# Innovation Adoption Processes of Chest X-ray Artificial Intelligence Innovation in Thai Public Hospitals
# กระบวนการนำนวัตกรรมปัญญาประดิษฐ์สำหรับวิเคราะห์ภาพถ่ายเอกซเรย์ทรวงอกมาใช้ในโรงพยาบาลรัฐของไทย

Kittisak Kaweekijmanee[1] and Kasemsarn Chotchakornpant[2]
กิตติศักดิ์ กวีกิจมณี[1] และ เกษมศานต์ โชติชาครพันธุ์[2]

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## บทคัดย่อ

การวิจัยครั้งนี้มีวัตถุประสงค์เพื่อวิเคราะห์ขั้นตอนของกระบวนการนำนวัตกรรมปัญญาประดิษฐ์สำหรับวิเคราะห์ภาพถ่ายเอกซเรย์ทรวงอก (chest X-ray AI: CXR-AI) มาใช้ในโรงพยาบาลรัฐในประเทศไทย และวิเคราะห์รูปแบบของกระบวนการนำนวัตกรรมดังกล่าวมาใช้งาน โดยใช้กรอบแนวคิดกระบวนการนวัตกรรมองค์การในการวิเคราะห์ การศึกษานี้ใช้ระเบียบวิจัยเชิงคุณภาพด้วยวิธีพหุกรณีศึกษา โดยเลือกโรงพยาบาลรัฐ 4 แห่งด้วยวิธีการเลือกแบบเจาะจง และเลือกกลุ่มเป้าหมายผู้ให้ข้อมูลจากกรณีศึกษาด้วยวิธีการเลือกแบบเจาะจงและแบบลูกโซ่ รวมทั้งสิ้น 17 คน การเก็บข้อมูลใช้วิธีการสัมภาษณ์เชิงลึกโดยใช้แบบสัมภาษณ์กึ่งโครงสร้าง ผลการวิจัยชี้ให้เห็นว่า 1. กระบวนการนำ CXR-AI มาใช้ในโรงพยาบาลในทุกกรณีศึกษาได้ดำเนินไปจนผ่านขั้นตอนการสร้างความชัดเจน (Clarifying Stage) แล้ว โรงพยาบาลที่ได้จัดเตรียมแผนระยะยาว เช่น จัดทำแนวทางการใช้ CXR-AI หรือจัดเตรียมงบประมาณสำหรับใช้งานนวัตกรรมดังกล่าวจะทำให้การใช้งาน CXR-AI กลายเป็นส่วนหนึ่งของงานประจำของโรงพยาบาล (Routinizing Stage) ในกรณีที่อุปสงค์ของการใช้งานเทคโนโลยีลดลง เนื่องจากสถานการณ์การแพร่ระบาดของโรคโควิด-19 ที่ผ่อนคลายลง จะนำไปสู่การเลิกใช้งาน CXR-AI 2. กระบวนการนำ CXR-AI มาใช้ในโรงพยาบาลที่เป็นกรณีศึกษา สอดคล้องกับรูปแบบกระบวนการนวัตกรรมองค์การของ Rogers โดยมีความแตกต่างบางประการ โดยการเริ่มต้นกระบวนการอาจเกิดจากอุปสงค์ของโรงพยาบาล หรือ ถูกผลักดันด้วยการมีอยู่ของตัวเทคโนโลยีเอง การปฏิเสธการใช้นวัตกรรมอาจเกิดขึ้นในขั้นตอนใดของกระบวนการก็ได้ ซึ่งทำให้กระบวนการนวัตกรรมมีลักษณะเป็นวงจรที่เกิดซ้ำ บางขั้นตอน เช่น ขั้นตอนการปรับเปลี่ยนรูปแบบนวัตกรรม (Redefining Stage) และขั้นตอนการสร้างความชัดเจนอาจเกิดขึ้นซ้อนกันได้ งานวิจัยนี้ให้ข้อมูลเชิงลึกเกี่ยวกับกระบวนการนำเอานวัตกรรม CXR-AI มาใช้ในโรงพยาบาลรัฐ ซึ่งจะเป็นประโยชน์ต่อผู้บริหารโรงพยาบาลในการวางแผนและส่งเสริมการนำนวัตกรรมนี้มาใช้งาน ผลลัพธ์ของการศึกษายังสามารถใช้เป็นกรอบแนวคิดในการติดตามความก้าวหน้าของการนำเอา CXR-AI หรือนวัตกรรมอื่นที่เกี่ยวข้องมาใช้ในโรงพยาบาลรัฐได้

**คำสำคัญ** : ปัญญาประดิษฐ์ ; ทฤษฎีการแพร่กระจายนวัตกรรมของโรเจอรส์ ; กระบวนการตัดสินใจนวัตกรรม ; การนำนวัตกรรมมาใช้ ; โรงพยาบาลรัฐ

[1] นักศึกษาปริญญาเอก คณะรัฐประศาสนศาสตร์ สถาบันบัณฑิตพัฒนบริหารศาสตร์, Doctoral Student in Public Administration, Graduate School of Public Administration, National Institute of Development Administration

[2] รองศาสตราจารย์ คณะรัฐประศาสนศาสตร์ สถาบันบัณฑิตพัฒนบริหารศาสตร์, Associate Professor, Graduate School of Public Administration, National Institute of Development Administration

## ABSTRACT

This research aimed to analyze the stages of the adoption of chest X-ray artificial intelligence (CXR-AI) in Thai public hospitals and the patterns of the adoption processes using a framework of organizational innovation process. This study employed a qualitative research method using a multiple-case study approach. Four cases of public hospitals in Thailand were selected using purposive selection. 17 key informants were selected from the cases using both purposive sampling and snowball sampling strategies. The data was collected using semi-structured, in-depth interviews. The study showed that: 1. All cases had reached at least the clarifying stages. Hospitals that had reached the routinizing stages were those that had made long-term arrangements, such as the introduction of a use guideline and budget preparation for the implementation. Decreased demand for use due to the containment of the COVID-19 pandemic led to the discontinuation of the adoption. 2. Patterns of the adoption followed the organizational innovation process suggested by Rogers with some variations. The initiation of AI adoption was either demand-driven or technology-driven. Active rejection during the process could happen at any point in the process, and double cycles of adoption were observed. Some stages, such as redefining and clarifying stages may overlap. This research provides insights into the CXR-AI innovation adoption process by public hospitals, which will benefit hospital managers in planning and promoting the implementation of this technology. The findings could also serve as a framework for monitoring the progress of the adoption of CXR-AI or related technologies in public hospitals.

**Keywords :** Artificial Intelligence ; Rogers' Theory of Diffusion of Innovation ; Innovation Decision Process ; Adoption of Innovation ; Public Hospitals

## Introduction

The public health system of Thailand is currently facing pressure to enhancing the efficiency of patient care through the utilization of technology. The expected rise in country's healthcare expenditures due to the aging population underlines the imperative for disease early detection to mitigate healthcare costs. The shortage of specialized medical professionals has posed a challenge to the quality of healthcare service delivery. A clear example of this is the scarcity of radiologists, particularly evident in community hospitals. This has impeded timely interpretation of patients' chest X-rays (Singweratham et al., 2021 ; Tangjai, 2020). It is anticipated that at least 5 million chest X-rays are generated annually, solely from routine health check-ups, while only approximately 2,000 radiologists are available in the country, indicating a significant imbalance. As a result, a considerable proportion of chest X-ray analyses are not conducted by specialized radiologists, potentially leading to misdiagnoses, or missed diagnoses. Even the interpretation by a sole radiologist still carries a 5-9 percent risk of error (Ingviya et al., 2022). Moreover, the shortage of radiologist professionals in Thailand may also pose a barrier to reducing the incidence of tuberculosis. This is one of the main diseases that significantly threatens the country's public health status, with the incidence rate standing at 155 individuals per 100,000 population in 2022 (World Bank, 2024). The scarcity of specialized medical professionals has worsened the already excessive workload during the COVID-19 pandemic, as evidenced by reported cases of burnout among healthcare practitioners in Thailand (Somboonviboon et al., 2023).

The aforementioned issues indicate the necessity to adopt assisting technology that could alleviate the workload among clinicians. The latest developments in artificial intelligence (AI) in the field of computer vision have contributed to addressing complex issues in medical image analysis including chest X-ray (CXR)

interpretation (Akhter et al., 2023). The chest X-ray artificial intelligence (CXR-AI) technology has been identified as a flagship in the Six-Year National Action Plan on Artificial Intelligence for Country's Development (2022-2027) adopted by the Thai government in 2022 (MHESI & MDES, 2022). Various models of CXR-AI have recently been developed and implemented in Thai hospitals as shown in Table 1. Other foreign-developed models have also been imported and used. The adoption of CXR-AI in public hospitals was still in its early stages and not yet widespread. For example, as of 2022, AI Chest 4All, a government-sponsored and developed CXR-AI, was being adopted in only 122 out of 1,080 public hospitals (Department of Medical Services, 2023). CXR-AI technology has been adopted to aid in diagnosing lung diseases, including tuberculosis, lung cancer, and pneumonia. Also, during the COVID-19 pandemic in 2021, the Radio Volunteer project, a charitable multistakeholder collaborative initiative, was launched by the Royal College of Radiologists of Thailand. This project mobilized volunteer radiologists to interpret chest X-ray images during the sudden outbreak of COVID-19 in large communities, with assistance from CXR-AI (Tanomkiat et al., 2021).

**Table 1** Examples of main CXR-AI technologies in Thailand

| Models of CXR-AI | Developers |
|---|---|
| AI Chest 4All | Department of Medical Services, MoPH ; Thammasat University |
| Inspectra CXR | Faculty of Medicine Siriraj Hospital, Mahidol University ; King Mongkut's University of Technology Thonburi ; Perceptra Co.,Ltd |
| RAMA-AI | Faculty of Medicine Ramathibodi Hospital and Faculty of Engineering, Mahidol University ; National Science and Technology Development Agency ; Other Private Companies |

**Sources:** Thammasat University (2021) ; King Mongkut's University of Technology Thonburi (2020) ; Mahidol University (n.d.)

Given the significant benefits of CXR-AI in assisting disease diagnosis, it is important to understand how this innovation is transferred to hospitals and accepted for long-term implementation for the following reasons. First, driving the innovation adoption at the organizational level would require collective changes at organizational level taking place in the specific steps of the adoption process. Understanding these would enable hospital managers to prepare effective interventions to address possible challenges and to engage with relevant stakeholders at the right step. Second, understanding the adoption process is necessary for designing the monitoring and evaluation of the adoption, which is essential for promoting the sustainable adoption of the technology. Moreover, without a thorough understanding of the adoption process, developing an adoption guideline for other hospitals will be impossible. Given such importance of the topic, recent studies on AI adoption in healthcare tend to focus more on influencing factors such as stakeholders' perceptions (Laï et al., 2020), technology-related factors (Morrison, 2021), or healthcare leaders' perspective (Petersson et al., 2022). There remains a gap in understanding the overall process leading to the sustainable implementation of this or related AI technology in healthcare organizations. This gap is also evident in studies of the innovation process within organizations in general (Vega & Chiasson, 2021).

The above discussion leads to the research question of this study: "What are the stages and patterns of innovation adoption processes for the adoption of CXR-AI innovation in Thai public hospitals?" This study aims to provide insights into the innovation adoption process for CXR-AI which will benefit hospital managers in planning and promoting the implementation of this innovation. Also, a better understanding of the adoption process can lead to more effective interventions to address adoption challenges, thus facilitating the initial implementation of the innovation.

This study is part of the doctoral dissertation of the primary author titled "The Adoption of Artificial Intelligence Innovation in Thai Public Hospitals: Multiple Case Studies."

**Objectives**

1. To analyze stages of the adoption of CXR-AI in the selected Thai public hospitals
2. To analyze patterns of the processes of the adoption of CXR-AI in the selected Thai public hospitals

## Literature Review

**Artificial Intelligence in Healthcare Sector**

AI has potential to revolutionize various aspects of the healthcare sector, with applications spanning both physical and virtual domains. The physical branch intersects with robotics which assist elderly patients or surgical procedures, while the virtual branch focuses on managing health systems, electronic records, and providing guidance to physicians in treatment decisions (Sun & Medaglia, 2019). McKinsey & Company estimated that AI can enhance efficiency of healthcare providers by automating the operation and reducing up to 15 percent of current healthcare-related work hours, particularly among medical equipment preparers, medical assistants, and occupational health and safety technicians. Moreover, hours spent on routine, administrative tasks which account for 70 percent of a healthcare practitioner's time can be removed by AI (Al-Haque et al., 2022). The healthcare sector has high potential to benefit from AI technology due to the following reasons. First, public health in many countries has been significantly pressured to contain or lower healthcare costs and to improve its outcomes. Second, a wide range of healthcare data such as genomic data or data obtained from electronic medical records have become widespread at an exponential speed. Third, continuously improved software and hardware allow health practitioners to leverage the data in more powerful ways (Aboshiha et al., 2019). The size of global market of AI in healthcare was estimated to increase from USD 11.20 billion in 2022 to reach USD 427.50 billion by 2032, with a compound annual growth rate (CAGR) of 44 percent (Acumen Research and Consulting, 2023).

Adoptions of AI-based innovation in healthcare sector have increasingly received attention from scholars. There are very few studies which employ qualitative case study methods in investigating adoption of AI in healthcare. To date, there is not any qualitative study of AI adoption in healthcare sector in developing countries, despite an enormous potential of AI for supporting development in these countries (Strusani & Houngbonon, 2019). Also, most of the recent studies focused on factors of adoption of AI in healthcare settings. Literature has not provided adequate account on the pathway leading to an adoption decision of AI technology in healthcare organizations.

**Rogers' Theory of Diffusion of Innovation (DOI)**

Rogers' Theory of Diffusion of Innovation (DOI) is a social science theory which explains the spread of an idea or behavior to a group of population or society over time (Rogers, 2003 ; Nguyen et al., 2022). The theory discusses several aspects of the adoption of innovation by individuals or organizations including the pathway of innovation-decision which leads to the adoption (or rejection) of innovation. The theory has served as a theoretical framework for examining the adoption of new technologies, including medical technologies (Morrison, 2021). It can be applied to investigate the adoption of technological innovations at both organizational and individual levels (Radhakrishnan & Chattopadhyay 2020).

Diffusion of innovation is defined as a process through which an innovation is communicated across specific channels over time among the members of a social system. Roger's DOI theory identifies four key factors influencing innovation adoption: innovation, communication channels, time, and the social system. Innovation refers to new ideas, practices, or objects perceived as novel by individuals or adoption units. Communication channels facilitate the transfer of information about innovation from one individual to another. The time element is related to diffusion processes and adoption timing within the innovation-decision process. The social system involves interconnected units collaborating to achieve common goals, including individuals, informal groups, organizations, and subsystems. Within a social system, individuals can be categorized into five groups based on their attitudes toward innovation: innovators, early adopters, earlier majority, later majority, and laggards. Innovators are the first to adopt innovation. They possess the technical expertise to integrate external innovations into the system. Early adopters, often opinion leaders or change agents, are knowledgeable and well-connected to new technologies. They exhibit a higher tolerance for risk in adopting innovations without relying heavily on social information. The earlier and later majority groups constitute the largest population segments within the social system. Laggards have the strongest resistance to the adoption of innovation. They have limited resources and awareness of innovation and are least likely to adopt (Rogers, 2003).

**Innovation Adoption Process**

In this research, an analysis of innovation adoption process is largely based on the organizations' innovation process proposed by Rogers (Rogers, 2003). These concepts help explain the pathway of adoption of certain innovation by adopting units. Rogers viewed organization as a stable system comprising individuals collaborating to accomplish shared objectives through a hierarchical structure and task specialization. The innovation process within organizations can be segmented into two main phases: initiation and implementation. The initiation phase is the process of information gathering, conceptualizing, and planning for the adoption, which consequently leads up to the adoption decision. Rogers (2003) proposed that this phase consists of agenda-setting and matching steps. However, it is possible that the initiation begins with exposure of the decision-making units (DMU) to innovation. This aligns with Gledson (2022)'s exposure stage, originally used to investigate technology adoption at individual level. The term exposure indicates passiveness of information-seeking behaviors of the DMU (Gledson, 2022). Therefore, in this research, the initiation phase will begin with either the agenda-setting or the exposure stage, followed by the matching stage. Another phase is the implementation phase. This includes all the events, activities, and decisions involved in making use of an innovation. In this phase, organizations need to overcome obstacles in terms of modification and acceptance of innovation. This phase includes three stages: redefining/restructuring, clarifying, and routinizing (Rogers, 2003).

1. Initiation

1.1 Agenda-setting

In this stage, an important problem is identified by individuals in an organization. An organization must precisely define their requirements to facilitate the subsequent step in the innovation process (Salim, 2021). Those individuals will then seek innovation as a tool to address such a problem. The discrepancy between the perceived organization's performance and their expectations can strongly encourage the organization to search for an innovation. Alternatively, organizations may actively conduct environmental scanning to search for novel ideas that have potential benefit to them. The agenda-setting process can continue endlessly in an organization.

1.2 Exposure

Alternative to the agenda-setting, the adoption process may commence when the DMU is exposed to innovation through chance, event participation, personal network, or media. Communication of innovation message at this stage to the DMU is often one-way and the messages received maybe either be discarded or investigated afterwards (Gledson, 2022).

1.3 Matching

During this stage, organizations attempt to conceptually match the problem with the innovations to examine their fitness into the organizations. Feasibility of the innovation in solving the organization's problem, planning, and designing activities may also be conducted during this stage (Salim, 2021). Moreover, organizations may anticipate problems that might arise if the innovation implementation took place. However, it is possible that the innovation may not match with the problem of interest, leading to rejection and termination of the innovation process even before the implementation.

2. Implementation

2.1 Redefining or restructuring

During this stage, the adopted innovation is gradually "redefined" or being modified to fit into the organization setting and to specifically address the organization's needs and structure more appropriately. Alternatively, the organization may be "restructured" to accommodate the innovation such as creating a new unit responsible for the innovation (i.e. an IT unit for adopting a new computer system) (Rogers, 2003). Moreover, external relationships of the organization could also be modified to suit the adoption (Vega & Chiasson, 2021).

2.2 Clarifying

During this stage, the use of innovation is gradually becoming widespread within the organization and its meaning will become clearer to the organization's members. Long-term arrangements may be created to accommodate the integration of such innovation into the organizational structure.

2.3 Routinizing

In this stage, the innovation loses its alien identity and thus becomes integrated into daily activities of the organization. Routinization may not be achieved because of a need to revisit earlier stages, temporarily halt the process, or discontinue the adoption right away.

The adoption process may be adjusted or reordered according to the type of innovation to be examined. For example, to investigate the adoption of information systems in small and medium enterprises, Vega & Chiasson (2021) described adoption as a multi-stage process that includes agenda-setting, matching, implementing, restructuring, clarifying, routinizing, and infusion. Their implementing stage includes acquisition and installation of the innovation, which characterizes the redefining stage proposed by Rogers (2003). Moreover, they defined the infusion stage as the phase where innovations are gradually adopted without any guarantee of full utilization (Vega & Chiasson, 2021).

Generally, the subsequent step in the adoption process cannot begin if the activity at the earlier stage has not been substantially completed. Furthermore, when the innovation is externally imported to the organization, the innovation-process stages usually take place following the steps discussed earlier. However, the process may step back to earlier stage if previously unrecognized problems become known. Also, one or more of the stages in the process may also be skipped (Rogers, 2003).

**Conceptual Framework**

A conceptual framework of this study is shown in Figure 1. This research uses the organizations' innovation process adapted from insights discussed by Rogers (2003) and Gledson (2022) as an analytical

framework. This leads to an analysis of stages of the adoption of CXR-AI in the selected Thai public hospitals. The main result of the study is patterns of the CXR-AI adoption processes. This conceptual framework aligns with the objectives of this research discussed previously.

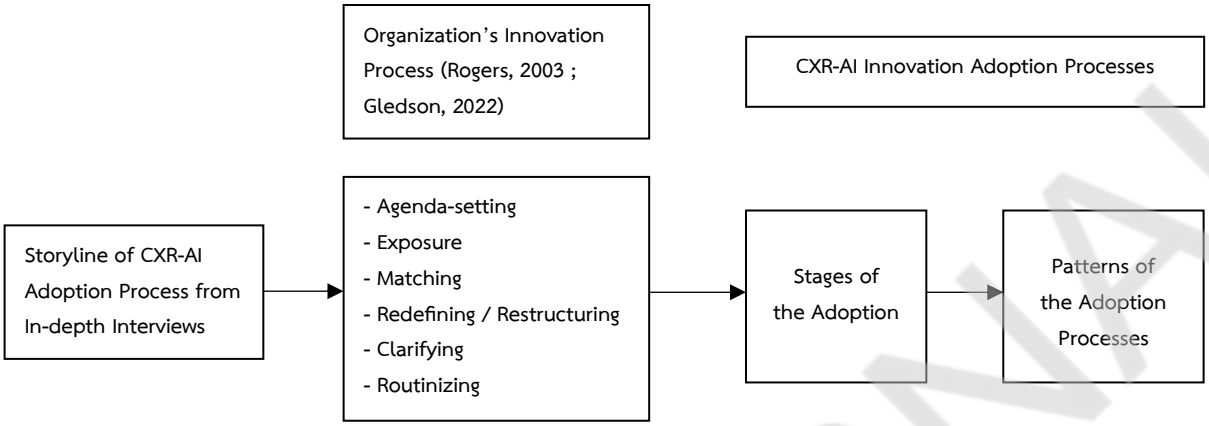


**Figure 1** Conceptual Framework

## Research Methodology

This study employed a qualitative research method. This method is suitable for investigating research questions that are exploratory in nature (Creswell, 2013). This is particularly relevant for issues that are new to the community and have not yet become widespread, such as the use of AI in public health in Thailand. Moreover, the method is well-suited for examining the innovation process within hospitals, as it involves analyzing the attitudes, behaviors, and decisions that affect the adoption of innovation (Morrison, 2021) and can gather the details of events that occur during the adoption process of innovation. Lastly, qualitative research aids researchers in understanding the contexts or environments in which study participants engage with a problem or issue (Creswell, 2013).

This study employed a multiple case study research approach which could provide deep understanding of complex current situations. By using this approach, researchers could answer "why" and "how" questions while addressing the context in which the events were embedded. Additionally, this approach allows for comparisons across different cases and contexts, thus leading to a strong basis for theory building (Yin, 2009).

### Target Group

The study used purposive sampling strategy to select four cases of hospitals which adopted CXR-AI innovations to assist in their chest X-ray work. The specific type of purposive sampling strategy employed is the intensity sampling strategy. This allowed for selection of very informative cases which represent an intensive phenomenon of interest and for representativeness or comparability (Tashakkori et al., 2020). As common criteria, each selected hospital must have implemented CXR-AI for a long-enough period so that substantial lessons could be drawn. Benefits of the CXR-AI implementation should have been clearly observed by the adoption unit. In this regard, the study selected all four hospitals located outside of Bangkok. It was anticipated that these hospitals would be relatively short of specialized health professionals and budget, thus expecting a rich narrative of the adoption process. Furthermore, the study maximized case characteristics by selecting hospitals that differed in type and the origin of the adopted CXR-AI. Besides the typical cases, the study selected atypical cases characterized by instances of rejection during the adoption

process. The primary author sought advice from experts or key persons involved in each case (such as the chief executive officer of the CXR-AI service provider or the hospital director) to justify their potential academic value from the investigation. Characteristics of selected hospitals are summarized in Table 2.

**Table 2** Characteristics of Selected Hospitals

| Characteristics | Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|---|
| Hospital Types | A general hospital | A region hospital | A community hospital | A community hospital |
| Location | Western border province | Central region province | Southern border province | Northeastern region province |
| Rural/ Urban | Urban | Urban | Rural | Semi-urban |
| Year founded | 1953 | 1941 | 2007 | 2007 |
| Number of Beds | 340 | 597 | 30 | 30 |
| Number of Staff | 830 | 1,289 | 194 | 155 |
| Number of Physicians | 75 | 126 | 7 | 6 |
| Available Radiologists | Yes | Yes | No | No |
| Origin of the Adopted CXR-AI | Commercially developed CXR-AI | Commercially developed CXR-AI | Commercially developed CXR-AI | Government-funded and developed CXR-AI |
| Data Year | 2022 | 2022-2023 | 2022 | 2022 |

**Sources :** MoPH, hospitals' annual reports, and hospitals' websites.

**Research Instruments**

In-depth interviews with stakeholders were conducted using semi-structured questions. The study defined constructs by using concepts from literature reviews in accordance with the objectives of this research to increase construct validity of the research instruments. The interview questions included background information of cases, background information of interviewees, and open-ended questions regarding the process of adoption of CXR-AI in the respective hospitals. The primary author continuously refined the interview questions as the data collection progressed, to ensure they were appropriate for each informant and could adequately answer the research questions. Also, such adjustments were made to explore further information in cases where emerging issues arose from the interviews. As proposed by Hayashi et al. (2019), validation in qualitative research should be an ongoing process, with the objective of analyzing debriefing and reflection from the start to the conclusion of the study.

**Data Collection**

Key informants in this study were those who have been involved in the adoption decision and implementation of the CXR-AI. These included hospital directors, deputy directors, physicians, other health professionals, IT staff members, and representatives from the AI service provider. The use of multiple key informants in each case enabled the primary author to triangulate the results and to develop converging lines of inquiry, thereby enhancing the level of persuasiveness and accuracy of the study. In total, seventeen key informants were interviewed. A summary of key informants in each case is given in Table 3.

**Table 3** A Summary of Key Informants

| Cases | Hospital Types | Key Informants |
|---|---|---|
| 1. | A general hospital | ● A deputy managing director |
| | | ● A radiologist |
| | | ● An IT manager |
| | | ● A chief executive officer of the CXR-AI service provider |
| | | ● A chief operating officer of the CXR-AI service provider * |
| 2. | A region hospital | ● An assistant managing director |
| | | ● A radiologist |
| | | ● A nephrologist |
| | | ● A radiographer |
| | | ● A chief operating officer of the CXR-AI service provider * |
| 3. | A community hospital | ● A managing director |
| | | ● A general practitioner |
| | | ● An IT manager |
| | | ● An IT officer |
| | | ● A chief operating officer of the CXR-AI service provider* |
| 4. | A community hospital | ● A managing director |
| | | ● A general practitioner |
| | | ● A radiographer |
| | | ● An IT officer |

Note: Chief operating officer of the CXR-AI service provider * is the same person across cases 1-3.

In each case study, purposive sampling was employed for selecting key informants. Purposive sampling is used when subject selection is based on particular goals related to addressing the research questions of a study. This study also used snowball sampling to allow a selection of additional informants based on other informants' recommendations (Tashakkori et al., 2020). Snowball sampling was exercised particularly in identifying key informants in each case where the gatekeeper of the case (often the hospital managing director) could suggest the right informants to answer the questions.

Data collection through in-depth interviews took place during February to July 2023. Most interviews were conducted individually through an online communication channel such as Microsoft Teams, Google Meet, Zoom, or phone call. However, some key informants preferred to give an interview in pairs. In the actual conversation with the key informants, the questions might be different from those prepared initially and were adjusted as the conversation progressed. Each interview lasted about 25-75 minutes, depending on how the interviewees had engaged in the case. The interviews were audio or video recorded subject to interviewees' permissions and then transcribed orthographically into written words. The primary author also conducted follow-up interviews or requested for additional information during September 2023 to February 2024 if there was some unclear information.

Before the data collection was commenced, ethical approval for this study was obtained from the Ethics Committee in Human Research of the authors' affiliation with Reference Number 2023/0004 which was valid from 12 January 2023 to 11 January 2024.

**Data Analysis**

Thematic analysis was conducted on the transcribed materials as well as relevant secondary materials. Scholars use thematic analysis to systematically identify, organize, and provide insight into patterns of meaning across a collected data set. It can be applied to a study with large datasets and large number of interviewees (Braun & Clarke, 2012). The primary author used ATLAS.ti software to facilitate thematic analysis by assigning themes to the transcribed interview data. The assigned themes align with steps of organization innovation adoption process in literatures including agenda-setting, exposure, matching, redefining or restructuring, clarifying, and routinizing. Then, the primary author applied Code-Document Analysis function in the software to draft the storyline of innovation adoption process in each case. The primary author ensured accuracy of the story line by having the draft story reviewed by the key informants. Subsequently, the author analyzed the revised storyline to derive the stages of the innovation adoption process and the pattern of adoption according to the research objectives.

The analysis process is characterized as an iterative process that frequently recurred at various stages. For instance, coding the transcribed material and synthesizing the research findings involved comparing the results across case studies to ensure consistent data interpretation. Occasionally, re-analysis occurred when additional theoretical insights emerged through literature review. The iterative process continued until the analysis results converged and showed no significant differences. Such an iterative process enables a more thorough exploration of the investigated phenomenon, uncovering multiple layers of understanding and maximizing the richness of qualitative data (Dierckx de Casterlé, et al., 2021), thereby increasing validity of the research results.

## Results and Discussion

Stages of the adoption processes of CXR-AI in Thai public hospitals, and patterns of the adoption in each case are shown in Table 4.

1. Stages of the adoption processes of CXR-AI in the case studies

According to Table 4, stages of the adoption processes of CXR-AI in Thai public hospitals in the four cases are shown with events corresponding to each stage of the adoption. At the time of data collection, all cases had reached at least the clarifying stages. However, in case 2, the adoption was discontinued after this stage due to decreased demand following the containment of the COVID-19 pandemic. In contrast, cases 3 and 4 progressed to the routinizing stage. Adopter hospitals in cases 3 and 4 were community-level hospitals with no available radiologists. Therefore, the hospitals perceived high relative advantages of the CXR-AI and decided to continue using them in the long term.

**Table 4** Adoption Process of CXR-AI in Four Cases

| Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|
| **Initiation** | **Initiation** | **Initiation** | **Initiation** |
| Agenda-setting<br>● Recognition of shortage of radiologists<br>● A search for innovation to support doctors' X-ray tasks | Agenda-setting (I)<br>● A search for innovation to support doctors' X-ray tasks | Exposure<br>● Invitation to trial the CXR-AI by the HIS provider free of charge | Exposure (I)<br>● Dissemination of the first version CXR-AI by the regional health office |
| | Matching (I)<br>● Technology demonstration<br>● Pending adoption decision | | Matching (I)<br>● Product trial<br>● Rejection |

**Table 5** (Continued)

| Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|
| **Initiation** | **Initiation** | **Initiation** | **Initiation** |
| Agenda-setting<br>● Recognition of shortage of radiologists<br>● A search for innovation to support doctors' X-ray tasks | Agenda-setting (I)<br>● A search for innovation to support doctors' X-ray tasks | Exposure<br>● Invitation to trial the CXR-AI by the HIS provider free of charge | Exposure (I)<br>● Dissemination of the first version CXR-AI by the regional health office |
| | Matching (I)<br>● Technology demonstration<br>● Pending adoption decision | | Matching (I)<br>● Product trial<br>● Rejection |
| Matching<br>● Technology demonstration<br>● Adoption decision | Agenda-setting (II)<br>● Urgent demand to ease COVID-19 pandemic issue | Matching<br>● A hospital team's search for more information about the CXR-AI<br>● Adoption decision | Exposure (II)<br>● Introduction of new version CXR-AI by the PACS vendor<br>● A visit to the early adopter hospital |
| | Matching (II)<br>● Subscription of charitable CXR-AI package | | Matching (II)<br>● Internal discussion<br>● Adoption decision |
| **Implementation** | **Implementation** | **Implementation** | **Implementation** |
| Redefining<br>● Integration of CXR-AI with HIS<br>● Integration of CXR-AI with PACS | Redefining<br>● Technology readily implemented | Redefining<br>● Integration of CXR-AI with HIS and PACS<br>● Users' doubt on CXR-AI performance | Redefining/ Restructuring<br>● Investment in digital radiography system<br>● Learning from the early adopter hospital |
| Clarifying<br>● Continued integration of CXR-AI with PACS<br>● Increased use cases in health check-up and tuberculosis screening | Clarifying<br>● Large number of use cases during COVID-19 outbreak<br>● Paid subscription decision | Clarifying<br>● Clearer benefits of CXR-AI during COVID-19 outbreak | Clarifying<br>● Use cases in tuberculosis and COVID-19 pneumonia screening<br>● Guideline issued by the patient care team |
| N.A. | Discontinuance<br>● Non-renewal of contract | Routinizing<br>● Continued use using hospital's revenue | Routinizing<br>● Continued use using hospital's revenue |

Regarding the initiation, in cases 1-2, important issues were identified during the agenda-setting stage, followed by efforts to search for solutions to address these problems. The issues identified included a shortage of radiologists, leading to an overwhelming chest X-ray interpretation workload for radiologists and potential risks for patients due to misinterpretation of chest X-ray films. Additionally, there was a significant increase in chest X-ray film interpretation workload during the COVID-19 outbreak. Such problems were identified and often raised by those with leadership roles or with a stark interest in solving them, including hospital directors, or deputy directors.

*"We had an issue of radiologist (shortage). Some years we did not have any radiologist. Later we had only one (radiologist). The problem was that (sometimes), they (radiologists) did not have time to interpret X-ray films that we requested them to do. We were not confident in interpreting because we were not specialized in X-ray."* (A hospital's deputy director, case 1)

In cases 3-4, the adoptions were initiated when hospitals' managing directors were exposed to knowledge about existence of CXR-AI through communication with outsource IT vendors (Health Information System [HIS] or Picture Archiving and Communication Systems [PACS] providers), a regional health office, or an early adopter hospital. In this regard, communication through network with these innovators or early adopters had enabled the transmission of information about the CXR-AI to the hospitals.

The matching stage involved events such as technology assessment, performance comparison, and feasibility analysis of choices of CXR-AI to be adopted. During this stage, the hospitals began engaging in two-way communication with the CXR-AI suppliers to gather more information that aids decision-making. Technology demonstration was a type of such communication which facilitated information acquisition. The technology assessment process considered various factors, including the accuracy of performance, limitations of usage, and available financial resources. Financial constraints were not an issue for the large-size hospitals in cases 1 and 2, nor for the community hospital in case 4, which adopted the affordable version of CXR-AI developed by the government. Additionally, the community hospital in case 3 received support from the HIS provider to trial the CXR-AI free of charge. Decision-makers within hospitals then started formulating decisions, which resulted in either rejection or adoption of the technology. Rejection was found in case 2. The region hospital in this case exhibited frequent changes of hospital directors during the adoption decision process, leading to changes in priority of the hospital's budgeting and resulting in interruption of adoption decision.

*"The second director had a different perspective on technology compared to the first one. She may not see the importance of technology as much. When I proposed to her (about this AI project), she did not show much interest."* (Nephrologist, case 2)

However, in case 2, shortly after the pending decision, the process returned to the agenda-setting stage, where the urgent need for CXR-AI to address challenge of COVID-19 pandemic became more clearly recognized, leading to the second round of matching and the adoption decision.

In case 4, the hospital was initially informed about the existence of CXR-AI at the meeting with the regional health office. The CXR-AI introduced by the regional health office was distributed to state hospitals for free use. However, the use of this version of CXR-AI was so complex due to its non-automated feature that it added more workload to the X-ray technician in the hospital. Thus, it did not receive much acceptance and had resulted in the initial rejection during the matching stage.

*"We did not use it for long, just briefly, then stopped because it was difficult to use. We had a lot of (chest X-ray) cases. But we only used it (this AI) 2-3 times, specifically for cases that the doctor needed confirmation on like when the doctor was unavailable or felt unsure. We used it for just a week."* (Radiographer, case 4)

The redefining step was crucial for internalizing the innovation into the hospitals' routine operation. This step was indicated by events such as integration of AI systems to hospital IT systems (HIS and PACS) and users' doubt on AI's performance, as shown in cases 1 and 3. However, in case 2, the CXR-AI was readily implemented as the integration with the hospital IT systems was already in place due to the existing business partnerships between the PACS vendor and the AI service provider. "Restructuring" of the hospital IT infrastructure to fit with the CXR-AI was reported only in the community hospital in case 4, where its existing X-ray infrastructure still did not accommodate the use of the AI software. The restructuring therefore involved transitioning its X-ray system from analogue to digital radiography as a prerequisite for CXR-AI installation which required significant investment. This finding reflects the lower level of technological infrastructure readiness in the smaller hospital compared to the larger ones. As a result, the hospital must undergo a restructuring process of their technological infrastructure, which requires a larger investment to

achieve implementation. Also, during this phase, continued learning about implementation of CXR-AI was facilitated by the hospital's relationship with another early adopter hospital.

A clarifying stage was characterized by a significant volume of the CXR-AI usages, especially for COVID-19 pneumonia screening, tuberculosis screening, and health check-up of local workers. As an example, the clarifying stage in case 3 saw obvious benefits of CXR-AI at the peak of COVID-19 outbreak. The CXR-AI helped shortcut a doctor's consultation step with an external radiologist who worked in a provincial hospital. This benefited COVID-19-positive patients who may urgently need to be prescribed with Favipiravir, at that time in short supply.

*"During the early stages of COVID-19, doctors had to bring cases of COVID-19 pneumonia to consult with radiologists at the provincial hospital to request film readings. . . . These reports were then sent to the responsible internal medicine physicians to obtain permission to administer Favipiravir. Initially, we had to go through this process, but our hospital was unique in that we had AI for initial (chest X-ray) readings. The physicians at the provincial hospital said, 'if AI readings showed a high likelihood of positive result, they approved it (the medicine) right away, skipping the step of consulting with radiologists.' This streamlined process showed significant advantages of the AI for our hospital."* (Managing director, case 3)

At the clarifying stage, preparations for long-term implementation commenced. For example, in case 1, integration of the CXR-AI with PACS was completed, thereby increasing compatibility of the system, and reducing complexity of use. In case 2, the hospital decided to adopt the paid subscription package of the CXR-AI after a trial period with a free charitable package offered by the same CXR-AI service provider in the earlier stage. During such a campaign, the hospital had an opportunity to witness the full, obvious benefits of AI technology in screening for COVID-19 pneumonia. In case 4, the hospital's patient care team issued a work guideline for integrating the CXR-AI to the hospital workflow. This helped support the long-term implementation that continued into the routinizing phase. As indicated earlier, routinizations of the use of CXR-AI were observed only in cases 3 and 4 which continued the adoption financed by hospital's revenue. In case 3, routinization was indicated by the use of CXR-AI in all chest X-ray cases.

The findings can be discussed in relation to previous research as follows. First, routinizations were observed where long-term arrangements, such as the introduction of use guidelines and budget preparation for implementation, were made, as shown in cases 3 and 4. Such integrations of the innovation into the daily activities of hospitals align with the description of the routinizing stage proposed by Rogers (2003). It is worth noting that community hospitals that lacked sufficient medical staff tended to perceive higher relative advantage of the CXR-AI. This increased the likelihood of reaching routinization, provided that sufficient resources were available for the adoption. Case 1 did not exhibit any indicators of routinization. For case 2, the decreased demand for use due to the containment of the COVID-19 pandemic led to the discontinuation of adoption.

Second, the events in each stage of the adoption corresponds with the description of each adoption stage in the literature (Rogers, 2003 ; Salim, 2021 ; Vega & Chiasson, 2021). However, there are some differing aspects. The process of redefining the innovation may not necessarily be incremental as described by Rogers (2003). As evidenced in case 2, the adopted CXR-AI was ready to be implemented since the AI service provider had prior experience in implementing this technology. Therefore, the CXR-AI was instantly integrated with the hospital's IT system in this stage. Additionally, the external relationships formed during the redefining stage to accommodate the modification of innovation, as proposed by Vega & Chiasson (2021), may also include formation of relationships among external actors themselves (the AI service provider and the PACS providers), also as shown in case 2.

2. Patterns of the adoption of CXR-AI in the case studies

According to Table 4, the adoption process of CXR-AI in the four cases exhibited different patterns. The initiation of CXR-AI adoption was either demand-driven or resource-pushed. In cases 1 and 2, the adoptions were demand-driven and began with the agenda-setting stage where issues were identified. On the other hand, cases 3 and 4 were regarded as "resource-pushed", or precisely "technology-pushed" adoption. The adoptions in cases 3 and 4 were initiated with the exposure stage when hospitals' directors were exposed to knowledge about existence of CXR-AI through communication with innovators or the early adopter. The term exposure suggested relative passiveness (at least at this stage) of information-seeking behaviors of hospitals' directors who were the gatekeepers of innovations in these cases. Rather than actively looking, opportunities for adopting the CXR-AI were offered by innovators or an early adopter. The agenda-setting and exposure stages were followed by the matching stage. In cases 1 and 3, the adoption processes continued after this stage, while cases 2 and 4 exhibited active rejection where an adoption was initially considered but was later rejected. The adoption process then stepped back to the earlier stages and double cycles of adoption were observed in cases 2 and 4. In case 4, the second round of exposure stage took place when the more user-friendly version of the CXR-AI was introduced to the hospital, leading to the adoption decision.

The duration of the redefining step depended on compatibility of the adopted CXR-AI with existing hospital's IT systems. The redefining step in case 1 was particularly lengthy due to the persistent incompatibility of the adopted CXR-AI with the HIS. In this case, the adopted CXR-AI product was still in an early stage of commercialization and the technical issue of usage resulting from integrating the AI with HIS in a large-sized hospital had not been fully known. Solving this issue required formation of business partnership between the AI vendor and the PACS vendor to allow for alternative integration of the CXR-AI to the hospital's IT systems. The lengthy process of partnership formation undermined the clarification of the advantages of innovation in the next step. Unlike the redefining stage, the "restructuring" of the hospital organization to fit with the CXR-AI was rarely reported which indicated a relatively compatible IT foundation of the hospital. However, this was an exception in case 4 where the transformation of the X-ray system from an analogue to digital version (digital radiography) was required with significant investment.

Redefining and clarifying may overlap. Case 1 showed that gradual diffusion of the CXR-AI within the hospital (the clarifying stage) can take place concurrently with lengthy process of integrating the CXR-AI with the PACS which continued from the earlier redefining stage. This implies that the benefit of the adopted CXR-AI started to be observed while the modification process was still ongoing.

Based on the findings, the adoption process of the CXR-AI in the case studies followed a pattern of organizations' innovation process suggested by Rogers (2003) in several aspects. First, the finding confirmed that rejection of innovation could take place at any point in the process due to perceived unfavorable relative advantage of the innovations over existing practices. This has implications on the importance of assessing feasibility and planning the adoption of the CXR-AI to best meet the hospital's needs. Additionally, the finding highlighted the significant influence of individual attitudes, particularly those of decision-makers, on the adoption decision. Changes in hospital management, which in this study were observed in the case of the region hospital, impacted the decision to adopt and led to rejection decisions during the process. However, hospitals that are exposed to the innovation or have trialed it beforehand are more likely to adopt the innovation once a clear need for its use is established. This finding also aligns with the study which has found that the perceived value of technology has a positive impact on the intention to use that technology (Dachjiramanee et al., 2022). Furthermore, the findings confirmed that the agenda-

setting process could continue indefinitely within an organization, implying that adoption processes can be initiated at any time.

However, contrary to the adoption process proposed by Rogers (2003) and Vega & Chiasson (2021), this study found that initiation of adoption may begin with the exposure stage, as defined by Gledson (2022), shown in cases 3 and 4. This highlighted the importance of networking with innovators or early adopters which could transfer knowledge about the existence of innovations to prospective adopters. Moreover, this study found that different stages of the adoption process may overlap. In case 1, the lengthy redefining stage might take place concurrently with the clarifying stage. This differed from Rogers (2003) who proposed that the subsequent step in the adoption process cannot begin if the activity at the earlier stage has not been substantially completed.

## Conclusion

This research used a framework of organizations' innovation process to analyze the adoption processes of CXR-AI in the four Thai public hospitals. It described the stages of the adoption process that these hospitals had gone through. Regarding the first research objective which is to analyze stages of the adoption of CXR-AI in the selected hospitals, the study found that the adoption of CXR-AI in all cases had reached at least the clarifying stages. Routinizations were found in cases where the long-term arrangements such as the introduction of a use guideline and budget preparation for the implementation were made. Decreased demand for use due to containment of COVID-19 pandemic led to discontinuation of the adoption. For the second objective which is to analyze patterns of the processes of the CXR-AI adoption, the study found that patterns of the adoption followed the organizations' innovation process suggested by Rogers (2003) with some variations. Initiation of adoption of CXR-AI could be demand-driven or technology-pushed. Rejection of innovation could also happen at any point in the process if the decision makers had unfavorable perception towards relative advantage of the innovation. Additionally, lengthy redefining stage might take place concurrently with clarifying stage.

### Contribution

This research provides insights into the innovation adoption process for CXR-AI which will benefit hospital managers in planning and promoting the implementation of this technology. The findings could serve as a guideline for hospital managers in managing the implementation process of CXR-AI utilization in hospitals. Additionally, a better understanding of the adoption process can lead to more effective interventions to address adoption challenges. This, thus, facilitates the decision to adopt this technology and can lead to its widespread acceptance within an appropriate timeframe. Besides, the findings could serve as an example of analysis of the progress of CXR-AI adoption. This could be used as a framework for MoPH or other state hospitals to monitor progress of adoption of CXR-AI or related technologies. Lastly, this study highlights the crucial role of innovators and early adopters in promoting hospitals' exposure to innovations, leading to considerations for adopting such innovations to enhance service efficiency.

### Suggestion for Future Research

Future research should consider examining other types of AI systems to compare with the findings from this study. AI with more advanced decision-making features may exhibit more complex adoption processes compared to the CXR-AI presented in this study. Additionally, research should explore the adoption of AI in other contexts, such as the adoption of CXR when COVID-19 has been designated as

endemic. Furthermore, future studies should compare the adoption processes of public hospitals with those of private hospitals to identify best practices for each type of hospital.

Regarding data collection methods, besides in-depth interviews, future research may consider conducting observation to investigate the innovation adoption process. This method offers several advantages, such as reducing the gap between the researcher and the subjects, uncovering unexpected relevant topics, and gaining deeper insights into the real-world aspects of the research problem (Busetto et al., 2020). This method is suitable not only for CXR-AI but also for advanced decision-making AI innovations (such as AI for cancer treatment planning) where there is limited prior local experience and a need for summative evaluation during the adoption process.

Additionally, collecting data about experiences of patients, the ultimate beneficiaries of the CXR-AI, will offer a comprehensive view of innovation acceptance and their perceived benefits at each adoption stage. Upon the adoption of this innovation, these experiences may be improved significantly in community hospitals that lack radiologists.

**Limitations**

This study may have limitations in terms of generalizability due to the following reasons. First, the research was conducted in only four cases of public hospitals in Thailand, all of which were purposively selected. Second, this study is only limited to the investigation of adoption CXR-AI. It is possible that other AI systems and/or areas of applications may exhibit different challenges of adoption (Petersson et al., 2022). Third, comparison across cases is limited by differing levels of routinizations owing to different duration of adoption. Lastly, participants who shared their perspectives about the adoption process in this study may differ from those of non-participants who had been involved in the adoption process.

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