAS, and Synthetic Vision play a crucial role in minimizing safety risks in aeromedical evacuation missions, particularly under challenging conditions such as night operations or instrument flight rules (IFR). Interviewees, including flight instructors and aircraft commanders, consistently agreed that these systems improve decision-making accuracy and reduce the risk of Controlled Flight Into Terrain (CFIT). This finding is in line with SKYbrary (2020) [7], which states that HTAWS significantly reduces terrain-collision risks in offshore and complex environments.However, some interviewees also pointed out limitations such as nuisance alerts and the need for pilot expertise to properly interpret system warnings. This aligns with the UK CAA (2015) [6], which notes that despite technological advancements, human factors remain a fundamental determinant of aviation safety.

1.2 Aeromedical Innovations and In-Flight Medical Care

HEMS physicians and nurses emphasized that modern medical devices such as transport ventilators, wireless patient monitoring systems, infusion pumps, defibrillators/AEDs, and modular medical mounting systems contribute greatly to mission success, especially for critically ill patients. The modular cabin design allows flexible arrangement of equipment and personnel according to mission needs. This aligns with Allerton & Lammertse (2023) [16], who noted that integrated medical equipment systems reduce errors and enhance the continuity of patient care during transport.

1.3 Communication and Data-Management Systems

Aviation safety officers and medical personnel agreed that Real-time Data Link and Telemedicine systems enable rapid transmission of patient vital signs to the receiving hospital, allowing real-time medical consultation. This enhances decision accuracy, reduces mortality risk during flight, and improves situational awareness. These findings correspond with ICAO (2013) [8], which highlights that integrated real-time data systems strengthen decisionmaking in airborne emergency scenarios.

1.4 Simulation-Based and Blended Training

Experts across all groups agreed that simulation training and blended learning are essential for preparing pilots and medical teams to handle emergency situations. Simulation reduces human error significantly, especially in scenarios that cannot be safely practiced in real flight environments. This is consistent with evidence from PubMed [17] and LinkedIn Learning (2025) [18], which showed that simulation-based training reduces flight-related errors and emergency-response incidents by 20-50%.

2. Supporting Factors and Operational Challenges

Key supporting factors include Royal Thai Army policies that prioritize aviation safety and the advancement of aviation technologies. These findings align with Chen & Park (2020) [12], stating that effective HEMS systems require integration of policy, technology, and sustainable funding.However, several major challenges remain for the Royal Thai Army Aviation Center, including budget limitations, a shortage of specialized personnel, and the absence of standardized protocols for joint operations with ground-based medical units. These challenges are coherent with

Rogers (2003) [5] Diffusion of Innovation Theory, which notes that innovation adoption depends on organizational structure, culture, and personnel readiness.When compared with HEMS systems in advanced countries such as the United States, Germany, and Japan, it is evident that these nations employ highly integrated medicallogistics systems encompassing early notification, resource allocation, and patient reception. Such systems reduce transport time and enhance continuity of care. In Thailand, the Air Medical Command and Control System remains in the development phase, and further integration between military and public health agencies is needed to strengthen interoperability and long-term efficiency in aeromedical evacuation missions.

3. Developmental Strategies and Policy Recommendations

The findings suggest that innovation development should be guided by concepts from Military Medical Logistics and Humanitarian Logistics Frameworks, which emphasize resource management, route planning, time control, and integrated information systems. These principles ensure that patient evacuation is performed rapidly, safely, and efficiently.

Key practical recommendations include: 1. Establishing a dedicated Air Medical Logistics Support Unit to coordinate planning and operations among aviation units, medical teams, and joint command centers. 2. Developing an Integrated Medical Evacuation Information System to enable real-time patient tracking and route-analysis capabilities. 3. Setting joint safety and operational standards between military and civilian agencies, following models such as the European HEMS and Air Rescue Association [20], to enhance mission safety and align operational procedures with international standards.

6. Recommendations

1. Practical Recommendations for Aviation Operation Units

1.1 Enhance capabilities and improve aircraft systems and medical equipment to align with the characteristics and requirements of aeromedical evacuation missions.

1.2 Expand the use of simulation training and blended training to reduce human error and strengthen the confidence of pilots and medical teams.

1.3 Develop a real-time data link system that covers remote areas to support decision-making and coordination between aircraft and ground units.

2. Policy and Management Recommendations

2.1 Promote systematic planning, management, and maintenance of aircraft and medical equipment to ensure the readiness and reliability of all operational assets.

2.2 Establish standardized procedures for aeromedical evacuation missions that conform to international standards.

2.3 Strengthen training programs and skill development for personnel in aviation technology and medical equipment operations.

3. Recommendations for Future Research

3.1 Investigate the effectiveness of emerging innovations such as AI, AR/VR, and IoT-based patient monitoring systems in HEMS operations.

3.2 Analyze the impact of human factors in the use of innovations on mission safety and operational effectiveness.

3.3 Evaluate the integration of statistical data and real-world mission scenarios to design risk-mitigation measures and enhance mission performance.

Declaration of Competing Interest

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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