Technology-Driven Perspective in a Sustainable Healthcare Supply Chain for Patient Safety in Radiology Service: A Case Study of Cambodia

เทคโนโลยีขับเคลื่อนในห่วงโซ่อุปทานด้านการดูแลสุขภาพที่ยั่งยืนเพื่อความปลอดภัยของผู้ป่วยในบริการรังสีวิทยา: กรณีศึกษาประเทศกัมพูชา

Chayada Kanokphanvanich[1], Wanchai Rattanawong[2] and Varin Vongmanee[2]*
ชญาฎา กนกพันธ์วณิช[1] วันชัย รัตนวงศ์[2] และวรินทร์ วงศ์มณี[2]*
[1]Graduate School, University of the Thai Chamber of Commerce, Bangkok Thailand
[1]บัณฑิตวิทยาลัย มหาวิทยาลัยหอการค้าไทย กรุงเทพ ประเทศไทย
[2]School of Engineering, University of the Thai Chamber of Commerce, Bangkok Thailand
[2]คณะวิศวกรรมศาสตร์ มหาวิทยาลัยหอการค้าไทย กรุงเทพ ประเทศไทย
*Corresponding author: varin_von@utcc.ac.th
Received: November 13, 2023
Revised: December 22, 2023
Accepted: December 28, 2023

Abstract

Radiology services are crucial for patient safety, serving as a cornerstone for accurate diagnosis. With advanced, high-tech equipment, the radiology department conducts intricate diagnostic examinations and treatments. Radiology’s intersection with sustainability spans multiple dimensions. Given Cambodia’s limited access to modern radiological tools, the challenges surrounding sustainable radiology and its implications for patient safety stand out prominently. A cross-sectional study was carried out in the radiology department of tertiary hospitals in Phnom Penh, Cambodia, between August and September 2023. This research melded a technology-driven perspective with a sustainability conceptual model, encompassing four dimensions and 20 attributes. To rank the significance of various attributes and dimensions, the Fuzzy TOPSIS method was utilized. The closeness coefficient indicated that the technology dimension ranked highest. From the viewpoint of radiologists, technology emerges as the essential factor in radiology services for bolstering patient safety sustainably. The model offers strategies that prioritize sustainable radiology services and patient safety, a fundamental goal in the healthcare sector. This is especially vital for a developing country like Cambodia, where resources are limited.

Keywords: radiology, sustainability, patient safety, technology, Fuzzy TOPSIS

บทคัดย่อ

บริการทางรังสีวิทยาเป็นสิ่งที่สำคัญสำหรับความปลอดภัยของผู้ป่วย โดยทำหน้าที่หลักในการวินิจฉัยโรคอย่างแม่นยำ โดยอุปกรณ์และเทคโนโลยีที่ทันสมัย สามารถทำให้แผนกรังสีวิทยาทำการตรวจวินิจฉัยและวางแผนการรักษาโรคให้กับผู้ป่วยได้อย่างมีประสิทธิภาพ ซึ่งหากกล่าวถึงงานทางด้านรังสีกับมุมมองของความยั่งยืนนั้นครอบคลุมหลายมิติเช่น ในการศึกษานี้ได้กล่าวถึงประเทศกัมพูชา ซึ่งยังเป็นประเทศที่มีข้อจำกัดในการเข้าถึงงานบริการทางรังสีวิทยาที่ทันสมัย และทำให้พบว่า เป็นข้อจำกัดต่าง ๆ นั้นเป็นอุปสรรคต่อความยั่งยืนของการบริการทางรังสีและส่งผลกระทบต่อความปลอดภัยของผู้ป่วยนั้นมีความสำคัญอย่างมาก งานวิจัยถูกดำเนินการในแผนกรังสีวิทยาของโรงพยาบาลตติยภูมิในกรุงพนมเปญ ประเทศกัมพูชา ระหว่างเดือนสิงหาคมและกันยายน พ.ศ. 2566 งานวิจัยนี้เป็นการนำเสนอแบบจำลองความยั่งยืนโดยควบรวมมิติทางด้านเทคโนโลยีเข้ากับความยั่งยืนแบบดั้งเดิมสามมิติ แบบจำลองสำหรับความยั่งยืนในงานบริการทางรังสีเพื่อความปลอดภัยของผู้ป่วย จึงประกอบไปด้วยสี่มิติ และ 20 ปัจจัยภายใต้สี่มิตินั้น จากนั้นการศึกษาได้ทำการจัดลำดับความสำคัญของปัจจัยและมิติต่าง ๆ โดยใช้วิธี Fuzzy TOPSIS จากผลการวิจัยแสดงค่า closeness coefficient ในแต่ละมิติ และแสดงให้เห็นว่ามิติเทคโนโลยีมีอันดับสูงสุดในโมเดลความยั่งยืนของงานรังสีวิทยาที่มุ่งเน้นความปลอดภัยคนไข้ จากมุมมองของรังสีแพทย์ เทคโนโลยีเป็นปัจจัยที่สำคัญในการให้บริการรังสีวิทยาเพื่อเสริมความปลอดภัยของผู้ป่วยให้ยั่งยืน แบบจำลองนี้สามารถใช้ในการวางกลยุทธ์ที่ให้ความสำคัญกับการให้บริการรังสีวิทยาที่ยั่งยืนและความปลอดภัยของผู้ป่วยซึ่งเป็นเป้าหมายที่สำคัญในกลุ่มสาธารณสุข โดยเฉพาะอย่างยิ่งสำหรับประเทศกำลังพัฒนาอย่างกัมพูชาที่มีข้อจำกัดในทรัพยากรที่มีอยู่

คำสำคัญ: รังสีวิทยา ความยั่งยืน ความปลอดภัยของผู้ป่วย เทคโนโลยี, Fuzzy TOPSIS

Introduction

In recent years, Cambodia, classified as a developing country, has witnessed significant advancements within its healthcare domain. Such progression is quantifiably manifested in metrics such as the decline in child mortality rates, the enhancement of maternal health infrastructure, and a noticeable reduction in the prevalence of communicable ailments, encompassing HIV, tuberculosis, and malaria (Teo et al., 2020). Nonetheless, amidst these progressive strides, Cambodia confronts formidable challenges, accentuated in light of the global COVID-19 crisis. Constraints such as restricted healthcare accessibility, a paucity of requisite medical apparatus-inclusive of radiological instrumentation and a limited healthcare infrastructure present persistent impediments (Grundy-Warr & Lin, 2020; Iwamoto et al., 2020). Cambodia's healthcare infrastructure, including its radiology sector, has experienced steady development over recent years, with marked advancements evident predominantly in urban centers such as Phnom Penh (Harrington, 2015). These urban hubs host a range of radiological equipment, from basic X-ray machines to more sophisticated CT and MRI scanners, primarily concentrated in private hospitals that have benefited from enhanced investments (Harrington, 2015). While the private sector seems to have an edge in terms of modern radiological amenities, public institutions often grapple with challenges linked to outdated equipment and limited resources (Annear et al., 2015). A salient concern remains the shortage of trained radiologists and radiographers, although initiatives involving foreign medical partnerships have been aiding in capacity-building and training (Harrington, 2015). However, rural regions of Cambodia still confront significant barriers in terms of access and affordability of radiology services. As the country strides toward improved radiology services, it must place equal emphasis on quality control and the establishment of stringent regulations to ensure safe and effective patient care.

While Cambodia has a pressing need to develop its radiological examination capabilities, it is also essential to consider other sustainability impacts. This is mainly because numerous international studies have presented the environmental consequences of radiology services. These impacts range from the high energy consumption of machines like CT and MRI scanners, medical waste resulting from radiological examinations, to the release of carbon dioxide, a greenhouse gas, from radiological equipment (Chua et al., 2021; Heye et al., 2020). Radiology also plays an indispensable role in social sustainability such as global health, making its social implications profound. Ensuring equitable access to radiological services, especially in underserved areas, is fundamental for health equity and social well-being. Continuous training is essential, allowing healthcare professionals to remain adept with evolving technologies. Furthermore, adherence to safe protocols, minimizing unnecessary scans, and transparent communication about risks ensures patient safety and reinforces public trust in the healthcare system (Welling et al., 2011). Radiology is both a significant expenditure and an economic catalyst within healthcare. The purchase, maintenance, and operation of advanced imaging systems represent substantial costs. However, the sector also offers numerous employment opportunities, bolstering economic stability. Medical tourism, spurred by top-tier radiological services, can rejuvenate local economies (Grundy et al., 2009). Moreover, timely and effective radiological interventions can lead to quicker diagnoses and reduced hospital stays, offering potential cost savings in the larger healthcare spectrum (Harrington, 2015; Welling et al., 2011).

The most important key factor for radiology these days is Technology, Technological advancements in radiology present a dual-edged sword. On one hand, the transition to digital imaging, the rise of teleradiology, and integration with AI enhance diagnostic precision and accessibility while potentially reducing environmental impact (de Reeder et al., 2023). Energy-efficient equipment designs, cloud storage solutions, and the seamless integration of radiological data with Electronic Health Records streamline operations and reduce waste (Chua et al., 2021; Schoen, McGinty & Quirk, 2021). On the other hand, rapid technological obsolescence can lead to challenges like electronic waste. Embracing technology with a sustainability lens is crucial to harness its benefits while mitigating its challenges and leads to the ultimate goal of patient safety (Kanokphanvanich, Rattanawong & Vongmanee, 2022, 2023).

Objective

This study aims to understand the perspectives of radiologists in developing countries facing resource challenges, such as Cambodia. The researcher seeks to comprehend which dimensions radiologists believe are most crucial for ensuring sustainability in radiology work and delivering maximum patient safety. The tools used in this study can be further developed to strategize for organizations to enhance sustainability and safety for both staff and patients, which are the utmost goals of healthcare

This research study provides significant contributions in the following areas:

1. Propose a model for sustainability assessment that integrates 'Technology' within its framework. This model can be employed to evaluate the significance of specific attributes and dimensions of sustainability in radiology.

2. Upon successful assessment, the model assists hospital administrators in prioritizing and selecting the most crucial dimensions and attributes. This prioritization facilitates the crafting of sustainable strategies for radiological operations to ensure patient safety.

3. The proposed model holds versatility, allowing for its adaptation in other sectors of medical services such as public health and nursing. Additionally, it can be applied to the broader context of overall hospital operations.

Literature review

Radiology, a critical component of modern medicine, involves the use of imaging to diagnose and treat diseases within the human body. As technology advances, radiological methods, from traditional X-rays to complex MRI scans, have grown in both capability and prevalence. However, with this growth comes the responsibility of ensuring these processes are sustainable. The concept of radiology sustainability blends the principles of long-term viability with medical imaging, covering environmental, social, economic, and technological facets (Kanokphanvanich et al., 2022).

Radiology in social sustainability

For radiology to be socially sustainable, it must remain accessible, equitable, and sensitive to patient needs. This entails ensuring all segments of the population, irrespective of socioeconomic status or geographic location, have access to quality radiological services (Chua et al., 2021; Harrington, 2015). It also emphasizes the importance of ethical considerations in radiology, such as informed consent, patient privacy, and minimizing exposure to radiation. Radiology's social dimension further touches upon professional education, emphasizing the need for continuous training and development to ensure radiologists maintain the highest standards of care (EuroCham Cambodia, 2021; Grundy et al., 2009).

Radiology in environmental sustainability

Radiological services, intrinsic to contemporary healthcare, carry a multifaceted environmental footprint that merits comprehensive scrutiny. Advanced imaging modalities, notably CT and MRI scanners, command significant energy reserves, often resulting in escalated electricity demands within healthcare facilities (McAlister et al., 2022). Such demands not only strain institutional utilities but contribute to broader energy consumption, with associated carbon emissions and environmental repercussions. Furthermore, the entire lifecycle of radiological consumables, especially contrast media and radiopharmaceuticals, warrants attention (Schoen et al., 2021). The manufacturing, usage, and eventual disposal of these agents introduce potential ecological risks, particularly when regulatory oversights are absent or inadequately enforced. Mismanaged disposal can lead to detrimental aquatic and terrestrial contamination, posing harm to ecosystems and potentially entering human consumption chains (Chua et al., 2021; Schoen et al., 2021). Moreover, the emergence of energy-efficient imaging apparatus, combined with robust waste management protocols and green procurement policies, can substantially mitigate environmental adversities (Woolen et al., 2023). By embracing these strategies, the radiology sector can fortify its commitment to both exemplary patient care and ecological stewardship.

Radiology in economic sustainability

From an economic vantage point, radiology stands as both a valuable asset and a strategic avenue for cost mitigation within healthcare. The acquisition and upkeep of advanced imaging equipment necessitate robust capital investment (Kc & Terwiesch, 2009). Yet, the dividends of such investments manifest in the form of precise and timely diagnoses, facilitating expedited and more efficacious treatments, which in turn, can curtail overarching healthcare expenses in the long run. This duality underlines the imperative for an economic equilibrium in radiology, harmonizing upfront technological investments with the enduring fiscal and therapeutic advantages they usher (Wald et al., 2018). The Sustainable Supply Chain Management--SSCM promotes cost-effectiveness and better operations in supply chains, while also strongly supporting environmental and social values (Swarnakar, Singh & Tiwari, 2021). This aligns with value-based healthcare, which focuses on wisely using resources based on patient needs and ensuring that the financial benefits in healthcare are always clear. Healthcare supply chain managers constantly face challenges balancing costs and risks. They must understand that while saving costs is important, it shouldn’t harm patient care (Smith et al., 2021; Swarnakar, Bagherian & Singh, 2022).

Technological dimension for radiology

In today’s fast-paced tech world, radiology stands out as a key player in medical advancements. But as radiology grows, we must think about sustainability. This involves using new innovations for better patient care while also considering the environmental and social impacts (Welling et al., 2011). This includes looking at how energy-efficient the equipment is, if we can recycle used equipment and the environmental effects of producing this technology. The digital transformation of radiology-manifested through the ascent of digital imaging and teleradiology-has reshaped how we archive, disseminate, and interpret medical images (Schoen et al., 2021; Woolen et al., 2023). Yet, digital horizons introduce nuanced challenges: data security, electronic refuse, and the carbon footprint of sprawling data centers. At the nexus of these technological shifts lies an unwavering commitment to patient safety (Smith et al., 2021). By synergizing radiology’s diagnostic prowess with technologies like IoT and AI, we can diminish manual errors, expedite clinical decision-making, and amplify the precision of patient-centric interventions (Alhasan & Hasaneen, 2021). Such a confluence not only bolsters patient outcomes in the present but augments healthcare resilience against future uncertainties, solidifying technology’s pivotal role in steering healthcare, and specifically radiology, towards a sustainable horizon (Kumar, Raut & Narkhede, 2020).

Fuzzy TOPSIS

TOPSIS was originally conceived by Hwang and Yoon (1981) as a tool for Multiple Criteria Decision Making-MCDM. Later on, Chen and Hwang (1992) integrated the fuzzy approach, enhancing its capabilities. Fuzzy TOPSIS is particularly adept at managing multifaceted criteria, given its incorporation of the fuzzy set theory. This allows it to adeptly navigate the uncertainties in the subjective evaluations made by decision-makers-especially when these evaluations are expressed through linguistic nuances or varying degrees of satisfaction and significance (Chen & Hwang, 1992; Hwang & Yoon, 1981).

Conceptual Framework

The Sustainable Healthcare Supply Chain--SHSC conceptual model focused on patient safety, as presented by Kanokphanvanich et al. (2023) in Figure 1, has been adapted as an evaluation tool. This allows radiologists to determine the significance of various attributes from their viewpoint, emphasizing patient safety.

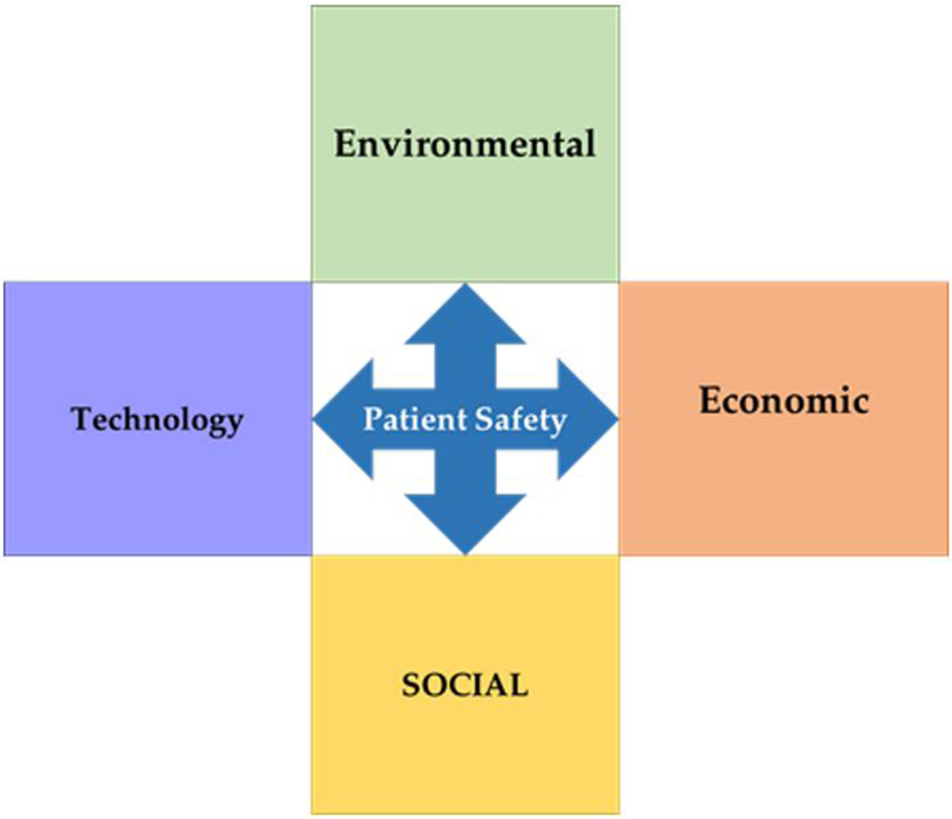

Figure 1 Sustainable Model for Patient Safety integrates technology dimension

Note. From A new model for a sustainable healthcare supply chain prioritizes patient safety: Using the Fuzzy Delphi Method to identify healthcare workers' perspectives by C. Kanokphanvanich, W. Rattanawong and V. Vongmanee, 2023, *Sustainability, 15*(9), 7123. Copyright by MDPI

Methodology

The conceptual model for Sustainable Healthcare Supply Chain--SHSC that prioritize patient safety is adopted (Kanokphanvanich et al., 2023). The model highlighted the importance of enhancing patient safety from the perspective of healthcare professionals in the context of developing countries. To delve deeper and assess real-world application, this study applied the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution--TOPSIS method, a sophisticate decision-making tool. This technique facilitated the ranking of various attributes based on their importance, helping organizations pinpoint the most crucial elements for formulating effective strategies.

Questionnaire design and distribution

The survey consisted of 4 dimension, 20 attributes adopted from Kanokphanvanich et al. 2023 and was made available in both English and Khmer to cater to the prevalent linguistic preferences in Cambodia. It was structured in two segments. The initial section solicited demographic information of the participants, while the latter section prompted them to gauge the significance of each SHSC attribute. Responses were captured using a 5-point Likert scale (1-Not important, 2-Slightly important, 3-Moderately important, 4-Very important, and 5-Extremely important). The study was conducted in accordance with the Declaration of Helsinki and approved by the National Ethic Committee for Health Research in Cambodia (protocol code No.097/NECHR, with an approval date of 31 March 2023) and the Human Research Ethics Committee of the University of the Thai Chamber of Commerce (protocol code UTCCEC/ Exempt019/2023, with an approval date of 20 February 2023. The informed consent was obtained from all participants in this study

The study was carried out in 5 tertiary hospitals in Phnom Penh, Cambodia's capital. The selection of the five tertiary hospitals in Cambodia based on their status as large-scale tertiary facilities, equipped with comprehensive radiology services, providing a representative sample that reflects the broader healthcare landscape in the context of Cambodia's resource constrains. For a homogenous expert group, satisfactory results can be achieved with a panel of 10-15 individuals (Rodriguez, Otero-Neira & Svensson, 2020; Serrou, Abouabdellah & Mharzi, 2015). Thus, 15 radiology experts were chosen for this study. Three senior radiologists from each hospital were invited as decision-makers. Questionnaires were disseminated to radiologists from July to September 2023. Participants were senior radiologists meeting at least one of these criteria: (1) a minimum of 10 years' experience in healthcare; (2) an executive role in the radiology department; or (3) possessing a doctoral or master's degree. These criteria ensured participants had a deep understanding of radiology and sustainability challenges. Web-based questionnaires were shared via Email, Telegram, and WhatsApp for evaluations and feedback.

Measurement

The variables employed in this research were sourced from healthcare-related literature and identified by experts in developing countries' healthcare. The potential attributes have been itemized and grouped into four dimensions, as depicted in Table 1 below.

Fuzzy TOPSIS

For this research, Fuzzy TOPSIS is utilized to evaluate and prioritize the pivotal attributes for the sustainability of the radiology service within a hospital-based case study in Cambodia. The method unfolds as follows

Step 1: A group of Decision-Makers--DMs, representing key stakeholders from the radiology department in private and public tertiary hospitals in Phnom Penh, are chosen to assess the significance of SHSC attributes. This study employs a five-point scale, permitting these decision-makers to convey their insights. To capture the inherent uncertainties of these evaluations, Triangular Fuzzy Numbers--TFNs are used. The specific TFNs deployed in this assessment process can be viewed in Table 2

Table 1

Attributes for healthcare sustainable model that prioritize patient safety.

Dimension	Attributes	Reference
Social	Health and Safety (SC1) Skills, Knowledge, and Training (SC2) Quality of life (SC3) Equity (SC4) Community health care accessibility (SC5) Collaboration (SC6)	(Cheang & Lee, 2010; Eizenberg & Jabareen, 2017.; Hussain et al., 2019; Tudor et al., 2021)
Environment	Healthcare Waste Management (EV1) Pollution prevention (EV2) Environment-friendly material (EV3) Energy efficiency (EV4)	(Chua et al., 2021; Elabed, Shamayleh & Daghfous, 2021; Harrington, 2015; Heye et al., 2020; de Reeder et al., 2023; Schoen et al., 2021; Welling et al., 2011; Woolen et al., 2023)
Economic	Financial (EC1) Process efficiency (EC2) Marketing (EC3) Relationship Management (EC4) Service Efficiency (EC5) Leadership and Governance (EC6)	(Hwang & Yoon, 1981; Kanokphanvanich et al., 2022, 2023; de Reeder et al., 2023; Swarnakar et al., 2021; Tejativaddhana et al., 2018)
Technology	Information Management (TE1) Cybersecurity (TE2) Transparency and Traceability of healthcare process (TE3) Healthcare Innovation and Advance Technology (TE4)	(Akinwale & AboAlsamh, 2023; Apostolopoulos, Makris & Stavroyianni, 2022; Bialas et al., 2023; Biswas et al., 2023; Chandra et al., 2022; Chen & Chiu, 2022; Garrido, Ramírez López & Álvarez, 2021; George & Elrashid, 2021a, 2021b; Kerr, 2020; Lu et al., 2016; Pennestrì & Banfi, 2022; Tsarfati & Cojocaru, 2022; Welling et al., 2011)

Table 2

Linguistic scale for evaluating 20 attributes of alternatives and criteria

Linguistic Scale for Rating	Abbreviation	TFNs
Not Important	NI	(0,1,3)
Slightly Important	SI	(1,3,5)
Moderately Important	MI	(3,5,7)
Very Important	VI	(5,7,9)
Extremely Important	EI	(7,9,9)

The Triangular Fuzzy Number--TFN Ã is defined as (*a, b, c*) where a indicates the smallest potential value, b indicates average possible value, and c indicates the largest potential value. The membership function $\mu_{\tilde{A}(x)}$ of Ã is described as follows

$$\mu(x) = \begin{cases} 0 \; x < a, x > c \\ \frac{x-1}{b-1} a \; \leq x \; \leq c \\ \frac{c-x}{c-b} b \; \leq x \; \leq a \end{cases} \quad (1)$$

Decision-makers, represented as DMs (s = 1,…,p) utilize linguistic scales to evaluate the significance of the 20 attributes based on n criteria. The criteria's relative weight vector is denoted by W = (w1,w2,…,wn). An elevated rating signifies greater attribute importance. Aggregated scores from decision-makers form the fuzzy decision matrix, symbolized as $\tilde{D}_s$ as expressed in equation (2).

$$\tilde{D}_s = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{k1} & \cdots & \tilde{x}_{kn} \end{bmatrix} \quad (2)$$

Step 2: The fuzzy decision matrix is normalized using a linear transformation. The normalized fuzzy decision matrix $\tilde{T}$ is conducted using the equations as follow

$$\tilde{T} = [\tilde{t}_{ij}]_{k \times n}, \; i = 1, 2, ..., k; \; j = 1, 2, ..., n \quad (3)$$

where

$$\tilde{t}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), a = \min_k \{a_k\}, b = \frac{1}{k}\sum_{k=1}^{k} b_k, c = \max_k \{c_k\} \quad (4)$$

and

$$c_j^* = \max \{c_{ij}\} \; \ldots \text{importance criteria} \quad (5)$$

Step 3: The weighted normalization matrix ($\tilde{Y}$) is then calculated using the equation as follows:

$$\tilde{Y} = [\tilde{y}_{ij}]_{k \times n} = [\tilde{t}_{ij} \times w_j]_{k \times n}, \; i = 1, 2, ..., k; \; j = 1, 2, ..., n \quad (6)$$

Step 4: The Fuzzy Positive Ideal Solution–FPIS, A^+ and Fuzzy Negative Ideal Solution--FNIS, A^- can be calculated as follows:

$$A^+ = (\tilde{y}_1^+, \tilde{y}_2^+, \ldots, \tilde{y}_n^+) \quad (7)$$

$$A^- = (\tilde{y}_1^-, \tilde{y}_2^-, \ldots, \tilde{y}_n^-) \quad (8)$$

where

$$\tilde{y}_1^+ = \max_i \{\tilde{y}_{ij}\}, \text{ and } \tilde{y}_1^- = \min_i \{\tilde{y}_{ij}\}, \; i = 1, 2, ..., K; \; j = 1, 2, ..., n \quad (9)$$

Step 5: The distance of each alternative from FPIS d_i^+ and FNIS d_i^- is computed as follows

$$d_i^+ = \sum_{j=1}^{n} d_y = \tilde{y}_{ij}, \tilde{y}_{1j}^+ \quad (10)$$

$$d_i^- = \sum_{j=1}^{n} d_y = \tilde{y}_{ij}, \tilde{y}_{1j}^- \quad (11)$$

$$d(\tilde{r}, \tilde{s}) = \sqrt{\frac{1}{3}(a_r - a_s)^2 + (b_r - b_s)^2 + (c_r - c_s)^2} \quad (12)$$

Step 6: The closeness coefficient (CC_i) of each attribute is computed as follows:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (13)$$

Step 7: The 20 attributes for radiology sustainability that prioritize patient safety from the perspective of radiologists are ranked. The most important attribute is closet to the FPIS and farthest from the FNIS.

Result

The model was applied to healthcare facilities in Phnom Penh, Cambodia. For this study, tertiary hospitals both private and public in Phnom Penh were chosen. Fifteen senior radiologists and hospital executives participated in the research, with their backgrounds detailed in table 3. The Fuzzy TOPSIS methodology was executed as follows

Step 1: The DMs assigned ratings using the linguistic scale based on the four dimensions of the sustainability model. The collective linguistic scale of these four dimensions is represented using TFN, as indicated in equation (1). The scores initially provided by the DMs were consolidated according to equation (2), with the outcomes presented in table 4.

Additionally, the DMs evaluated the 20 attributes using a linguistic scale, reflecting their significance. This linguistic evaluation of the 20 attributes was then structured into a fuzzy decision matrix to facilitate the subsequent phase.

Step 2: The fuzzy decision matrix is normalized using a linear transformation as equation (3-5).

Step 3: The equation (6) then was used to calculate the fuzzy weight normalized matrix.

Step4: The fuzzy positive ideal solution (FPIS, A^+) and fuzzy negative ideal solution (FNIS, A^-) were calculated using equation (7) and (8). Subsequently in step 5, the equation (9)–(11) were used respectively to calculate the distance of each distribute from FPIS (d_i^+) and FNIS (d_i^-). The results of the distance of each attribute from the FPIS and FNIS are presented in table 5.

Step 6 and 7: The equation (12) was applied to compute the closeness coefficient (CC_i) of each attribute. The 20 attributes for a sustainable model for radiology that prioritize patient safety were ranked. The most important attribute was closet to the FPIS and farthest from the FNIS. The results are displayed in table 6.

Based on the data presented in Table 6, the CCi values for the four dimensions-social, environmental, economic, and technology-are 0.653, 0.638, 0.580, and 0.672, respectively. These findings indicate that, from the viewpoint of the hospital's radiologists and healthcare executives, the technological aspect is paramount for radiology services. Within this technology dimension, 'Healthcare Innovation and Advance Technology' (TE4) emerged as the top priority. 'Cybersecurity' (TE2) followed in importance, with 'Information Management' (TE1) and 'Transparency and Traceability' (TE3) ranking third and fourth, respectively.

Table 3

Background of five experts in Radiology and healthcare executives

	Job title	Gender	Education	Work experience
DM1	Head of Radiologist	M	M.D	Over 20 years
Hospital A	Interventional Radiologist	M	M.D	15-20 years
	Head of Radiology Department	F	M.D	Over 20 years
DM2	Chief of Medical Affair	M	M.D	Over 20 years
Hospital B	Head of Radiologist	M	M.D	Over 20 years
	Senior Radiologist	F	M.D	Over 20 years
DM3	Interventional Radiologist	M	M.D	15 – 20 years
Hospital C	Senior Radiologist	F	M.D	15 Years
	Patient Care Unit Director	F	M.D	Over 20 years
DM4	Hospital Director	M	M.D	15 – 20 years
Hospital D	Head of Radiology Department	F	M.D	Over 20 years
	Senior Radiologist	F	M.D	Over 20 years
DM5	Head of Radiology Department	M	M.D	Over 20 years
Hospital E	Radiologist	F	M.D	15 Years
	Interventional Radiologist	M	M.D	15-20 years

Table 4

Linguistic assessment score and aggregated fuzzy weight of criteria by DMs

Criteria	Linguistic assessment of criteria					Aggregated fuzzy weight of criteria		
	DM1	DM2	DM3	DM4	DM5			
Social	SI	VI	EI	EI	EI	1	7.40	9
Environmental	EI	EI	EI	VI	EI	5	8.60	9
Economic	EI	EI	EI	EI	EI	7	9.00	9
Technology	EI	VI	VI	VI	EI	5	7.80	9

Table 5

Distance of each attribute for sustainable radiology from the FPIS and FNIS

Attributes			FPIS			d_i^+			FNIS			d_i^-
SC1	0.96	0.00	0.00	0.96	0.96	2.87	1.50	2.24	2.24	1.50	1.50	8.98
SC2	0.00	0.00	0.00	0.00	2.24	2.24	2.24	2.24	2.24	2.24	0.00	8.95
SC3	0.00	2.24	0.96	2.24	0.00	5.43	2.24	0.00	1.50	0.00	2.24	5.97
SC4	0.96	2.24	0.96	0.96	0.96	6.07	1.50	0.00	1.50	1.50	1.50	6.00
SC5	0.00	0.96	0.00	0.96	0.00	1.92	2.24	1.50	2.24	1.50	2.24	9.71
SC6	2.24	0.96	0.96	2.24	2.24	8.63	0.00	1.50	1.50	0.00	0.00	3.00
EV1	0.00	0.00	0.00	0.00	1.28	1.28	1.72	1.28	2.80	1.28	0.00	7.08
EV2	1.72	0.00	2.80	1.28	0.00	5.80	0.00	1.28	0.00	0.00	1.28	2.55
EV3	0.00	1.28	0.00	0.00	0.00	1.28	1.72	0.00	2.80	1.28	1.28	7.08
EV4	0.00	0.00	1.28	1.28	1.28	3.83	1.72	1.28	1.72	0.00	0.00	4.72
EC1	1.45	3.14	0.00	1.45	0.00	6.03	1.86	0.00	3.14	1.86	3.14	10.00
EC2	0.00	1.45	0.00	0.00	0.00	1.45	3.14	1.86	3.14	3.14	3.14	14.41
EC3	3.14	3.14	1.45	3.14	3.14	14.00	0.00	0.00	1.86	0.00	0.00	1.86
EC4	1.45	1.45	0.00	0.00	0.00	2.90	1.86	1.86	3.14	3.14	3.14	13.14
EC5	0.00	1.45	3.14	0.00	1.45	6.03	3.14	1.86	0.00	3.14	1.86	10.00
EC6	1.45	0.00	0.00	1.45	0.00	2.90	1.86	3.14	3.14	1.86	3.14	13.14
TE1	0.00	1.19	1.19	0.00	1.19	3.57	1.19	0.00	1.66	1.19	0.00	4.03
TE2	1.19	0.00	0.00	0.00	0.00	1.19	0.00	1.19	2.64	1.19	1.19	6.21
TE3	0.00	0.00	2.64	1.19	0.00	3.83	1.19	1.19	0.00	0.00	1.19	3.57
TE4	1.19	0.00	0.00	0.00	0.00	1.19	0.00	1.19	2.64	1.19	1.19	6.21

Table 6

Linguistic scale for evaluating 20 attributes of alternatives and criteria.

Dimension	Attributes	d_i^+	d_i^-	CC_i	Rank
	SC1	6.03	10.00	0.624	3
	SC2	1.45	14.41	0.909	1
	SC3	14.00	1.86	0.118	4
	SC4	2.90	13.14	0.819	2
	SC5	6.03	10.00	0.624	3
	SC6	2.90	13.14	0.819	2
Social		5.55	10.43	0.653	(2)
	EV1	1.28	7.08	0.847	1
	EV2	5.80	2.55	0.306	4
	EV3	1.28	7.08	0.847	3
	EV4	3.83	4.72	0.552	2
Environment		3.05	5.36	0.638	(3)
	EC1	2.87	8.98	0.757	3
	EC2	2.24	8.95	0.800	2
	EC3	5.43	5.97	0.524	4
	EC4	6.07	6.00	0.497	5
	EC5	1.92	9.71	0.835	1
	EC6	8.63	3.00	0.258	6
Economic		4.87	6.73	0.580	(4)
	TE1	3.57	4.03	0.531	3
	TE2	1.19	6.19	0.817	2
	TE3	3.83	3.57	0.482	4
	TE4	1.19	6.21	0.839	1
Technology		2.44	5.00	0.672	(1)

Discussions

In this research, the sustainable healthcare supply chain conceptual model, emphasizing patient safety, was utilized in a practical case study at tertiary hospitals in Phnom Penh, Cambodia. The aim was to assess and prioritize dimensions crucial to radiology services. This model integrated a technological dimension into the traditional sustainable framework. The Fuzzy TOPSIS method was employed to rank 20 attributes across 4 dimensions. Senior radiologists and hospital executives from five tertiary hospital in Phnom Penh participated as the Decision-Makers--DMs. Findings suggest that, from the viewpoint of radiologists and hospital executives, the Technology Dimension is paramount for sustainable radiology that emphasizes patient safety. The most vital attribute identified was 'Healthcare Innovation and Advance Technology (TE4)'. This outcome aligns with prior research, such as Andronikou S.'s study on the significance of teleradiology in low-income countries (Andronikou, 2014). This study highlighted the benefits of teleradiology in addressing challengesin regions lacking experienced radiologists (Andronikou, 2014). Amidst the COVID-19 pandemic, both telemedicine and teleradiology usage surged to accommodate social distancing measures (Haleem et al., 2021; Mohammed et al., 2021). One key advantage of teleradiology, as noted by Cambodian hospital executives, is the ability to 'consult on complex cases and solicit opinions from radiology specialists worldwide'. Furthermore, advanced technologies like Artificial Intelligence--AI elevate state-of-the-art radiology, enhancing patient safety. A senior Cambodian radiologist emphasized that AI currently holds a significant role in radiology. Advanced radiological tools, such as MRI, CT, and Radiology Intervention, are often equipped with cutting-edge AI features, assisting radiologists in detecting abnormalities in radiological images. Yet, another senior radiologist from Cambodia cautioned that AI technology is a double-edged sword: radiologists should employ AI as a supportive tool and must not become overly reliant, allowing AI to overshadow their expertise. For cybersecurity in radiology services is crucial as it safeguards sensitive medical information and ensures the integrity of diagnostic procedures. With the increasing digitization of medical records and the interconnected nature of healthcare systems, the vulnerability to cyber threats escalates. A breach in radiology cybersecurity not only jeopardizes patient confidentiality but also poses a direct risk to diagnostic accuracy and treatment plans. Protecting against cyber threats is essential to maintain the trustworthiness of medical data, uphold patient privacy, and ultimately ensure the reliability of radiological assessments crucial for patient care. Radiological Information Management encompasses the effectiveness, accuracy, reliability, and accessibility of data within the healthcare system, specifically within radiology services, facilitating seamless communication among stakeholders. It plays a critical role in ensuring the precision of diagnostic information and the availability of essential data for medical practitioners. Effective information management in radiology not only enhances diagnostic accuracy but also aids in identifying and mitigating potential risks that could disrupt the radiological supply chain. Moreover, by providing robust data tracking and traceability, coupled with efficient communication among stakeholders, radiological information management contributes significantly to patient safety, reducing the likelihood of adverse events and enhancing overall healthcare outcomes. Transparency and traceability in radiology services are pivotal elements for ensuring patient safety and improving overall healthcare quality. Transparent processes in radiology involve clear communication and accessibility of information among healthcare providers, ensuring that all stakeholders have a comprehensive understanding of diagnostic procedures and results. This transparency fosters collaboration and reduces the likelihood of errors. Additionally, traceability in radiology, through meticulous documentation and tracking of diagnostic processes, contributes to a safer healthcare environment. It enables healthcare professionals to follow the trajectory of patient care, identify any discrepancies, and promptly address potential issues, thereby minimizing the risk of adverse events and enhancing patient safety in the realm of radiological services.

Although numerous studies have explored the environmental impacts resulting from radiology work, in this study, from the perspective of radiologists in a private hospital in Phnom Penh, Cambodia, it was found that the environmental dimension was ranked third in terms of importance. In the researcher's opinion, it's not that Cambodian radiologists don't consider the environmental aspects important, but they prioritize technological advancements that enhance accurate radiology examinations and ensure patient safety even more. The significance given to technology is ranked foremost.

In this research analysis and interpretation of results, the authors recognize the pivotal role of transparency and methodological rigor. To fortify the validity of the findings, the authors have provided a comprehensive data collection approach. The meticulous design not only guards against the introduction of unintended dimensions but also encourages participants to thoughtfully weigh their preferences on specific dimensions. This dual emphasis on preventing biases and eliciting informed responses contributes to the overall robustness of our study. By fostering transparency in the methodology, we aim to enhance the reliability of the results and ensure a comprehensive understanding of the factors influencing research's findings. This commitment to methodological clarity aligns with our broader goal of delivering insights that withstand rigorous scrutiny and contribute meaningfully to the existing body of knowledge.

Conclusion

The role of technology in driving sustainable radiology practices, with a specific focus on patient safety, is paramount, especially in contexts like Cambodia. The utilization of the SHSC conceptual model in a tertiary hospital in Phnom Penh underscored the significance of integrating technological dimensions into traditional sustainable frameworks. As the global healthcare landscape evolves, the importance of technological advancements in radiology cannot be understated. The emphasis on 'Healthcare Innovation' as the most crucial attribute amplifies the potential of technologies such as Artificial Intelligence--AI in reshaping the radiological landscape. The benefits derived from this research are that hospital administrators, managers, and radiologists in Cambodia can utilize this tool to evaluate and prioritize the importance of dimensions and attributes in their organizations. This can guide the development of strategies for sustainable radiology services that ensure patient safety, which is a primary objective in the healthcare industry

Limitation and future research

While a novel model of sustainability integrated Technology dimension for radiology proposed in this research study offers valuable in-sights for healthcare executives and leaders in their pursuit of holistic sustainability, it is important to acknowledge certain limitations, which include the following:

1. The survey, tailored to a group of Cambodian radiology specialists and hospital executives of a private hospital in Cambodia, may limit the model's generalizability to other sectors or countries. Future research should validate this model in varied contexts, explore its relevance across regions, and compare it with other MCDM methods to enrich the model's understanding and applicability.

2. This study reviewed the key attributes from various literatures which pinpointed key attributes from the vantage of the healthcare supply chain experts in Southeast Asia's developing nations. It's crucial to note, however, that our regional focus and literature review approach might have missed some pivotal attributes tied to patient safety in sustainable healthcare supply chain. Expanding the pool of decision-makers in future research could enhance accuracy and provide richer insights.

3. The assignment of weights to criteria in Fuzzy TOPSIS is often subjective, based on expert judgment or decision-maker preferences. This subjectivity can introduce potential biases in this study. Therefore, for a more comprehensive understanding, future research should explore and compare other methods, enriching the in-sights and potentially addressing some of the mentioned limitations

References

Akinwale, Y. O., & AboAlsamh, H. M. (2023). Technology innovation and healthcare performance among healthcare organizations in Saudi Arabia: A structural equation model analysis. *Sustainability, 15*(5), 3962. https://doi.org/10.3390/su15053962

Alhasan, M., & Hasaneen, M. (2021). Digital imaging, technologies and artificial intelligence applications during COVID-19 pandemic. *Computerized Medical Imaging and Graphics: The Official Journal of the Computerized Medical Imaging Society, 91*, 101933. https://doi.org/10.1016/j.compmedimag.2021.101933

Andronikou, S. (2014). Pediatric teleradiology in low-income settings and the areas for future research in teleradiology. *Frontiers in Public Health, 2,* 125. https://doi.org/10.3389/fpubh.2014.00125

Annear, P. L., Grundy, J., Ir, P., Jacobs, B., Men, C., Nachtnebel, M., Oum, S., Robins, A., & Ros, C. E. (2015). The Kingdom of Cambodia Health System Review. *Health Systems in Transition, 5*(2), 20–41. https://www.jstor.org/stable/resrep28461.1

Apostolopoulos, S., Makris, I., & Stavroyiannis, S. (2022). Healthcare innovation in Greece: The views of private health entrepreneurs on implementing innovative plans. *Journal of Open Innovation: Technology, Market, and Complexity, 8*(2), 78. https://doi.org/10.3390/joitmc8020078

Bialas, C., Bechtsis, D., Aivazidou, E., Achillas, C., & Aidonis, D. (2023). A holistic view on the adoption and cost-effectiveness of technology-driven supply chain management practices in healthcare. *Sustainability, 15*(6), 5541. https://doi.org/10.3390/su15065541

Biswas, S., Sanyal, A., Božanić, D., Puška, A., & Marinković, D. (2023). Critical success fFactors for 5G technology adaptation in supply chains. *Sustainability, 15*(6), 5539. https://doi.org/10.3390/su15065539

Chandra, M., Kumar, K., Thakur, P., Chattopadhyaya, S., Alam, F., & Kumar, S. (2022). Digital technologies, healthcare and Covid-19: Insights from developing and emerging nations. *Health and Technology, 12*(2), 547–568. https://doi.org/10.1007/s12553-022-00650-1

Cheang, S., &. Lee, J. (2010). *Evaluation telecenter performance in social sustainability context: A Cambodia case study. 2010 6th International Conference on Advanced Information Management and Service (IMS)* (pp. 135-141). Seoul, Korea (South): IEEE.

Chen, S., & Hwang, C. (1992). *Fuzzy multiple attribute decision making methods*. Berlin, Germany: Springer Nature

Chen, T-CT., & Chiu, M-C. (2022). Evaluating the sustainability of Ssmart technology applications in healthcare after the COVID-19 pandemic: A hybridising subjective and objective Fuzzy Group decision-making approach with explainable artificial intelligence. *Digital Health, 8*, 205520762211363. https://doi.org/10.1177/20552076221136381.

Chua, A. L. B., Amin, R., Zhang, J., Thiel, C. L., & Gross, J. S. (2021). The environmental impact of interventional radiology: An evaluation of greenhouse gas emissions from an academic interventional radiology practice. *Journal of Vascular and Interventional Radiology: JVIR, 32*(6), 907–915.e3. https://doi.org/10.1016/j.jvir.2021.03.531

Eizenberg, E., & Jabareen, Y. (2017). Social sustainability: A new conceptual framework. *Sustainability, 9*(1), 68. https://doi.org/10.3390/su9010068

Elabed, S., Shamayleh, A., & Daghfous, A. (2021). Sustainability-oriented innovation in the health care supply chain. *Computers and Industrial Engineering, 160*(2), 107564. https://doi.org/10.1016/j.cie.2021.107564.

EuroCham Cambodia. (2021). *Sector brief Cambodia: Health care*. Retrieved from https://www.giz.de/en/downloads/SectorBrief_Cambodia_HealthCareSector.pdf

Garrido, A., Ramírez López, L. R., & Álvarez, N. B. (2021). A simulation-based AHP approach to analyze the scalability of EHR systems Using Blockchain Technology in Healthcare Institutions. *Informatics in Medicine Unlocked, 24*, 100576. https://doi.org/10.1016/j.imu.2021.100576

George, S., & Elrashid, S. (2021). The role of information technology and information sharing in pharmaceutical supply chain performance: Private hospitals' perspective. *2021 International Conference on Decision Aid Sciences and Application (DASA)* (pp. 601-606). Sakheer, Bahrain: IEEE. doi: 10.1109/DASA53625.2021.9682265

Grundy, J., Khut, Q. Y., Oum, S., Annear, P., & Ky, V. (2009). Health system strengthening in Cambodia-A case study of health policy response to social transition. *Health Policy, 92*(2–3), 107–115. https://doi.org/10.1016/j.healthpol.2009.05.001

Grundy-Warr, C., & Lin, S. (2020). COVID-19 Geopolitics: Silence and Erasure in Cambodia and Myanmar in Times of Pandemic. *Eurasian Geography and Economics, 61*(4–5), 493–510. https://doi.org/10.1080/15387216.2020.1780928

Haleem, A., Javaid, M., Singh, R. P., & Suman, R. (2021). Telemedicine for healthcare: Capabilities, features, barriers, and applications. *Sensors International, 2*, 100117. https://doi.org/10.1016/j.sintl.2021.100117

Harrington, S. (2015). Imaging in the Khmer's Land: Cambodia Country Report. *Journal of Global Radiology, 1*(2), 2. https://doi.org/10.7191/jgr.2015.1016.

Heye, T., Knoerl, R., Wehrle, T., Mangold, D., Cerminara, A., Loser, M., Plumeyer, M., Degen, M., Lüthy, R., Brodbeck, D., & Merkle, E. (2020). The energy consumption of radiology: Energy-and cost-saving opportunities for CT and MRI operation. *Radiology, 295(*3), 593–605. https://doi.org/10.1148/radiol.2020192084

Hussain, M., Khan, M., Ajmal, M., Sheikh, K. S., & Ahamat, A. (2019). A multi-stakeholders view of the barriers of social sustainability in healthcare supply chains: Analytic hierarchy process approach. *Sustainability Accounting, Management and Policy Journal, 10*(2), 290-313. https://doi.org/10.1108/SAMPJ-05-2018-0140

Hwang, C.-L., & Kwangsun, Y. (1981). *Multiple Attributes Decision Making Methods and Applications*. Berlin: Springer.

Iwamoto, A., Tung, R., Ota, T., Hosokawa, S., & Matsui, M. (2020). Challenges to neonatal care in Cambodia amid the COVID-19 pandemic. *Global Health & Medicine, 2*(2), 142–144. https://doi.org/10.35772/ghm.2020.01030

Kanokphanvanich, C., Rattanawong, W., & Vongmanee, V. (2022). Meta-analysis of health care supply chain performance for patient safety. *International Conference on Software, Knowledge Information, Industrial Management and Applications, SKIMA. Vols. 2022-December* (pp. 13–20). Phnom Penh, Cambodia: IEEE

Kanokphanvanich C, Rattanawong W, Vongmanee V. (2023). A new model for a sustainable healthcare supply chain prioritizes patient safety: Using the Fuzzy Delphi Method to identify healthcare workers' perspectives. *Sustainability, 15*(9), 7123. https://doi.org/10.3390/su15097123

KC, D. S., & Terwiesch, C. (2009). Impact of workload on service time and patient safety: An econometric analysis of hospital operations. *Management Science, 55*(9), 1486-1498. http://dx.doi.org/10.1287/mnsc.1090.1037

Kerr, R. S. (2020). Surgery in the 2020s: Implications of advancing technology for patients and the workforce. *Future Healthcare Journal, 7*(1), 46–49. https://doi.org/10.7861/fhj.2020-0001

Kumar, S., Raut, R. D., & Narkhede, B. E. (2020). A proposed collaborative framework by using artificial intelligence-internet of Things (AI-IoT) in COVID-19 pandemic situation for healthcare workers. *International Journal of Healthcare Management, 13*(4), 337–45. https://doi.org/10.1080/20479700.2020.1810453

Lu, C., You, J-X., Liu, H-C., & Li, P. (2016). Health-care waste treatment technology selection using the interval 2-tuple induced TOPSIS method. *International Journal of Environmental Research and Public Health, 13*(6), 562. https://doi.org/10.3390/ijerph13060562

McAlister, S., McGain, F., Petersen, M., Story, D., Charlesworth, K., Ison, G., & Barratt, A. (2022). The carbon footprint of hospital diagnostic imaging in Australia. *The Lancet regional health, Western Pacific, 24*, 100459. https://doi.org/10.1016/j.lanwpc.2022.100459

Mohammed, T. J., Albahri, A. S., Zaidan, A. A. Albahri, O. S., Al-Obaidi, J. R., Zaidan, B. B., Larbani, M., Mohammed, R. T., & Hadi, S. M. (2021). Convalescent-plasma-transfusion intelligent framework for rescuing COVID-19 patients across centralised/decentralised telemedicine hospitals based on AHP-group TOPSIS and matching component. *Applied Intelligence, 51*, 2956–2987. https://doi.org/10.1007/s10489-020-02169-2

Pennestrì, F., & Banfi, G. (2022). The experience of patients in chronic care management: Applications in Health Technology Assessment (HTA) and value for public health. *International Journal of Environmental Research and Public Health, 19*(16), 9868. https://doi.org/10.3390/ijerph19169868

de Reeder, A., Hendriks, P., Plug-van der Plas, H., Zweers, D., van Overbeeke, P. S. M., Gravendeel, J., Kruimer, J. W. H., van der Meer, R. W., & Burgmans, M. C. (2023). Sustainability within interventional radiology: Opportunities and hurdles. *CVIR Endovascular, 6*(1), 16. https://doi.org/10.1186/s42155-023-00362-1

Rodriguez, R., Otero-Neira, C., & Svensson, G. (2020). Sustainability endeavors and sustainable development in Spanish public hospitals: The case for upstream social marketing. *Journal of Social Marketing, 10*(2), 215-242. https://doi.org/10.1108/JSOCM-11-2018-0136

Schoen, J., McGinty, G. B., & Quirk, C. (2021). Radiology in our changing climate: A call to action. *Journal of the American College of Radiology: JACR, 18*(7), 1041–1043. https://doi.org/10.1016/j.jacr.2021.02.009

Serrou, D., Abouabdellah, A., & Mharzi, H. (2015). Proposed an approach for measuring the performance of hospital logistics systems by integrating quality, safety and environment. *International Journal of Scientific Engineering and Technology, 4*(1), 24–27. doi: 10.17950/ijset/v4s1/106.

Smith, S. W., Tiu, J., Caspers, C. G., Lakdawala, V. S., Koziatek, C. A., Swartz, J. L., Lee, D. C., Jamin, C. T., Femia, R. J., & Haines, E. J. (2021). Virtual urgent care quality and safety in the time of coronavirus. *Joint Commission Journal on Quality and Patient Safety, 47*(2), 86–98. https://doi.org/10.1016/j.jcjq.2020.10.001

Swarnakar, V., Bagherian, A., & Singh, A. R. (2022). Modeling critical success factors for sustainable LSS implementation in hospitals: an empirical study. *International Journal of Quality & Reliability Management, 39*(5), 1249-1280. https://doi.org/10.1108/IJQRM-04-2021-0099

Swarnakar, V., Singh, A. R., & Tiwari, A. K. (2021). Evaluating the effect of critical failure factors associated with sustainable lean six sigma framework implementation in healthcare organization. *International Journal of Quality and Reliability Management, 38*(5), 1149–1177. doi: 10.1108/IJQRM-07-2020-0243.

Tejativaddhana, P., Briggs, D., Singhadej, O., & Hinoguin, R. (2018). Developing primary health care in Thailand: Innovation in the use of socio-economic determinants, sustainable development goals and the district health strategy. *Public Administration and Policy: An Asia-Pacific Journal, 21*(1), 36-49. https://doi.org/10.1108/PAP-06-2018-005

Teo, A. K. J., Ork, C., Eng, S., Sok, N., Tuot, S., Hsu, L. Y., & Yi, S. (2020). Determinants of delayed diagnosis and treatment of tuberculosis in Cambodia: A mixed-methods study. *Infectious Diseases of Poverty, 9*(1), 49. https://doi.org/10.1186/s40249-020-00665-8

Tsarfati, B., & Cojocaru, D. (2022). The importance of receiving training in computerized technology for nurses to maintain sustainability in the health system. *Sustainability, 14*(23), 15958. https://doi.org/10.3390/su142315958

Tudor, M. A., Filimon Benea, A., & Bratosin, S. (2021). COVID-19 pandemic lockdown and religious mediatization of social sustainability. A case study of Romania. *International Journal of Environmental Research and Public Health, 18*(5), 2287. https://doi.org/10.3390/ijerph18052287

Wald, J. T., Lowery-Schrandt, S., Hayes, D. L., & Kotsenas, A. L. (2018). Mayo clinic care network: A collaborative health care model. *Journal of the American College of Radiology: JACR, 15*(1 Pt B), 167–172. https://doi.org/10.1016/j.jacr.2017.09.031

Welling, R. D., Azene, E. M., Kalia, V., Pongpirul, K., Starikovsky, A., Sydnor, R., Lungren, M. P., Johnson, B., Kimble, C., Wiktorek, S., Drum, T., Short, B., Cooper, J., Khouri, N. F., Mayo-Smith, W. W., Mahesh, M., Goldberg, B. B., Garra, B. S., Destigter, K. K., Lewin, J. S., ... & Mollura, D. J. (2011). White paper report of the 2010 RAD-AID conference on international radiology for developing countries: Identifying sustainable strategies for imaging services in the developing world. *Journal of the American College of Radiology: JACR, 8*(8), 556–562. https://doi.org/10.1016/j.jacr.2011.01.011

Woolen, S. A., Kim, C. J., Hernandez, A. M., Becker, A., Martin, A. J., Kuoy, E., Pevec, W. C., & Tutton, S. (2023). Radiology Environmental Impact: What Is Known and How Can We Improve?. *Academic radiology, 30*(4), 625–630. https://doi.org/10.1016/j.acra.2022.10.021