User Centred Design and Implementation of Useful Picture Archiving and Communication Systems for Effective Radiological Workflows in Public Health Facilities in Zambia

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Abstract. Radiological workflows in public health facilities in The Republic of Zambia are performed using manual processes. With a broad spectrum of stakeholders—physicians, radiographers and radiologists involved in radiological workflows, the efficiency of health service provision is drastically reduced, subsequently compromising clinical care. While there are a number of software platforms that are used in radiological workflows, Picture Archiving and Communication System platforms are important as they are primarily used to store, manage and facilitate access to Medical Images. This paper outlines the user-centred design and implementation of a Picture Archiving and Communication System for storing, managing, and facilitating access to medical images in public health facilities in Zambia, in order to demonstrate the feasibility of automating manual medical imaging workflows in public health facilities. Semi-structured interviews were conducted with two (2) radiologists and four (4) radiographers in order to understand medical imaging workflows in public health facilities. A Picture Archiving and Communication System was designed and implemented using Dicoogle as the base platform and, subsequently evaluated—using the TAM 2 questionnaire—in order to assess its perceived usability and usefulness. The interviews conducted provide insight into the extent towards which manual workflows are employed, with DICOM viewers used as the main technology in the workflow. The impementation and evaluation of the Picture Archiving and Communication System demonstrates the feasibility of implementing these platforms in public health facilities and their potential usefulness, respectively.

Keywords: Enterprise Medical Imaging · Medical Images · Picture Archiving and Communication System · Radiological Workflows

1 Introduction

The automation of radiological workflows, such as through implementation of Picture Archiving and Communication System (PACS)—software tools used to store, manage and access medical images such as X-rays—and Radiology Information System (RIS)—software tools used to manage radiological workflow processes as requests for patients to be examined, has undoubtedly proved valuable at improving the productivity and efficiency of radiology departments. Although the implementation of PACS systems often result in increased workload for some individual stakeholders—such as radiologists, gains are ultimately realised through the resultant time efficiency and enhanced image storage, access, management and transfer.

However, the lack of PACS has been identified as the critical missing element for international radiology development in resource constrained countries [13]. In The Republic of Zambia, public health facilities lack this important software platform and as such, radiological workflows are currently performed using manual processes. For instance, historical medical images are stored on optical discs and external hard drives. Coupled with other confounding challenges including the critical shortage of radiologists, low utilisation of technology among stakeholders and the broad spectrum of stakeholders involved in the radiological workflows, this drastically reduces the efficiency of the radiological services thereby compromising clinical care. Zulu and Phiri [18] highlighted challenges and opportunities associated with the implementation of Enterprise Medical Imaging (EMI) strategies, whose important infrastructure components are PACS platforms.

Open source PACS platforms are increasingly becoming available and offer multiple advantages for PACS platform implementation to resource-limited institutions, including relative cost-effectiveness, flexibility for customisation to meet local users' imaging needs and interoperability with other existing and future software systems within the domain of electronic health record systems.

This paper outlines the design, implementation and subsequent evaluation for usefulness, of a prototype user-centered PACS platform aimed at demonstrating the feasibility of designing and implementing potentially cost-effective PACS platforms for use in public health facilities in Zambia.

The remainder of this paper is organised as follows: Section 2 describes relevant literature related to this work; Section 3 outlines the methodological approach employed to conduct this study; Section 4 describes and interprets the results associated with the study and, finally, Section 5 presents concluding remarks and potential future work.

2 Related Work

2.1 Radiological Workflow Challenges

The challenges associated with access to radiological services in Low and Middle Income Countries (LMICs) are extensively documented in literature. Hricak et al. report that a global assessment of medical imaging revealed significant shortages of human resource and equipment in LMICs [11]. Frija et al. further emphasise seriousness of these challenges and highlight the importance of access to imaging services in LMICs due to the rise in cases of non-communicable diseases [9]. Zambia faces a challenge of not having enough radiology workers countrywide, a situation that slows down the process of delivering radiological findings to support medical diagnosis and decision making, with a recent study reporting the existence of only nine (9) radiologists in public health facilities, servicing a population of 18 million [6].

In one of our most recent work [18] aimed at identifying potential ways of addressing radiological workflow challenges in public health facilities in Zambia, a SWOT analysis conducted revealed challenges and potential opportunities that exist through the use of Enterprise Medical Imaging—"a set of strategies, initiatives, and workflows implemented across a healthcare enterprise to consistently and optimally capture, index, manage, store, distribute, view, exchange, and analyze all clinical imaging and multimedia content to enhance the electronic health record" [16]. While EMI strategies involve the use of various technological infrastructures, PACS platforms are considered a important technological infrastructure. This study focused on early attempts at designing and implementing PACS platforms to be used in public health facilities in Zambia.

2.2 Free and Open Source Picture Archiving and Communication System Platforms

In the recent past, a number of Free and Open Source Software (FOSS) PACS platforms have been designed and implemented, focused on facilitating the storage of medical images.

ClearCanvas is an open source PACS platform and archive that conforms to the DICOM standard. It offers features such as storage, compression, retrieval of objects and a single user login for secure access [7]. It provides a solution for managing medical image data and organisation of studies. It also offers several plugins that add additional features to the system.

Dicoogle is a PACS archive platform based on a modular architecture, allowing for quick development of auxiliary functionalities [15, 14]. The Dicoogle design enables for the automated information extraction, indexing and storage of metadata associated with medical images, addressing limitations with DICOM-compliant query services.

Orthanc functions as a standalone PACS server aimed at providing relatively easy implementation with ease of installation, configuration, running and integration [12]. Orthanc's design focuses on improvement of DICOM workflows in

health facilities and is reported to have a design that hides the complexities of the DICOM format and protocol in order for users to focus on the content of medical images.

DCM4CHEE is a widely used PACS platform used to archive and manage images. It offers a modular architecture and allows for system customization and flexible data flow configuration [3]. It contains utilities developed in Java for performance and portability, with a strong focus on adherence to the DICOM standard, providing robust and scalable services for healthcare enterprise applications.

EasyPACS is a PACS server that incorporates an online DICOM viewer. It utilises the DCM4CHE API tools, rewritten using modern frameworks such as Spring Boot and Gradle Build Environments. The server accepts DICOM files, generating entity data representing patients, studies, series, equipment and instances which are stored in a relational database management system [2]. It also offers affordable PACS server capabilities and the flexibility to customise the system according to the workflow logic of different health facilities.

While the design and implementation considerations and approaches are different, the vast majority of FOSS PACS platforms are integrated with basic features necessary to store, manage and access medical images. As part of this study, a systematic comparative analysis—outlined in Section 3.3—was done by focusing on crucial feature offerings.

3 Methodology

This section explores the methodology used to understand current challenges, design a potential solution, and evaluate its user acceptance.

A mixed-method approach was used as the basis for conducting this research, combining the use of guided interview sessions and questionnaires.

Ethical clearance was granted by The University of Zambia Biomedical Research Ethics Committee (Reference Number: 2731-2022) and The National Health Research Authority (Reference Number: NRHA000024/10/05/2022), to conduct this study at two (2) public health facilities—University Teaching Hospitals (UTHs) and Levy Mwanawasa University Teaching Hospital (LMUTH). In addition, formal permission was granted from the two (2) facilities.

3.1 Research Design

The primary aim of this study is to understand current challenges in radiological workflows, design a potential solution in the form of a PACS platform, and evaluate its user acceptance in public health facilities in Zambia. Sections 3.2 to 3.4 provide details about the radiological workflow challenges, the implementation of the PACS platform and the evaluation details of the PACS platform, respectively.

3.2 Medical Image Workflows

To gain insights into existing challenges associated with storage, management and acess to medical images, in medical image workflows, semi-structured interviews were conducted with two (2) key stakeholder groups: radiologists and radiographers. Radiographers are technicians who perform imaging examinations on patients and generate medical images in various modalities. Radiologists, on the other hand, are medical professionals who interpret these images and report their findings.

This study was conducted at two (2) large referral hospitals in Zambia: UTHs and LMUTH. The target population for the study included trainee radiologists and radiographers working at these public health facilities. Convenience sampling was employed to select participants from this population.

The audio data collected during the interview sessions were transcribed and thematically analysed to identify recurring themes and pain points related to image storage, management, and access.

3.3 Design and Implementation of Picture Archiving and Communication System Platform

Picture Archiving and Communication System Frameworks Feature Evaluation An evaluation of the identified FOSS PACS Platforms—ClearCanvas [7], Dicoogle [14], DCM4CHEE [3], EasyPACS [2] and Orthanc [4] was carried out to assess the suitability and effectiveness of the platforms. The evaluation involved the assessment of the PACS platforms considering the following factors which were systematically arrived at during experimentation:

- Base Programming Language—Programming language used as the foundation for implementing the PACS platform
- Extensibility—PACS platform's ability to easily be extended with additional functionalities
- Extension Languages—Programming languages supported during development of plugins or extensions
- Operating System Support—Operating system software supported by the platform
- Database—Database management systems used by the PACS platform
- Search Service—Search service integrated with the PACS platform to facilitate effective searching and browsing
- Authentication Support—Platforms used to support authentication
- DICOM compliance—Ability to adhere to the DICOM standard
- DICOM Modality Worklist—Ability of PACS platform to support the DICOM Modality Worklist
- API Support—API support used by the PACS platform
- Scalability—Ability to handle increased workloads
- Relative Adoption—Level of adoption and usage of the PACS platform
- Community Support—Free support including documentation, forums and user-communities

Table 1 is a feature matrix, showing a summary of the results of the evaluation exercise conducted to assess the various FOSS PACS platforms. Ultimately, the Dicoogle platform was chosen as the base framework to be used to implement the PACS Server.

Table 1. Free and Open Source Picture Archiving and Communication Systems Software Evaluation Matrix

Feature	Dicoogle	DCM4CHEE	EasyPACS	ClearCanvas	Orthanc
Base Programming Languages	Java	Java	Java	C#	C++
Extensibility	High	High	High	Medium	High
Extensibility Programming Languages	Java	Java	Java, Python, Ruby	C++, VB.NET	C++, Python
Operating System Support	Windows, Linux, MacOS	Windows, Linux, MacOS	Windows, Linux, MacOS	Windows, Linux, MacOS	Windows, Linux, MacOS
Database Support	NoSQL	Apache Derby, Postgre SQL, MySQL, Oracle	MySQL	PostgreSQL	NoSQL
Search Service	Lucene	Lucene	Lucene	PostgreSQL	SQLite
Authentication Support	Local Auth	LDAP	LDAP, SSO, 2FA	OAuth 2.O	Local Auth
DICOM Compliance	Yes	Yes	Yes	Yes	Yes
DICOM Modality Worklist	Yes	Yes	Yes	Yes	Yes
API Support	RESTful	RESTful	RESTful	.NET	RESTful
Scalability	High	High	High	Low	High
Relative Adoption	Low	High	Medium	Low	High
Community Support	Yes	Yes	Yes	No	Yes

Picture Archiving and Communication System Design and Implementation Using input from the interactions with key stakeholders—outlined in Section 3.2—and the systematic comparative analysis of existing FOSS platforms—outlined in Section 3.3—an appropriate base PACS framework was identified

as the basis for the design and implementation of the UTHs PACS prototype platform.

The design and implementation of the PACS platform necessitated the development of two (2) software components—the PACS Server/Archive and a corresponding PACS Client:

- PACS Server/Archive—responsible for the storage and retrieval of medical images
- PACS Client—used to ingest/deposit medical images into the PACS Server. In essence the medical images are deposited into one of many storage locations integrated with the PACS Server.

Figure 1 shows the Context diagram, illustrating how the various external entities interact with the two (2) software components comprising the PACS platform ecosystem. Radiographers would ideally use the PACS Client to ingest/deposit medical images after performing an examination with an applicable modality, while Radiologists and Physicians would primarily use the PACS server to retrieve medical images

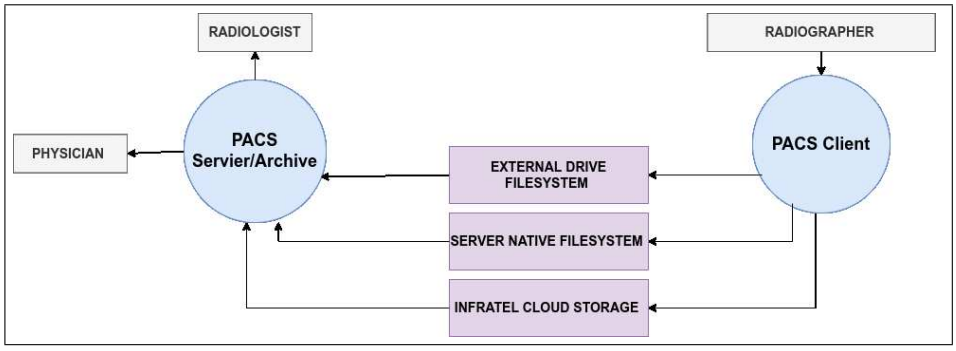

Fig. 1. Context Diagram Outlining High-Level Elements of the Picture Archiving and Communication System Platform

Radiographers would ideally use the PACS Client to ingest/deposit medical images after performing an examination with an applicable modality, while radiologists and physicians would primarily use the PACS server to retrieve medical images.

As stated in Section 3.3, the Dicoogle FOSS toolkit was used as the base platform framework for the implementation of the UTHs PACS Server. Specifically, extensive changes were made to the front-end and, additionally, the platform was modified in order to facilitate password authentication. Furthermore, the feasibility of utilising cloud storage services was explored by using Amazon Web Services [1] as a case example.

The PACS Client is a standalone thin client implemented to facilitate seamless upload of DICOM images to the appropriate storage services associated with

the PACS Server. The Python Flask [5] Web framework was used to implement the PACS Client.

3.4 Prototype Usability Evaluation

Table 2. Study Deisgn Experiment Tasks

INPUTS	PACS URL: pacs.xxxxx.zm:8081 Login details: (username = xxxxx, password = xxxxx) Patient Full Name Patient Last Name Patient ID
STEPS	1. Insert website URL "pacs.xxxxx.zm:8081" in address bar 2. Login into PACS platform using username "xxxxx" and password "xxxxx" 3. Go to the search bar and search an image by: – Patient Full Name: Shankalu Lazarous – Patient Last Name: Shankalu – Patient ID: US222
EXPECTED DURATION	10 Minutes

The PACS platform, implemented as outlined in Section 3.3, was evaluated in a controlled environment in order to assess relative potential to being adopted into a typical public health facility in Zambia. Radiology Registrars from UTHs were recruited, using convenience sampling, in order to participate in the controlled study which involved interacting with the deployed PACS prototype platform and subsequently completing a questionnaire.

Participants were required to perform a series of predefined tasks, outlined in Table 2, which involved searching and browsing for a medical image stored in the PACS platform. Participants were then required to complete a TAM 2 based questionnaire comprising of a section to capture participants' demographics, TAM 2 construct items—TAM 2 helps explain perceived usefulness and usage intentions in terms of social influence and cognitive instrumental processes [17]—and a questionnaire item for participants to provide general comments about the PACS platform and the study in general. TAM 2 instrument comprises questionnaire items—measured on a 7-point likert scale—associated with constructors that helped in the assessment of the perceived usefulness and usage intention for the PACS platform. The TAM 2 constructors are interpreted as follows:

- Perceived Usefulness—Extent of PACS platform in enhancing participants' job performance
- Perceived Ease of Use—Extent towards which PACS platform will be free of effort
- Result Demonstrability—Extent to which PACS produces observable benefits or outcomes
- Output Quality—Quality and reliability of PACS output
- Job Relevance—Extent to which PACS will be relevant and beneficial to a user's job
- Subjective Norm—Pressure or influence from others regarding the acceptance and use of PACS
- Voluntariness—User's freedom and autonomy in deciding whether or not to adopt the PACS
- Intention to Use—User's personal inclination or readiness to adopt and use the PACS platform

4 Results and Discussion

The findings of this research on improving radiological workflows in Zambian public health facilities are presented, exploring the challenges of current practices, showcasing the prototype PACS platform designed to address these challenges, and analysing the user evaluation of the prototype.

4.1 Workflow Challenges

Guided interviews were conducted with six (6) participants—four (4) radiographers and two (2) trainee radiologists. All the participants had more than four (4) years experience with radiological workflows. Table 3 shows a summary of the interview responses.

Interactions with radiographers focused on determining challenges associated with image storage and management. The results indicate that medical images are primarily stored in both analog and digital formats, with a combination of compact discs (CDs), external hard drives and storage rooms used as primary storage techniques. Interestingly enough, there was reference to patients being given physical copies of their medical images on film (such as X-rays) to carry and go home with for safe keeping. This practice might be used to ensure that medical images are available to referring physicians when needed. Expectedly, the main themes linked to challenges with medical image storage were largely associated with retrieval of existing medical images and storage capacity.

The interviews with radiologists were primarily aimed at determining challenges associated with accessing medical images during the interpretation process. The main issue raised is associated with long-term preservation of medical images. For instance, [Radiologist 1] emphasised that follow-ups with patients are difficult as images are typically given to patients and will generally be unreadable, making it difficult to determine the progression of diseases. [Radiologist 2]

Table 3. Summary of Interview Responses

Participants	Facility	Experience	Storage Mediums	Image Formats	Challenges Themes
Radiographer 1	UTHs	5+ Years	Hard Drive · Basement	Analog · Digital	Retrieval Challenges
Radiographer 2	UTHs	5+ Years	Imaging Machine Computer · Store Room	Analog · Digital	Retrieval on Patients' Request
Radiographer 3	UTHs	5+ Years	Hard Drive · Films · Patients	Analog · Digital	Storage Capacity Challenges
Radiographer 4	UTHs	7+ Years	CDs · Films	Analog · Digital	Difficulties Accessing Images
Radiologist 1	LMUTH	11+ Years	-	Analog · Digital	Image Preservation · Follow Ups
Radiologist 2	UTHs	4+ Years	-	Analog · Digital	Limited Space · Images Discarded

echoed this point by highlighting that films will frequently be discarded in order to reclaim space for recent medical images. Interestingly enough, [Radiologist 2] made mention of the importance of preservation of medical images in order to further research.

The research illustrates several key principles, relationships, and generalizations. Centralising and digitalising image storage is crucial for addressing retrieval and long-term preservation challenges, effectively resolved by a PACS platform. While issues related to storage capacity may not be directly addressed by PACS alone, these can be mitigated through proper policies, procedures, and management investment in storage infrastructure. The study reveals a clear relationship between PACS deployment and the resolution of image retrieval issues, emphasising the need for organizational commitment to address storage capacity. Generalizations from user feedback indicate a positive perception of PACS, suggesting that mandatory organizational policies are essential for consistent usage. Continuous improvement and expert involvement are also necessary for refining a production-quality PACS platform.

4.2 Prototype Picture Archive and Communication System Platform

As earlier mention in Section 3.3, the Dicoogle was ultimately used as the base platform for the implementation of the PACS. Figure 2 shows a search result page rendered using the final version of the PACS Server high fidelity prototype that was designed and implemented. Once successfully logged into the PACS Server, a physician or radiologist can search for medical images using open ended text queries corresponding to metadata linked to the medical image.

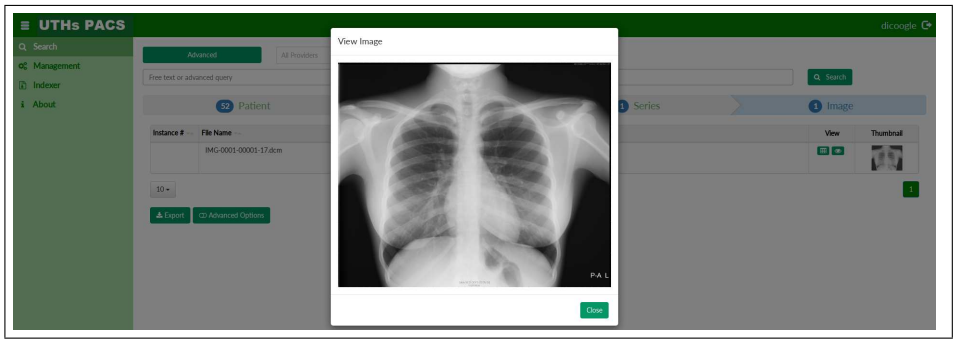

Fig. 2. Screenshot of the Prototype Picture Archiving and Communication System

Using the content rendered on the search result page, the user can then browse to the desired medical image using the DICOM hierarchy [8], making it possible for patient, study, series and image data to be accessed. The access to specific images associated with a Study Series has a provision for users to view thumbnails of medical images.

While the current basic discoverability features would be sufficient for physicians and radiologists to engage with the platform, further enhancements are required to implement vital functionalities, including the downloading of DICOM formatted medical images and seamless integration with other platforms prevalent in public health facilities. This iterative process aligns with the principles of continuous refinement and advancement to achieve a production-quality PACS platform. Notably, the prototype's implementation serves as a pivotal step in probing and refining requirements, illustrating the relationship between iterative development and meeting evolving clinical needs. This underscores the generalization that continuous improvement is essential for optimising the platform's utility and effectiveness within healthcare settings.

4.3 Usability Evaluation Using TAM 2 Questionnaire

Participants Demographics A total of eight (8) radiology registrars (trainee radiologists), from UTHs, at different levels of training participated in the study. Table 4 shows a summary of demographic factors for the study participants. Most of the study participants were females, with those at higher levels of training having had prior exposure to other training sites besides the study site (UTHs). In addition, most of the participants had "1—5 years" medical practising experience. Furthermore half of the participants had no experience using PACS platforms.

Analysis 1. TAM 2 Constructs The TAM 2 questionnaire items for each of the constructs described in Section 3.4 were aggregated and average score computed. Figure 3 is a radar chart that illustrates average scores for the TAM 2 constructs.

Table 4. Participants' Demographic Factors

Demographic Factors		Radiology Residency Year				
		1st	2nd	3rd	4th	5th
Gender	Male	0	1	0	1	0
	Female	1	1	1	2	1
Experience in Practising	1—5 Years	0	2	0	1	0
	5—10 Years	1	0	1	2	1
Prior Experience Using PACS	Yes	0	0	1	2	1
	No	1	2	0	1	0

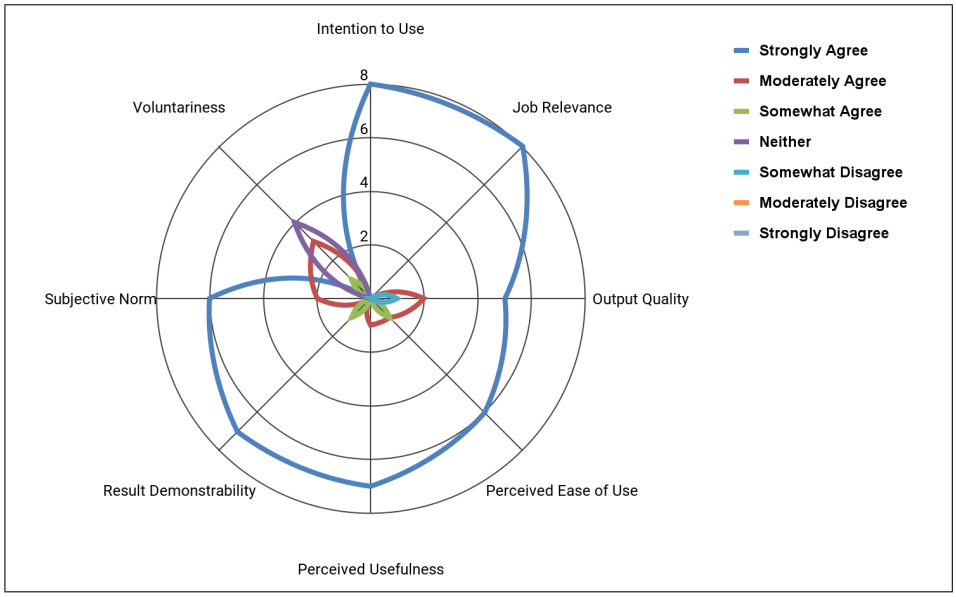

Fig. 3. Spider/Radar Chart Illustrating Average Ratings for the Seven TAM 2 Constructs

The results indicate that most of the participants felt positive about "Intention to Use," "Job Relevance," "Perceived Usefulness," and "Result Demonstrability." This positive feedback suggests that participants recognized the clear benefits of using a PACS platform compared to the manual workflows currently in use. Comments made by [Radiologist 1] and [Radiologist 2] during the interview sessions, as outlined in Table 3 in Section 3.2, support this assertion, underscoring the principle of streamlining radiological workflows through centralized digital platforms. However, the lower ratings for "Output Quality," "Perceived Ease of Use," and "Subjective Norm" likely reflect the prototype's limited features and the study's brief duration, highlighting the relationship between platform functionality and user perception. Notably, the low ratings for "Voluntariness" suggest the need for organizational policies mandating PACS adoption to ensure its integration into radiological practices.

Analysis 2. Participants Remarks The general comments provided by study participants mostly consisted of suggestions on how to improve the PACS platform. The general comments suggest a need to further involve experts during the refinement of requirements as the production-quality PACS platform is being designed and implemented.

Some open ended general comments specified by the study participants are as follows:

> "Integration to an online patient clinical records would significantly enhance patient care" [Participant 1]
> "It's a step in the right direction" [Participant 2]
> "Suggestions are that it should be a multimodality platform and should have a provision for reporting images" [Participant 3]
> "Incorporating a DICOM viewer (digital imaging and communication in medicine) would help to large data sets (CT scans and MRI Scans)" [Participant 4]
> "There is supposed to be free access to the internet in the department." [Participant 5]
> "IT WOULD ADD A LOT OF VALUE IF IMAGES WERE EXPORTABLE." [Participant 6]
> "Order of metadata should prioritise patient pertinent details as opposed to technical lingo" [Participant 8]

5 Conclusions and Future Work

This paper outlined a study conducted to design, implement and evaluate a prototype PACS platform. The research aimed to demonstrate the feasibility of designing and implementing cost-effective PACS platforms for use in public health facilities, particularly in resource-limited settings like Zambia. The results from the usability study conducted with Radiology Registrars suggest that

deploying a PACS at the UTHs has the potential to improve radiological workflows, primarily due to the fact that medical imaging workflows currently utilise manual processes. Deploying a PACS platform has the obvious potential of facilitating efficient and effective medical imaging workflows. The study is aligned with existing study focused on PACS evaluation, such as the study by Hasani et al., in which improvements of mean reporting time and utilisation of CT scans were reported [10].

This work contributes to the growing body of research on affordable healthcare IT solutions. By focusing on a prototype with limited functionalities, we aimed to establish a foundation for developing PACS platforms that are both functional and mindful of budgetary constraints. Additionally, the emphasis on interoperability during the prototype's development aligns with theoretical considerations for future healthcare IT systems, where various software platforms need to seamlessly interact.

Presently, ongoing work is focused on implementing production-quality PACS platforms informed by the learnings from the prototype. These platforms are expected to significantly improve image management workflows within public health facilities. Furthermore, efforts are underway to explore the potential of using machine learning techniques to automatically classify medical images once ingested into PACS. This integration has the potential to further streamline workflows and potentially assist healthcare professionals in diagnosis.

PACS platforms typically operate within a complex ecosystem of heterogeneous software platforms. As such, interoperability was a key consideration during the development process. While current efforts are confined to well-resourced public health facility settings in Zambia, there is a need for PACS that can function effectively in settings with limited bandwidth, common in remote locations. Potential future work could explore the design and implementation of tools for devices with significantly small form factors to cater to such settings. Additionally, further research could focus on developing strategies to ensure that future PACS platforms are interoperable with a wide array of software platforms used in public health facilities.

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