Future Developments and Trends in Use of Picture Archiving and Communication Systems

---

A Thesis submitted for the degree of Doctor of Philosophy

By

Mona Alhajeri

Supervisor: Dr Malcolm Clarke

April 2016

Department of Computer Science
College of Engineering, Design, Physical Sciences
Brunel University London, UK

ABSTRACT

Objectives: This study identifies modern information technologies that can improve the clinical practice of Picture Archiving and Communication Systems (PACS) and determines the approaches that are needed to improve the functionality of current PACS to provide better next generation PACS and to improve the future of radiology practices and workflow with future PACS generations.

Method: A parallel mixed method approach was adopted including qualitative method (semi-structured interviews), quantitative method (questionnaire survey) and observation of online discussion groups on PACS. Five databases were searched to find salient literature, including Science Direct**,** Springer Link, Scopus, CINAHL Plus and Google Scholar. Six radiologists were interviewed and questionnaires were collected from 120 radiologists. Four online discussion groups related to PACS were monitored via LinkedIn. The data were analysed thematically using the thematic analysis method. Finally, a focus group was held with a separate group of radiologists to validate the findings.

Results: Eight themes emerged from the thematic analysis of the data: (1) limitations of traditional PACS; (2) user needs and requirements that can increase PACS functionality; (3) Web based solutions of PACS; (4) PACS on mobile phones; (5) Vendor Neutral Archive (VNA); (6) full integration of voice recognition in PACS; (7) backup solutions for the system and (8) continuous training for PACS users.

Discussion: With the development of healthcare information and communication technology (ICT) and with the increased demands of the radiologists to expand PACS usability, traditional PACS must be updated to follow the changes.

Modern technologies can provide better solutions to enhance the functionality of current PACS. The next generation of PACS can fulfil the future requirements of users.

This study considers the issues between the needs and requirements of the users of a PACS system in the future and the developing solutions in ICT and the PACS industry. Moreover, highly developed PACS systems with advanced features will have a direct impact in changing and improving radiology workflow. Accordingly, a model has been developed that proposes new features for the next generation PACS system, which may be applied to the next generation radiology practice. The model was validated with the focus group and, by using a separate group of radiologists in another country, was determined to be generalisable.

Conclusion: It is widely recognised that traditional PACS must be updated to adopt recent advances in ICT. This research has identified themes that, when incorporated, will enhance the functionality of PACS and radiology workflow and provide better quality clinical practice.

The findings from this empirical research can be used: as recommendations to vendors; for technology development; and by medical institutes to consider aspects when undertaking implementation of PACS and training future radiologists.

Keywords: 'Picture archiving and communication system', PACS, Future trends, next generation, Organisational efficiency, Productivity, Clinical practice, Ubiquitous.

DEDICATION

There are a number of people without whom this research might not have been completed and this thesis might not have been written, and to whom I am greatly indebted.

To my beloved parents, mum and dad (late) Mubarak Eid (may his soul rest in peace).

Your belief in the richness of learning has been the biggest motivation that led me all the way throughout this thesis. I dedicate this to you for giving me all the love and moral support I have needed in the accomplishment of this work. Thank you for being proud that much of me; I am honoured to have you as my parents.

To my kind son Omar,

To my precious daughter Areej,

To my lovely son Fawaz,

You have shared with me a wonderful experience, and you have been my companion through the hard days. You have inspired me to succeed. I love you (Omar, Areej and Fawaz)

I would dedicate this thesis to my brother Yousef (may his soul rest in peace) and to my sister (*Amal*) thank you for the help and encouragement you offered me when I most needed it.

Thank you all!

Mona

ACKNOWLEDGEMENTS

I would like to extent my sincere thanks and gratitude to Dr Malcolm Clarke, Brunel University for his support and guidance throughout my PhD research studies.

I hereby acknowledge that the Ministry of Health, Government of Kuwait, sponsored my PhD studies at Brunel University London, UK.

I wish to thank all radiologists and PACS users who took part in the research reported in this PhD thesis.

DECLARATION

I, the undersigned, hereby declare that the following publications / conferences papers / posters were written and presented from the empirical research presented in this doctoral thesis.

Conferences

Alhajeri, M. and Clarke, M. (2014) 'Contribution with poster about the literature review of the Future Trends in PACS system'. In: The 25th European Medical Informatics Conference (EMI 2014), Istanbul, Turkey. August 31 - September 3, 2014.

Alhajeri, M. and Clarke, M. (2015) 'Contribution with poster the Future Trends in PACS system'. In: The 8th Saudi Students Conference, Imperial College London, January 31 – February 1, 2015.

Alhajeri, M. and Clarke, M. (2015) 'Contribution with an oral presentation about the Future Trend in PACS qualitative results'. In: SPIE Medical Imaging Conference 2015, Orlando, Florida, USA, February 21- 26, 2015.

Alhajeri, M. and Clarke, M. (2015) 'Contribution with poster about the Future Trend in PACS quantitative results'. In: 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society MiCo - Milano Conference Centre - Milan, Italy, August 25-29, 2015.

Alhajeri, M. and Clarke, M. (2015) 'Contribution with oral presentation and poster about the quantitative and qualitative data analysis of the Future Trend in PACS'. In: Middle East Association for Health Informatics (MEAHI), Standards and Interoperability in Healthcare Informatics, Kuwait University, Jabria, State of Kuwait, Health Sciences Centre, December 15-17, 2015.

Signature ……..

Date…….

Table of contents

List of Tables

List of Figures

Acronyms and Abbreviations

AET	Application Entity Title
ARP	Address Resolution Protocol
BTO	3D Image Files primarily associated with Baytex Organix! 2001 Language Kit
CAD	Computer-Aided Diagnosis
CIO's	Chief Information Officer
CT	Computed Tomography
DICOM	Digital Imaging and Communication in Medicine
DIR	Directory
EHR	Electronic Healthcare Records
EMR	ElectronicMedical Record
EPR	Electronic Patient Record
FHIR	Fast Health Interoperable Resources
GAE	Google App Engine
GE	General Electronics
HIPAA	Health Insurance Portability and Accountability Act
HIS	Hospital Information Systems
HTTPs	Hyper Text Transfer Protocols
ICT	Information and Communication Technology
IHE	Integrating the Healthcare Enterprise
IP	Internet protocol
IS	Information systems
LAN	Local Area Network
MACS	Multimedia Archiving and Communication Systems
MD-PACS	Multi-departmental PACS
MI Cloud	Medical Image Cloud

MOH	Ministry of Health
MPLS	Multiprotocol Label Switching
MRI	Magnetic Resonance Imaging
NATO	North Atlantic Treaty Organisation
PACS	Picture Archiving and Communication System
PCoIP	PC-over-internet protocols
PEOU	Perception of ease of use
PMM	PACS maturity model
PU	Perception of the usefulness
QIDO-RS	Query based on ID (for DICOM Objects) by RESTful Services
RAID	Redundant Array of Inexpensive (Independent) Disks
REST	Representational State Transfer
RIA	Rich Internet Application
RIS	Radiology Information Systems
ROI	Region of interest
STP	Spanning Tree Protocol
STOW-RS	STore Over the Web by RESTful Services
TAM	Technology Acceptance Model
UCP	Universal Clinical Platform
UK	United Kingdom
UN	United Nations
USA	United States of America
UTAUT	Acceptance and Use of Technology
VNA	Vendor Neutral Archive
WADO	Web Access to DICOM
XDS	Cross Enterprise Document Sharing profile

1 Chapter One: Introduction

1.1 Introduction

At present, Picture Archiving and Communication System (PACS) is used to replace hard copy based film with filmless environments. It acquires, stores, transmits, and archives medical images electronically. The rapid development in health care Information and Communication Technology (ICT) has increased demand from clinicians for improved usability of PACS; traditional PACS must be updated to follow the changes. However, the next generation of PACS must not only solve the existing problems of PACS and enhance its functionality to reach maximum potential, but it must also incorporate modern technical developments to increase its productivity.

PACS has undergone rapid development and changes over several years since its implementation in clinical practice. The main purpose for using PACS was to replace film based medical images and improve the workflow in hospitals and medical practice. This included images acquired from several imaging modalities such as Computer Tomography (CT), X-ray and nuclear medicine; images being stored and transmitted electronically within the medical environment. The intention of PACS was to make images available on multiple workstations, making images easily accessible for everybody at the same time (Hecht, 2008)

1.1.1 Basic components of PACS

The basic components of PACS (Figure 1-1) are:

1. Interfaces to hospital information systems and image acquisition component

2. Imaging modalities

3. Digital Imaging and Communication in Medicine (DICOM) gateway

4. PACS controller and archive

5. Viewing workstations

6. Related systems (HIS/RIS)

(Valente, Costa and Silva, 2013; Huang, 2010; Hecht, 2008; Law and Zhou, 2003)

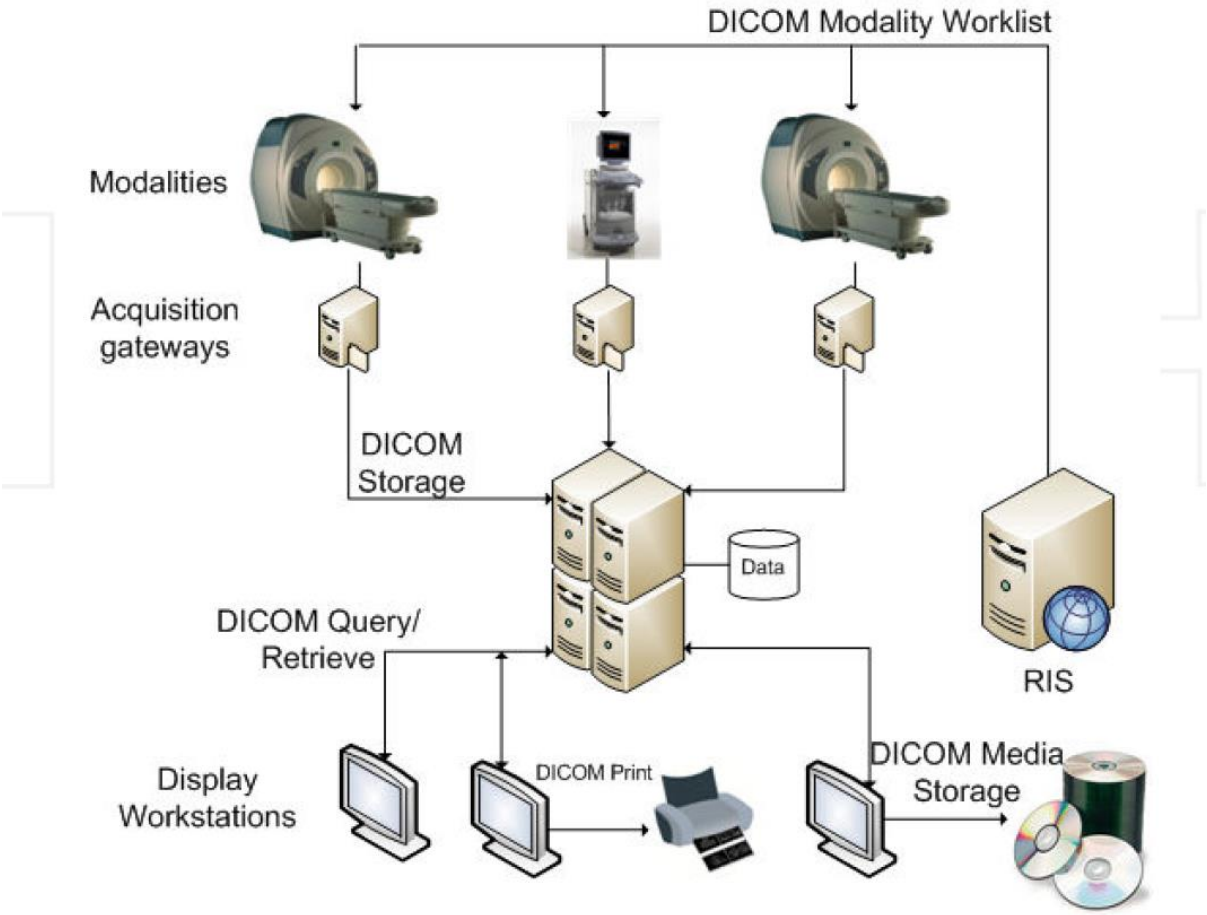


Figure 1-1 Outline of a PACS infrastructure comprising the most common components in an imaging institution

Source: (Valente, Costa and Silva, 2013)

The filmless environment, on which PACS is based provides many advantages for hospitals, physicians, radiologists, and patients, making it invaluable in the health sector (Liang *et al.*, 2010; Xue and Liang, 2007).

The rapidly changing technology with its increasing cost is considered as the major factor that limits PACS implementation and introduction of filmless environment. PACS uses the Internet as a medium for organizing, storing, retrieving, disseminating, and transporting images to different hospital locations (Liang *et al.*, 2010; Xue and Liang, 2007; Majid and Misra, 2002). Some researchers have pointed out that there is a bright future for PACS, with advanced technology solutions that will improve PACS performance, such as holographic PACS, which combines a single department through new storage technologies; enterprise PACS, which provides vertical and horizontal integration between specialities and departments; and virtual PACS, which crosses the enterprise (Faggioni *et al.*, 2011b).

PACS displays, acquires, transports, and stores medical images electronically, creating a filmless environment that reduces material costs, physical storage space, and the manual labour of traditional film based environments (Xue and Liang, 2007).

Law and Zhou (2003) define PACS as an image information technology system that transmits and stores medical images. In a PACS, digital networks connect many different imaging modalities such as magnetic resonance imaging (MRI), CT, ultrasound scanners, Digital Imaging and Communications in Medicine (DICOM) gateways, Hospital Information Systems (HIS) and Radiology Information Systems (RIS).

By using PACS medical images can be acquired electronically, stored and presented for diagnosis anywhere at any time. Electronic management of patient data also needs an Electronic Patient Record (EPR), which is formed from the HIS and RIS. PACS can increase the quality of the electronic patient record. Moreover PACS needs multimedia hardware because it integrates information media in multiple forms

such as video, recording, text, voice, and medical records (Hussein, 2009; Maglogiannis, Delakouridis and Kazatzopoulos, 2006).

1.2 History of PACS

Digital radiology and PACS were first developed in 1970s. Practical implementation started in the 1980s. The acronym PACS was first created by Duerinckx in 1982, before the first international conference and workshop on PACS (Duerinckx, 2003). Further details about the evolution of PACS development is provided in chapter 3, which provides a review of literature on the PACS.

Subsequently, numerous conferences have been held on PACS, such as the Japan Association of Medical Imaging Technology (JAMIT) in 1982 and Euro PACS in 1984, which have become regular series (Hecht, 2008).

1.3 PACS Implementation and Use

An important aspect in the use of PACS is to understand best practice for implementation. Much work has been conducted on defining guidelines for using PACS with respect to the technology. There are many factors that affect the use and performance of technology in health services. This includes a lack of knowledge about technological innovation, financial resources, and local regulations. Issues also include limited facilities because of technological delay, limited market for the technology, and cultural differences. Therefore, it is important to review these factors for improving the implementation of PACS in healthcare systems (Ortiz-Posadas *et al.*, 2007).

The practicalities of the implementation and evaluation of a modern PACS in terms of design and introduction in an already operating hospital are well studied. Such research highlights how an existing hospital is converted to a fully digital

environment by connecting all the medical equipment to the central archiving system. One such study reports how the implementation of PACS makes it easy to connect with other hospitals and thereby increasing the use and spread of the system (Hussein, 2009).

However issues remain for the implementation of PACS, related to the hospital employees who are not ready for change and have no experience in terms of system behaviour, informatics, or digital archiving of medical images. Such issues slow down the workflow and integration of the system.

Further issues include an insufficient financial plan for the implementation, and a technology supplier with incomplete knowledge of the clinical requirement. In addition, training courses on the system should be provided for the PACS users, especially the new ones. It is also recommended that PACS is combined with existing hospital information systems (HIS/RIS). Moreover, to assist employees moving to a new system, there should be a sufficient number of PACS work stations, especially in the offices of doctors. It is also important to ensure there is balance between costs and benefits (Maass and Suomi, 2004).

In most European countries, PACS is considered to be an important diagnostic tool within hospitals and the usage of PACS in Europe countries is shown in Figure 1-2.The major role of PACS is to distribute images electronically, and so save cost and time. In addition, training of the PACS team was identified important because it could lead to implementation of PACS (Dubey *et al.*, 2009).

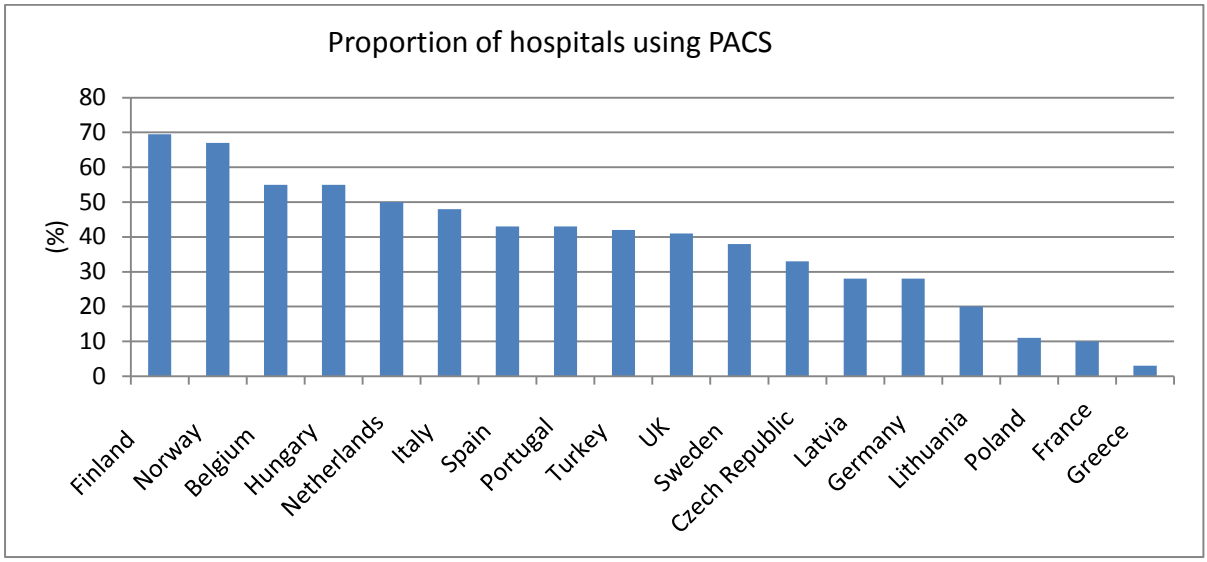


Figure 1-2 PACS usage inEuropean countries, 2009

Source: (Dubey *et al.*, 2009)

1.4 Workflow and Integration of PACS

An important aspect in the integration of PACS is to redesign the workflow before introducing the filmless process. Correct redesign of workflow can help in reducing cost and improving productivity. PACS helps in: displaying images anywhere, anytime; accelerating film retrieval; protecting film from loss or being stolen; and improving overall image quality. However, many departments that use PACS fail to achieve benefit. Although there are cost savings from no longer using film, and image access is improved, there are no savings in terms of radiologist or staff productivity.

The literature shows that the greatest benefits of PACS are gained by using it as a tool to redesign workflow in radiology and imaging departments, rather than using it as a tool in itself. Therefore, the use of PACS in the radiology or imaging department without redesign of workflow will fail to deliver expected benefits. For example, although a radiology department may become filmless, problems may remain in the

workflow if images are ordered and reports produced by paper. Therefore, the effective and productive use of PACS is only achieved with workflow analysis and redesign (Siegel, 2003).

Effective implementation of PACS requires additional aspects. This should include a PACS administrator, regular training of the radiologists, regular maintenance, and updating and upgrading of the system. Moreover training users on PACS should begin before its implementation for the best productivity. In addition, periodic review sessions should be given to radiologists to update and upgrade their knowledge and experience (Kalyanpur, Singh and Bedi, 2010).

1.5 Economics of PACS

Implementation of PACS generally reduces cost by removing the need for film, chemicals, film processors, storage, and staff time. Moreover, correct implementations of PACS will save physician time, reduce patient waiting time, and increase clinical efficiency (Ayal and Seidmann, 2009).

PACS brings further advantages. It can improve the communication between the radiologist and the referring physician, reduce the number of lost images, improve image access speed, provide internal and external image access, improve physician job satisfaction, and make departments more efficient (De Backer, Mortelé and De Keulenaer, 2004).

1.6 Advantages and Disadvantages of PACS

The practical results of the introduction of PACS have been variously reported, and advantages and disadvantages have also been identified (Silva *et al.*, 2014; Jackson and Langlois, 2005), which are outlined below.

1.6.1 Advantages

- Productivity of both Medical Imaging Department (MID) and individual radiologist is improved
- Examination cost decreased
- Patient overall treatment cost decreased
- Immediate access to films anywhere at any time
- Image quality improved
- High storage capacity
- Physician satisfaction increased
- Patient satisfaction increased
- Time saved

1.6.2 Disadvantages

- Possibility of total system failure due to some software and hardware problems, network connection problems, and human errors
- Decreased face-to-face clinical contact
- Complex transition period
- Not all services are ready to make digital images

PACS can save time. For example, in one study where film based radiological procedures took 25 hours and 19 minutes, the same number of the filmless procedures took 3 hours and 40 minutes. This can also result in reduced staying time in hospital and improved patient management (Zacharia, Sumner and Saini, 2004; Twair *et al.*, 2000).

1.7 Other Systems Relevant to PACS

The following two systems are relevant to the PACS.

1.7.1 Hospital Information System

A Hospital Information System (HIS) is used by hospitals as it is an important tool for managing the administrative information e.g. financial and employee data, clinical tasks and patient information, as well as information about the hospital performance (Liu, Zhou and Huang, 2006)(Wong and Huang, 1996). PACS, when connected to the HIS, can provide a paperless integration in the workflow of the hospital, with images, patient data and examinations combined together to provide improved treatment processes (Hecht, 2008).

1.7.2 Radiology Information System

A Radiology Information System (RIS) can be stand-alone or connected to the hospital HIS. Its advantages are to organise the workflow in a radiological department by scheduling examination dates, setting examination structure and forwarding results. PACS and RIS are complementary: PACS manages the imaging data whilst RIS manages administrative tasks. For this reason, many venders sell PACS as a combined RIS/ PACS product (Hecht, 2008).

1.8 Research Gap

The systematic review of empirical literature on PACS revealed that there has been little empirical evidence on the maturity of PACS and the future developments in PACS. There is a dearth of empirical literature on various issues related to PACS technology such as what limitations exist in current PACS and how these limitations could be addressed. In addition, there was no empirical evidence that addresses the

issue of what new features in PACS would be required to meet the future needs of PACS users and improve the functionality and accessibility of PACS.

There is therefore a need to study the opinions of the main stakeholders of PACS, such as radiologists, about the kind of improvements that they believe are required in the future generation of PACS. Also, earlier generations of PACS had limitations and there is a need for research of how the limitations and issues in current PACS could be better resolved. Moreover, it is also important to identify the most advanced technology solutions, such as using multi-hospital PACS and PACS on mobile phone, which could lead to the maximum improvements in PACS use.

The present study attempted to seek the answers to the following questions.

Q1. How the functionality of current Picture Archiving and Communication Systems (PACS) could be improved?

Q2. What information technologies and approaches would enhance the functionality and maturity of current PACS and improve the radiology practice.

Q3. What are the new features and user requirements that could be considered as new trends in PACS development?

1.9 Research aim, objectives and approach

1.9.1 Study Aim

The aim of this study was how to improve the functionality of PACS and study PACS users' unmet needs vis-à-vis PACS functions and accessibility.

1.9.2 Study Objectives

The study objectives were:

- To identify the limitations of current PACS
- To determine the future requirements of PACS users
- To identify state of the art technologies and solutions that can improve PACS functions and accessibility

1.9.3 Study Approach

A mixed method approach is used to achieve the objective of this research:

- Review the relevant literature
- Consult the main PACS stakeholders (the radiologists) about their needs and requirements in future PACS (qualitative and quantitative approaches)
- Observe relevant online discussion groups to determine wider stakeholder opinion and comment on the recent developments in PACS
- Develop a model of next generation PACS that includes the new features and solutions
- Validate the model with an independent group of radiologists

1.10 Researcher's Motivation

The motivation and interest of the researcher in undertaking this study is drawn from her experience in working as a nuclear medicine specialist in the nuclear medicine departments in a Cancer hospital and a general hospital in Kuwait. While working as a nuclear medicine specialist, the researcher experienced two generations of radiology practice; the film based environment using chemical films, and the filmless environment of the early implementation and use of PACS. The researcher perceived how the introduction of PACS could bring significant improvement in the radiology practice and was intrigued by the potential that new generations of PACS could bring to improve still further.

1.11 Potential contributions of the study

Potential contributions of the findings of this study include:

- Improving the future use of PACS through inclusion of the most advanced ICT
- Helping in identifying the rapid development in PACS technology such as solutions for organising and distributing the radiology imaging
- Identifying advanced web based technologies for PACS
- Using PACS in Ubiquitous devices
- Adding features and technologies to PACS

1.12 Organisation of the thesis

The thesis is structured into seven chapters (Figure 1-3). A brief description of the content of each chapter follows. The first chapter introduces the study. The second chapter provides the background of the area of the study. The third chapter presents a systematic review of relevant literature. The fourth chapter reports the research methodology applied in this study. The fifth chapter presents the data analysis and findings of this empirical research. The sixth chapter provides discussion of the findings of this study in the context of prior published literature. The last (seventh) chapter concludes this study and suggests directions for further research on PACS.

The next chapter presents the background of the area where this empirical research was undertaken.

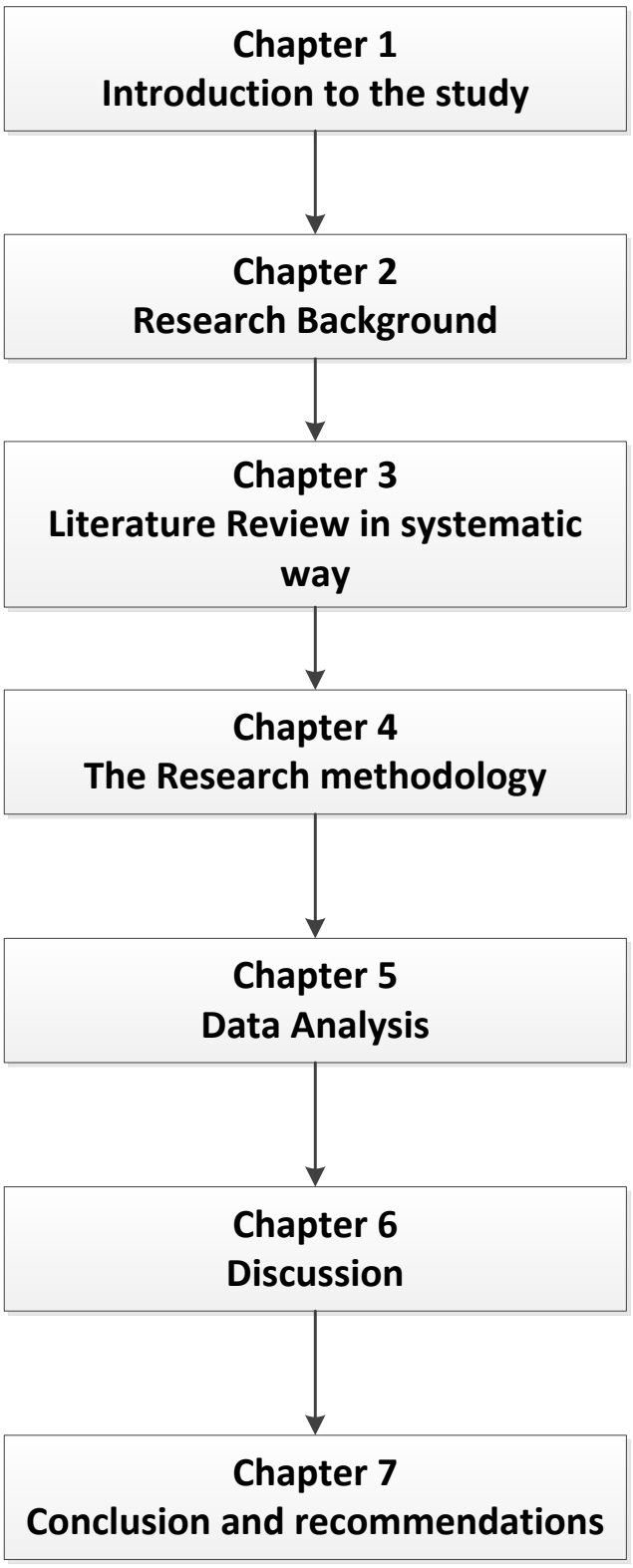


Figure 1-3 Structure of thesis

2 Chapter Two: Research Background

This chapter provides information about the healthcare services and the current state of use of PACS in Kuwait (a developing country with high income) and the United Kingdom (a developed country with high income)..

2.1 Kuwait

2.1.1 General Information

The State of Kuwait is the official name for the county commonly called Kuwait. The State of Kuwait is located in the Middle East and considered as a small country in Asia. The geographical area of Kuwait is 17,818 sq km. The State of Kuwait lies on the north-west side of the Arabian Gulf. It shares borders with Iraq and Saudi Arabia, as shown in Figure 2-1 (Central Intelligence Agency, United States., 2014).

Figure 2-1 Geographical location and map of the State of Kuwait

Source: Google Images

The population of the State of Kuwait is 2,788,534 comprising 31.3% Kuwaiti, 27.9% other Arab, 37.8% Asian, 1.9% African, and 1.1% other that includes European, North American, South American, and Australian (Central Intelligence Agency, United States., 2014).

2.1.2 History of the state of Kuwait

The State of Kuwait has a rich history. The State of Kuwait was a protectorate of Britain from 1899 until independence in 1961. The Al-Sabah family are the hereditary rulers of Kuwait. In 1990 Kuwait was invaded and occupied by Iraq for seven months. During the Iraqi invasion Sheikh Jabber Al Ahmad signed a treaty with the United States of America (USA) to protect and liberate the state of Kuwait. Kuwait was liberated on 26th February 1991 (Central Intelligence Agency, United States., 2014).

2.1.3 Economy in Kuwait

The State of Kuwait is considered as a high income country due to its crude oil reserves. This is estimated as 102 billion barrels and considered more than 6% of the world reserves. Petroleum accounts for 89% of government income. This income allows Kuwait to provide high quality health services to its population (Central Intelligence Agency, United States., 2014).

2.1.4 Healthcare services in Kuwait

The health care services in Kuwait are divided into three sectors. Primary healthcare provides basic care and is located in primary health centres. Secondary health care comprises the regional general hospitals. Tertiary healthcare is given in speciality hospitals. There are currently 92 primary health centres, which are distributed throughout the country (World Health Organization, 2014). There is one primary

health centre in each residential area and some of these centres include various medical speciality clinics. These specialities include radiology, diabetes, dermatology, ophthalmology and maternity.

The State of Kuwait is divided into five health regions and each region runs a general hospital. A patient will visit their local primary health sector where they are registered. The assigned physician diagnoses their condition and refers the patient to the region's general hospital (one of the five hospitals) when required.

The five regions or governorates are:

1- The governorate of Kuwait City (the capital)

2- The governorate of Hawalli

3- The governorate of Al-Ahmadi

4- The governorate of Al-Jahra

5- The governorate of Al-Farwaniya (Ministry of Health Kuwait, 2010).

Tertiary health care includes nine speciality hospitals. These are mainly in the Al-Sabah medical region (specialised), and include radiology, cardiology, ophthalmology, oncology, neurology, orthopaedics and surgery.

The Kuwait Ministry of Health (MOH) is constantly improving the health care infrastructure of the country. This includes adopting modern solutions from the developed countries.

According to the World Health Organization (2014), the State of Kuwait ranks as a highly developed country in providing health care services.

- The density of physicians per 1000 population (2008) is 1.716.
- The density of nurses and midwives per 1000 population (2008) is 4.268
- Total expenditure on health on health per capita (2013) $2,375
- Total expenditure on health is 2.9% of the GDP (2013)
- General governmental expenditure on health is 5.9% of total government expenditure (2011)
- Private expenditure on health is 17.8% of total expenditure on health (2011)

2.2 United Kingdom

2.2.1 General Information

The United Kingdom (UK) has a long history and considered as one of the most advanced parliamentary and democratic countries. At its peak in the 19th century, the British Empire extended over one-fourth of the earth's surface. In the 20th century, the strength of the UK was affected by two world wars and the withdrawal of the Irish Republic from the Union. The UK has since rebuilt itself and is becoming one of the modern and prosperous European countries. It is a member of the United Nations (UN) Security Council, North Atlantic Treaty Organisation (NATO) and the Commonwealth. Even though the UK is outside the EU economic and monetary unit (Euro), it remains in the EU as an active member. In 1999, the UK introduced devolved rule and established the Scottish Parliament, the National Assembly for Wales, and the Northern Ireland Assembly (Central Intelligence Agency, United States., 2014). Each of these has responsibility for the management of the health services under its jurisdiction.

Figure 2-2 Map of the UK

Source: http://www.map-of-uk.com/

2.2.2 Economy in UK

The UK is considered as a wealthy country. It is ranked as the third largest economy in Europe after Germany and France. It is also considered as a leading country in financial and trading power. It has a variety of resources including intensive agriculture, oil resources, natural gas, and large coal resources (Central Intelligence Agency, United States., 2014).

2.2.3 Healthcare services in UK

According to the WHO, the UK ranks as a highly developed country in providing health care services. It has one of the most modern healthcare infrastructures in the world.

- The density of physicians is 2.8 per 1000 population (2011)
- The density of nurses and midwives is 8.2 per 1000 population (2008)
- Total expenditure on health on health per capita (2013) $3,311
- Total expenditure on health is 9.1% of the GDP (2013)
- General governmental expenditure on health is 16.2% of total government expenditure (2013)
- Private expenditure on health is 16.5% of total expenditure on health (2013) (Organisation for Economic Co-operation and Development, 2015)).

2.3 Current state of use of PACS

The current state of use of PACS in Kuwait and England is briefly described as follows.

2.3.1 Use of PACS in Kuwait

PACS systems are commonly used in hospitals in Kuwait. PACS systems in Kuwaiti hospitals are provided by several vendors, including Siemens and GE (General Electric). In some hospitals, the PACS of the same vendor are connected but there is little or no integration between PACS systems of different vendors. In addition, there is no integration of PACS in the hospitals in the same region. In Kuwait, the use of web based PACS allows manipulation PACS images and data through the Internet, but the use of Web based PACS is limited. There are well trained technologists who do the imaging procedures, but the availability of radiologists is important because

they have to write the report on the radiology image and suggest the release of the patient. For archiving of the radiology images and radiological data, hospitals keep adding more storage on site. However, they are not yet using mobile phones or ubiquitous devices for viewing radiological images via PACS. The use of voice recognition is limited and the users are not well trained or encouraged to use it on a regular basis. Therefore, it can be said that the use of PACS systems in Kuwait is advanced but needs improvements.

2.3.2 Use of PACS in UK

PACS system usage in the UK is well advanced and updated. Different vendors run PACS systems in the country but there is no connection / integration between PACS to connect the hospitals in the same region. In the UK, the use of web based PACS to allow manipulation of PACS images and data is available through the Internet. There are well trained technologists who do the imaging procedures and can release the patient. The radiologists check the radiology image and write their findings, which are then sent to the patient's clinician. For example, a simple X-ray is accepted and performed by technologists without the need for the availability of a radiologist and the radiologist can write the radiology report at home if it is urgent and during out of hours. A whole procedure can be undertaken within an hour. In addition, hospitals can contact an outsourcing company to write the report on a radiology image either for out of hours work or as additional work. The practice of outsourcing of reports on radiology images in the UK is not used in hospitals in Kuwait. Moreover, in UK hospitals, the use of ubiquitous devices is limited and there are no proper PACS applications that can be used on mobile phones. The use of voice recognition in the UK hospitals is more advanced than its use in Kuwaiti hospitals.

2.4 Summary

This chapter has provided an overview of the healthcare systems and the use of PACS in two countries i.e. Kuwait and the UK. These two countries have been reported here as examples of countries that are high income with a considerable experience in PACS. However, these two countries differ in terms of healthcare services and current state of PACS practice. For example, the use of PACS in Kuwait is common but it needs further improvements while the use of PACS in the UK is more advanced and mature. The description of PACS in Kuwait and the UK reported here suggests that the PACS practitioners in the two countries could have different experiences and perspectives about the current PACS and the future developments that could affect their PACS practice. The current study would therefore involve the PACS practitioners in these two countries, in particular, as well as in many other developed and developing countries to broaden the scope of the study and generalisability of the study findings.

3 Chapter Three: Literature Review

This chapter provides a review of extant literature on PACS and is divided into seven sections as follows. The first section reports the evolution of PACS research and development. The second section reports the latest developments in the PACS domain. The third section presents empirical evidence based on a systematic literature review on PACS. The fourth section provides a critique on the findings of the literature review. The fifth section critically evaluates various theoretical models and frameworks applied in PACS research. The sixth section identifies a gap in the PACS literature. The seventh section suggests a theoretical framework to be applied in the present research study. The last section summarises the present chapter.

3.1 PACS Research and Development Evolution

The research and development of PACS started in the late 1980s and has evolved thereafter (Table 3-1). According to Huang (2010, p. 18), the research and development of PACS can be divided in three periods; from late 1980s, early 1990s, and from late 1990s to 2010 (Table 3-1)

Table 3-1 PACS technology research and development

Decade	***PACS Research and Development Progress***
Late 1980s	Imaging systems, integration • PACS,DICOM, high speed networks
Early 1990s	Integration of PACS/HIS/RIS • DICOM,HL7,Intranet and Internet
Late 1990s-2010	Workflow and application servers • Enterprise PACS, Web-based PACS, IHE, EPR

Source: adapted from Huang (2010, p. 18)

PACS research and development started in the late 1980s and the earliest PACS were developed on an ad-hoc basis and on a small scale. These were considered as isolated islands that were serving the small modules of radiology departments (Huang, 2010, p. 17). In the early 1990s, research and development of PACS focused on the integration of PACS with other health information systems (HIS) and radiology information systems (RIS), both within a hospital and between different hospitals, and the development of DICOM (Table 3-1). PACS research and development from late 1990s to 2010 was focused on PACS in relation to workflow and application servers, such as the web-based PACS (Table 3-1) (Huang, 2010, p. 18).

The literature shows that first generation PACS had limitations. The main limitations of the early PACS were the communication speed and the storage capability (Rosset, Rosset and Ratib, 2005). However there were further limitations that prevented wide spread use of PACS. For example, there was the issue of restricted access of PACS due to the availability of the limited number of local PACS workstations, which prevented the clinicians in other departments from retrieving and displaying digital images (Ivetic and Dragan, 2011; Tang *et al.*, 2004). The inability to have communication and remote consultation between referring physicians and radiologists in different departments reduced the efficiency of patient care (Rosset, Rosset and Ratib, 2005). In addition, traditional PACS did not support emergency medicine or remote access to digital images, because the image transfer was limited to using CD and DVD as the transfer medium to distribute images to different users (Rosset, Rosset and Ratib, 2005). Moreover, in most cases, the PACS were standalone systems with little or no integration with other hospital information systems (HIS) (Benjamin, Aradi and Shreiber, 2010). More importantly, the access to

PACS was limited to one hospital, because there were separate PACS and radiology systems in each hospital, which were mostly under different ownership (Benjamin, Aradi and Shreiber, 2010). These arrangements were problematic for the radiologists who worked across different hospitals (Benjamin, Aradi and Shreiber, 2010). Furthermore, the first generation PACS had limited search facilities that were generally limited to the patient name, patient number, study type and the date (Santos *et al.*, 2011).

3.2 Latest development in PACS

The following sections report the most notable latest developments in PACS.

3.2.1 Teleradiology and PACS

It is important for medical images to be provided outside the radiology department as some non-radiological departments have a need to view medical images for health care purposes (Foord, 2005). Studies show how images and workflow can be shared on multiple levels and how medical images can cross borders. Digitisation can make the distribution and manipulation of medical images and data possible over a wide scope. In one study, medical images and workflow were shown to include sharing medical images and data inside the organisation, between national medical organisations, and finally sharing the medical images and data across national borders (Ross and Pohjonen, 2011).

Teleradiology is defined as “the electronic transmission of radiological images from one location to another for interpretation and/or consultation” (Lienemann *et al.*, 2005). In most developed countries the filmless radiology environment has become the standard as a result of the implementation of PACS in almost every main centre. However, despite the capability, there remains little exchange of images and

communications between sites. In addition, ethical and security issues may exist for the implementation of teleradiology.

Radiologists raised concerns over the impact of nationwide teleradiology and the regulation regarding data security (Lienemann *et al.*, 2005). However, teleradiology has been shown to have a number of benefits, which according to Ranschaert and Binkhuysen (2013) include the following:

- Teleradiology is helpful in emergency cases and on call duties.
- Remote access to medical images allows the radiologist to review and continue their work at home.
- Ability to share consultation between senior and junior radiologists.
- Ability to share images inside and outside the radiology department.

Teleradiology and telecommunications have been shown to increase productivity. For example, teleradiology supports simple exchange of radiological data and images between departments in the hospital and between hospitals. This can reduce the time to exchange images and so result in an increase in the number of radiology procedures. It can also reduce the time to produce diagnostic reports and so reduce the overall time for the treatment of patients (Aas and Geitung, 2005).

There is also a benefit of merging PACS with teleradiology to allow sharing of data and workflow between health institutions. Teleradiology allows PACS to make medical data and images accessible to the remote physician, especially out of hours and for emergency cases. Teleradiology enhances the efficiency of PACS and it provides better communication between separate radiological sites (Benjamin, Aradi and Shreiber, 2010).

Teleradiology with PACS is a successful solution for improving healthcare services by making medical data and images accessible for physicians anywhere at any time. It decreases the reporting turnaround time, which is an important step in improving the functionality of healthcare services. One study about real world teleradiology and PACS experiences in the US, as a lesson learned for Europe, applied three case studies to examine the successful radiological data and workflow sharing in the US and Canada. Therefore, the results of this study can be helpful for creating a nationwide health information network that has images integrating with electronic healthcare records (EHR) (Pechet, Girard and Walsh, 2010).

However, some areas of technological challenge remain for image distribution in the hospital following introduction of web-based image distribution:

- The need to connect PACS with the electronic medical record system (EMR) to allow mobile or smart phones as a medium for storing and transferring radiological images
- Enhance PACS to include three and four dimensional data (Kotter *et al.*, 2006).

3.2.2 Web based PACS

Web-based PACS refers to connecting the local PACS stations with web servers to present and share the radiological images and data in a wider domain, as shown in Figure 3-1, which can lead to advanced improvement and change in the workflow of traditional radiology departments (Faggioni *et al.*, 2011a). Thus, through web-based PACS, the radiologists would have easy access to the radiological images and data from different hospitals, departments and even from home. Therefore, the performance of the radiologist would improve in terms of reduction in time for writing

a diagnostic report, increasing job satisfaction and reducing the job effort (Faggioni *et al.*, 2011a).

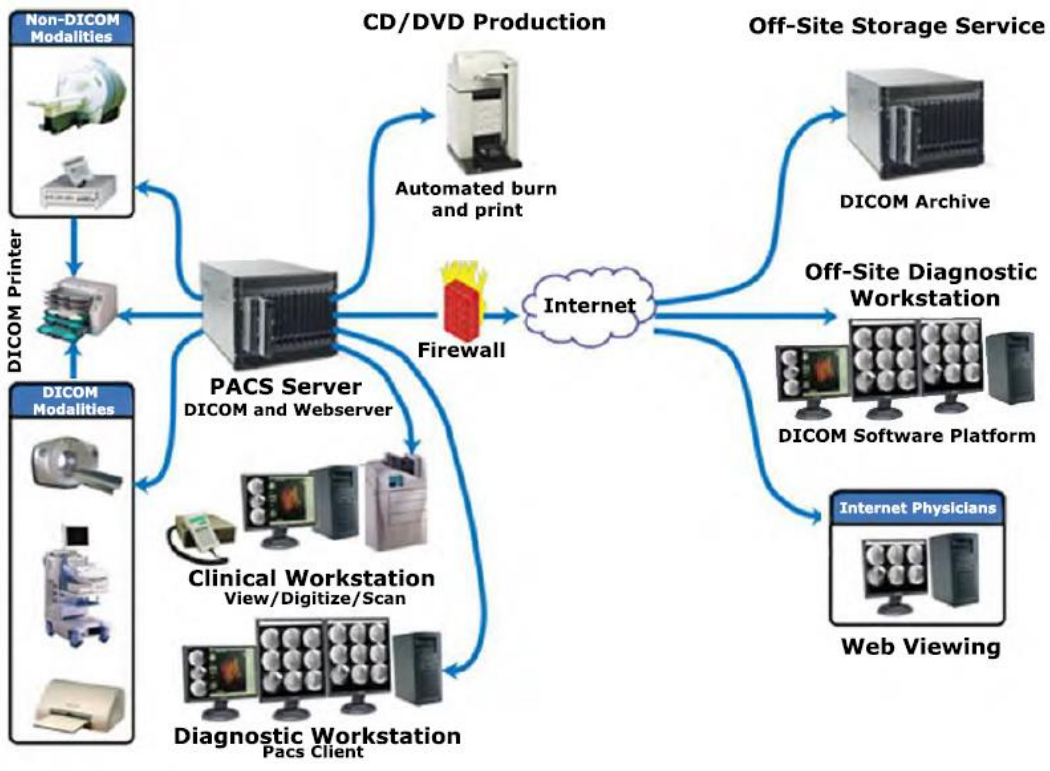


Figure 3-1 Web-based PACS - local PACS stations with web servers

Source: (Mata Miquel, 2015)

Literature reveals that a number of web based technologies can be used for PACS. Some of these web based technologies are described below.

3.2.2.1 Holographic PACS, enterprise PACS, virtual PACS

PACS plays an important role for better data management in hospitals. PACS technology is considered as a new tool for managing diagnostic images. Hospital workflow can be improved by the development technology by 20-60%, whilst its effect on radiologists can be more than 40% (Siegel and Reiner, 2003).

Future PACS implementation and integration can occur at three hierarchical levels. The first level of integration is known as holographic PACS, and integrates a single department through new storage technologies. The second level is enterprise PACS, which provides vertical and horizontal integration between specialities and departments. The final level is virtual PACS, which crosses the enterprise level through scalable GRID technology (Faggioni *et al.*, 2011b). PACS has reached beyond the boundaries of the radiology department. Its applications have broadened to range from teleradiology to computer-assisted diagnosis (CAD). The constant evolution of PACS technology now supports access to images and data from outside the radiology department. Also, it leads to multidimensional imaging. PACS based applications promise a major role in improving the overall activity and productivity of radiology (Faggioni *et al.*, 2011b).

There are benefits to using virtual PACS and sharing DICOM data over the internet. One study presented the framework and functionality of using Virtual PACS for secure, efficient, and easy access to data. As a research tool, the implementation of virtual PACS and its software components were provided as open source (Sharma *et al.*, 2009).

Current implementations of PACS tend to limit access to the hospital or office workstation. However with web based solutions, access may be opened to home working or even mobile access. Nowadays, the use of the smart phone is a fundamental trend in the digital radiology environment.

3.2.2.2 Rich Internet Application (RIA) web pages for PACS

Rich Internet Application (RIA) has been investigated as a solution to present medical images through a PACS user interface that is implemented as part of an

internet browser. RIA web pages can overcome not only the traditional PACS limitation of adequate presentation of medical images but also support a PACS user interface with additional web page applications for better image and information presentation. For example, RIA technology can provide the clinician with an interface based on browser technology that allows them to view multiple forms of medical data, including both (DICOM) and non-(DICOM) images, and patient reports and data (Hsiao *et al.*, 2011).

3.2.2.3 Multi departmental PACS

The PACS architecture tends to be implemented as separate instances in each of the hospitals of the same organisation, whereas it would be preferable if institutions were connected as a single multi-site PACS. Therefore, Bergh (2006) focused on expanding the classical radiology PACS to multi-departmental PACS (MD-PACS), providing four MD-PACS principles. The four integration principles of PACS included; direct modality integration, DICOM acquisition software integration, specialised systems with PACS connection integration, and specialised systems without PACS connection integration. The main advantage of MD-PACS is to provide PACS images and data for many hospitals. In addition, MD-PACS can; provide cost-effective solutions, enhance patient care services, and save patients. Moreover, MD-PACS can reduce the time for viewing images and writing reports by radiologists, minimise the need for transportation of patient from radiologist to referring doctors, and remove the need to carry the physical images and reports. The main disadvantage of MD-PACS is the dependency on vendors, who could differ from one hospital to another hospital, with resulting performance and stability problems of the PACS that could affect the users (Bergh, 2006).

3.2.2.4 Super PACS

Super PACS is defined as “a system that allows a radiology group serving multiple sites having disparate PACS, RIS, reporting and other relevant IT systems (the disparate Model) to view these sites as virtually one site and use one virtual desktop to efficiently complete all radiology work including reporting” (Benjamin, Aradi and Shreiber, 2010). The disparate model is characterized by multiple sites with many information systems from different vendors with no cooperation between the sites, only that each site allows remote access to all the radiology members to improve delivery of radiology services (Benjamin, Aradi and Shreiber, 2010).

3.2.2.5 Regional PACS

Regional PACS is a system that allows medical images to be shared between hospitals or health care institutions through an integrated electronic patient record (EPR). Integrating the Healthcare Enterprise (IHE) is considered to be the best solution for sharing medical data and images between hospitals. Moreover, the use of the cross enterprise Document Sharing profile (XDS) allows medical images to be shared even if they are from different PACS vendors and different hospitals. IHE saves medical images in a central document registry that allows any hospital to retrieve these images no matter which PACS vendor is used (Fernandez-Bayó, 2011).

3.2.2.6 Web based DICOM

Web based DICOM is increasingly being reported as a solution for sharing images in wider domains. Some studies provide evidence of the ability and necessity to implement Web DICOM solutions. For example, in one study that describes a technical solution for web based DICOM, a web development language, Java, is

used to build an open source web interface. The study shows how DICOM images can be stored and accessed in a fast and secure way (Aryanto *et al.*, 2015). A further study on DICOM web based solutions determined how radiology workflow can be improved, which also minimised the workflow time (Haak *et al.*, 2015). A further recent study working on practical implementation of web clients demonstrated Web Access to DICOM, developed the term “Web Access to DICOM” (WADO) to refer to this technique (Liu *et al.*, 2015).

3.2.2.7 Electronic Patient record (EPR) with PACS

It is important not to implement PACS as an isolated system; rather it should be connected to many hospital systems to create homogeneous systems with simple access to the images and data. Integrating a DICOM web viewer into the EPR facilitates access to historical patient images and data within the system (Aryanto *et al.*, 2015; Huang, 2011).

3.2.2.8 Wireless LAN-Based PACS

Using wireless LAN based PACS devices can reduce the time interval from image acquisition to storage in the main PACS. Despite potentially slower network speed, the flexibility in physical access over fixed LAN devices can provide time saving and enhance PACS productivity (Lee *et al.*, 2010).

3.2.2.9 WIKI web-based DICOM with PACS

The use of WIKI (defined as “a piece of server software that allows users to freely create and edit web page content using a simple mark-up language with any web browser” (Reddington and Francis, 2012)) has been investigated as part of a mobile DICOM server. The WIKI was found to be helpful not only in saving time and effort for the radiologist in terms of ease of use but also the ability to collect and save

numerous patient images and data and select interesting cases as a web page for educational and research purposes (Nakata *et al.*, 2004).

3.2.2.10 Open source web based PACS

The use of open source web based PACS can be effective for small and medium size health institutions with minimal financial and human resources. In one example of the use of an open source operating system with PACS server, the Veterinary Teaching Hospital of the University of Torino, Italy, determined Web based PACS can provide a cost effective solution for small and medium size institutions that can include security and accessibility to the radiological data and images (Iotti and Valazza, 2014).

3.2.2.11 Dicoogle – search engine for PACS

Dicoogle is a recent development in healthcare ICT, which so far has been investigated in several studies. Dicoogle is an indexing peer to peer search engine that is based on cloud computing technology supplied by the Google App Engine (GAE). Studies to date demonstrate positive outcomes for Dicoogle as an important development for traditional PACS (Costa *et al.*, 2011).

It is widely recognised that one of the limitations of traditional PACS is the lack of search facility, with search fields typically limited to only patient name or some study features such as patient ID. To overcome these limitations, Dicoogle adds information to the record to allow search within PACS. Dicoogle, by providing free text search and other search techniques, provides greater ability to search, especially for searching through large amounts of data, such as searching for colour, text, intensity, shape, and area of interest. This allows radiologists to search through similar studies and select images to write reports more efficiently and with minimum

time. Dicoogle can be considered as a solution to the traditional PACS limitation of inflexible search queries. The advantages of Dicoogle have been assessed after it has been installed in personal computers in small hospitals, which are: providing hierarchical content indexing of the DICOM metadata including patient study, series, and image as well as a free text content query (Valente, Costa and Silva, 2013; Viana-Ferreira, Costa and Oliveira, 2012; Santos *et al.*, 2011; Costa *et al.*, 2011; Costa *et al.*, 2009; Muller *et al.*, 2004).

Further advantage arises by connecting multiple PACS archives to improve the current PACS archive. Integrating the current isolated PACS archives as a central PACS archive can enhance the DICOM services. A Dicoogle implementation was used to demonstrate access to medical images in two separate PACS. This implementation showed that indexing the data in the separate PACS archives could be used not only to access individual patient information but also to combine medical information such as the number of patients, images, and studies done in the separate institutions. Thus, by combining DICOM data from separate healthcare institutions, continuous improvement in radiology departments can be made (Ribeiro, Costa and Oliveira, 2012; Santos *et al.*, 2011).

3.2.3 Cloud computing in radiology departments

Cloud computing is defined as “a computer grid created using the Internet with the sole purpose of utilizing shared resources such as computer software, and hardware, on a pay-per-use model”. It also “uses various software, data access, and data storage services that do not demand end-user knowledge of actual physical location and arrangement of services” (Kharat *et al.*, 2012). The cloud computing concept was started in the 1960s by Licklider (1960); however, it was not called

“cloud” at that time, rather, ‘’interconnected grid of computers’’ (Licklider, 1960). The real development of cloud computing started in the late 1990s, with the rapid development of software, hardware, and Internet bandwidth (Kharat *et al.*, 2012).

Cloud computing can bring many advantages to radiology departments (Kharat *et al.*, 2012), the main being:

1. Radiology departments can update to the latest software in imaging modality with minimum cost.
2. The productivity of radiology can increase by enhancing the data storage and retrieval.
3. Radiological images and reports can be provided to radiologists outside the hospital.
4. PACS images and data are immediately available to radiologists and clinicians.

One drawback of cloud computing is the issue of security and privacy, which is expected to be overcome in the future (Kharat *et al.*, 2012).

Nowadays, cloud computing is considered to be a leading trend in healthcare services. Cloud computing issues are increasingly being considered in current literature related to advances in eHealth. Reviews on cloud computing in healthcare show that the largest number of articles focusing on cloud computing are found in telemedicine and teleconsultation (34 articles out of 102 articles). The second largest number was for medical imaging research with15 articles out of 102 articles. Such a significant number shows that cloud computing will play an important role in storage, sharing, and presenting medical images (Griebel *et al.*, 2015).

Providing PACS in the cloud with secure internet will lead to improved solutions. In this way, healthcare institutions, including those with limited financial or human resources are enabled to archive their medical images (Philbin, Prior and Nagy, 2011).

Several studies consider how cloud computing can enhance the functionality of PACS. According to Philbin, Prior and Nagy (2011), technologies that can enable the Medical Image Cloud (MICloud) include: (a) remote rendering of medical images, which can process the 2D, 3D, and 4D images remotely on the desktop and solve the limitation of the PACS archive having to provide large amounts of data to the diagnostic workstation; (b) the virtual desktop, which can transmit images from the virtual desktop to the client using the technology of remote terminal PC-over-internet protocols (PCoIP), which enables the images to be accessible anywhere on the internet with a connection of 4 Mb/s or more. In addition, medical institutions can benefit from public cloud resources to share information through medical devices in different medical institutions. The main advantages of using cloud is that it is a cost effective solution, affordable especially for small and medium size institutions, which have minimal financial and human resources (Silva, Costa and Oliveira, 2013; Silva, Costa and Oliveira, 2012) . Moreover, semantic web technology can enhance cloud based PACS / RIS systems through the use of semantic annotation and semantic based retrieval (Berlanga *et al.*, 2013).

3.2.4 PACS and mobile phone

The use of the mobile phone as a tool for viewing medical images is a step forward in diagnostic medicine. With the most advanced technology, ubiquitous devices, such as mobile phones, have the resolution and capability to be used as a medical

image viewing device. Nowadays, many physicians, clinicians, technologists and nurses use smart phones. Therefore, use of these devices as a way to present medical images can provide a solution for the limitation of access in current PACS. With the many advantages of mobile phones having web access, the best future of PACS can be achieved (Ivetic and Dragan, 2011).

There are three forms of device for viewing medical images; static devices (desktop, and dedicated medical devices), movable devices (laptops and personal medical assistants), and handheld devices (PDAs and mobile phones). Each has advantages and disadvantages.

The mobile phone has the main advantage of its geographic mobility through the mobile network, so that medical images may be accessed anywhere and at any time that the network is available. However, the mobile phone still has limited resolution, processing, and storage capabilities (Ivetic and Dragan, 2011).

The early investigation of PACS showed that some of the limitations of PACS can be overcome through the use of mobile phones. The efficiency of healthcare services could be improved by speeding up the delivery of medical images. The mobile phone, with its access via the wireless network, can overcome the limitation of current PACS of restricting the display of images to a fixed location. Therefore, the radiologist, physician, and clinician can exchange medical images, medical reports, and imaging workflow inside and outside the hospital (Tang *et al.*, 2004).

The impact of providing three Apple computer platforms (iPod, iChat, and iDisk) with integrated open source image navigation and display software were investigated to determine the effect of enhancing the functionality of PACS. The advantages of using these technologies were:

1) Storing medical images on the iPod “a MP3 portable player with hard disk storage” has the same advantages as storing them in DICOM compliant CD-ROM.
2) Supporting teleradiology by using iChat” (a video conference and instant-messaging software) has positive impact on transmitting audio and video data over the web.
3) Providing shared medical images and data using “iDisk” (a file-sharing service based on the WebDAV technology) facilitates medical image access (Rosset, Rosset and Ratib, 2005).

It appears that using consumer market technology can provide insight into the improvements that can be introduced to next generation PACS, and demonstrate that they are convenient and easy to use. Use of consumer technology and products, which are convenient, low cost, and technically capable, will support future PACS and bring improvements to the PACS industry (Rosset, Rosset and Ratib, 2005).

For example, by over-coming the limitation in current PACS of restricting access to medical images to inside the hospital, and making medical images immediately accessible for physicians anywhere at any time, enhances PACS functionality by reducing the time to physically access the image, especially in emergency cases (Lee *et al.*, 2008).

A number of technologies have been developed to use the mobile phone for viewing medical images and demonstrate the advantages. One example is the Osirix mobile program “Digital imaging and communication in medicine” that is available for the iPhone/iPod touch platform and was designed to “enhance the communication between radiologist and referring physicians” (Choudhri and Radvany, 2011).. Three

generations of iPhone and iPod have been supported (iPhone 3, iPhone 3G, and iPhone3GS; iPod Touch 2007, iPod Touch 2008; and iPod Touch 2009) (Choudhri and Radvany, 2011).

The impact of using smart phones and tablets in the oncology department for supporting the findings has been reported (Gomez-Iturriaga *et al.*, 2012). Other researchers have confirmed that the modern smart phone is able to be used as a workstation for viewing medical images. However, the main limitation of using the smart phone remains the time to the transfer images, which is far longer than if retrieved at a local workstation. However, continued advances in device technology will improve image display resolution and clarity and transfer speed (Filip *et al.*, 2012).

Further developments to increase ease of access to medical images and data includes using the Representational State Transfer (REST) methodology to develop medical repositories (Fielding, 2000). Results from using REST to implement a gateway for multiple medical image repositories was shown to provide improved assess for image search and retrieval (Valente *et al.*, 2012).

However the use of tablets and smart phones is not limited to viewing images and they can be used for many purposes, such as providing notifications of the need to view an image. Investigations of the time between availability of an image in PACS and the time of view by the physician shows this is much reduced when the physician can be alerted by pager. Tablets and smart phones have in-built capability to provide notifications and so can improve radiology workflow (Chandratilleke and Honeybul, 2013).

The use of the smart phone in radiology will increase, and not just for simple viewing of images. There are solutions that allow the mobile device to be used as a digital radiology environment. This includes the capability to manipulate the image in the same way as a full radiology system, such as image zoom, rotation, and setting the region of interest (ROI). Further capability would include search tools for patient by name, age, ID, or date of procedure (Jeong *et al.*, 2014).

3.3 Systematic Literature Review of Studies on PACS

The following section presents a systematic review of the research and development in the PACS domain.

3.3.1 Aim and objectives

The aim of this systematic literature review was to identify studies on the developments of PACS, with objectives to review and critically assess the findings and identify the gaps in the literature on PACS.

3.3.2 Methodology of Literature Review

The approach for this literature survey was to follow standard methodology of the systematic review. In detail, this included:

3.3.2.1 Search strategy

The literature search was carried out in January 2014 and repeated on 31st December 2015 to include the most recent literature relevant to the topic. Five online bibliographic databases were searched including Science Direct**,** Springer Link, Scopus, CINAHL Plus, and Google Scholar from 1st January 2004 to the date of the search, using medical subject heading and keywords. The full search strategy is shown in Table 3-2.

3.3.2.2 Inclusion criteria

The inclusion criteria for the literature searches were:

Language of publication: English

Publication dates: from January 2004 to date of search (last search December 2015)

Study type: Empirical studies

Study population: Human

Study domain: Health informatics, computer science, medicine, radiology, public health, engineering, image processing

3.3.2.3 Exclusion criteria

The exclusion criteria were:

Discursive or hypothetical articles

Studies in languages other than English

Studies reporting other applications in the radiology department relating to productivity and improvement in workflow with the most advanced ICT.

3.3.2.4 Keywords used for literature searches:

The following key words were selected as being most relevant to identify the future trends in information technologies and approaches to improve the functionality of current PACS. Further keywords were selected to identify improving the organisational efficiency of clinical practice.

- 'Picture archiving and communication system'
- PACS

- Future trends, next generation
- Organisational efficiency
- Productivity
- Clinical practice
- Evaluation
- Improvement
- Cloud computing
- Information storage and retrieval
- Ubiquitous

The keywords were combined as appropriate to form mesh terms that were used with each of the bibliographic databases.

3.3.2.5 Bibliographic databases searched

Following five online bibliographic databases were searched to identify the relevant empirical studies.

- Springer Link
- Scopus
- Science Direct
- CINAHL Plus
- Google Scholar

Table 3-2 Databases and search terms used to identify literature

Database	**Search terms**
Springer Link	(Radiology information systems* OR PACS OR 'picture archiving and communication system$') AND (Future trends) OR (next generation) OR (Organizational efficiency) OR (productivity) OR (clinical practice) OR (evaluation) OR (improvement) OR (cloud computing) OR (information storage and retrieval) OR (ubiquitous) OR (user interface) OR (design)
Scopus	(Radiology information systems* OR PACS OR 'picture archiving and communication system$') AND (Future trends) OR (next generation) OR (Organizational efficiency) OR (productivity) OR (clinical practice) OR (evaluation) OR (improvement) OR (cloud computing) OR (information storage and retrieval) OR (ubiquitous) OR (user interface) OR (design)
Science Direct	(Radiology information systems* OR PACS OR 'picture archiving and communication system$') AND (Future trends) OR (next generation) OR (Organizational efficiency) OR (productivity) OR (clinical practice) OR (evaluation) OR (improvement) OR (cloud computing) OR (information storage and retrieval) OR (ubiquitous) OR (user interface) OR (design)
CINAHL Plus	(Radiology information systems* OR PACS OR 'picture archiving and communication system$') AND (Future trends) OR (next generation) OR (Organizational efficiency) OR (productivity) OR (clinical practice) OR (evaluation) OR (improvement) OR (cloud computing) OR (information storage and retrieval) OR (ubiquitous) OR (user interface) OR (design)
Google Scholar	picture archiving and communication system picture archiving and communication systems

3.3.3 Process of article shortlisting

The process of shortlisting and identifying the relevant studies comprised five steps (Figure 3-2):

Step 1: Read article title, if the title found relevant then the article retained for abstract review otherwise the article discarded.

Step 2: Read abstracts of all articles retained from step 1. If the abstract found to be relevant then the article retained for full article review otherwise the article excluded from further review.

Step 3: Full copies of all articles retained from step 2 obtained and read in full. All articles found relevant retained for data abstraction otherwise excluded from the study.

Step 4: From all articles retained from step 4, data was abstracted on a template (Table 3-3).

Step 5: Synthesise the key findings of the systematic literature review.

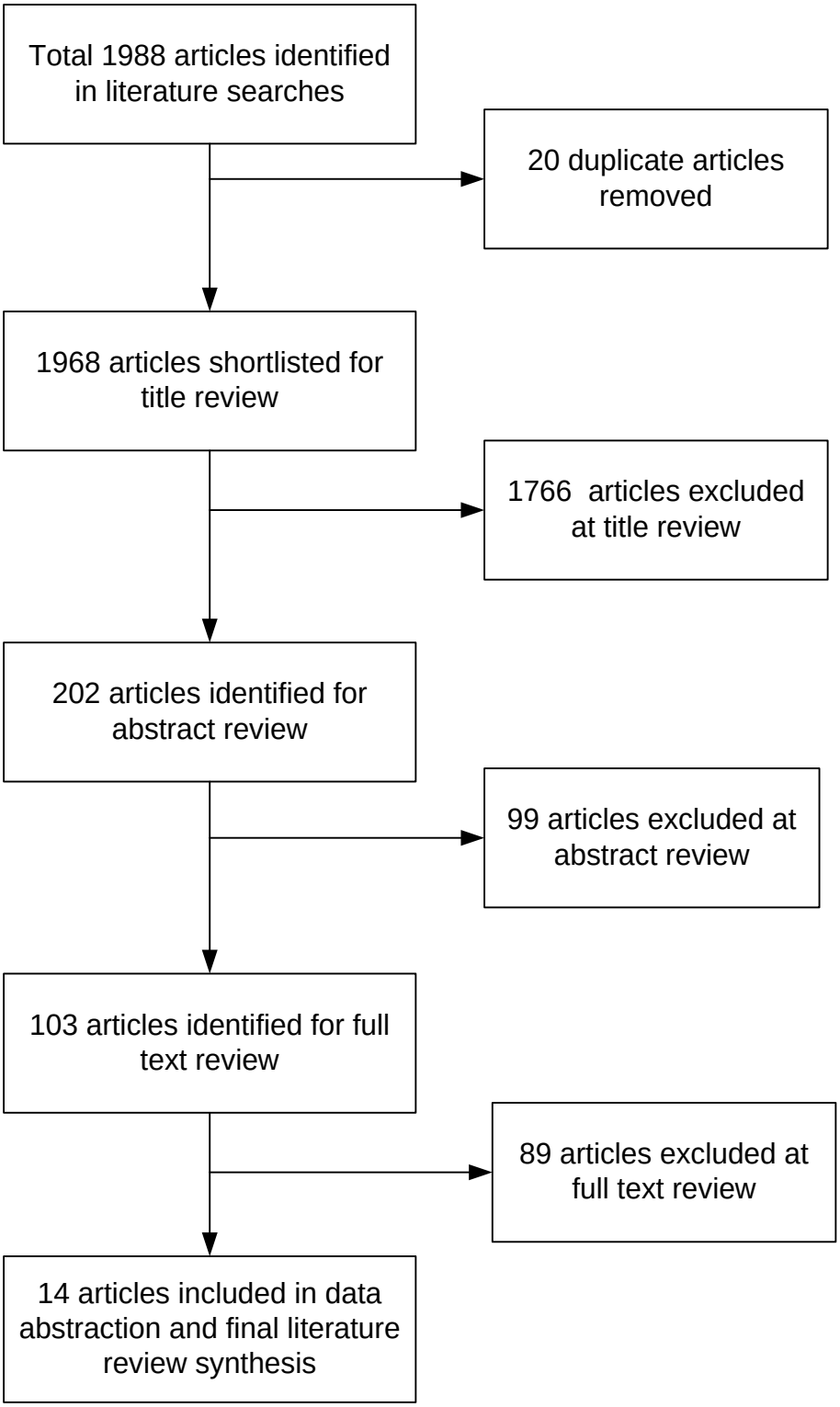


Figure 3-2 The literature review process with the number of studies identified, excluded and included

Table 3-3 Data extracted from empirical studies on PACS identified in the literature review

Authors (Year)	Study Place	Technology / product / issue investigated	Study design	Data collection methods	Participants (Type & No)	Key findings	Theoretical base	Authors' conclusion
Aas and Geitung (2005)	Norway	Impact of teleradiology and PACS on clinico-radiological conferences	Cross sectional Interview survey (Qualitative)	Interviews	23 resource persons experienced with problems related to PACS and teleradiology. Response rate 91% (21/23). Total respondents = 21 (radiologists =10 and radiographers = 11). 2 refused due to lack of time.	Regarding abolition of clinico-radiological conferences, 29% of respondents (n=6) answered yes, 52% answered no (n=11) and 19% (n=4) answered both yes and no.	None reported	'clinico-radiological conferences' could be abolished for some clinical departments, but only after consultation between radiology and clinical departments. If the conferences are abolished, clinicians and radiologists may spend more time on treatment and interpretation, with a probable productivity gain.
Lienemann et al. (2005)	Switzerland	Current usage pattern, technical characteristics and the anticipated Future of teleradiology	Cross sectional online questionnaire survey	Survey questionnaire (Internet based)	All radiologists members of the Swiss Society of Radiology invited (n = 450), Surveys returned = 102. Response rate = 22.7%). Respondents were current teleradiology Users (n=42,	The most important purpose for the use of teleradiology in order of high to low) was in emergency service, image distribution and expert consultation	No theory used	In Switzerland, a wide range of teleradiology applications and technologies are used; however, reimbursement of teleradiology costs remains to be resolved.

					41.2%); planned to use teleradiology in the future (n=36, 35.3%) and did not use or plan to use teleradiology (n=25, 24.5%).			
Fridell et al. (2007)	Sweden	PACS. The impact of PACS use on radiologists' work practice	Longitudinal study (from 1999 to 2005) qualitative research design	Interviews (structured)	Radiologists =46 Time 1 (1999) = 12; Time 2 (2000) =12; Time 3 (2002) = 12 and Time 4 (2005) =10.	PACS impacted radiologists' work practices in 3 areas: professional role (changed from individual professional expertise to consulting to actor in network), diagnostic practice (moved from art form (x-ray films) to technical discussions to distributed to skill accessible to everyone) and technology in use (shifted from digital images to digital	Grounded theory	No specific concluding remarks reported

						limitations to greater details to increased specialisation)		
Duyck et al. (2008)	Belgium	User acceptance of PACS by the radiology department staff	Cross sectional questionnaire survey	Survey questionnaires (internal mail)	94 surveys distributed, 56 usable surveys returned. 19 radiologists and 37 technologists. Response rate = 56/94 = 60%	Performance expectancy and facilitating conditions significantly predicted behavioural intention to use PACS. Effort expectancy and social influences had no significant effect on behavioural intention to use PACS.	Unified Theory of Acceptance and Use of Technology (UTAUT)	Radiologists and technologists positive towards PACS use and had strong intentions to use PACS. Participants appear to make their technology acceptance decision independent from their superiors, by focusing on usefulness rather than on ease of use.
Fridell et al. (2009)	Sweden	PACS. How the use of PACS influences trends in radiographers' workplace	Cross sectional qualitative interview	Interviews (structured)	Radiographers =73 (out of 133 potential respondents) as follows: Time 1 (1999) = 17; Time 2 (2000) =24; Time 3 (2002) = 20 and Time 4 (2006) =12.	Production of images increased; leading to increase in radiographers' work related stress,	Grounded theory	PACS seen as a *technical deterministic* system with a little human control over the work organisation
Duyck et al. (2010)	Belgium	PACS acceptance by radiologists and hospital physicians – at	Longitudinal study design, questionnaire survey at time 1 (pre	Survey questionnaires (internal mail)	Time 1 (T1): 203 total participants (Radiologists = 19, physicians = 184). Time 2 (T2): 159	At both T1 and T2, the main predictors of the intended use of PACS	Unified Theory of Acceptance and Use of Technology	Implementation of PACS was a success at the hospital from the users' perspectives

		a university hospital	implementation) and time 2 (1 year after implementation)		total participants (Radiologists = 12, physicians = 147).	were Performance expectancy followed by facilitating conditions.	(UTAUT)	
Sicotte et al. (2010)	Canada	User satisfaction with Virtual Organisation of Medical Imaging department in hospital settings	Cross sectional mail / postal survey	Survey questionnaires (mail / postal)	Sample size = 192 (radiologists = 15, radiological technologists = 106, medical specialists = 71). Response rate = 66% (127 out of 192 surveys).	Overall satisfaction = very High (8.9 out of 10). Intended future use of the system very high (intra-hospital use =8.9 out of 10 and inter-hospital use = 8.7 out of 10).	Information systems (IS) success model by Delone and KcLean (1992)	Overall, radiologists, radiological technologists and medical specialists have positive attitude towards the virtual medical imaging; However, their perceptions differ from each other.
Joshi et al. (2011)	North America (mainly in USA)	Find radiologists' perspective on the relative importance of the required features when selecting or developing a PACS	Cross sectional questionnaire survey	Survey questionnaires (using e-mails and an online discussion group)	Surveys emailed to a random sample of 435 radiologists; Complete surveys retuned = 58 (53 via email and 5 via online discussion group) Response rate = 12% (email group). Data analysed using the Analytical hierarchy process (AHP) approach	Most important dimension: System continuity and functionality followed by system performance and architecture, user interface for workflow management, user interface for image manipulation,	No specific theory applied.	Radiologists' prioritisation of the key dimensions of PACS application could be useful in the development of different PACS

						and display quality. **Sub-dimensions:,** top features were: security, backup, and downtime prevention; and voice recognition, transcription, and reporting		
Aldosari (2012)	Saudi Arabia	Users' acceptance of PACS	Cross sectional questionnaire survey	Survey questionnaires (method of survey administration not reported)	120 surveys distributed, 89 survey returned, Response rate 74%, Radiologists (n=5), consultants (n=12), residents (n=6), technologists (n=64) and others (not specified, n=2)	PACS use / acceptance explained by 3 factors i.e. perceived usefulness, perceived ease of use and change (moving from current practice to a new practices in the future)	Technology Acceptance Model (TAM)	Successful adoption of PACS depends on users' acceptance; therefore, users need to be consulted prior to PACS implementation
Ranschaert and Binkhuysen (2013)	The Netherlands	Study of current and future use of teleradiology in Europe	Web based / online questionnaire survey	Survey questionnaires (web-based)	All members of the European Society of Radiologists invited. Respondents = 368 radiology professionals (i.e. radiologists = 71%, residents = 14% and radiology	Of 368 respondents, 329 (65%) currently used teleradiology, Main usages: in-house image distribution (71 %) and on-	No theory used	Teleradiology is widely used in Europe but its usage in the private sector is limited. There is a need for price regulation, development of a quality assurance framework and

					managers = 6%)	call readings from home (44 %). Major advantages: improved collaboration with other radiologists (46 %) and efficient distribution of workload (38 %). Outsourcing of teleradiology performed by 35% of the participants (of which 68% used commercial services). Major advantages of outsourcing: availability of second opinions (82%) and additional capacity for on-call services (71%). Major disadvantages : insufficient integration of patient history and priors		legislation at the Europe level.

						(69%), and limited communicatio n with clinicians (68%). Eighty percent respondents positive about the future of teleradiology and 46% predicted a growing importance. Future Opportunities in: emergency reading services, flexible support of small practices and collaborative platforms.		
Tzeng et al. (2013)	Taiwan	Proposing and validating a PACS success model emphasising on technical and social factors	Cross sectional questionnaire survey	Survey questionnaires (print copies)	Response rate = 79% (109 out of 138 radiology technologists returned completed surveys). Data analysed using the Structural Equation Modelling.	Significant determinants of PACS success model were technological factors (i.e. system quality, information quality and	Information systems (IS) success models	Satisfaction of radiology technologists could play an important role in the successful implementation of PACS

						service quality) and social factors (i.e. perceived usefulness, user satisfaction, and PACS dependence		
Joshi et al. (2014)	USA	Study of the important features for the best PACS selection	Cross sectional questionnaire survey	Survey questionnaires (via e-mail)	Surveys emailed to = 422 PACS administrator: Complete surveys retuned = 68, useable surveys = 48. Response rate = 16%. Data analysed using the Analytical hierarchy process (AHP) approach	important features of PACS: system continuity and functionality, system performance and architecture, user interface for workflow management, user interface for image manipulation, and display quality. Sub dimensions: security, backup, and continuity; tools for continuous performance monitoring; support for multispeciality	No specific theory applied.	The key dimensions of PACS application prioritized by PACS administrators are mostly similar to those dimensions prioritised by the radiologists

						images; and voice recognition / transcription.		
Van De Wetering and Batenburg (2014)	The Netherlands	Validation of an integrative PACS maturity framework	Cross sectional questionnaire survey (postal and online)	Survey questionnaire (postal and online) to 91 hospitals and medical centres.	Response rate = 70% (64 hospitals out of 91 invited) total surveys returned 82. Participants= radiologists and heads of radiology departments (n=29), heads of technologists and department managers (n=26), and PACS / RIS administrators in radiology departments (n=27).	PACS performance is significantly affected (β = 0.62, p <0.0001) by PACS business alignment, which is determined by strategy and policy, organisation and processes, monitoring and control, information technology and people	PACS maturity framework	PACS maturity framework provided useful checklists that could help in identifying areas of improvements in hospital settings for PACS implementation
Tesoriero, Eddy and Hasso (2015)	USA	Prevalence of different diagnostic image viewing platforms (PACS) used by radiologists while on-call	Cross sectional questionnaire survey	Survey questionnaire (online)	online survey sent electronically (e-mail link) to radiology residency program directors and chief residents). Response: radiology program directors: n= 42, 24.9%; chief	Most common used PACS platforms = GE (25%), Phillips (17%), and Agfa (15%). Participating Radiologists neutral to slightly positive vis-à-	Did not report use of any specific theory or model	A need for unified PACS at the institutional level and integration of PACS with the EMR are the key outstanding issues from the users' perspectives

					residents: n=25, 8.5%)	vis PACS functionality and ease of use. Integration of PACS with EMR reported by 53% respondents.		

3.3.4 Findings of Literature Review

Using the literature review process as described, the empirical published research studies have been reviewed and the key findings of the literature review are presented.

Fourteen (14) empirical studies on PACS were identified and reviewed by the researcher. The data extracted from these empirical studies are presented in Table 3-3. The abstracted data show that the majority of studies (n=9, 64%) were published from 2010 onwards (Tesoriero, Eddy and Hasso, 2015; Van De Wetering and Batenburg, 2014; Joshi *et al.*, 2014; Ranschaert and Binkhuysen, 2013; Tzeng *et al.*, 2013; Aldosari, 2012; Joshi *et al.*, 2011; Duyck *et al.*, 2010; Sicotte *et al.*, 2010). Most of the studies were undertaken in Europe (n=7, 50%) (Van De Wetering and Batenburg, 2014; Ranschaert and Binkhuysen, 2013; Duyck *et al.*, 2010; Fridell *et al.*, 2009; Duyck *et al.*, 2008; Lienemann *et al.*, 2005; Aas and Geitung, 2005); followed by the North America (n=4, 28%) (Tesoriero, Eddy and Hasso, 2015; Joshi *et al.*, 2014; Joshi *et al.*, 2011; Sicotte *et al.*, 2010), and Asia (n=2, 14%) (Tzeng *et al.*, 2013; Aldosari, 2012). The country with most of the studies (n=3, 21%) was the USA (Tesoriero, Eddy and Hasso, 2015; Joshi *et al.*, 2014; Joshi *et al.*, 2011) followed by two studies each in Belgium (n=2, 14%) (Duyck *et al.*, 2010; Duyck *et al.*, 2008) and the Netherlands (n=2, 14%) (Van De Wetering and Batenburg, 2014; Ranschaert and Binkhuysen, 2013);).

The cross sectional study design was used in all studies (Tesoriero, Eddy and Hasso, 2015; Joshi *et al.*, 2014; Van De Wetering and Batenburg, 2014; Ranschaert and Binkhuysen, 2013; Tzeng *et al.*, 2013; Aldosari, 2012; Joshi *et al.*, 2011; Sicotte

et al., 2010; Fridell *et al.*, 2009; Duyck *et al.*, 2008; Fridell *et al.*, 2007; Aas and Geitung, 2005; Lienemann *et al.*, 2005) except for one study (Duyck *et al.*, 2010) that used the longitudinal research design.

Quantitative survey questionnaires were used in 11 studies (Tesoriero, Eddy and Hasso, 2015; (Van De Wetering and Batenburg, 2014; Joshi *et al.*, 2014; Ranschaert and Binkhuysen, 2013; Tzeng *et al.*, 2013; Aldosari, 2012; Joshi *et al.*, 2011; Duyck *et al.*, 2010; Sicotte *et al.*, 2010; Duyck *et al.*, 2008; Lienemann *et al.*, 2005) and qualitative interviews were conducted in three studies (Fridell *et al.*, 2009; Fridell *et al.*, 2007; Aas and Geitung, 2005).

The most common method to administer the questionnaire survey was by internet / web / online or email, and was reported in five studies (Tesoriero, Eddy and Hasso, 2015; Joshi *et al.*, 2014; Ranschaert and Binkhuysen, 2013; Joshi *et al.*, 2011; Lienemann *et al.*, 2005). A postal / mail method was used in two studies (Duyck *et al.*, 2010; Sicotte *et al.*, 2010); by hand / in person method in one study (Tzeng *et al.*, 2013); mixed online and postal methods in one study (Van De Wetering and Batenburg, 2014); mixed by hand and postal methods in one study (Duyck *et al.*, 2008) and one study did not report the method (Aldosari, 2012).

Various health professionals were involved in the reviewed studies but all were relevant to PACS and teleradiology. Only radiologists were involved in three studies (Joshi *et al.*, 2011; Fridell *et al.*, 2007; Lienemann *et al.*, 2005), PACS administrators in one study (Joshi *et al.*, 2014), only radiographers in one study (Fridell *et al.*, 2009) and radiology technologists in one study (Tzeng *et al.*, 2013). A number of studies involved more than one type of health professionals as follows. Aldosari (2012)

involved Radiologists, consultants, residents and technologists, Sicotte et al. (2010) engaged radiologists, radiological technologists and medical specialists, Duyck et al. (2010) involved radiologists and physicians, Ranschaert and Binkhuysen (2013) involved radiologists, residents and radiology managers, Aas and Geitung (2005) involved radiologists and radiographers, Duyck et al. (2008) involved radiologists and technologists, Tesoriero, Eddy and Hasso (2015) involved radiology residency program directors and chief residents and Van De Wetering and Batenburg (2014) involved radiologists and heads of radiology departments, heads of technologists and department managers, and PACS / RIS administrators in radiology departments.

The data abstracted relating to the technology / product / issue revealed that teleradiology and PACS were investigated in three studies (Ranschaert and Binkhuysen, 2013; Aas and Geitung, 2005; Lienemann *et al.*, 2005), user acceptance of PACS in three studies (Aldosari, 2012; Duyck *et al.*, 2010; Duyck *et al.*, 2008), features of the selection of the best PACS in two studies (Joshi *et al.*, 2014; Joshi *et al.*, 2011), the influence of PACS on the workplace of radiologists (Fridell *et al.*, 2007), and the influence of PACS on the workplace of radiographers (Fridell *et al.*, 2009). There was one study on each of user satisfaction with the virtual organisation of a medical imaging department (Sicotte *et al.*, 2010), PACS success model (Tzeng *et al.*, 2013), the PACS maturity framework (Van De Wetering and Batenburg, 2014) and image viewing platforms (Tesoriero, Eddy and Hasso, 2015).

Eight studies (57%) reported the use of a theory, model or framework as follows. There were two studies that each used grounded theory (Fridell *et al.*, 2009; Fridell *et al.*, 2007), the Unified Theory of Acceptance and Use of Technology (UTAUT)

(Duyck *et al.*, 2010; Duyck *et al.*, 2008), and the Information Systems (IS) Success Models (Tzeng *et al.*, 2013; Sicotte *et al.*, 2010). One study each applied the Technology Acceptance Model (TAM) (Aldosari, 2012), and the PACS Maturity Framework (Van De Wetering and Batenburg, 2014). The remaining six studies (43%) did not report use of any theory, model or framework (Tesoriero, Eddy and Hasso, 2015; Ranschaert and Binkhuysen, 2013; Joshi *et al.*, 2014; Joshi *et al.*, 2011; Aas and Geitung, 2005; Lienemann *et al.*, 2005) .

The key findings of the studies are reported in the following sub-sections that are based on the technology / product / issue investigated.

3.3.4.1 Studies on Teleradiology and PACS

The key findings of the studies that investigated teleradiology and PACS (Ranschaert and Binkhuysen, 2013; Aas and Geitung, 2005; Lienemann *et al.*, 2005) were as follows.

The study by Aas and Geitung (2005) investigated whether clinico-radiological case conferences could be replaced by teleradiology and PACS and found that the majority (52%) of participants were not in favour of completely replacing the clinico-radiological case conferences. However, there was some support for the replacing the clinico-radiological conferences only after consultation between the clinical and radiology departments because it could free the time of radiologists and clinicians that could be used for other activities (Aas and Geitung, 2005).

The study by Lienemann et al. (2005) studied the present and future trends of teleradiology in Switzerland and found that use of teleradiology was the highest in emergency services followed by image distribution and expert consultations. They

also found that the importance of teleradiology would increase in the future and it would be applied in domains such as image distribution, emergency teleradiology, seeking consultations, and supporting education (Lienemann *et al.*, 2005).

A study by Ranschaert and Binkhuysen (2013) investigating the current and future use of teleradiology in Europe found that PACS was widely used in most European countries and its main use was for in-house image distribution and on-call readings from home. The key advantages were improved collaboration with other radiologists and efficient distribution of workload. The main disadvantages were insufficient integration of patient history and priors, and limited communication with clinicians. The study also found that outsourcing of teleradiology mainly involved use of commercial services and that outsourcing was advantageous in terms of the availability of second opinions and additional capacity for on-call services(Ranschaert and Binkhuysen, 2013). Regarding the future of teleradiology, the study found that the importance of teleradiology would increase with its application in emergency reading services, small practices and collaborative platforms (Ranschaert and Binkhuysen, 2013).

3.3.4.2 Studies on User Acceptance of PACS

Three studies investigated user acceptance of PACS (Aldosari, 2012; Duyck *et al.*, 2010; Duyck *et al.*, 2008). Duyck et al. (2008; 2010) conducted two studies on user acceptance of teleradiology in healthcare settings in Belgium and found that the expectation of performance and facilitating conditions were statistically significant for the acceptance of PACS by users, who were radiologists, technologists and physicians.

A further study on user acceptance of PACS was conducted in Saudi Arabia by Aldosari (2012), who found that PACS use and acceptance was determined by the perceived usefulness, perceived ease of use and the degree of change, i.e. the move from current practice to a new practice. The study concluded that there must be consultation with the PACS users prior to implementation of the PACS (Aldosari, 2012).

3.3.4.3 Features of the best PACS

Two studies investigated features of the selection of the best PACS (Joshi *et al.*, 2014; Joshi *et al.*, 2011). These empirical studies investigated the user perspectives and reported the most important features of the best PACS were system continuity and functionality, system performance and architecture, user interface for workflow management, user interface for image manipulation, and display quality (Joshi *et al.*, 2014; Joshi *et al.*, 2011). Additional important features of PACS included security, backup, prevention of downtime and continuity; voice recognition, transcription, and reporting tools for continuous performance monitoring; and support for multi-speciality images (Joshi *et al.*, 2014; Joshi *et al.*, 2011).

3.3.4.4 PACS influence on work practices

Two studies investigated the influence and impact of PACS on work practices and the skills of the radiologists (Fridell *et al.*, 2007) and radiographers (Fridell *et al.*, 2009). The study of radiologists found a positive impact from PACS on work practices in three areas:

(a) Professional role (changed from individual professional expertise (to) → consulting → actor in network),

(b) Diagnostic practice (moved from art form (x-ray films) → technical discussions → distributed → skill accessible to everyone)

(c) Technology in use (shifted from digital images → digital limitations → greater details → increased specialisation) (Fridell *et al.*, 2007).

The study of radiographers found that the use of PACS led to increased production of images, which resulted in greater work related stress between radiographers, who saw PACS as a technically deterministic system with little human control over the organisation of workflow (Fridell *et al.*, 2009).

3.3.4.5 User satisfaction with virtual organisation of medical imaging department

One study investigated user satisfaction with virtual organisation of a medical imaging department (Sicotte *et al.*, 2010). The key findings of the study showed that the users (e.g. radiologists, radiological technologists and medical specialists) had positive attitudes and very high overall satisfaction with the virtual organisation of medical imaging departments; however, there were differences in the perceptions of different types of the users (Sicotte *et al.*, 2010).

3.3.4.6 PACS success model

One study tested the PACS success model (Tzeng *et al.*, 2013), which is based on system quality, information quality, and service quality as technological factors; and perceived usefulness, user satisfaction, and PACS dependence as social factors.

The radiology technologists' satisfaction had a significant role in the successful implementation of PACS.

3.3.4.7 PACS platforms

One study (Tesoriero, Eddy and Hasso, 2015) studied the prevalence and use of the different PACS platforms (diagnostic image viewing platform) by on-call radiologists and found that the most commonly used PACS platform was manufactured by GE, followed by Phillips and then Agfa. The study also found users (radiologists) were neutral to slightly positive about functionality and ease of use of PACS. In addition, unified PACS at the institutional level and integration of PACS with the EMR were reported as the main outstanding issues.

3.3.4.8 PACS maturity framework

One study evaluated an integrated PACS maturity framework (Van De Wetering and Batenburg, 2014). The study found that PACS performance was significantly affected by PACS business alignment, which was determined by strategy and policy, organisation and processes, monitoring and control, information technology and people and culture at the hospital / organisation (Van De Wetering and Batenburg, 2014). The study also reported that the framework could help identify areas of improvement in hospital settings for PACS implementation (Van De Wetering and Batenburg, 2014).

3.4 Critique of the findings of the Literature Review

This section provides a critique on the studies selected in the literature review.

The findings of the data extracted from the studies showed that 43% (n=6) of the empirical studies did not report use or application of any specific theory, model or framework (Tesoriero, Eddy and Hasso, 2015; Joshi *et al.*, 2014; Ranschaert and Binkhuysen, 2013; Joshi *et al.*, 2011; Aas and Geitung, 2005; Lienemann *et al.*, 2005). The critique on each study is given below.

The study by Lienemann et al. (2005) used only simple analytical techniques such as the descriptive statistics and only the t-test for inferential statistical analysis.

The first study by Duyck et al. (2008) had an effective sample size (n=56), which was rather small from a multivariate statistical modelling point of view. In addition, they tested their model by using linear regression rather than structural equation modelling, which is more robust and a widely used statistical technique for evaluating a UTAUT model. The second study by Duyck et al. (2010) had a good sample size at both T1 and T2 and used regression modelling. However, they could have used structural equation modelling, which is a robust multivariate statistical technique compared to the simple regression modelling.

The two studies by Fridell *et al*. (2007; 2009) had limitations such as not involving different types of PACS user. For example, their first study (Fridell *et al.*, 2007) involved only radiologists and their second study (Fridell *et al.*, 2009) involved only radiographers. They did not involve other PACS users such as PACS technologists and PACS administrators

The study by Sicotte et al. (2010) used a multiple linear regression technique to test their model; however, the use of structural equation modelling could have been better as it is a more robust technique than the linear regression.

In the study by Aldosari (2012), the sample size was satisfactory. The PACS acceptance model was tested through multiple linear regression (stepwise method), which could have been better assessed by using structural equation modelling as it is a more robust technique than linear regression. The method of administering the survey questionnaires to the study participants was not reported.

In the study by Ranschaert and Binkhuysen (2013), data were analysed by using the descriptive statistics and only t-tests as an inferential statistical technique.

Tzeng et al. (2013) studied only the technological and social factors that affect the success of PACS, but did not include other types of factors such as economic or organisational. A further limitation was the inclusion of only radiology technologists and did not include other types of PACS users such as radiologists, radiographers and clinicians.

Tesoriero, Eddy and Hasso (2015) studies different types of PACS platforms used by radiologists while on-call. The most noticeable weaknesses of the study were neither reporting the sample size, nor did it use any theory, model or framework.

The two studies by Joshi *et al*. (2011; 2014) provided empirical evidence on the importance / weight of different dimensions of PACS but they did not report the use of any theory, model or framework.

The study by van De Wetering and Batenburg (2014) used structural equation modelling for validating their model, known as the PACS maturity framework (van de Wetering and Batenburg, 2009). However, their sample size was relatively small for structural equation modelling and the data were from only one country. Therefore,

their PACS maturity framework (van de Wetering and Batenburg, 2009) requires validation in the context of other countries. Moreover, the data on which the PACS maturity framework was based on the literature only up to the year 2006. It therefore has limitations because there has been much progress in the domain of PACS research and development since 2006.

3.5 Theoretical models and frameworks used in PACS literature

Research in the PACS domain has applied different theoretical models and frameworks to studying its acceptance and development. The most notable theoretical models and frameworks used in PACS research are briefly described below.

3.5.1 Technology Acceptance Model

The technology acceptance model (TAM) is "an information systems theory that models the determinants of computer acceptance across a broad range of end-users computing technologies" (McCoy, Everard and Jones, 2005). The TAM was developed by Davis (1986) and it has been extensively applied by researchers, mainly in the information systems domain during the last 30 years to assess user perceptions towards acceptance and behavioural intentions to use IT systems prior to the actual adoption of a system. In the TAM model (Figure 3-3), user perception of the usefulness (PU) and ease of use (PEOU) of the system / Technology determine the behavioural intention of the user to use / adopt the system / technology (Davis, 1989). Davis, Bagozzi and Warshaw (1989) defined the PU as: "the prospective user's subjective probability that using a specific application system will increase his or her job performance within an organisational context" and he defined the PEOU

as "the degree to which the prospective user expects the target system to be free from effort" (Davis, 1989). In addition, the TAM included the potential behavioural intentions of the user that relate to how the users consider the PU and PEOU with regard to the adoption and actual use of the system (Holden and Karsh, 2010).

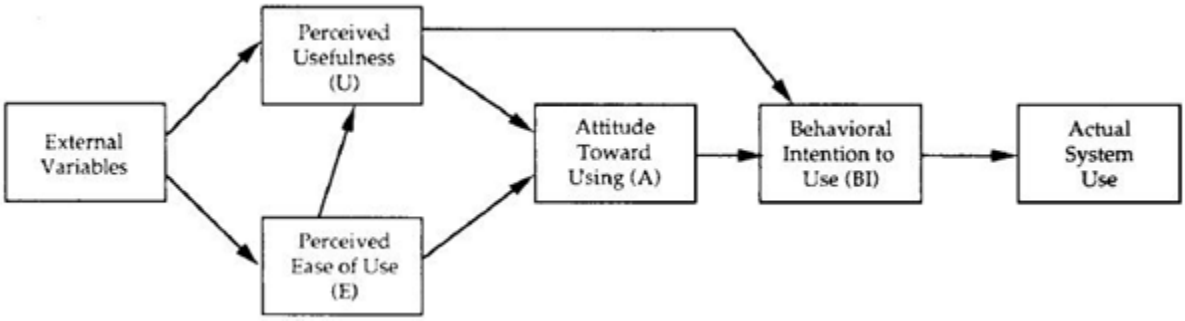


Figure 3-3 The Technology Acceptance Model
Source: (Davis, 1989)

Within PACS research, the TAM model has been used by Aldosari (2012), who studied user acceptance of PACS. However, the TAM has several limiations limitations (Chuttur, 2009). For example, use of the intention construct rather than the actual use (Bagozzi, 2007) and focus on the voluntary use rather than on the actual use in situations where the use of the system is mandatory (Brown et al., 2002) and there are no other alternative systems (Lee et at., 2003). Therefore, the TAM was not suitable as a theoretical model for this study because of the above limitations and its limitations in studying how the latest developments in PACS could influence future radiology practice..

3.5.2 Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT) model was developed by Venkatesh et al. (2003) and the model was later updated by Venkatesh and Bala (2008). The UTAUT model considers user specific variables such as age, gender and experience, as well as the factors related to the expected performance and effort, influence of social factors and conditions that facilitate use of the system (Figure 3-4).

Within the PACS domain, the UTAUT was applied by Duyck et al. (2008; 2010) to study user acceptance of PACS. The UTAUT is an important model for studying user perspectives of technology; however, the model is not appropriate for studying the future needs of users and the effect of advanced developments in technology such as PACS. Therefore, the UTAUT would not be an appropriate theoretical model to study the latest developments in the PACS and how the new developments could help in PACS related radiology practices. Therefore, this model was not suitable for this study.

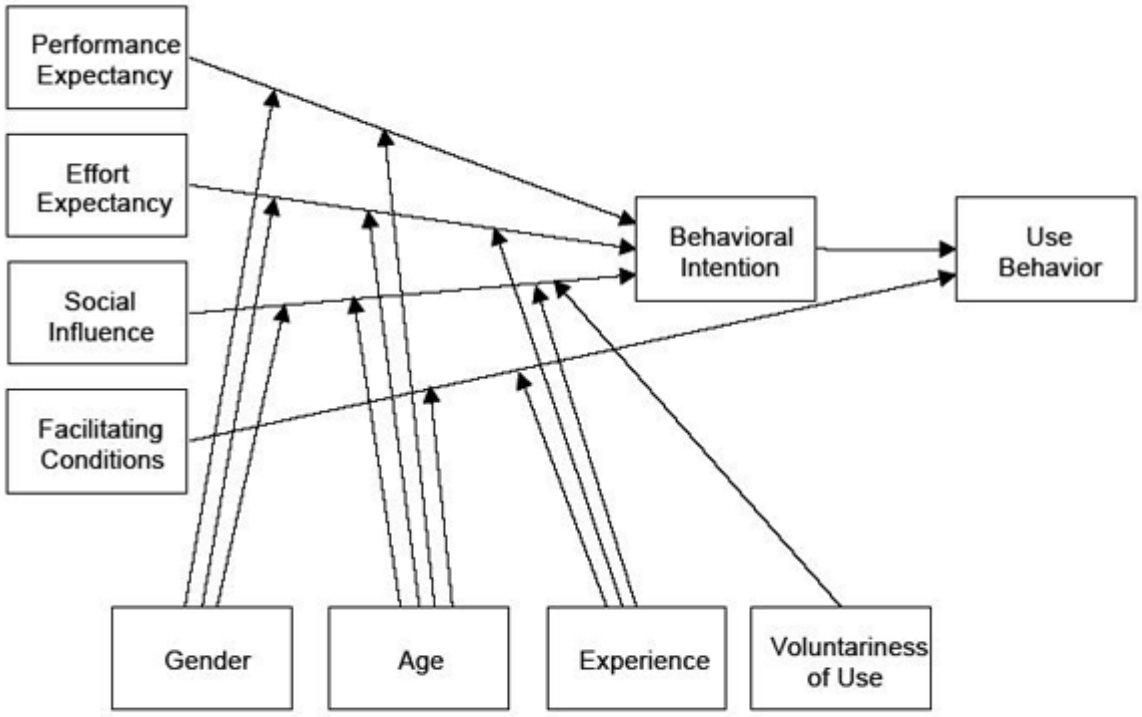


Figure 3-4 Unified Theory of Acceptance and Use of Technology (UTAUT) model
Source: Venkatesh et al. (2003)

3.5.3 Information Systems Success Models

The information systems (IS) success models were developed by DeLone and McLean (1992) for evaluating the success of information systems. The original IS success model (Figure 3-5) suggested that the quality of the system and the quality of the information have an impact on the use of the system, as well as the satisfaction of the user with the IS system, which will result in an impact on the user of the system as well as the organisation where the system is used (DeLone and McLean, 1992).

The original model also proposed that use of the IS system and user satisfaction have impact on each other (Figure 3-5).

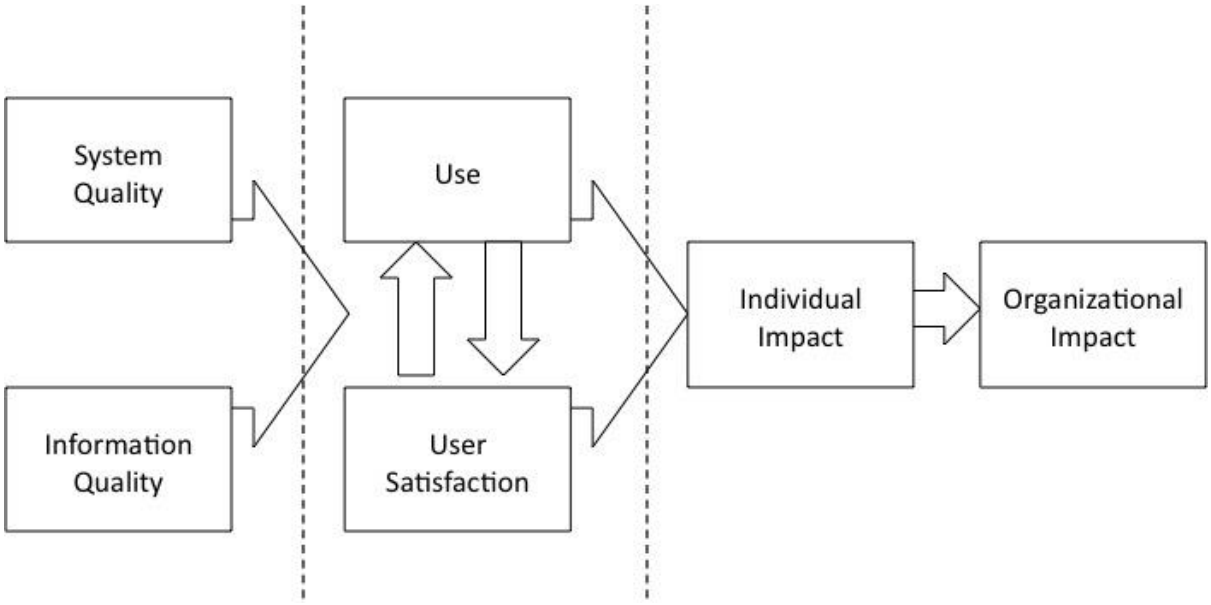


Figure 3-5 The original IS Success Model

Source: DeLone and McLean (1992)

After 10 years since the development of the original IS success model, DeLone and McLean (2003) evaluated and refined their model and suggested an updated IS success model (Figure 3-6). The updated IS success model (Figure 3-6) added a new variable termed the ‘service quality’, which added the ‘intention to use’ in addition to the ‘use’ variable and replaced the two variables, ‘individuals impact’ and ‘organisational impact’ with a single new factor termed the ‘net benefits’ (DeLone and McLean, 2003).

The information systems (IS) success models have been used in PACS research by Tzeng et al. (2013) to study the successful implementation of PACS in radiology

departments. The IS success models focus mostly on factors related to the users and systems, such as the PACS, but ignore the development aspects, for example the maturity levels of the PACS, the future needs of the PACS users and the technologies that could support PACS use. Therefore, the IS success models were not applied in this study.

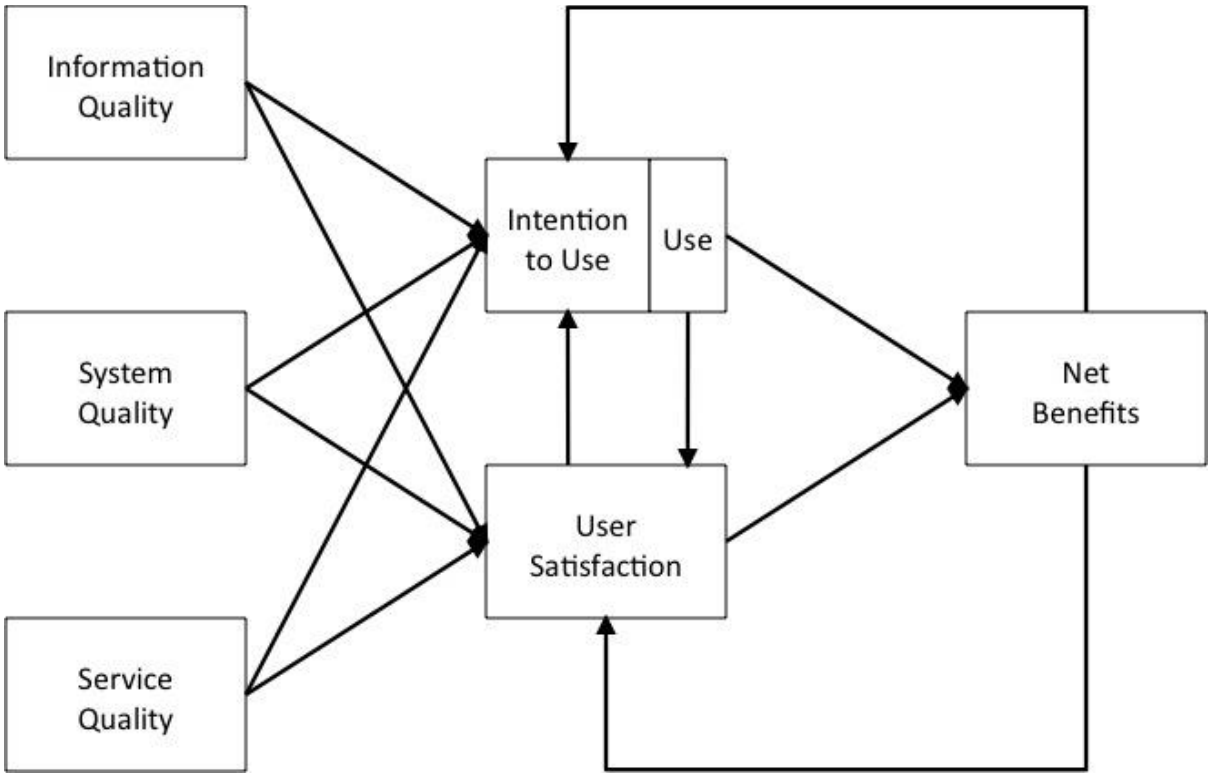


Figure 3-6 The updated IS Success Model

Source: DeLone and McLean (2003)

3.5.4 PACS Maturity Model

The concept of maturity and adoption of IS / IT was initially introduced in business literature in the early 70s; however, since then the maturity models have been developed to evaluate different types of IS / IT in various types of organisations and

sectors. In the health sector, however, there is a theoretical and empirical gap in the literature on PACS maturity. To fill this gap in the literature, van den Wetering and Batenburg (2009) developed a PACS maturity model based on a systematic meta-analytical review of literature on the evolvability and maturation of PACS in hospitals. The PACS maturity model includes five different stages of PACS evolvability as shown in Figure 3-7. These maturity stages of the PACS are described as follows.

Maturity level-1: PACS infrastructure

The first maturity level of the PACS concerns the PACS infrastructure and focuses on the initial unstructured PACS implementation and use that includes image acquisition, storage, distribution and display.

Maturity level-2: PACS process

The second stage of the PACS maturity model includes the PACS processes. This stage focuses on four major issues; PACS process redesign, quality and transparency, optimising the manual PACS processes, and initiation of system integration.

Maturity level-3: Clinical process capability

The third stage of the PACS maturity model concerns the clinical process capability. This stage / level includes hospital-wide PACS distribution and communication, status management, image-based clinical action, PACS integration with health information systems such as the HIS and RIS, workflow and patient folder management, and teleconferencing, consultation and e-learning.

Maturity level-4: Integrated managed innovation

The fourth stage of PMM concerns the integrated managed innovation of the PACS. This stage of PACS maturity includes qualitative/ statistical control mechanisms, clinical diagnosis and decision support, technological adoption, cross enterprise PACS exchange, initiation of PACS integration within EPR (electronic patient record), intelligent data mining and clinical collaboration.

Maturity level-5: Optimised enterprise PACS chain

The final stage of PMM concerns the 'optimised PACS enterprise chain'. This stage of the PACS maturity model includes continuous clinical PACS optimisation, PACS processes innovation, full enterprise PACS chain integration and full integration with the EPR (van de Wetering and Batenburg, 2009).

The PACS maturity framework has been empirically validated as an integrative model to determine PACS business alignment and PACS performance in hospitals by van den Wetering and Batenburg (2014), who reported that the PACS performance (i.e. efficiency and effectiveness) was statistically significantly and positively affected the PACS business alignment, which was determined by strategy and policy, organisation and processes, monitoring and control, information technology and people and culture at the hospitals. On the basis of their findings, van den Wetering and Batenburg (2014) suggested that the PACS maturity model could be used to identify any technical improvement in PACS, which usually involve changes in the existing processes, organisational structures, and stakeholders' interests.

The PACS performance framework suggested by van den Wetering and Batenburg, (2009) is a useful framework that can be applied in empirical research that determines the latest developments in PACS and their impact on radiology practices. However, the PACS performance framework was developed based on 34 studies on PACS maturity and evolution that were published up to 2006. The PACS performance framework therefore needs updating in the light of empirical evidence on PACS performance and maturity after 2006.

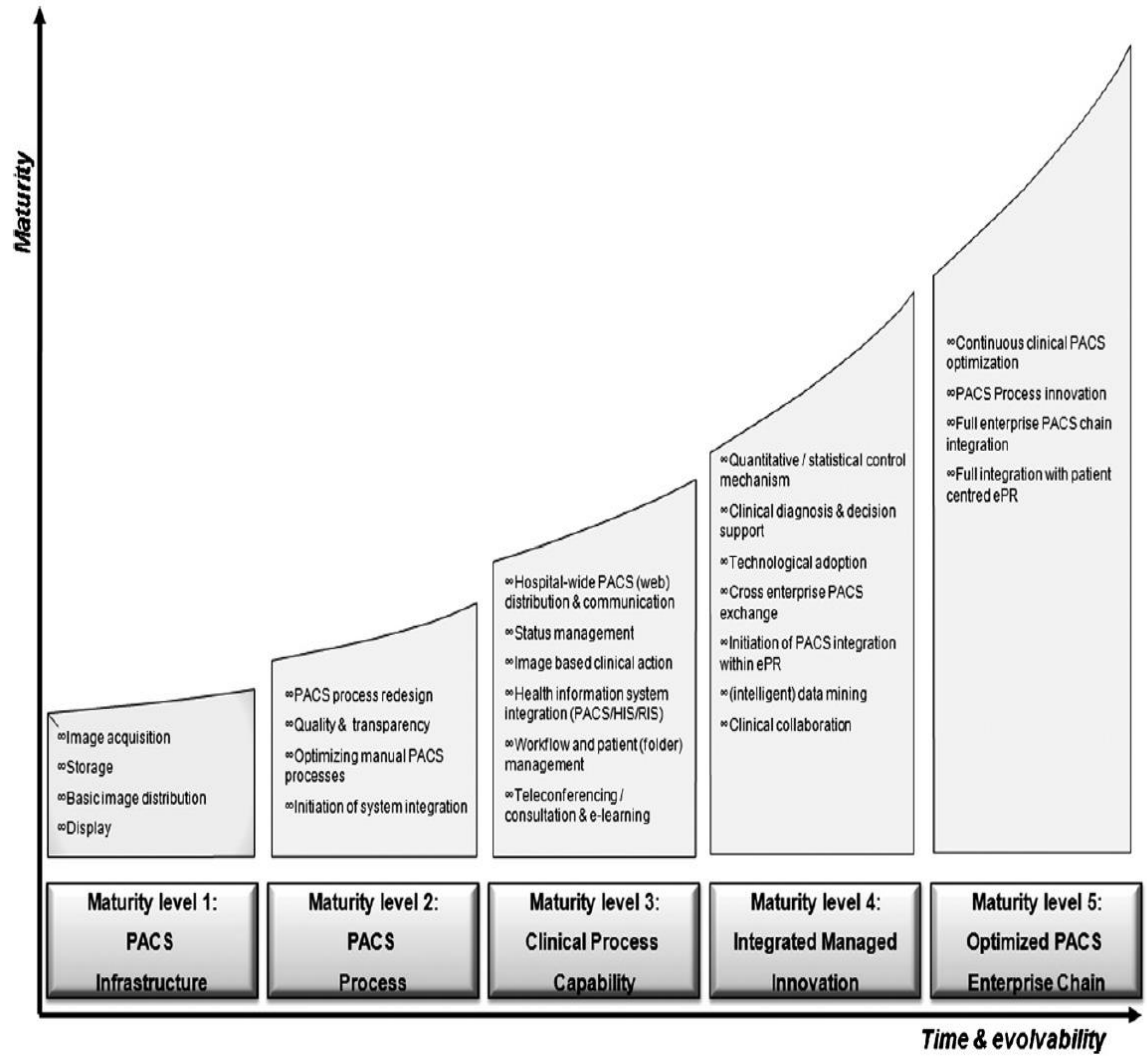


Figure 3-7 PACS maturity model

Source: (van de Wetering and Batenburg, 2009)

The following section presents the research gap in the published literature in the PACS domain and provides the justification for this study.

3.6 The research gap

The findings of the present systematic literature review have identified that there has been little empirical evidence on PACS maturity or PACS developments since 2006,

or the future developments in the PACS. In addition, none of the studies included in the literature review reported study of what are limitations in the current PACS and how these limitations could be addressed. In addition, there was no study that addressed the issue of what new features would be required in PACS to meet the future needs of PACS users and improve the functionality and accessibility of PACS.

The findings of the literature review also reveal that different theoretical models and frameworks have been applied in the empirical research in the PACS domain such as the application of the TAM (Aldosari, 2012), the UTAUT (Duyck *et al.*, 2010; Duyck *et al.*, 2008), information systems (IS) success models (Tzeng *et al.*, 2013; Sicotte *et al.*, 2010) and PACS maturity framework (Van De Wetering and Batenburg, 2014).

However, most of these theoretical models and frameworks (TAM, UTAUT and IS success) focus mostly on factors related to user acceptance and ignore the development aspects and maturity levels of the technology. This makes these models and frameworks inappropriate for studies focusing on the maturity of PACS and the emergence of the latest developments in the PACS and their impact on working practices (Dennison, 2014). Therefore, the most appropriate existing theoretical framework to study the latest developments in the PACS could be the PACS maturity framework (van de Wetering and Batenburg, 2009).

However, the existing PACS maturity framework has several limitations including that it is based only on literature published up to year 2006 and so omits the effects of further developments in PACS that have occurred in the last ten years since 2006. Furthermore, the framework was tested / validated in the context of only one country

i.e. The Netherlands (Van De Wetering and Batenburg, 2014). The framework therefore needs to be tested and validated in the context of other health organisations and countries. It is therefore important that new empirical evidence should be collected to evaluate the validity of the PACS maturity framework in other contexts and determine if it requires updating with the addition of maturity levels beyond level 5 of the current framework (van de Wetering and Batenburg, 2009).

Moreover, it is clear that research and development of PACS is continuing and research is required to determine how the latest developments will impact on radiology practice and its users. The present study therefore focuses on these gaps in the literature and attempts to seek the answers of the following questions:

Q1. How can functionality of current PACS be improved?

Q2. What information technologies and approaches will enhance the functionality and maturity of current PACS and improve radiology practice.

Q3. What are the new features and user requirements that can be considered as new trends in PACS development?

3.7 Theoretical Framework proposed for this study

From the findings of the systematic literature review and the research gaps that have been identified in the PACS domain, the PACS maturity framework (van de Wetering and Batenburg, 2009) has been selected as the most appropriate theoretical framework to study the latest and future developments in PACS. Moreover, by applying the PACS maturity framework in further contexts, empirical evidence will be gained to enhance future research, developments and applications of PACS. In

addition, the evidence may be used to update the PACS maturity framework and validate it in further contexts, thereby contributing to the literature in the PACS domain.

Therefore, this study will adopt the PACS maturity framework (Figure 3-7) as its theoretical framework. The study will seek to enhance the framework based on technological developments in PACS domain since 2006 and propose an updated PACS maturity framework (Figure 3-8) that will be validated in several contexts (Kuwait and UK). In an effort to bring the framework as up to date as possible, triangulation is used to acquire evidence from several sources including the literature and empirical study.

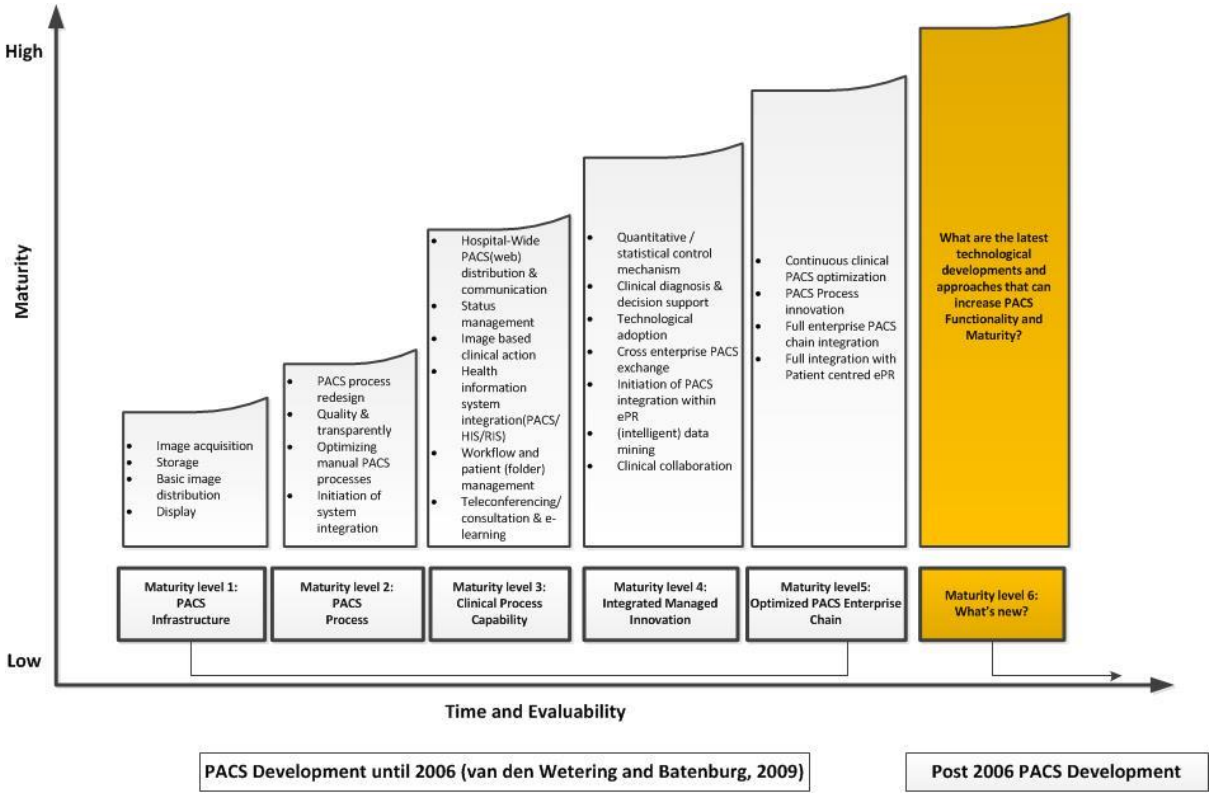


Figure 3-8 Proposed Theoretical Framework

3.8 Summary

This chapter presents a review of the literature on PACS including; traditional PACS and its limitations, preferences and perceptions of PACS users, research and development in PACS, theoretical models and frameworks applied in PACS research. The chapter also presents the findings of a systematic literature review of empirical research on PACS. The systematic literature review identified the main themes of study that included; teleradiology and PACS (Ranschaert and Binkhuysen, 2013; Aas and Geitung, 2005; Lienemann *et al.*, 2005), user acceptance of PACS (Aldosari, 2012; Duyck *et al.*, 2010; Duyck *et al.*, 2008), features of the best PACS selection (Joshi *et al.*, 2014; Joshi *et al.*, 2011), PACS influence on the workplace of radiologists (Fridell *et al.*, 2007) and radiographers (Fridell *et al.*, 2009), user satisfaction with virtual organisation of the medical imaging department (Sicotte *et al.*, 2010), PACS success model (Tzeng *et al.*, 2013), image viewing platforms (Tesoriero, Eddy and Hasso, 2015) and the PACS maturity framework (Van De Wetering and Batenburg, 2014). The literature review also determined that almost half of the studies did not apply / report any theory, model, or framework. The theoretical models and framework that were reported include; the UTAUT (Duyck *et al.*, 2010; Duyck *et al.*, 2008), the TAM (Aldosari, 2012), information systems success models (Tzeng *et al.*, 2013; Sicotte *et al.*, 2010) and the PACS maturity framework (Van De Wetering and Batenburg, 2014).

The findings of the literature review showed that there was a gap in the literature i.e. there was little empirical evidence on PACS maturity and future developments. The PACS maturity framework (van De Wetering and Batenburg, 2014; 2009) was

identified as the most appropriate theoretical framework to study the latest and future developments of PACS. Therefore, a theoretical framework was developed to undertake the present empirical study on the PACS. The next chapter describes the methodology used for the study.

4 Chapter Four: Research Design and Methodology

This chapter describes the research design and the methodology of this study. This chapter comprises twelve sections.

Section 1: describes the philosophical paradigms: epistemology and ontology.

Section 2: explains various research positions: positivism, interpretivism, realism, objectivism and pragmatism.

Section 3: presents research approaches: deductive and inductive.

Section 4: describes five main methodological approaches: survey, case study, action research, grounded theory and ethnography.

Section 5: explains the quantitative and qualitative research methods and the methodological choices: mono methods, multi methods and mixed methods.

Section 6: explains the time horizon in the research, leading to the description of the cross sectional and longitudinal studies.

Section 7: describes the methodology of the current study, including the type of research approach, methods of data collection, and difficulties in data collection.

Section 8: describes the data analysis techniques for both the qualitative and the quantitative data.

Section 9: explains data quality issues; validity and reliability of the data and the validity of the content of the survey questionnaire.

Section 10: reports the pilot study.

Section 11: presents the ethical issues

Section 12: summarises the chapter.

4.1 Philosophical Paradigms

The types of research paradigms and approaches and their relationships are shown in Figure 4-1.

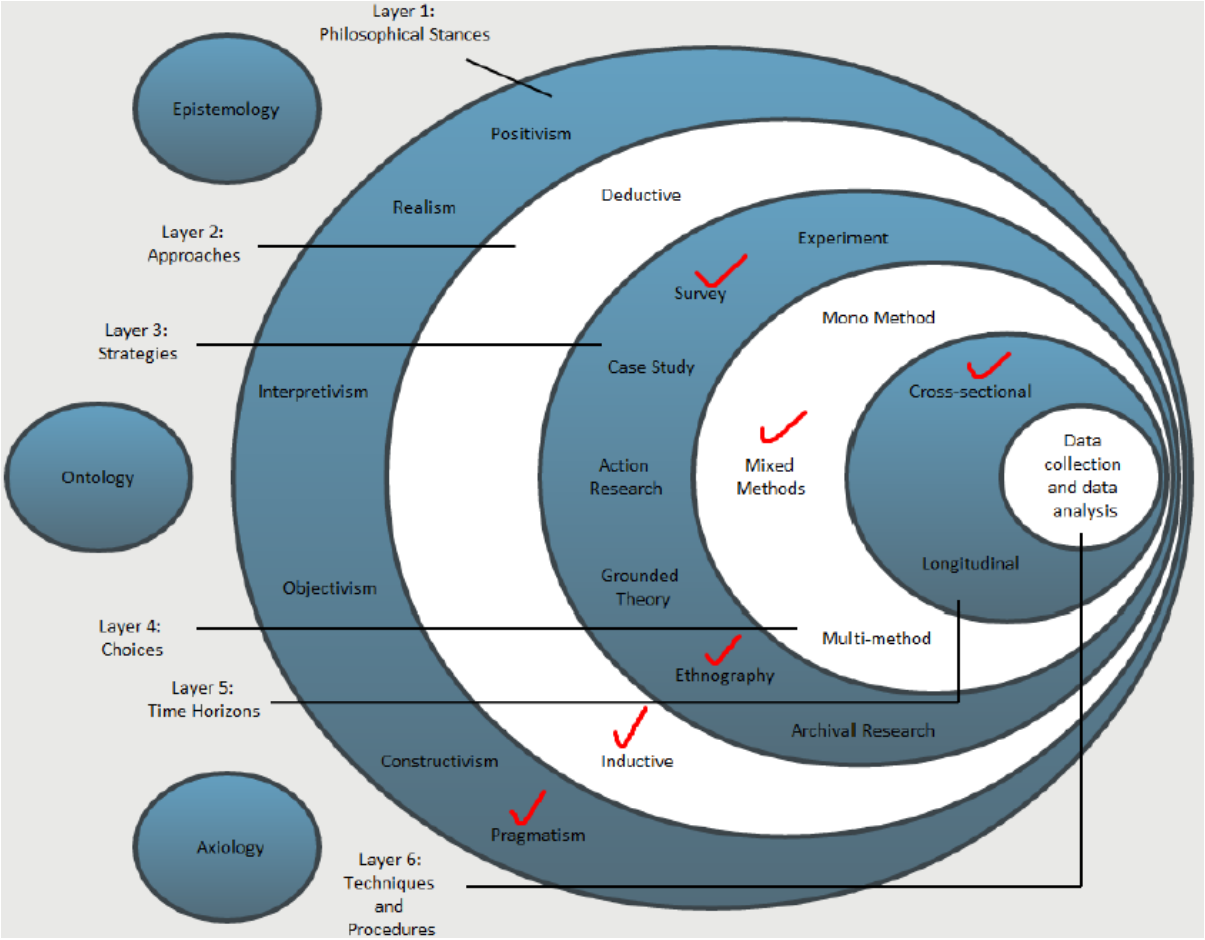


Figure 4-1 The research onion

Source: Adapted from (Saunders, Lewis, & Thornhill, 2009).
[NB. Tick marks show the methodology used in this study]

There are two philosophical paradigms of inquiry i.e. epistemology and ontology (Oates, 2006). The epistemology relates to the nature of knowledge whilst the ontology relates to the social phenomena being studied (Allan, 2010); thus, the epistemology is used in scientific research and the ontology is used mostly in social research. Researchers have agreed that the philosophical stances that commonly come under the philosophy of epistemology include positivism, interpretivism and (critical) realism (Norris, 2005) and the philosophical positions that usually come under the philosophy of ontology include objectivism, constructivism and pragmatism (Goodson and Phillimore, 2004). These philosophical stances concerning research enquiries are explained below.

4.2 Research positions

4.2.1 Positivism

Positivism is a philosophical position in research that is based on the supposition that social realism is singular and that the objective and the act of investigation does not affect it (Collis and Hussey, 2009, p. 338). The positivism paradigm has a number of characteristics (Orlikowski and Baroudi, 1991)(Chen and Hirschheim, 2004)(Oates, 2006), which include:

1. Physical and social reality is independent of humans. In the positivism approach the researcher determines the objective physical and social reality by doing experiments, measuring variables, and testing hypotheses.
2. The positivist approach depends on models and measurements. The researcher examines theories to prove or disprove a hypothesis concerned with the truth about specific aspects of the world.
3. The researcher plays a neutral role in the positivist approach to the investigation. The researcher believes a value will not be affected by the process of investigation.
4. Mathematical and statistical data analyses are the best approach for quantitative data analysis. Working with the positivist approach needs strong evidence and results to prove or disprove the hypothesis.
5. Positivist research works towards generalisation of the facts in order to determine theories applicable to similar situations.

In information technology research, the positivist paradigm has been criticised as having a number of limitations (Orlikowski and Baroudi, 1991):

1. Positivist studies neglect the historical and contextual phenomena of events and social interaction resulting in an incomplete picture of the particular phenomena.
2. Positivist research may focus on only one aspect of the situation and disregard other important aspects of the events. For example, to study user satisfaction, it is also important to consider user involvement and system

usage as well as studying how the organisation history and context affects the investigation.

3. The positivist approach focuses on explanation of the external reality of phenomena. The researcher is limited to gathering answers to specific questions based on the research interest. Physical and social reality of humans is neglected in this approach.

4.2.2 Interpretivism

Interpretivism is a philosophical stance in research that is based on the assumption that the social reality is multiple and subjective and it rests in our minds; thus it is affected by the act of investigation (Collis and Hussey, 2009, p. 336).

In the interpretive approach the subjective meaning of reality depends on human experiences and their social interaction process. The typical method for generating interpretive knowledge is the field study (Chen and Hirschheim, 2004).

The interpretive paradigm has characteristics (Orlikowski and Baroudi, 1991; Chen and Hirschheim, 2004; Oates, 2006) that include:

1. There is no single reality to the truth or knowledge and will depend on what the individual or group perceive as reality or knowledge.
2. The outcome of interpretive research can be influenced by different social constructs including language and shared meaning for an individual or a group. Moreover the meaning of constructs is dynamic and can change across groups and over time.

3. The assumptions, beliefs, values and actions of the researcher can affect the interpretive research process. Therefore, researchers must be 'self-reflective' about how they might influence the outcomes of the study.
4. Interpretive research undertakes studies on people in their own natural and social setting. This means that the researcher should impose as little influence as possible on the environment of the participants.
5. There is no single technique for qualitative data analysis in interpretive research, where the words and actions are investigated. Many instruments are available for use.
6. There can be different explanations for the outcome of interpretive research and the researcher should emphasise the best explanation as the outcome of the study.

The interpretive paradigm has some limitations such as interpretive research examines the phenomena of interest by focusing on individuals and their social interactions; thus, the finding of the investigation can be directly affected by the status of the participant, e.g. if the participants are unaware, confused, or unreliable then results may be misleading (Orlikowski and Baroudi, 1991).

4.2.3 Realism

The philosophical stance of realism is based on the assumption that the social reality exists but the scientific methods are less appropriate for studying it; social reality and the researcher are independent from each other, therefore there will be no bias in the results. In addition there is a need for continuous research using different

methods of research. In IS and Computing research, realism is also known as critical realism, which is “concerned with identifying power relations, conflicts and contradictions, and empowering people to eliminate them as sources of alienation and domination” (Oates, 2006). Unlike the positivism and interpretivism approaches that focus on explaining and predicting the status of a phenomenon through investigation, critical realism investigates the social reality of a phenomenon by evaluating it (Orlikowski and Baroudi, 1991).

The (critical) realism paradigm has the following characteristics (Orlikowski and Baroudi, 1991; Oates, 2006):

1. The critical realism researcher is more involved than in any other paradigm because critical research will not only discover and explain a phenomenon but also empower people who affect the social organisations.
2. Critical realism investigates the phenomena deeply by questioning and challenging it. This kind of approach will not accept any phenomena as it is without any further investigation.
3. Critical realism studies consider the role of the humans and organisations and how they adjust to using the new technology. This kind of investigation argues that people will adapt to the new technology and then determines the changes.
4. Critical realism investigations are influenced by the organisational, social and historical factors of the organisation they study.

4.2.4 Objectivism

Objectivism is a philosophical stance that suggests that social reality / phenomenon exists independently of the social actors (Ratner, 2008). The objectivism stance is mostly applied in the ontological approach to research enquiry.

4.2.5 Constructivism

Constructivism is a philosophical position that is based on the assumption that the social reality exists due to the social actors (Costantino, 2008; Burr, 2004). The constructivism position is generally used in the ontological approach to research enquiry.

4.2.6 Pragmatism

Pragmatism is a philosophical position that states that both the objectivism and constructivism stances are valid assumptions about the research enquiry; hence, either or both of them can be applied to the study of a social reality (Collis and Hussey, 2014).

The pragmatism stance is also commonly used in the ontological approach to research enquiry.

4.3 Research approaches

There are two main research approaches; these are the deductive approach and the inductive approach.

4.3.1 Deductive approach

The deductive approach or reasoning (Figure 4-2) starts with the theory, from which a hypothesis / hypotheses is (are) developed, and these are confirmed by

observation / data collection in an experiment / study. Conclusions are developed in relation to the original hypothesis/ hypotheses (Allan, 2010). The deductive reasoning is usually used in the objective approach by undertaking quantitative research (Allan, 2010).

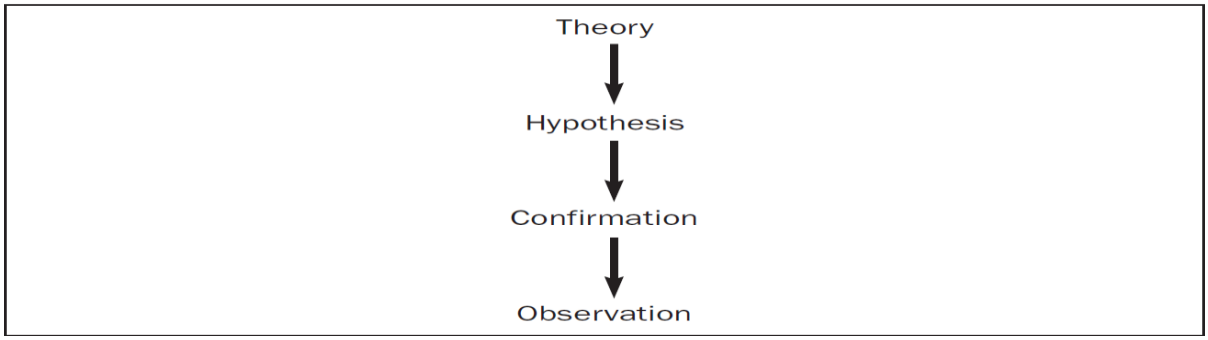


Figure 4-2 Deductive approach

Source: (Allan, 2010)

4.3.2 Inductive approach

The inductive reasoning approach (Figure 4-3) starts with the observation or data collection. The data are analysed to determine trends and develop potential hypothesis or hypotheses that lead to a theory being developed (Allan, 2010). Inductive reasoning is used in the subjective approach by undertaking qualitative research (Allan, 2010).

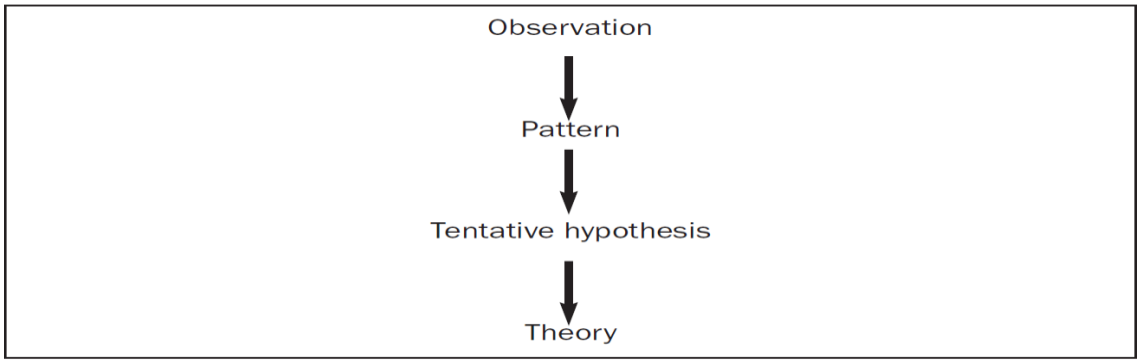


Figure 4-3 Inductive approach

Source: (Allan, 2010)

4.4 Methodological approaches

There are a number of methodological approaches to undertake a research study. Seven methodological approaches within the layer 3 strategies in the research onion illustrate various research philosophies and approaches, stances, strategies, research designs and data collection methods (Figure 4-1) (Saunders, Lewis, & Thornhill, 2009) include. The main methodological approaches to research include the survey, case study, action research, grounded theory, ethnography and archival (historical) research, experiments and scientific methods (Saunders, Lewis, & Thornhill, 2009; Allan, 2010). Table 4-1 shows that these methodological approaches can be used in either objective or subjective studies or in both types of studies; for example surveys and archival (historical) research can be used in both objective and subjective studies (Allan, 2010).

Table 4-1 Methodological approaches

Methodological approach	*Objective study*	*Subjective study*
Action research	x	✓
Archival (historical) research	✓	✓
Case study	x	✓
Ethnography	x	✓
Experiments	✓	x
Grounded theory	x	✓
Scientific methods	✓	x
Survey	✓	✓
Symbols ✓ = Yes, X =No		

Source: Adapted from (Allan, 2010)

The most common methodological approaches used in research involving studies of information systems include surveys, case studies, grounded theory, and ethnography (Oates, 2006).

The literature review of empirical studies on PACS (Table 3-3) shows that research in the PACS domain has mostly used the survey; both questionnaire surveys (Tesoriero, Eddy and Hasso, 2015; Joshi *et al.*, 2014; Tzeng *et al.*, 2013; Ranschaert and Binkhuysen, 2013; Aldosari, 2012; Sicotte *et al.*, 2010; Duyck *et al.*, 2010; Duyck *et al.*, 2008; Lienemann *et al.*, 2005; Van De Wetering and Batenburg, 2014) and interview surveys (Aas and Geitung, 2005).

A few researchers have used the grounded theory approach for structured interviews in studying the impact of PACS on the workplace of radiographers (Fridell *et al.*,

2007) and radiologists (Fridell *et al.*, 2009). Therefore, the most commonly used methodological approaches in the PACS research reported in the literature are questionnaire surveys and interviews.

4.4.1 Surveys

The survey refers to the research methodology that includes the selection and study of a sample of people from the population in order to undertake research on a specific topic and thereby make inferences for the population (Allan, 2010). There are two types of survey; the questionnaire and interview survey (Trochim, 2006).

4.4.1.1 Questionnaire surveys

The questionnaire survey is undertaken to collect quantitative information in a research study. In this method, a questionnaire is prepared in advance for a specific group of people in order to collect information on the issue / issues of interest (Lydeard, 1991)(Oates, 2006). The strength of the method includes the ability to design the survey for the specific aims and objectives of the study and collect data from a large number of people (Oates, 2006).

In IS research, the questionnaire survey is the main quantitative method for undertaking research, which is evident from a review of IS research articles published from 1983 to 1988 that revealed that 49.1% of the studies had used the questionnaire survey (Orlikowski and Baroudi, 1991).

In the systematic review of literature of empirical studies on PACS undertaken in this work (Table 3-3), the questionnaire survey was used in the majority of studies (Duyck *et al.*, 2010; Duyck *et al.*, 2008; Lienemann *et al.*, 2005; Aldosari, 2012;

Sicotte *et al.*, 2010; Ranschaert and Binkhuysen, 2013; Tzeng *et al.*, 2013; Tesoriero, Eddy and Hasso, 2015; Van De Wetering and Batenburg, 2014; Joshi et al., 2011; Joshi et al., 2014).

4.4.1.2 Interview surveys

The interview is a type of survey that is used for collecting qualitative information in a research study by asking questions to the research participants (Collis, Hussey and Hussey, 2003). Interviews are mostly used in case studies and ethnographic studies and there are three types of interview; structured interview, semi-structured interview, and unstructured interview (Oates, 2006). Interviews can be conducted face to face, via phone, and using internet interactive tools such as Skype.

In structured interviews, the researcher (interviewer) only asks questions from a set of predetermined questions to the interviewees. However in the semi-structured interview, the researcher (interviewer) starts by asking questions from the predetermined list, but may ask supplementary questions or explore questions more deeply (Oates, 2006). The semi-structured interview is more flexible compared to the structured interview and provides the opportunity to collect extra information from the research participants. Therefore, semi-structured interviews are more appropriate for exploratory studies (Pope and Mays, 2006).

In comparison to the structured and semi-structured interview, the unstructured interview is highly flexible and open-ended; the researcher introduces the research topic to the interviewees but then may talk at length about any aspect of the topic (Oates, 2006).

The literature review (Table 3-3) conducted in this work shows that interviews were used in PACS research by some researchers. This includes Aas and Geitung (2005) who used interviews to study the impact of PACS and teleradiology; and Fridell et al, who used structured interviews to study the impact of PACS and teleradiology on the work practice of radiologists (Fridell *et al.*, 2007) and radiographers (Fridell *et al.*, 2009).

4.4.2 Case study

The case study is a research design in which the researcher undertakes an in-depth study of an organisation, activity, event or information system as well as a programme, department or project (Oates, 2006)(Creswell, 2014). The focus of a case study is the in-depth study of one setting (Collis, Hussey and Hussey, 2003) and the study can be exploratory, descriptive and explanatory in nature (Oates, 2006). In the case study, researcher(s) collect data by using a range of methods and procedures (Creswell, 2014) including questionnaires, observations, interviews and document analysis (Oates, 2006).

The review of empirical studies on PACS research (Table 3-3) in this work shows that the case study was not used in any of the 14 studies included in the literature review. This may suggest that the case study is not appropriate for undertaking research on the experience of users of PACS. However, the case study could be useful in some aspects of PACS research, such as studying the development processes related to PACS, especially by the vendors.

4.4.3 Action research

Action research is a research design that investigates and evaluates work practices to determine where improvements can be made (Oates, 2006). Action research is commonly used in healthcare settings to improve clinical practice, workflow and working conditions through systematic evaluation of the practices and workplace settings (Koshy, Waterman and Koshy, 2011). Action research is also known as participatory action research (Oates, 2006)(Koshy, Waterman and Koshy, 2011), which is increasingly being used in information systems research, but its use is seldom reported in computer science literature (Oates, 2006). In the systematic literature review (Table 3-3) conducted in this work, there was no study that reported use of action research in studying PACS.

4.4.4 Grounded theory

Grounded theory is a qualitative research methodology that involves a set of systematic procedures to develop an inductively derived theory about a phenomenon (Collis, Hussey and Hussey, 2003), which is grounded in the views of the study participants, their interactions and actions (Creswell, 2014). In grounded theory, interviews are the most common method of data collection but other data collection methods such as observations, documents and even some quantitative data tools are also used (Kinnunen and Simon, 2012). Grounded theory is increasingly being used in IS literature. In the systematic literature review (Table 3-3) conducted in this work, the use of grounded theory was reported in empirical research that investigated the impact of PACS and teleradiology on the work practice of

radiologists (Fridell *et al.*, 2007) and radiographers (Fridell *et al.*, 2009), when semi-structured interviews were used for the data collection.

4.4.5 Ethnography

Ethnography refers to the systematic study of people and their cultures (Oates, 2006). Ethnography is a research methodology that has roots in anthropology, through which researchers use the socially acquired and shared knowledge to understand the observed patterns of human activity (Collis, Hussey and Hussey, 2003). In ethnography, data are collected by using different data collection methods, of which the most important methods are interviews, observations and field notes (Oates, 2006). Ethnography is used in IS and computing literature (Button *et al.*, 2015); however, in the systematic review of literature on PACS (Table 3-3), no empirical study was found that reported use of ethnography.

4.5 Research Methods

The main research methods include the quantitative and qualitative methods.

4.5.1 Quantitative methods

The quantitative research method has been defined as a “means for testing objective theories by examining the relationship between variables, which, in turn, can be measured, typically on instruments, so that numeric data can be analysed using statistical procedures” (Creswell, 2014). Thus, the quantitative research method involves defining variables that are measured quantitatively in an experiment and the data that are collected are analysed statistically to test a hypothesis or many hypotheses. This type of research is most frequently used under the positivism approach (Kaplan and Duchon, 1988). In the quantitative research method, the most

common tool of data collection is the survey questionnaire, which is designed to be completed by the study participants themselves.

4.5.2 Qualitative methods

The qualitative research method refers to a “means for exploring and understanding the meaning individuals or groups ascribe to a social or human problem” (Creswell, 2014). In qualitative research, the researcher attempts to determine the social reality of a situation by observing and examining the social reality through human reactions and behaviours (Kaplan and Duchon, 1988). The main data collection tools in qualitative research include interviews, observations and documents; however, the selection of a particular data collection tool depends on the objectives and design of the research study. For example, interviews and observations are the best methods in healthcare quality assessment research (Pope, Ziebland and Mays, 2000).

4.5.3 Methodological choice

The choice of the quantitative or qualitative method depends on the research question and the study objectives. Methodological choice depends on the number and type of data collection techniques and the data analysis procedures that are used (Saunders and Tosey, 2012). Researchers may therefore use different methodologies that could be single method, multi-method or mixed methods.

4.5.4 Mono methods

In mono methods, researchers use one method for data collection and apply a single corresponding data analysis procedure, e.g. quantitative questionnaire and statistical analysis (mono method quantitative) or qualitative interviews and narrative analysis (mono method qualitative) (Saunders and Tosey, 2012).

4.5.5 Multi-methods

In multi-methods, researchers use more than one type of data collection technique and more than one data analysis procedure, for example use of a quantitative questionnaire and structured observation and application of relevant and corresponding data analysis procedures (multi-method quantitative) or use of qualitative interviews and diary accounts and application of corresponding data analysis procedures (multi method qualitative) (Saunders and Tosey, 2012).

4.5.6 Mixed methods

In mixed method research design, the researcher can use both quantitative and qualitative data collection methods and corresponding data analysis procedures / techniques (Saunders and Tosey, 2012). For example, questionnaire surveys analysed with statistical analysis followed by focus groups and prioritisation of measured items.

4.6 Time horizon in research studies

Research studies are divided into two forms of time horizon, cross sectional and longitudinal. The time horizon is important because it determines the design of the study and data collection methods.

4.6.1 Cross sectional study

A cross sectional study is one that involves data collection at a single point in time. Such studies include surveys and case studies as the research strategy / design (Saunders and Tosey, 2012).

4.6.2 Longitudinal study

A longitudinal study is one that involves data collection at more than one point in time or over an extended period of time. Such studies include grounded theory, action research, experiment and archival research as research strategy / design (Saunders and Tosey, 2012).

4.7 Methodology of the current study

The present study follows the epistemological philosophy and has adopted the pragmatism paradigm. It applies the mixed methods strategy. A cross sectional time horizon is used. The research strategy of the survey and ethnography were chosen and semi-structured interviews, survey questionnaires and un-structured observations were selected for data collection. The following sections describe the main steps of the research methodology used in this study. The methodology is illustrated in Figure 4-4.

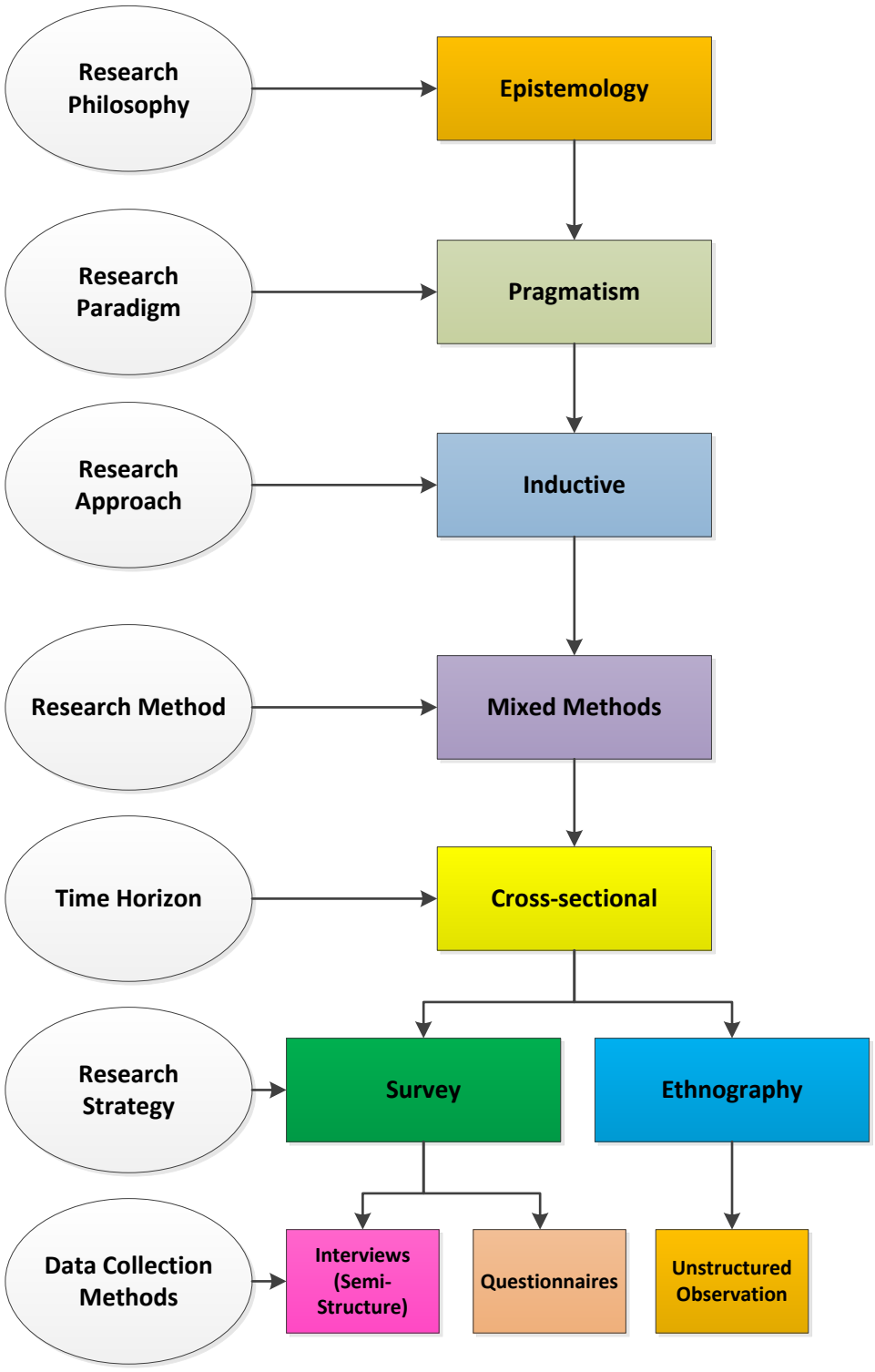


Figure 4-4 Methodological approach adopted in this study

4.7.1 Mixed method approach

A combination of qualitative and quantitative methods was used in this study; the qualitative method gave a deep understanding of the research phenomenon whilst the quantitative method ensured a solid base of quantitative facts to validate the findings. The rationale was that the qualitative and quantitative approaches are complementary and using them together combines the advantages of each approach (Morgan, 2007; Onwuegbuzie and Leech, 2005; Bryman, 2004) Furthermore, the mixed method approach is frequently used in health science research due to the complicated nature of the phenomena being studied (Östlund *et al.*, 2011).

However, when both qualitative and quantitative approaches are used, there is a need for careful consideration of the design of the study. For example, the research might use the qualitative approach as the main instrument and use quantitative approach to validate the results. Alternatively, the quantitative method could be used as the primary approach and the qualitative method is used to understand the outcomes (Creswell, 2014). In this study, the qualitative approach was used as the main and first approach and the quantitative approach was then applied to validate the findings.

4.7.2 Data collection methods

In this study, three types of data collection methods have been used; semi-structured interviews, survey questionnaires and un-structured observations. The process of applying these data collection methods is described below

4.7.2.1 Interviews (semi-structured)

In healthcare research, researchers experience a variety of interactions between people, technology, information, culture and other physical environments (Johnson and Barach, 2008). Thus, most healthcare researchers use qualitative research methods due to the complexity of the healthcare settings and because the qualitative interview-based research focuses on describing and clarifying the experience people have of their life "as it is lived, felt, undergone, made sense of and accomplished by human beings" (Schwandt, 2001).

The review of research on PACS showed that researchers have used semi-structured interviews to study the impact of PACS and teleradiology on teleconferencing (Aas and Geitung, 2005) and on the work practice of radiologists (Fridell *et al.*, 2007) and radiographers (Fridell *et al.*, 2009). Therefore, the present research used semi-structured interviews.

For conducting interviews, a list of interview questions (Appendix- 7) was developed that included four themes; usage of current PACS, limitations in current PACS, additional features that can increase PACS functionality, and expectations from the next generation PACS.

Semi-structured interviews were conducted with a sample of six radiologists of different positions (two senior radiologists, two junior radiologists and two trainee radiologists). The selection of the sample size of six radiologists was based on an earlier study by Joshi et al. (2014) who interviewed six participants (3 radiologists and 3 PACS administrators) for investigating the important features that affect PACS

selection. Another earlier study by Guest el at (2006) reported that they reached to saturation after interviewing six participants. In addition, Kuzel (1992:41) recommended interviewing six to eight participants of a homogenous sample. In the present study, the selected sample of six radiologists was homogenous in the sense that they were specialised and working in the same clinical speciality i.e. radiology and all of them were users of PACS. The participant radiologists were approached in their offices at the Al-Sabah Hospital, which is the main government hospital in Kuwait. This hospital was selected for conducting the interviews because it has the radiology department with the largest number of radiologists in the country. Also, this hospital trains the trainee radiologists. In this way the interviews of not only the seniors and juniors radiologists but also the trainee radiologists could be conducted in the single hospital.

Each interviewee was provided a copy each of cover letter for interviews (Appendix-4), participant consent form (Appendix-5) and participant information sheet (Appendix-6) that provided the background of the research study. Interviewees were assured of the confidentiality and anonymity of their interview that they had the right to withdraw at any time during the research process. In addition, verbal permission was gained to audio record the interviews for the purpose of analysis. The typical time of an interview varied from 35 to 45 minutes.

4.7.2.2 Questionnaire survey

A survey is a process to collect information to investigate attitudes, opinions, behaviours, and situations (Connelly, 2009; Fink, 1995). Several steps are required to construct the survey (Kitchenham and Pfleeger, 2002):

- The literature related to the research interest is searched
- The questions and structure of questions are designed
- The questions are pilo-ed before the main study
- The questions and strategy are finalised for survey distribution

This research followed these steps by starting with a search of the literature related to the future trends of PACS to:

- Determine what topics have been questioned in other studies
- Determine how other studies conducted their research and what kind of data collection methods they used.
- Ensure that the contribution of this research will be unique and will add to existing knowledge (Kitchenham and Pfleeger, 2002).

The next step was to design the questionnaire by relating the questions to the research questions, research objectives, and the primary themes that emerged from the literature review. The outcome of the review also helped in the choice of the type and the format of the questions. The questionnaire was prepared and designed to be distributed to radiologists, who are the main stakeholders in using PACS. Sample size and techniques were considered during the design process of the questionnaire.

The survey questionnaire is attached as Appendix-8.

The survey questionnaire consisted of four pages. The first page included a fact sheet that provided the title of the study, brief background about PACS, the aim and objectives of the research study, a statement about the anonymity and confidentiality of the participant and their collected data, and the name and contact details of the researcher including a direct telephone number, email and university address. The survey questionnaire included four sections:

Section 1: Information regarding the use of PACS

Section 2: Perception about the next generation PACS

Section 3: Comfort with the technology

Section 4: Demographic and background characteristics of the participants

Section 1: Information regarding the use of PACS

This section included four close-ended questions.

The first question (Q1) sought information about PACS usage on a 5-point Likert scale (5 = Always, 4 = Often, 3 = Sometimes, 2 = Rarely, and 1 = Never).

The second question (Q2) was to determine the satisfaction level of the radiologists with the current PACS. This question was measured on a 4-point Likert scale (4 = Extremely Satisfied, 3 = Slightly Satisfied, 2 = Slightly Dissatisfied, and 1 = Extremely Dissatisfied).

The third question (Q3) asked about the concern of the radiologists in relation to limitation issues of PACS such as the limited search functionality, inadequate connection of PACS between hospitals, and the restricted access to PACS in office

only. This question was also measured on a 4-point Likert scale (4 = Strongly Agree, 3 = Agree, 2 = Disagree, and 1 = Strongly Disagree).

The last question (Q4) asked for the level of agreement with a statement i.e. “Web PACS solutions such as multi hospital PACS and PACS on mobile phones could be a solution for handling the previous issues”. This question was also measured on a 4-point Likert scale (4 = Strongly Agree, 3 = Agree, 2 = Disagree, and 1 = Strongly Disagree). The use of 4 point Likert scale in questions 2-6 was used because the omission of mid-point in Likert scale help in avoiding any social desirability bias in answering the research questions, mostly in face to face surveys, and thus reduces the distortions (Garland, 1991; Albert and Tullis, 2013, p. 127).

Section 2: Perception about the next generation PACS

This section comprised only one question (Q5) that asked the level of agreement of the radiologists with four statements about problem solutions in the next generation for PACS. All four statements in this section were measured on a 4-point Likert scale (4 = Strongly Agree, 3 = Agree, 2 = Disagree, and 1 = Strongly Disagree).

Section 3: Comfort with the technology

This section included two questions, which asked the level of agreements of the radiologists with six statements about their comfort with technology (Q6) and their opinions about nine issues that could affect the adoption of web PACS solutions (Q7). Both questions were measured on a 4-point Likert scale (4 = Strongly Agree, 3 = Agree, 2 = Disagree, and 1 = Strongly Disagree). This section also provided an opportunity for any other comments in an open ended answer option.

Section 4: Participants demographic and background characteristics

The last (fourth) section asked information about the demographic and background characteristics of the participants under five headings (current position, gender, nationality, age, and work experience in the present organisation). This part provided the option to tick one option from a list of available options.

Note that section 3 (comfort with technology) was adapted from published research on telemedicine (Buabbas, 2013) whereas the remaining sections of the survey questionnaire were developed by the researcher.

The questionnaire included a number of closed-end questions with a list of possible answers to help the radiologists choose the appropriate response. Closed-ended questions were used for this study to make it easier and quicker for the radiologists to participate and complete the questionnaire due to their busy schedule. Open-ended questions were avoided because of the extra time that would be required to complete the responses (Oates, 2006).

Permission was obtained from the director of each radiology department prior to undertaking the questionnaire survey. The survey questionnaires were distributed by hand to the radiologists working in the radiology departments of six large government hospitals in Kuwait, which are shown in the order of the largest to the smallest in Table 4-2. The researcher was present in the department until the participants had finished the questionnaire to be on hand to answer any questions and explain any issues about the survey to them.

Table 4-2 Health regions and related hospitals in Kuwait

No.	Hospital name (Type)	Health Region
1	Al-Sabah (General)	Capital (Al-Sabah)
2	Mubarak (General)	Hawalli
3	Al-Jahra (General)	Al-Jahra
4	Al-Adan (General)	Al-Ahmadi
5	Al-Farwaniya (General)	Al-Farwaniya
6	Al-Ameri (General)	Capital

4.7.2.3 Observations (Un-structured) of online discussion groups in LinkedIn

In this study, the third method used for data collection was observation of online discussion forums. These are "*computer supported communication technologies that facilitate virtual interaction on the internet"* and these kinds of communication technologies are growing rapidly on the World Wide Web (da Cunha and Orlikowski, 2008). Online forums are formulated by different discussion threads, which start with posting of a message that either contains information or a question. Further messages will be in the form of a reply, and these will develop as a kind of discussion. This is stored and archived and made available online for others to read and search.

There are both advantages and disadvantages in using internet based online discussion groups for collecting data. Advantages include (Seale *et al.*, 2010; Adair *et al.*, 2006):

- A large amount of data can be collected within a short time.
- Information can be collected from people who have similar experiences and interests but are located in different geographical areas. This supports the research in context and financially.
- Using the Internet removes the issues of in-person contact and provides the participant with the opportunity to present their opinions freely without the feeling that they may be judged.

However, there are limitations with using the Internet as a medium for data collection. These include (Seale *et al.*, 2010):

- The participants are self-selecting.
- Some participants will be excluded from the study because they do not have internet access or they have no interest in using or participating in such social-technical media.

These limitations of the online discussion group could introduce bias and therefore should be considered carefully in research studies (Seale *et al.*, 2010).

This work collected data using unstructured observations of four online discussion groups on PACS from the professional social network known as LinkedIn. This is currently the largest global network of professionals (Linkedin.com, 2016). LinkedIn was selected as it is an expert online discussion social website that allows individual

professionals to share and exchange knowledge and information on technical topics and issues of interest. A unique feature of the discussion forums on LinkedIn is that the participants in each group are experts in their own fields and have prior knowledge of the discussion topics. In addition, online discussion groups break geographical boundaries and allow stakeholders from different countries to comment on specific topics. The participants have the opportunity to know about each other from the personal profile link that contains details about each participant, including their name, position, and experience.

However, there are ethical considerations about using data from online discussion forums. Firstly, the role of the researcher in this research method was as an outside observer. The researcher only observes the discussions with no interaction with the group discussion and did not influence the opinions of the participants or the direction of the discussion threads.

Observations of the online discussion groups on PACS were made every three months over a period of two years; from January 2014 to December 2015. A three month gap in the observations of the online groups allowed for accumulation of new discussion threads. Each group contained various discussion threads and the comments of participants relevant to PACS were collected starting retrospectively from 2013 until December 2015 when the data collection from these groups stopped. Comments from each thread were collected where there were four or more comments that were relevant to the study. Qualitative textual data from comments were analysed by creating nodes in the NVivo software (Version 10 for Windows). Similar nodes were combined under themes using the thematic analysis process.

Overall, for online discussion groups, the data collection and analysis process involved the following steps:

1. Identify relevant online discussion groups (group name relevant to study topic (i.e. PACS) and questions and answers relevant to PACS related issues such as PACS features, PACS issues and PACS improvements.
2. Seek permission from the group moderator / administrator to join the group (not all groups accepted the researcher to be a member of the group).
3. Scan the group discussion topics / threads to select relevant topics and sufficient comments (minimum 4).
4. Export relevant comments by using the screen capture feature provided in the NVivo 10 software.
5. Read and code the imported comments in the NVivo 10 software.
6. Combine similar codes into themes using thematic analysis.
7. Review and finalise the themes.

4.7.3 Difficulties in the data collection

There were a number of difficulties in the data collection process. The important issues in conducting the interviews and questionnaire surveys included:

- Not all the radiologists were present during the time of the data collection process; some of them were on vacation.
- Some radiologists refused to participate because they were busy.
- Radiologists were busy and it was difficult to find time to conduct the interviews, even with an appointment.
- Some of the radiologists were unaware of future solutions for PACS, especially putting PACS on mobile phone.

The main difficulty faced in conducting the unstructured observations of online discussion groups was that the researcher was not accepted as a member of the group by some of the online discussion groups, even though the content of the group discussion was very important for the present research.

4.8 Data analysis techniques

In this study, collected data were analysed using a variety of data analysis techniques, which depended on the type of data collected.

4.8.1 Qualitative Data analysis

There are different methods to analyse qualitative data including thematic analysis, content analysis, narrative analysis and textual analysis. The main purpose of these different techniques of data analysis is to clarify the content of the phenomena and provide clear understanding of the words and actions of the qualitative data (Hoff and Witt, 2000). There are several software packages that may be used to analyse qualitative data, which include Atlas.ti, NUDIST, NVivo and QDA. However it is important to understand that these software tools do not analyse the data automatically but simplify the data analysis process by providing database

searching, coding, and indexing of the words for developing concepts and themes. Therefore, the selection of qualitative data analysis software depends on the type of data being analysed and analysis required (Johnson and Barach, 2008).

In this study, the NVivo software tool was used to analyse the qualitative data that were collected in the interviews of the radiologists and the observation of the online discussion groups on the PACS. The qualitative data analysis process was accomplished by allocating descriptive codes to each group of words to identify the emerging themes across the interviews and across the online discussions. After identifying the themes separately in the interviews and the observation data, the themes were merged together for categorisation and reporting purposes.

4.8.2 Quantitative Data analysis

The quantitative data was collected as a questionnaire survey from 120 out of the 200 radiologists in Kuwait. The data from the paper based survey questionnaires were entered manually into an Excel spreadsheet. The data were analysed using frequency and descriptive statistics. The results are presented in tables, as histograms and pie charts, as appropriate.

The researcher used the convergent parallel mixed methods design that included parallel collection of qualitative data, through in-depth interviews of radiologists (N=6) and unobtrusive observation of ‘online discussions’ on PACS by various types of professionals interested in the PACS via LinkedIn discussion groups (N=5), and quantitative data by a questionnaire survey of radiologists (N=120). Data collected through each data collection method mentioned above were analysed separately and then the findings from each type of data were compared for convergence (as

shown in Figure 4-5 (Creswell, 2014)) and identification of common themes and issues about the research topic i.e. latest developments in and maturity of PACS. The use of convergent parallel mixed methods design helped in collecting rich data from various perspectives on the same issue (Wisdom and Creswell, 2013) and studying the similar and complementary dimensions of the research topic (Jick, 1979), which could not be captured in detail by using only one method (Classen et al, 2007). More importantly, the use of convergent parallel mixed methods design enabled collection, analysis and interpretation of the findings that were convergent and complementary to each other (Creswell, 2014).

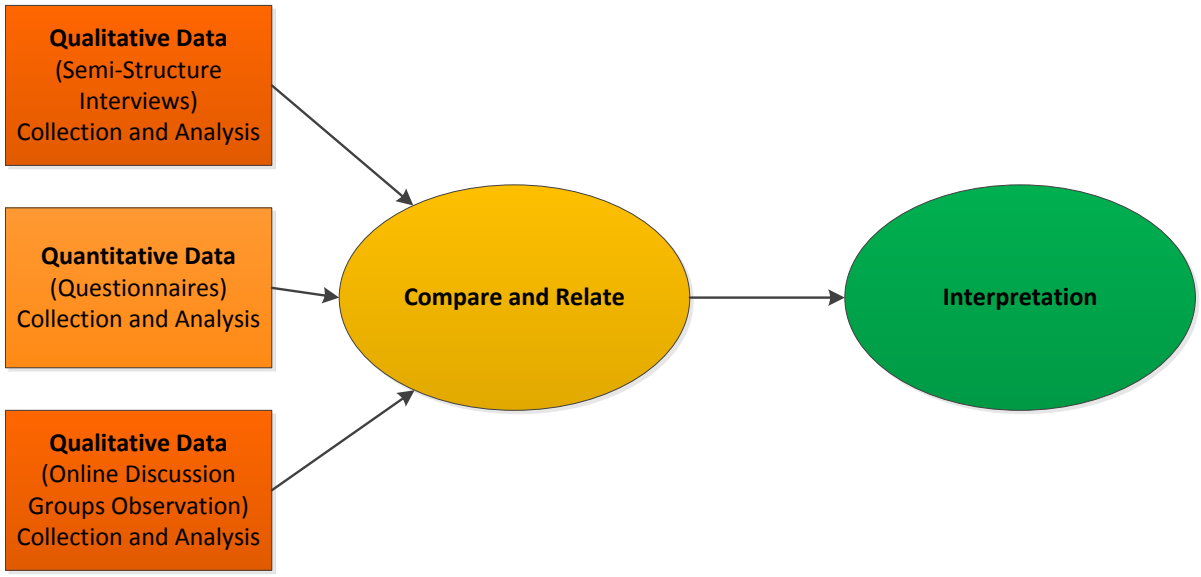


Figure 4-5 Convergent parallel mixed methods design for data collection and analysis in mixed methods research

Source: adapted from (Creswell, 2014)

The researcher did not use the explanatory sequential mixed methods design because it suggests collection of quantitative data in the first phase followed by collection of qualitative data (in the second phase) to supplement the findings of the

quantitative data (Ivankova et al., 2006; Creswell, 2014). Thus, the use of explanatory sequential mixed methods design was not deemed appropriate for the present study that focused on the maturity and future developments of PACS, for which application of the convergent parallel mixed methods design was more appropriate. Finally, triangulation of the findings of both the qualitative data and quantitative data was used (Erzberger and Kelle, 2003) to draw inferences (Figure 4-6). Data triangulation is described below.

4.8.2.1 Data triangulation

Data triangulation has been defined as "The combination of methodologies in the study of the same phenomenon" (Jick, 1979; Denzin, 1978). The strategy of triangulation is to use multiple sources to study certain objects (Jick, 1979; Smith, 1975). The main strength of triangulation in research design is that it can give greater accuracy to the research because of the range of procedures used to collect the data (Jick, 1979). For data triangulation, at least two data-collection methods are required in the same research design (Kimchi, Polivka and Stevenson, 1991). For example use of qualitative and quantitative data collection methods in an empirical study as shown in Figure 4-6 (Erzberger and Kelle, 2003).

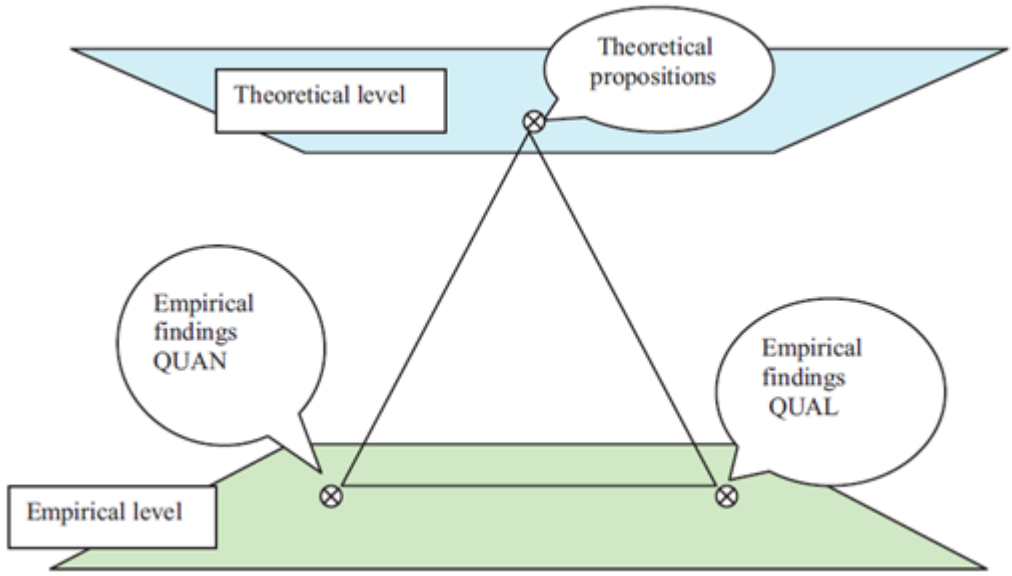


Figure 4-6 Data triangulation triangle

Source: (Erzberger and Kelle, 2003)

Triangulation has advantages: a multiple data collection strategy can increase confidence in the outcome of the investigation; provides in-depth understanding of the research topic; and can help validate the findings (Jick, 1979)(Östlund *et al.*, 2011) (Thurmond, 2001)(Creswell, 2014). The disadvantages of triangulation include: extra time and effort compared to a single research method; need for significant amounts of data from many sources and with different approaches; more probable to be affected by investigator bias; and a need for a clear purpose for triangulation rather than “more is better” (Fielding and Fielding, 1986; Östlund *et al.*, 2011; Sohier, 1988).

The present research used data triangulation using quantitative data collected in the questionnaire surveys, qualitative data collected in semi-structured interviews, and online discussion group observations. The qualitative and quantitative data were

analysed using the appropriate data analytical techniques for drawing the valid inferences in the present empirical study.

4.9 Data Quality issues

4.9.1 Validity and reliability

Any research data and instrument must be tested for validity and reliability to reduce errors in the measurement process (Oates, 2006; Kimberlin and Winterstein, 2008). Validity is defined as “the extent to which an instrument measures what it purports to measure” (Kimberlin and Winterstein, 2008), whereas reliability is defined as "whether the questionnaire would yield the same results if given repeatedly to the same respondents" (Oates, 2006). Validity requires that an instrument is reliable, but an instrument can be reliable without being valid or neither valid nor reliable (Oates, 2006; Kimberlin and Winterstein, 2008). In this study, both interviews and questionnaires were tested for reliability and validity by doing a pilot study involving a panel of experts to guarantee that the research instrument was designed to measure the intended research aims and objectives.

4.9.2 Content validity of survey questionnaire

The reason to ensure 'content validity' is that the instrument questions should cover and measure the content of the research area. Whilst there is no statistical test to measure how well the research instrument covers the research area, content validity can be measured from feedback and judgement of experts in the field (Oates, 2006; Kimberlin and Winterstein, 2008). The research instrument (survey questionnaire and interviews) was designed to raise the main points that serve the research topic. The content validity procedure was applied to validate the research instruments

designed for this study. The content validity of the survey questionnaire was checked by a group of experts directly related to the research topic and by a group of experts generally related to designing research instruments. In this case, the questionnaire design experts (n=5) included two lecturers with expertise in designing questionnaires and three postgraduate research students having experience in the questionnaire designing process at Brunel University London. These experts were approached during a one day workshop on designing survey questionnaires for postgraduate students held at the Brunel Graduate School. The themes of the interviews were validated by radiologists (n=4) at Al-Farwaniya Hospital in Kuwait.

The radiologists suggested amendments and replacements to both the interview questions and the survey questionnaire questions in order to improve the content according to the study objectives. The questionnaire designers suggested rewording and reorganising of research questions in order to reduce bias. In addition, the scale score was rearranged to provide the respondents with a clear understanding and provide a wide choice to give the best answer

In addition to the content validity procedure, other methods were used to reduce research errors including:

- Doing a pilot study (discussed in detail below).
- Using the data triangulation approach, which has proven that using a multiple data collection strategy will increase the data validity in research (Creswell, 2014; Kaplan and Duchon, 1988; Oates, 2006).
- Survey questionnaires were distributed by hand and the researcher was present to provide any extra explanations or answer and clarify any questions that the respondents might have.
- Collecting data from a large sample (targeted a sample of 200 radiologists) to reduce potential errors.

4.10 The pilot study

Prior to the main study, the survey questionnaire was pilot tested on four radiologists working at Al-Farwaniya hospital in Kuwait to ensure that: questions were clear; and that there were no ambiguities, misunderstandings or errors in the questions. Based on the comments of the radiologists, changes were made as follows:

- Wording in the questionnaire was changed to make it simpler for the participant.
- Punctuation errors were corrected.
- Four separate questions were merged into one detailed question (Q5 in section 2.).
- The type of a question was changed to avoid it being a leading question (Q7 in section 3).

- Changes were made in the age groups in the demographic section (section 4).

4.11 Ethical issues

Ethical issues were considered and procedures followed. These include:

- A research ethic application describing the research objectives, methods, instruments, and participants was submitted to the research ethics committee at Brunel University London for its approval to undertake this empirical study. The ethics committee reviewed the application and granted the ethics approval for this study (Appendix-1).
- A support letter for this study was obtained from the Head of Nuclear Medical Council, Ministry of Health, Kuwait (Appendix 3).
- Informed consent was obtained from all participants for both the interviews and the questionnaire using a consent form that explained the research objectives and background to the research (Appendix-5).
- Participants were informed in the consent form that participation in the study was voluntary and that they could withdraw from the study at any time.
- Participants were informed in writing and verbally of the anonymity and confidentiality in storing and analysing their data and communicating the study findings.
- During the final stage of the research, an extended ethics approval from Brunel University was also obtained for holding a focus group meeting of radiologists in the UK (Appendix-2).

- The internet is considered to be an essential medium for retrieving and exchanging data due to its ease of use and the richness of contents; however, there are many ethical issues in using online data and quoting and publishing opinions of participants without their permission (Sixsmith and Murray, 2001).
- To address the ethical issues involved in the collection of data by observation of online discussion groups, the opinions of the online group discussion participants were reported anonymously without presenting the name of the discussion group or the name of individual used in the discussion groups (Eysenbach and Till, 2001).

4.12 Summary

This chapter presents the methodological approach adopted in this study. After presenting methodological issues in general, the methodology used in undertaking this study was described. The methodology of this study involved epistemological philosophy and the pragmatism paradigm, which led to adoption of the inductive approach and application of mixed methods, which included semi-structured interviews, questionnaire surveys and unstructured observations. The process of designing the interview structure and questionnaire survey was followed by a pilot study on four radiologists at Al-Farwaniya hospital in Kuwait. Ethics approval for this study was obtained from the Brunel University Research Ethic Committee prior to collection of data in the main study. After data collection, analysis of data was undertaken. This process is illustrated in Figure 4-7 and described below.

Following the findings of the literature review on the PACS presented in chapter 2, the structure of the interviews (Appendix-7) was developed. The interview structure comprised four themes: usage of current PACS; limitations in current PACS; additional features that can increase PACS functionality; and expectations from the next generation PACS. The themes of the interviews were validated by radiologists (n=4) working at Al-Farwaniya Hospital in Kuwait.

Thereafter, a survey questionnaire (Appendix-8) was developed. The questionnaire comprised four sections: information regarding the use of PACS (section 1); perception about the next generation PACS (section 2); comfort with the technology (section 3); and demographic and background characteristics of the participants (section 4). The content validity of the survey questionnaire was checked by two academic experts in designing questionnaires and three postgraduate research students experienced in the process of designing questionnaires from Brunel University London. The survey questionnaire was pilot tested on four radiologists at Al-Farwaniya hospital in Kuwait A few minor adjustments were made in the survey questionnaire in the light of the findings of the pilot study.

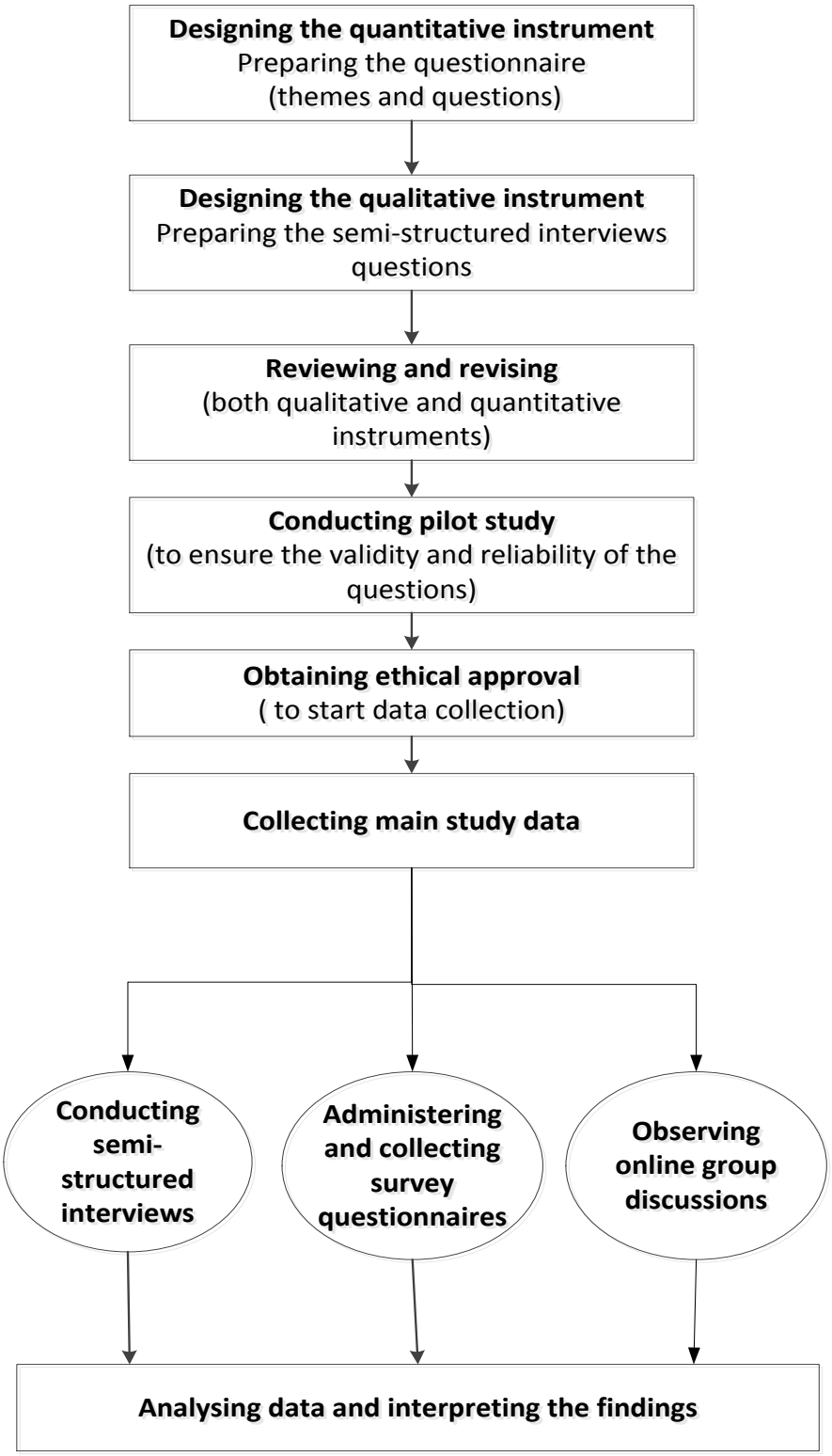


Figure 4-7 Illustration of the data collection and analyses process

Prior to approaching participants for the interviews and questionnaire survey, an ethics approval for the present research was obtained from the research ethics committee at Brunel University, London (Appendix-1). In addition, permission (as a support letter) for the study was obtained from Ministry of Health, Kuwait (Appendix-3).

Data were collected: by semi-structured interviews involving six radiologists; questionnaire surveys involving a sample of 120 out of 200 radiologists; and unstructured observations of four online discussion groups on the PACS, which was observed every three months periodically over a period of 24 months i.e. from January 2014 to December 2015. Qualitative data collected in the interviews and observations were inductively analysed by thematic analysis using the NVivo software and the quantitative data collected by survey questionnaires were entered onto the Microsoft Excel spreadsheet and analysed using the frequencies and descriptive statistics. The findings of the data analysis are presented in the following chapter.

5 Chapter Five: Data Analysis and Results

This chapter presents results of this study. This chapter is divided into three sections: findings of the semi-structured interviews; results of the questionnaire survey; and findings of the observation of online group discussions on PACS.

5.1 Data analysis and Findings of Semi-structured interviews

5.1.1 Study area

The interviews were conducted at Al-Sabah Hospital, which is one of the main government hospitals in Kuwait. The Al-Sabah Hospital was selected because it has a large radiology department and a large number of radiologists work there including trainee radiologists. In addition, this hospital is a centre for training radiologists.

5.1.2 Study population and sample size

Radiologists formed the research population of the semi-structured interviews, which involved a sample of six radiologists at the Al-Sabah Hospital in Kuwait. The radiologists who participated in interviews included two senior radiologists, two junior radiologists, and two trainee registrars. These radiologists were selected for interviews on the basis of different years of experience, which might affect the level of using of and experience with PACS. The interviews were arranged with the participating radiologists in the radiology department at the Al-Sabah Hospital in Kuwait.

5.1.3 Data collection and analysis procedure

Interviews were conducted with radiologists (n=6) to inform the research questions of this study. The participating radiologists were asked questions on different PACS

related issues: mainly on user preferences for selecting PACS and the most modern advanced technology and approaches in PACS. The researcher explained the objective of the study to all the interviewees and provided a consent form for the radiologists to participate in the study. All six interviews were conducted in English Language and were digitally audio tape recorded.

The interviews were transcribed and analysed thematically using the thematic data analysis technique (Braun and Clarke, 2006). The interview data were coded inductively and then the codes were categorised to form larger themes using the theory driven themes. Codes that did not fall in the theory based themes were categorised into new data driven themes. The interview data were analysed thematically using NVivo® software (version 10 for Windows).

The specific steps involved in the data analysis process were as follows:

a) Transcription of the audio recordings.

b) Reviewing of the interview data transcripts

c) Transferring the data transcripts on to NVivo® software

d) Creating nodes (codes) as sub-themes for each topic.

e) Merging similar sub-themes together to form larger themes.

The thematic analysis of the qualitative interview data led to identification of six major themes:

I. Limitations in current PACS

II. Features and requirements that can increase PACS functionality

III. Web based solutions for PACS

IV. PACS on mobile phones

V. Full integration of voice recognition in PACS

VI. Training and development of PACS users

Each of the above mentioned six larger themes comprised a number of sub-themes (topics), which related to specific questions asked in the interviews (Table 5-1)

Table 5-1 Themes and subthemes identified in interviews with radiologists

Question No.	**Themes and sub-themes**	
Q. 5	**Theme 1: Limitations in current PACS**	
	Sub-theme 1	Restricted access to PACS
	Sub-theme 2	PACS acts as a single unit in each hospital with minimum connection among different hospitals
	Sub-theme 3	Not all PACS systems are connected with other systems such as hospital information system (HIS) and radiology information system (RIS)
	Sub-theme 4	No proper PACS application for mobile phones
	Sub-theme 5	Limited number of accessible PACS stations
Qs. 6,7,8,9	**Theme 2: Features and requirements that can increase the PACS functionality**	
	Sub-theme 1	Connecting PACS to the Internet and Web cloud
	Sub-theme 2	Multi-site PACS integration
	Sub-theme 3	Linking data with the patient's hospital ID and civil ID
	Sub-theme 4	Merging PACS with all other radiological display systems to provide all radiological images in one unit

	Sub-theme 5	Increasing the storage capacity of PACS
	Sub-theme 6	Having multiple windows in the PACS
Q.10	**Theme 3: PACS on mobile phones**	
	Sub-theme 1	Launching PACS applications on mobile phones
Qs. 11,12	**Theme 4: Using web based solutions for PACS**	
	Sub-theme 1	Integrating PACS between different hospitals (inter hospital PACS connectedness)
	Sub-theme 2	Connecting PACS with other systems such as Hospital Information System and Radiology Information System (inter hospital system PACS connectedness)
	Sub-theme 3	Accessing PACS on the Internet
Qs. 6,7,8,9	**Theme 5: Full integration of voice recognition in PACS**	
	Sub-theme 1	Full integration of voice recognition in PACS
Qs. 5, 6,7,8,9	**Theme 6: Training and development of PACS users**	
	Sub-theme 1	Lack of proper training on PACS
	Sub-theme 2	Educating radiologists about the upcoming mobile PACS application

The findings regarding each of the six larger themes are presented below.

5.1.4 Limitations in current PACS

The interviews with the radiologists revealed that current PACS has limitations including: access to PACS restricted to office only; PACS as a single unit in each hospital with minimum connection among different hospitals; no access to PACS from home; no universal PACS connection with other hospital systems including HIS

and RIS; no proper PACS application for mobile phones; limited number of accessible PACS stations; and insufficient training on PACS.

5.1.4.1 Restricted access to PACS

The participating radiologists reported issues of restricted access to PACS outside their departments, which was limiting the use of the PACS. A radiologist expressed this issue by saying:

> *"Well... The Current limitations for me as a junior radiologist or registrar are that I don't have an access from home...I don't have like connection or web address to connect from any PC that I can't login into the PACS..."* (Junior radiologist # 1)

Another, radiologist complained of having no access to PACS from home, which was restricted to only senior radiologists. He said:

> *"Second thing we don't have PACS access at home especially for the PACS system in Sabah hospitals...Ah... We have only home access for the head of the department and some seniors in our department."* (Junior radiologist # 2)

5.1.4.2 PACS acting as a single unit in each hospital with minimal connection between hospitals

A further limitation of PACS was reported as the lack of connectivity between PACS in different hospitals. This issue was raised by senior, junior and trainee radiologists. A senior radiologist put this issue in the following words:

"Mmm I think connecting with other hospitals archiving system so we will have access to patient images, which is done in other hospitals to follow the patient case." (Senior radiologist # 1)

This issue was raised by a junior radiologist who said:

"The limitations may be the access to others hospital in Kuwait using PACS system…" (Junior radiologist # 2)

The lack of connection between PACS in different hospitals was also raised by trainee radiologists. A trainee radiologist expressed these issues by saying:

"Limitations is like when you want to retrieve images from other hospitals, sometimes we cannot if the patient study is done in another hospital, you can't take it because there are no connection between PACS systems in different hospitals" (Trainee radiologist # 1)

5.1.4.3 Not all PACS systems are connected with other hospital systems

Radiologists participating in this study complained about the lack of connectivity of PACS with other hospitals systems such as the HIS and RIS. A senior radiologist raised this issue and said:

"….also connecting PACS with the hospital information system (HIS) so we will have access to the patient file and information easily in the same system." (Senior radiologist # 1)

This issue was also raised by a junior radiologist as follows:

"…plus we don't have in our PACS in our hospital Sabah hospital connection to the HIS so I can't view the images or the PACS images from other computer in

another department. I can only view the images in radiology department." (Junior radiologist # 1)

5.1.4.4 No proper PACS application for mobile phones

The lack of applications for PACS on mobile phones was also reported as a limitation of the current PACS. This issue was reported as under:

"…Another limitation is that we don't have a proper application for the mobile like for the androids or for the IOS. Still so may be from any upcoming years." (Junior radiologist # 1)

5.1.4.5 Limited number of accessible PACS stations

Radiologists considered the limited number of accessible PACS stations as a limitation in the current PACS. A senior radiologist described this limitation by saying:

"We need to increase the capacity of the PACS …the number of PACS stations…we are in need for more PACS stations" (Senior radiologist # 1)

5.1.5 Features and requirements that can increase PACS functionality

Radiologists reported a number of features and requirements that could enhance the functionality of the PACS. The features and requirements suggested by the radiologists were as following.

5.1.5.1 Connecting PACS to the Internet and Web cloud

Most of the respondents raised the issue of the importance of having PACS access on the Internet, such as a website for use with mobile phones, IPads or personal computers (PCs) at home. This would allow direct use of PACS to access medical images from other hospitals and so minimise the need to ask the patient to bring

their old images and study images. It would also allow to report on medical images from home.

The availability of PACS on the Internet was described by radiologists in the following way:

> *"What feature can increase PACS functionality...like if it is connected to the Internet… You can go directly to the Internet if you have something, you can collate disease together with each other so you know normal finding or it is an abnormal finding if you have all the studies I mean but sometimes you have asked the patient to bring his studies from different hospitals and you have to merge them together and put them in the system".* (Trainee radiologist # 1)
>
> *"I think ah ah! if it is used by an internet access like by phone, Ipad, or my computer at home it will be more functional and you can work even at home to report your cases...So even if you don't have time to report them at the hospital you can also continue your job at home*". (Junior radiologist # 2)

5.1.5.2 Multi-site PACS integration

Most of the radiologists agreed that integrating PACS between hospitals would increase the functionality of PACS. They stated that with multi hospital PACS they would be able to access full record of patients and follow reports of their medical investigations and procedures.

A senior radiologist explained this issue as follows:

> *"I mean… multi hospitals PACS...I mean, if a patient gets scanned at different hospitals and comes for us scan again at this hospital it is easier if it is*

connected, so we don't have to ask about the CD and upload them to the system…and look at them" (Senior radiologist # 2)

Some of the interviewed radiologists also suggested that multi-site PACS integration and PACS integration with health information systems in hospitals will be a good feature for using PACS.

"Again by implementing all the PACS systems and integrating PACS with health information systems in all hospitals in Kuwait because not all of them are connected." (Junior radiologist #1)

5.1.5.3 Linking data with the hospital ID and civil ID of the patient

The participants suggested linking data and images with a single patient ID, which could be the hospital ID or civil ID.

"I think the main item is they keep all the data of the patient on his ID/civil ID for all international use… Or even local in the country so I can see all the studies of the patient and even medical reports and surgical reports in anywhere in the same country….so it is a problem for us …so I heard about a communication like this…They are trying now to put the archiving and communication system of the patients on his civil ID number for all studies of the patient not like us…please bring your old images like MRI from (xx- name of the hospital omitted) hospital or your operative report from elsewhere…it is a problem for us…" (Senior Radiologist #1)

5.1.5.4 Merging PACS with all other radiological systems to create a single radiological display unit

For some radiologists, merging the PACS with other radiological systems in order to allow all radiological images to be viewed in a single unit was an important feature that would led to increased use of PACS. This issue was reported as under:

> *"The problem in our department …We only have access for ultrasound, CT, MRI… We can't see the X-ray, the simple X-ray images for the patient in Codac software…, which is another system to look for the X-rays of the patients. It is better that for each patient, all the radiological investigations will be under his name under a file name…So we can go through all the images of the patient instead of using Codac for plain X-ray and GE for the CT, ultrasound. This is wasting (of) time". (Junior radiologist # 2)*

5.1.5.5 Increasing the storage capacity of PACS

While talking about the features for enhancing PACS, a senior radiologist suggested increasing the storage capacity of the PACS, which would help them, for example, in storing and retrieving old images. He said:

> *"I mean...it may be the storage...I mean we could retrieve all images...more easily…or they are available all the time that could be helpful. So,...the storage backup of the old images...if it is there or… at the different hospitals…if the scan (is) done at different hospitals we don't have access to those images." (Senior Radiologist #2)*

5.1.5.6 Having multiple windows in the PACS

One of the respondents recommended having multi-windows PACS. Such a PACS would improve the PACS functionality by reducing the need to close the whole PACS system just to open the Word application.

5.1.6 Using web based solutions for PACS

In response to a question that determined the opinions of the radiologists regards using Web PACS solutions such as multi-hospital PACS and PACS on mobile phones, all six respondents agreed that such solutions for PACS could solve the problems of traditional PACS. They all had a positive expectation of using the central PACS that connected hospitals together as a single unit.

Two radiologists mentioned that the stakeholders are proceeding to do this but it is so far not well developed. One radiologist expected that with central PACS, access to the data would increase to the level of students, residents, doctors, researchers, and conferences as well. The solution would facilitate sharing information and doing consultation between radiologists in separate departments and provide better patient care and services. It would also make it easier to have direct access to the patient medical record. One radiologist added that it would be better to have a full electronic record to overcome the issue of reading the handwriting in a request as he described it as a problem for them and they misread handwriting of some of the doctors.

5.1.7 PACS on mobile phones

As a result of the question about determining the expectations of the radiologists regarding the use of mobile phones as a method for retrieving and displaying medical images, all of the respondents agreed that putting PACS on mobile phones

would be very helpful, especially in emergency cases. Some of them had concerns about the screen size and image resolution, but they believed that the new technologies in the smart phone would support proper PACS applications to be used in mobile phone. A junior radiologist said:

> *"I think it's helpful and very effective not only for working, but also for teaching like me as a resident. I can go for other cases interesting cases at home so it helps me not only for work, but even for learning in advance so by mobile I can discuss the cases with my friends like any resident in other hospitals like I want to show him a case I can use my mobile to show him and vice versa. Even the other resident (radiologists) in other countries can share images on phones so both of us can have access to all PACS systems in Kuwait by phone. It will be a very nice idea!"* (Junior Radiologist # 2)

In addition a senior radiologist said:

> *"….also regarding PACS on mobile phones...our junior radiologists now tend to use their mobile phones sometimes to send me a video recording of images by mobile phone ...to give them consultations. But there is a probability of missing some features...but I think it is better to have a special application on mobile phone for displaying radiology images...to help the junior radiologists in taking consultations from the seniors. If the senior is elsewhere" (Senior Radiologist #1)*

In addition, one of the radiologists said that putting PACS on mobile phones will be an important feature in PACS functionality.

5.1.8 Full integration of voice recognition in PACS

Full integration of voice recognition in PACS to enhance its functionality is already supported. However, providing training in the use of voice recognition in the PACS was needed by some radiologists. A trainee radiologist stated:

> *"Ah, some doctors use voice recognition but it is only for certain doctors and not all the doctors know how to use it and they didn't provide us with any training on how to use voice recognition in PACS system.. But only they provide the equipment without any training".* (Trainee radiologist # 1)

5.1.9 Training and development of PACS users

This theme comprised the following two sub-themes.

5.1.9.1 Lack of proper training on PACS

The issue of proper training on PACS was also raised in connection to the limitations of PACS. Raising the issue of training in PACS, a trainee radiologist said:

> *"The current limitations of picture archiving and communication system in my opinions …the training .We are not trained for using PACS and…Ah! This is the most common. Yes."* (Trainee radiologist # 2)

5.1.9.2 Educating the radiologists about the upcoming mobile PACS application

A junior radiologist suggested a need for training especially about the forthcoming PACS applications on mobile phones. He said:

"Plus aa…ah…ah educating the radiologists about the mobile applications...so it will be more easy and more functionality em…em.. that it." (Junior radiologist #1)

5.2 Data analysis and results of the questionnaire survey

A questionnaire survey was conducted involving radiologists working at six main government general hospitals (Al-Sabah, Mubarak, Al-Jahra, Al-Adan, Al-Farwaniya, and Al-Amiri) in Kuwait (Table 4-2). There are 200 radiologists working at six Kuwait governmental hospitals; however, it was not possible to contact all the radiologists working in these hospitals during the period of the study as some were on vacation or otherwise absent. Therefore, only 120 questionnaires were distributed in August 2014. All 120 distributed questionnaires were returned completed, with a response rate of 100% (Table 5-2). The effective sample size in the study covers 60% of the whole population. Questionnaire survey was conducted in English language because the participants were radiologists were working in Kuwait where English is the second official language in the country. In addition, the participants were radiologists who studied their medical degree and post-graduation in English language.

Table 5-2 Number of questionnaire surveys distributed, returned and response rate

Number of participants Contacted / questionnaire surveys distributed	Number of completed questionnaires returned	Response rate (%) (Percentage of complete questionnaires returned)
120	120	100%

The results of the questionnaire survey are reported below by each of the four sections included in the survey questionnaire.

5.2.1 Section-1 Background Information

This section included four questions and results regarding these questions were as follow.

5.2.1.1 The use of PACS, Internet, and smart phones at work (Q. 1)

This question was asked to determine the percentage of using PACS, Internet, and smart phones in work. The results showed (Figure 5-1) that most of the radiologists were always using PACS at the work (98%) followed by using the Internet at the work (44%), and then using smart phones at the work (42%).

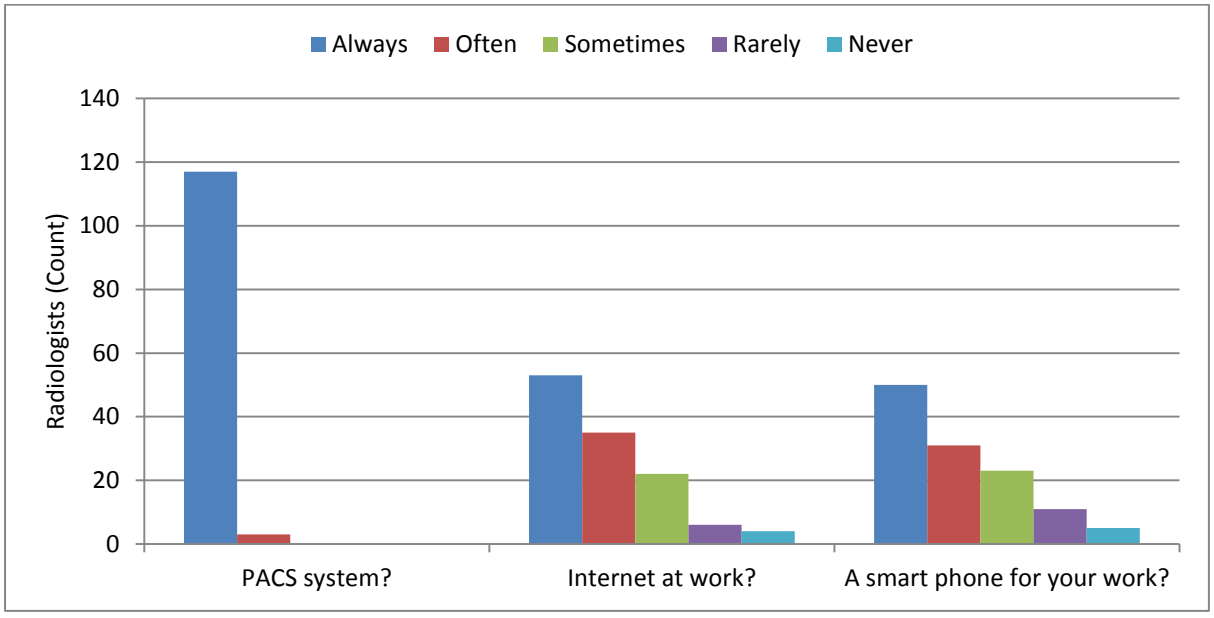


Figure 5-1 Use of PACS, Internet, and smart phones at work

5.2.1.2 The level of satisfaction on the current Picture Archiving and Communication Systems (Q. 2)

This question was asked to determine the level of the user satisfaction with the current PACS. Results (Figure 5-2) revealed that almost four out of ten (38%) radiologists were extremely satisfied with the system while a little more than a half (52%) of the participating radiologists was slightly satisfied with the current PACS. The percentage of radiologists slightly dissatisfied and extremely dissatisfied with the current PACS was very low i.e. (8%) and (2%) respectively.

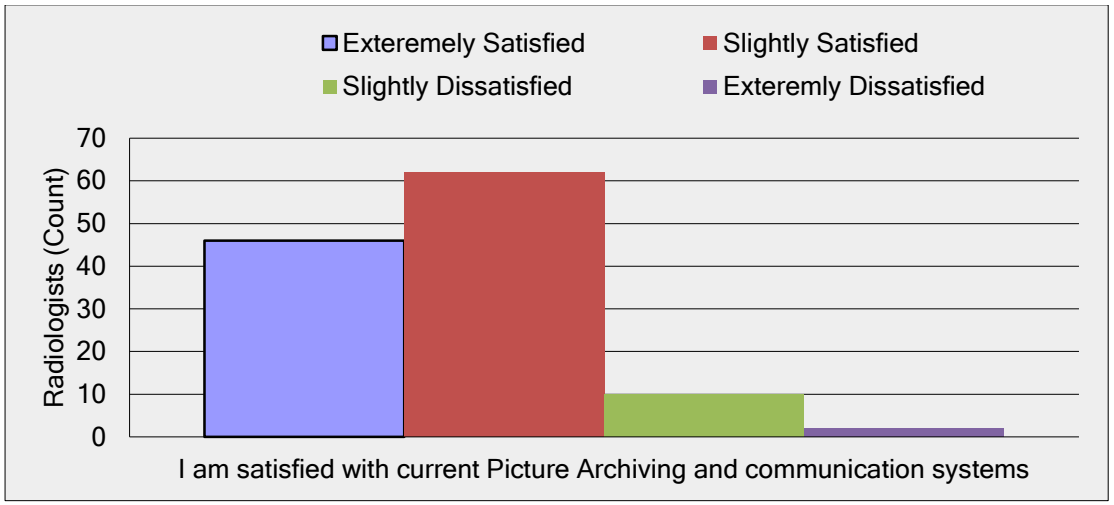


Figure 5-2 Radiologists' level of satisfaction with the current PACS

5.2.1.3 Issues of concern in the current PACS (Q. 3)

This question was asked to determine the factors that can limit PACS functionality. The results showed that the majority (70%) of radiologists agreed or strongly agreed with the statement that there was no PACS connection between hospitals, whilst 30% of the radiologists disagreed or strongly disagreed with the statement (Figure 5-3).

Regarding the issue of limited search functionality of the system, 57% of radiologists agreed or strongly agreed with the statement while 43% of participating radiologists disagreed or strongly disagreed (Figure 5-3). Note one of the participants omitted this part of the question.

About the issue of restricted access to the PACS in office only, results revealed that there was an equal percentage of radiologist who agreed (50% agreed or strongly agreed) and disagreed (50% disagreed or strongly disagreed) with the statement (Figure 5-3).

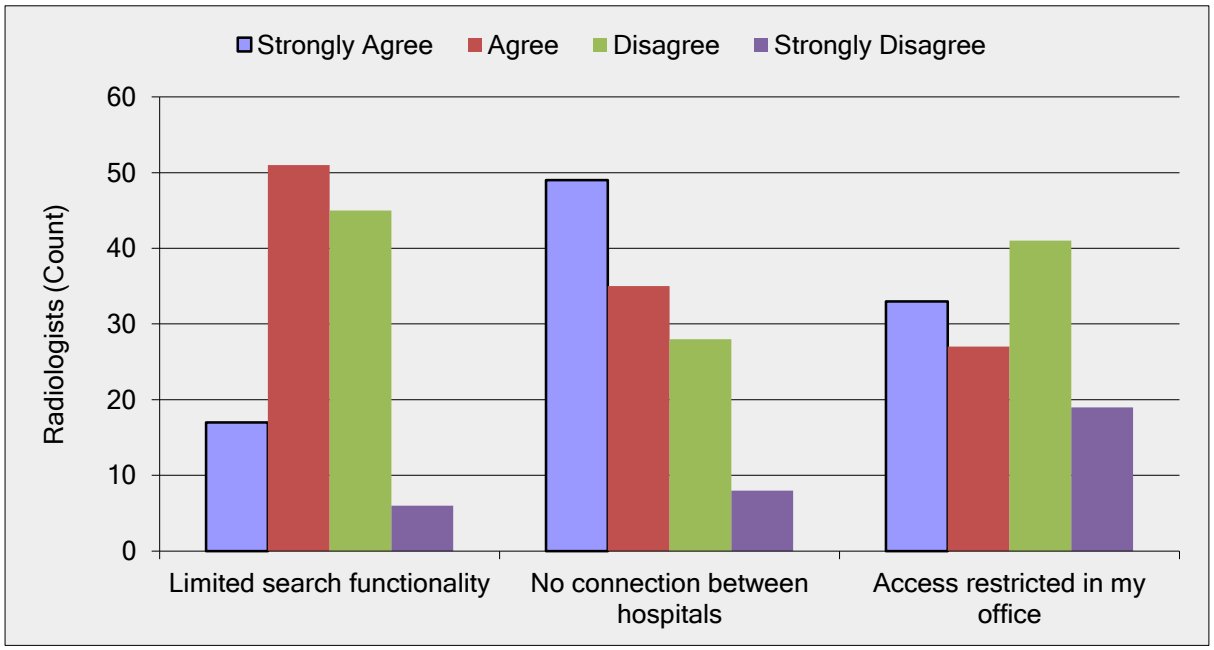


Figure 5-3 Issues of concern in the current PACS

5.2.1.4 Web PACS solutions such as multi hospital PACS and PACS on mobile phones could be a solution for handling the previous issues (Q. 4)

This question was asked to determine the opinion of radiologists about using web based PACS such as multihospital PACS and PACS on mobile phones as a solution to the traditional PACS limitations. The results (Figure 5-4) showed that 64% of the

radiologists strongly agreed and 33% of them agreed with these solutions whereas, only 3% of them disagreed and no one of them strongly disagreed with these solutions.

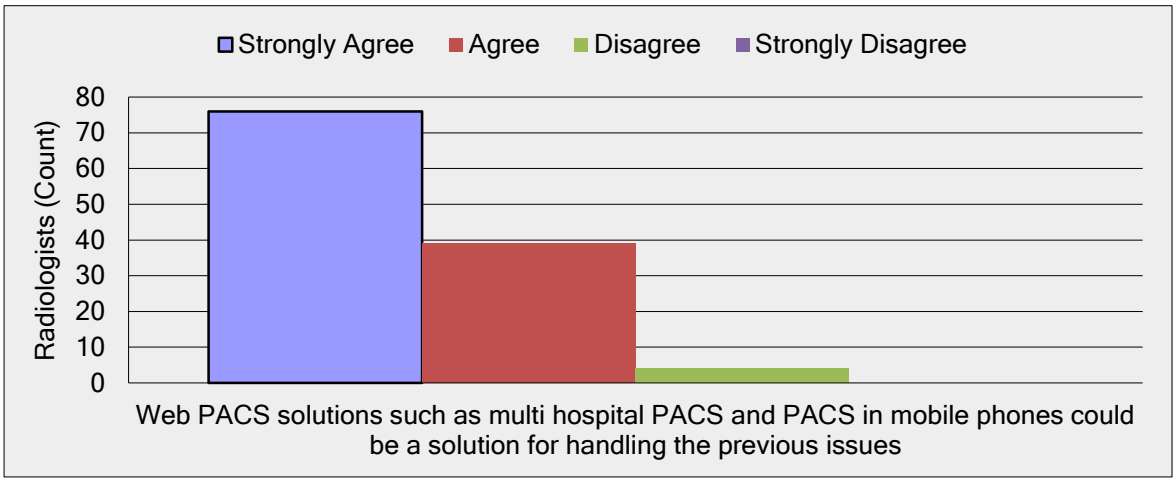


Figure 5-4 Using web based solutions for PACS

5.2.2 Section 2 Perception of next Generation PACS

This section included only one question (Q. 5) to determine the opinion of radiologists about some of the future trends in PACS. Question (Q. 5) asked for radiologists' level of agreement with four statements. The results showed that most of the radiologists agreed and welcomed the new techniques and approaches in the PACS industry for the best next generation PACS functionality. The results regarding each of the four statements included in this section were as under.

5.2.2.1 There is a potential role for advanced Information and Communication Technology (ICT) in improving health care services

There was complete agreement (100% agreed and strongly agreed) that there was a potential role for advanced Information and Communication Technology (ICT) in improving health care services (Figure 5-5).

5.2.2.2 Providing PACS on mobile phones can provide flexible access to medical images anywhere at any time.

Results (Figure 5-5) revealed that most of the radiologists strongly agreed and agreed (97%) with the statement that providing PACS on mobile phones can offer flexible access to medical images anywhere at any time whilst only a few disagree with the statement (3%). No one strongly disagreed with this statement.

5.2.2.3 Providing PACS on mobile phones as an application can provide better patient services especially in emergency cases.

Results showed the majority (95%) of the radiologist strongly agreed and agreed with the statement that providing PACS on mobile phones as an application can provide better patient services, especially in emergency cases (Figure 5-5). Results also revealed that only 5% of radiologist disagreed with this statement and no one strongly disagreed with the statement.

5.2.2.4 Connecting hospitals with single multi-site PACS can improve PACS functionality and productivity

Regarding the statement of connecting hospitals with single multi-site PACS can improve PACS functionality and productivity, results showed that 99% of radiologists strongly agreed and agreed with the statement while only 1% disagreed and no one strongly disagreed with the statement (Figure 5-5).

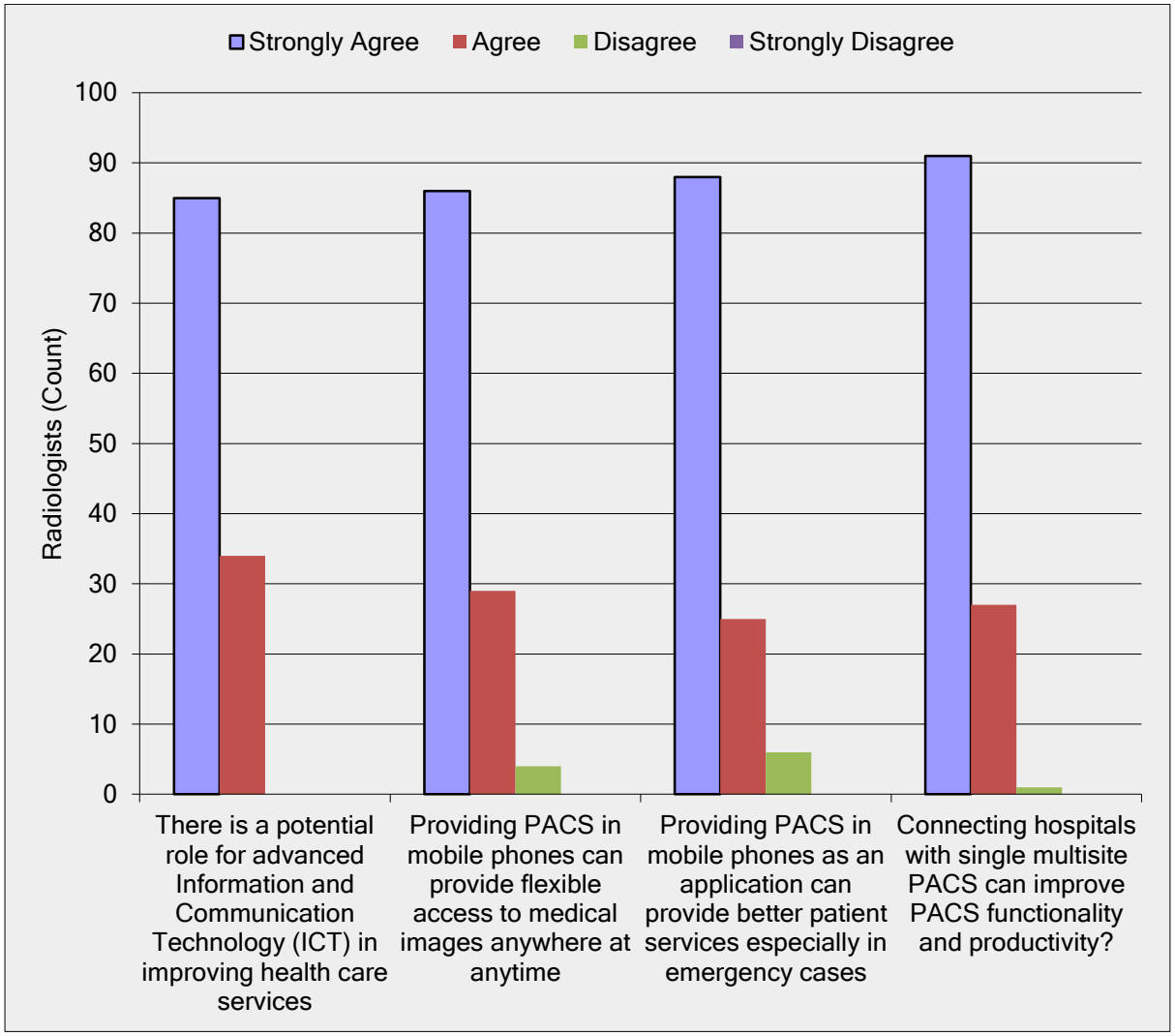


Figure 5-5 Perception about the next Generation PACS

5.2.3 Section 3 Comfort with technology

This section included two questions regarding technology: Question 6 asked radiologists six statements about their comfort with technology and Question 7 asked their opinions on nine issues that could affect the adoption of web PACS solutions. Results were as follows.

5.2.3.1 Comfort with technology (Q 6)

a) I can trust the technology at work

Results regarding this statement revealed that 52% of radiologists trusted and 47% strongly trusted technology at work. In contrast, only 1% of radiologists disagreed and none of them strongly disagreed with the statement (Figure 5-6).

b) I am happy in using ICT/internet for the purpose of patient care

Results showed that 68% of the radiologists were very happy in using ICT/internet for the purpose of patient care and 30% were just happy about using it (Figure 5-6). However, only 2% of the radiologists disagreed and none of them strongly disagreed with using ICT / the internet for patient care and education (Figure 5-6).

c) I would like to use ICT / Internet to communicate medical images and information with other health institutions

Results showed that all radiologists strongly agreed (69%) and agreed (31%) to use ICT / Internet to communicate medical images and information with other health institutions (Figure 5-6).

d) I would like to consult large centres in my specialty using patient medical images and information

Regarding this statement, results revealed that 97% radiologists strongly agreed and agreed to consult large centres in their specialty using patient medical images and information (Figure 5-6). Only 3% disagreed and none strongly disagreed with the statement (Figure 5-6).

e) I would like to have access to medical images and data anywhere at any time

Results about this statement showed that 98% of radiologists strongly agreed and agreed to have access to medical images and data anywhere at any time. Only 2% of participants disagreed with this statement and no one strongly disagreed (Figure 5-6).

f) The web PACS solution can be integrated within our existing system

Results revealed that 95% of participant radiologists strongly agreed (61%) and agreed (34%) with this (Figure 5-6). Only 5% of the total radiologists disagreed while none strongly disagreed with the statement (Figure 5-6).

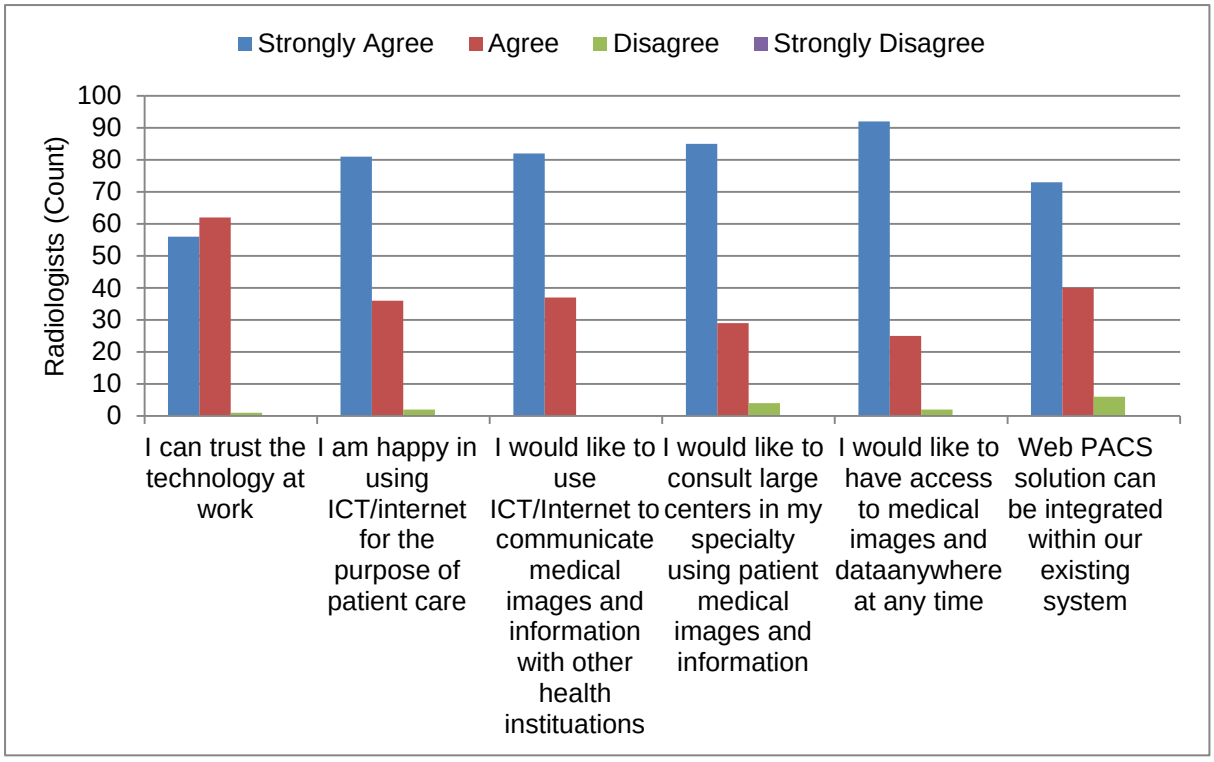


Figure 5-6 Comfort with technology

5.2.3.2 Issues that could affect the adoption of web PACS solutions (Q 7)

Results on the opinions of radiologists regarding nine statements included in this question were as follows.

a) High cost

Results of the questionnaire survey revealed that 76% radiologists agreed (strongly agreed = 20% and agreed = 56%) with the statement that high cost could affect adoption of web based PACS solution. The remaining (24%) of participants either disagreed (22%) or strongly disagreed (2%) with this statement (Figure 5-7).

b) Negative attitudes of staff involved

Regarding the statement that negative attitudes of staff could affect adoption of web based PACS solution, a little more than half (53%) of the participant radiologists agreed (strongly agreed = 15% and agreed = 38%) whilst the remaining (47%) of radiologists disagreed (41%) and strongly disagreed (6%) with this statement (Figure 5-7).

c) Suitable training in the use of system

Results revealed that the majority (85%) of participants agreed (strongly agreed = 32% and agreed = 53%) that suitable training in the use of system is important for the adoption of web based PACS solution; however, the rest of participants either disagreed (13%) or strongly disagreed (2%) with the statement (Figure 5-7).

d) Perceived increase in workload

Results of the questionnaire survey showed that a little more than six out of ten (63%) radiologists agreed (strongly agreed = 9% and agreed = 54%) with the

statement (i.e. perceived increase in workload in Using web based solutions for PACS) whereas 32% radiologists disagreed and 5% radiologists strongly disagreed with the statement (Figure 5-7).

e) Technical concerns

Regarding the statement that technical concerns would affect the Web based PACS solution, results showed that 91% participant radiologists agreed (strongly agreed = 18% and agreed = 73%) with the statement and only 9% of the participants disagreed and none strongly disagreed with the statement (Figure 5-7).

f) Lack of user-friendly software

Results showed that the majority (69%) of participants either agreed (57%) or strongly agreed (12%) with the statement that the lack of user-friendly software could affect the web based PACS solution; however, the remaining (31%) of the participants disagreed (29%) and strongly disagreed (2%) with the statement (Figure 5-7).

g) Lack of perceived clinical usefulness

Results of the questionnaire survey revealed that a little more than half (55%) of the respondent radiologists agreed (strongly agreed = 13% and agreed = 42%) with the statement that the lack of perceived clinical usefulness could affect the web based PACS solution (Figure 5-7). However, the remaining (45%) participant radiologists disagreed (disagreed= 37% and strongly disagreed = 8%) with the statement (Figure 5-7).

h) Lack of consultation with clinicians

Regarding the statement that the lack of consultation with clinicians was an issue that would affect the adoption of web-based PACS solution, results revealed that the majority (63%) of radiologists agreed (strongly agreed = 16% and agreed = 47%) with the statement whereas the remaining (37%) participant radiologists disagreed (disagreed= 31% and strongly disagreed = 6%) with the statement (Figure 5-7).

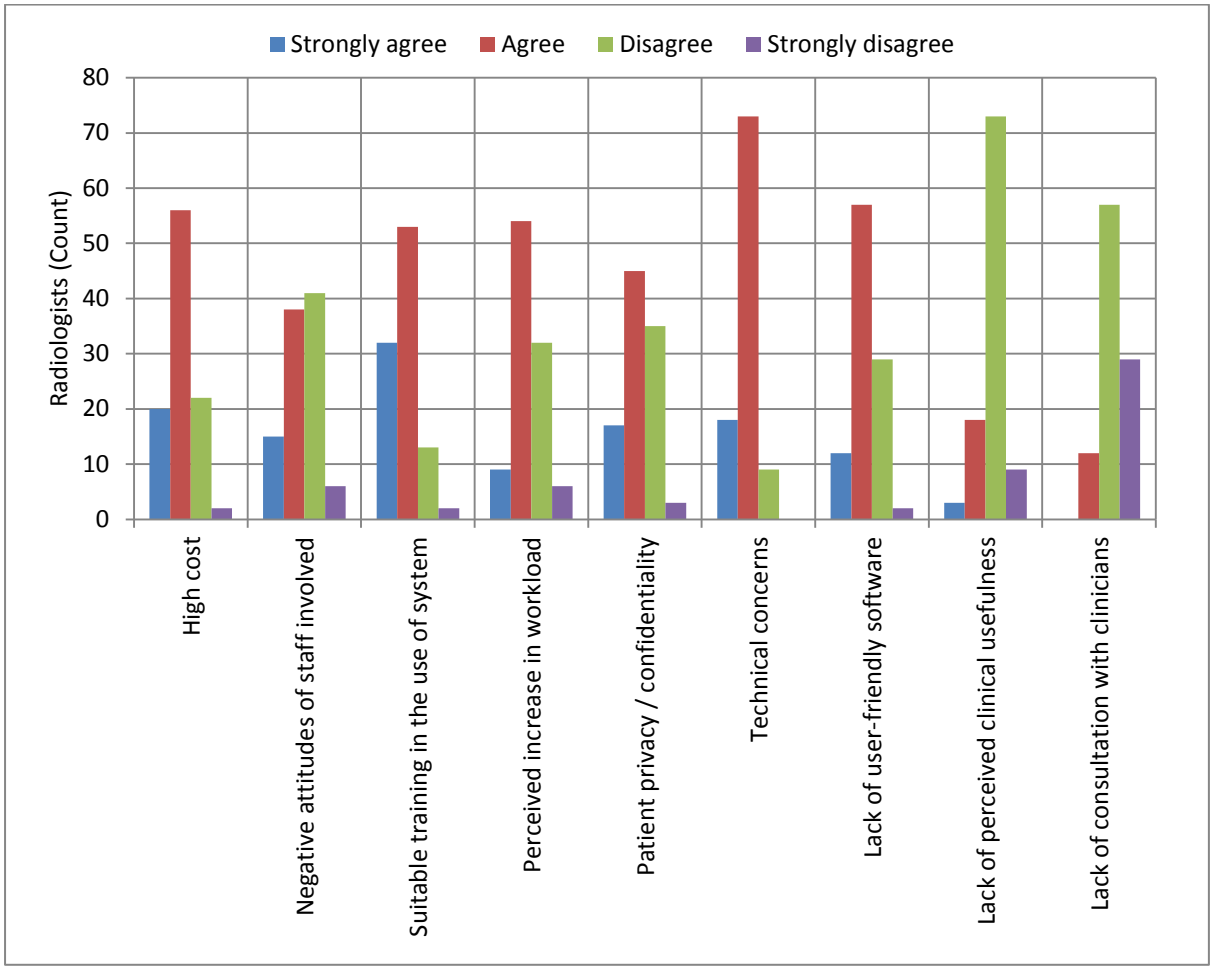


Figure 5-7 Issues that could affect the adoption of web PACS solutions

5.2.3.3 Open comments by questionnaire survey participants

Nine participant radiologists provided open comments in the completed questionnaires. The comments are shown in Table 5-3.

Table 5-3 Open comments by participants of the questionnaire survey

#	**Open comments**
1	I need multi sites PACS as interventional radiology because I move always.
2	It's the lack of technical in the generation that limit the evolution of PACS. Non specialised people are taking the decisions on the PACS and other health information system services.
3	Clinical data should be provided on PACS. All medical institution should be connected on PACS number of PCS should be increased.
4	Diagnostic quality of mobile computing device screen.
5	We need PACS connecting between the hospitals and provides us with more PACS computer systems because if the large number of doctors in each hospitals.
6	No HIS in most of hospitals. No electronic records.
7	Mobile and IPad PACS applications are widely discussed yet not applied. Hope to see sooner!
8	Provide a library for gynaecology, obstetrics and radiology text books.
9	Data mining facility for searching RIS for key words should be allowed. Radiologists should be able to carry out web based repository. All ministry radiologists should be able to do web based repository and validation from all hospitals. Local teleradiology in Kuwait.

5.2.4 Section 4 Demographic and background characteristics

a) Gender

75% were male and 25% were female.

b) Age

Results showed the ages of the respondents were:

21-29 years old – 6%

30-39 years old - 56%

40-49 years old - 24%

50-59 years old - 8%

60 years and above – 6% (Figure 5-8).

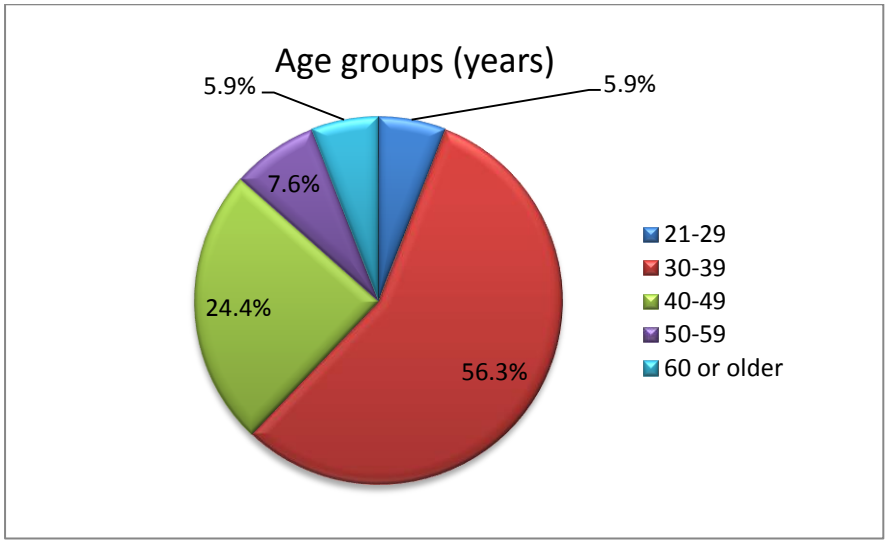


Figure 5-8 Age of participants

c) Current position

Results on the current position of the participating radiologists:

Trainee radiologist – 0%

Junior radiologists - 56.3%

Senior radiologists - 43.7%

d) Length of work experience in the present organisation

Results regarding the length of service revealed:

0 -5 years - 23%

5-9 years - 44%

10 years or more - 33%

(Figure 5-9).

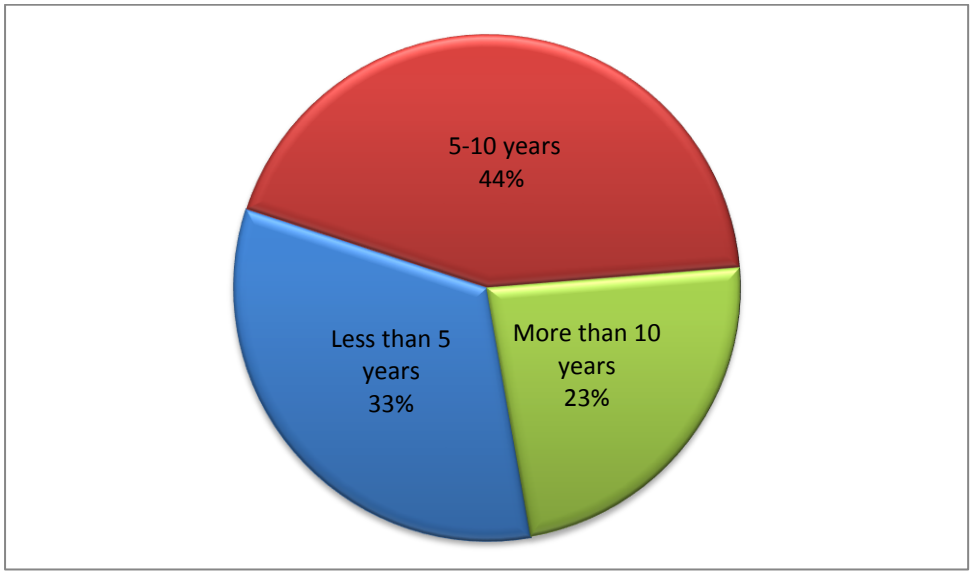


Figure 5-9 Length of work experience in the present organisation

5.3 Data analysis and findings of online discussions group on PACS

Results of the data collected by unstructured monitoring of four online discussion groups of PACS professionals on the LinkedIn website are presented here. The language of discussion in all four observed discussion groups was English. The total number of members per group varied from 502 members to 5,261 members (Table 5-6). Data collected from the four discussion groups are summarised in Table 5-6. Data comprised 250 comments (posts) made by 136 participants. Some participants made comments more than once; thus, there were 124 unique participants. The geographical location of these participants is presented in Table 5-4, which reveals that the participants were from 24 countries. The majority of the participants by the continent was from the North America (n=88, 71%) followed by Europe (n=16, 13%) and Asia (n=6, 5%). The maximum number of participants by the country was from the USA (n=81, 65%), followed by Canada (n=6, 5%) and the UK (n=5, 4%) (Table 5-4).

Table 5-4 Geographical location of participants of the observed discussion groups on the LinkedIn

	North America	**Europe**	**Latin America**	**Middle East**	**Asia**	**Africa**	**Australia**	**Information not available**
	USA = 81	Belgium = 3	Peru =1	Kuwait = 1	India =2	Botswana = 1	Australia = 1	1
	Canada =6	Spain = 2	Venezuela = 3	Saudi Arabia =3	China =1	Egypt = 1		
	Mexico =1	UK = 5	Panama = 1	UAE =1	Pakistan =3			
		Netherlands = 1						
		Germany =1						
		Switzerland =1						
		France = 1						
		Malta = 1						
		Norway = 1						
Total	88	16	5	5	6	2	1	1

The information extracted about the job roles of the discussion groups' participants is presented in Table 5-5, which shows that the majority of participants was Engineers and manufacturing managers (n=33, 26.6%) followed by IT and informatics consultants (n=30, 24.2%) and PACS administrators and implementers (n=29, 23.4%).

Table 5-5 Job roles / positions of participants of the observed discussion groups on the LinkedIn

Job Role / Position	**Count**	**%**
Engineers and manufacturing managers	33	26.6
IT and informatics consultants	30	24.2
PACS administrators and implementers	29	23.4
Miscellaneous	7	5.6
Sales and Marketing consultants	6	4.8
Regulators	5	4.0
Chief Executive Officers (CEOs)	5	4.0
Radiologists	4	3.2
Technologists	3	2.4
Clinicians	2	1.6
Total	124	100

The total number of comments (posts) extracted per group was 80 comments from group 1, 89 comments from group 2, 55 comments from group 3 and 17 comments from group 4. The total number of discussion threads (topics) monitored per group was seven threads each in group 1 and group 2, four threads in group 3 and three threads in group 4. Total number of participants making comments (posts) per groups was 56 in group 1, 50 in group 2, 35 in group 3 and 17 in group 4.

Table 5-6 Online discussion groups by total number of members, comments, threads and members making a comment

Discussion group ID	Number of members	Comments	Threads	Members making a comment
1	1,739	80	7	56
2	5,261	89	7	50
3	1,833	55	4	35
4	502	17	3	17
Total:	9,335	250	21	136

The nature of the discussion topics / threads was different in each discussion group apart from one topic, medical image viewer, which was present in group 1 (discussion thread No. 2) and group 3 (discussion thread No. 3) (Table 5-6).

Table 5-7 Breakdown of data collection by discussion groups and threads

Group	Discussion thread (topic)		Participants		Comments / posts
ID	#	Description	Total	Number of participants who also participated in other discussion groups and threads	
Discussion group 1	1	Future trends in picture archiving and communication system (PACS)	11	7	16
	2	Medical image viewer	4	2	4
	3	PACS and the EMR / EHR	6	2	8
	4	Critical problems and solution to consider while implementing open source PACS	5	3	8
	5	A plea to PACS and modality implementation engineers, change the default AE title.	18	5	28
	6	Concerns about the way US modalities number images	7	2	12
	7	DICOM for mobile devices	5	3	4
Discussion group 2	1	EMR and Imaging: Interface designs to enable viewing of patient images in an EMR / API, URL, PDF, SC and How well did it work, any pros or cons to share?	8	1	8
	2	How much should a PACS administrator know, do when it comes to (PACS) interfaces?	6	1	10
	3	The quest for IT expertise to support healthcare technology	4	1	4
	4	The RIS is dead	8	0	20
	5	Tracking patient radiation dose reports in PACS	7	2	25

	6	full functional PACS using DCM4chee and e-film workstation with some difficulties	5	1	5
	7	Problem in cardiology, the stress room when sending images to PACS it never goes on the first try, when sent a 2nd time it goes. Any thoughts why?	12	3	26
Discussion group 3	1	3D Mammography: Study storage	6	0	7
	2	Scoping and planning for new PACS project at a referral hospital	8	1	13
	3	Medical image viewer	7	2	14
	4	Import / Export DICOM on CD / DVD	14	1	21
Discussion group 4	1	Do we need a PACS solution?	9	2	9
	2	How to back-up EMR / PACS data, Tape, Optical Disk, or Hard Disk?	4	1	4
	3	What's the average cost for cloud based pay per use PACS?	4	1	4

5.3.1 Analysis and Findings

The thematic analysis of qualitative comments (posts) collected by unstructured observation of four online discussion groups of PACS professionals revealed eight themes as follows:

(1) Limitations in current PACS

(2) Features and requirements that can increase PACS functionality

(3) Using web based solutions for PACS

(4) PACS on mobile phones

(5) Vendor Neutral Archive (VNA)

(6) Full integration of voice recognition in PACS

(7) Providing backup solutions for PACS

(8) Training and development of PACS Users

The findings of each of the above mentioned eight themes are described below.

5.3.1.1 Theme 1- Limitations in current PACS

Under the theme of limitations of current PACS, four sub-themes were identified: critical problems for implementing open source PACS; image transmission issues; network hardware issues and difficulties in changing specific settings including IP (internet protocol), hostname, AET (application entity title); and hardcoded DICOM attributes (data element) (Table 5-8), which are presented below.

Table 5-8 Theme 1- Limitations in current PACS: Sub-themes

Thematic Group and Sub-themes	
Thematic Group 1: limitations in traditional PACS	
Sub-theme (1)	Critical problems for implementing open source PACS
Sub-theme (2)	Imaging transmission issues
Sub-theme (3)	Network hardware issues
Sub-theme (4)	Not allowing change IP, hostname, AET, or any hardcoded DICOM attribute

Critical problems for implementing open source PACS

The participants raised a number of critical problems in implementing open source PACS, including the issues of storage, databases, processing and migration.

> *"PACS is 50% software and 50% hardware, especially storage, database, processing. Getting these specifications right is very important."*
>
> *"Last but the most basic stuff, is plan for migration. This again first time PACS users will ignore and will realize the moment they are hit with bottlenecks like storage space." (Discussion group 1 , Discussion thread 4)*

Another issue reported with regard to use of an open source PACS was problems in workflow such as routing and reporting as under:

> *"Workflow, not all open sources provide the necessary workflow that fits your Radiology department, especially when it comes to Routing and Reporting. This needs additional software"*

The next issue in implementing an open source PACS was security and related protocols, which required additional software.

> *"Security and HIPAA, simple HTTPs are beyond the scope of the software's alone, it needs bit more than installing software."*

The issue of possible crash of an open source PACS system and its consequences were also raised as critical and costly issues.

> *"Disaster recovery, not many people see this important until you are hit with data-loss. I have seen hospitals don't invest on this, but spend thousands $$ when they get hit. Disaster recovery is not just storage - it includes Application*

and Database Servers. RAID, Server virtualisation are some of the key features of DR."

"One thing that enterprises both large and small need to realise is that Disaster Recovery is not backup. You can RAID a SAN, but if you lose the SAN, you still have no data. True Disaster Recovery is a replica either online or offline, of all your data in a different geographical location. That may be another rack in the server room, or an offsite location. Just remember a fire in the server room or burst water main above the server room that fills the server room with water, and you still has no data". (Discussion group 1, Discussion thread 4, # 3)

Imaging transmission / importing issues

Viewing old reports of a patient is important for providing better diagnosis and therefore better treatment; however, some participants raised the issue of difficulties in importing and transmitting images due to a variety of PACS CDs / DVDs by different vendors.

"A lot of the CDs from various vendors do not have the DICOM directory in the root directory of the CD/DVD. This causes a lot of issues. Options are to manually copy the DICOM files into the appropriate processing folder(s). Or to have the vendors re-burn the CD using strictly a DICOM format. A lot of vendors are using their own viewers on the CDs that use jpegs." Discussion group 3, Discussion thread 4, #11)

> *"I use a number of programs – send image… My biggest issue with CDs is that there are some vendors who don't send Part 10 files in their CD."* (Discussion group 3 , Discussion thread 4, # 12)

While other participant agreed that nowadays using CD/DVD is considered as a traditional way of exchanging data when all the reports and images could be presented for both the referring physicians and the patients through the internet.

> *"Why are facilities still using CD / DVD when study / report viewers can be made available to patients and ref physicians via the internet? (It) seems real time consuming and expensive."* (Discussion group 3, Discussion thread 4, # 13)

Network hardware issues

The issue of networking hardware was raised in the discussion as under:

> *"We have a problem in Cardiology, the Stress room. When sending images to our PACS it never goes on the first try, when sent a 2nd time it goes. Any thoughts why anyone? Thanks"* (Discussion group 2, Discussion thread 7, #7)

The participants replied that the issue was due to some network/hardware issues faced in the early generation of PACS. A participant referred this problem to the age of the PACS system and said that if it was used for about 10 years then it probably results in slow transmission of orders.

> *"Performance on the network is only as good as the weakest link. Any device that was put into place in the last 10 years is probably already at 100. Hard coding it can work for misbehaving devices, but this should not be necessary.*

Have your network person check the speed of the port that the device is connected to.

To check with the issue of difficulties in transmitting images, checking the network was advised in the group.

If you have a laptop with DICOM software, try plugging the laptop into the network in the same area and see if the performance is any different." (*Discussion group 2, Discussion thread 7, #7)*

Additional suggestions such as checking the network hard drive and issues in the system at the receiving end were also suggested to solve the problem of image transmission.

"Sounds like a network hardware issue. ... Some switches can take up to a minute or so to allow a network device back on the network due to STP (spanning tree protocol).... Additionally it could be an ARP caching issue depending upon how the receiving device is configured." (*Discussion group 2, Discussion thread 7, # 7)*

Not allowing change of IP, hostname, AET, or any hard coded DICOM attributes

The issue of PACS administrators facing difficulties in changing some parameters such as the IP (internet protocol), hostname, AET (application entity title) and hardcoded DICOM attributes (data element) in some PACS systems was also raised in the group. To solve this issue, it was suggested that the PACS administrators must be involved in the early stages of PACS implementations so that they have

sufficient information and directions from the installation engineer to have experience in coping with some installation issue regarding PACS implementations such as how to change the naming structure etc.

> *"Using duplicate AET (i.e. default) can also cause big problem. Particularly with QR. As mentioned above, the PACS Admin should be in control of AET naming structure. Also mentioned above, the PACS Admin needs to be involved during planning stages of equipment installation. Having an open dialog with the installation engineer is crutial (crucial). Installation engineers (like most of us) are under time constraints. Sometimes it's difficult to get in contact with PACS Admins, so they might be forced to make up their own AET's. Not a good scenario!!"* (*Discussion group 1, Discussion thread 5, # 25)*

5.3.1.2 Theme 2 - Features and requirements that can increase PACS functionality

Under the theme of user needs and requirements that can increase PACS functionality, four sub-themes were identified: multi-site PACS integration; technical solutions for PACS; advances in PACS technology; and multimedia solutions for PACS (Table 5-9), which are presented below.

Table 5-9 Theme 2 - Features and requirements that can increase PACS functionality: Sub-themes

Thematic Group and Sub-themes	
Thematic Group 2: Features and requirements that can increase PACS functionality	
Sub-theme (1)	**Multi-site PACS integration :** • Standardisation discussions • Sharing images rather than storing them. • Multiple hospitals with integrated PACS • MULTI modalities PACS platform. • Integrated multi viewer • Access to shared patient data • Integrating with HIS / RIS / EMR • Integrating EMR and PACS • PACS as a tool helping in real time surgery • Information exchange with IHE profiles
Sub-theme (2)	**Technical solutions for PACS:** • Use of open standards for data interoperability and system integration • Security and migration away from Windows XP
Sub-theme (3)	**Advances in PACS technology** • Fast network access • Secure access to patients images from any hospital • Providing PACS with real time imaging surgery • Implementing radiation dose exposure reports into PACS
Sub-theme (4)	**Multimedia solutions for PACS:** • Holographic images • 3D type • Store video in PACS systems • PACS and EMR non-PACS EMR video • MACS (Multimedia Archiving and Communication Systems)

Multi-site PACS integration

The findings showed that most of the PACS users were in agreement that integrating PACS between hospitals would increase the functionality of PACS. The participants suggested that multi-site PACS integration would provide a number of benefits such as leading to standardisation, sharing images, integrating several hospitals, providing multi-modality platforms, integrating multi-viewers, sharing data and HER, accessing shared data for multiple patients. Participants suggested advanced levels of integrating PACS between hospitals and suggested common data governance model.

> *"Advanced level of Enterprise PACS integration (multiple sites with a common data governance)." (Discussion group 1, discussion thread 6, #13)*
>
> *"Cloud, multi site integration, VNA and enterprise PACS." Discussion group 1, discussion thread 6, #7)*

The findings also revealed that integration of PACS with other hospital systems such as HIS (health information systems), RIS (Radiology Information System) and EMR (electronic medical records), and exchanging information with IHE (integrating health enterprises) profiles would increase the functionality of PACS. In addition, the participants also suggested that the PACS should be considered as a surgical tool for storing images.

The benefits of PACS integration with other hospital systems were suggested to be a single point of storing all medical images resulting in lowering the costs, reducing the risks and enabling the efficiency across the users and the departments. Thus, the

overall benefits of such integration were lead to the consolidation of medical images and delivery of better care via the approach that is patient centred.

> *"Technologies have a solution that includes enterprise-wide and content-based medical records that is accessible via any electronic medical record (EMR) system. …Technologies' Universal Clinical Platform (UCP) is a vendor neutral foundation that drives better care delivery through a patient-centric approach by consolidating medical images. … Technologies' offerings include a single integration point for all medical imaging assets, lowering costs and risks through the UCP's ability to work with different systems – enabling flexibility and efficiency across users and departments. My money is on the new technologies - RIS/PACS is safe for now - but the handwriting is on the wall."* (*Discussion group 2, Discussion thread 4, #8)*

The findings showed that in the future the radiology information systems must be merged with PACS and expanded so to serve better radiologists' needs and improving the radiology workflow.

> *"I agree with the statement, "the RIS is Dead". The problem as we all move into the EHR environment, is that they too have RIS products or interface into RIS products. Yes it has been a year since I have seen a hospital using the film tracking function which was one of the reasons why we developed a "RIS" in the first place, but on the other hand I do not feel that the PACS vendors are providing us the proper tools either. Most of our PACS vendors are still offering Silo'd systems, Radiology, Cardiology and some have meagre "othero logies" incorporated into their products. I agree that a company like Medicals does*

provide this glue between the EHR and Imaging in general, but they too will probably to the same way as small specific third parties especially when the CIO's and Presidents of large healthcare groups have placed their hearts and dollars into the thirsty throat of the few EHR companies. We still are dealing with RIS driven workflow within these monsters since they too have spent so many dollars to build or purchase this functionality within their infrastructure. I don't see RIS systems going away too soon even though we should be migrating to a Workflow that addresses everything outside of Radiology that "oh by the way" includes Radiologists needs." (Discussion group 2, Discussion thread 4, #2)

"I guess it depends on your vendor and if you interface your PACS with your RIS. Our vendor offers custom fields that we can name anything we want. The techs pull the dose info of the modality and enter this into a custom field in PACS. We have a great interface gal who mapped our custom field in PACS (using the OBR segment to map) to insert the information into our final report in our RIS and ultimately our EMR. We are able to send dose info from our CT scanner directly to our PACS, but to have this information automatically inserted into the report costs more than we are willing to pay now." (Discussion group 2, Discussion thread 5, # 1)

Technical solutions for PACS

The participants suggested that PACS functionality could be improved with some additional technical solutions such as the use of open standards for data

interoperability and system integration and security and migration away from Windows XP.

> *"Security and migration away from Windows XP. User names and passwords Access to only your patients HIPAA compliance is key!" (Discussion group 1, Discussion thread 1, # 6)*

Advances in PACS technology

Participants discussed the need for advances in PACS technology such as fast network access; secure access to patients' images from any hospital; providing PACS with real time imaging surgery; and implementing radiation dose exposure reports into PACS.

> *"Fast multidimensional visualisation methods with parallel processing for rendering on the server side with fast network access from thin clients for display (mobile devices)." (Discussion group 1, Discussion thread 1, # 15)*

Multimedia solutions for PACS:

Most of the participants discussed the needs for some technical solutions for PACS such as using multimedia solutions; Multimedia Archiving and Communication Systems (MACS); PACS and non-PACS EMR video.

The findings revealed that the participants suggested that the PACS functionality could be enhanced by adopting multimedia solutions such as adoption of the Halogenic PACS with 3D functionality.

> *"Hologic is a system that will produce 3D images and receiving/storage PACS is … Syngo Imaging. Our PACS is able to store and display processed DICOM*

images, but our ultimate goal to store entire study as well. As of this moment, I'm trying to clarify if our PACS will be able to store/archive BTO files and would be able send back upon request. Also, I found out from our partner that …PACS is able to store BTO objects and Hologic is able to query/retrieve back. I will keep post my future findings." (D*iscussion group 3, discussion thread 1, # 4)*

"There are "MACS" = Multimedia Archiving and Communication Systems... one of these is from TELEMIS. - We have good experiences with them. Agile, flexible, open..." (Discussion group 1, Discussion thread 3, # 7)

5.3.1.3 Theme 3 - Web based solutions for PACS

Findings revealed that under the web-based solutions for PACS there were three sub-themes: multihospital PACS, Connecting all PACS with other hospital systems, RIS/HIS, and Connecting PACS to the Internet (Table 5-10), which are presented below.

Table 5-10 Theme 3 - Using web based solutions for PACS: Sub-themes

Thematic Group and Sub-themes	
Thematic Group 3: Web based solutions of PACS	
Sub-theme (1)	**Connecting Multi hospitals PACS**
Sub-theme (2)	**Connecting all PACS with other hospital systems, RIS/HIS**
Sub-theme (3)	**Connecting PACS to the internet** • Web/HTTP • Cloud • Medical Image Viewer • Open source PACS • Open-source, lightweight DICOM server • Implementation of big data analytics in medical imaging domain

The findings showed that participants suggested that web based solutions such as use of Internet for connecting multi-hospital PACS and connecting PACS with other hospital systems e.g. RIS, HIS and EMR will be very helpful. In addition, the participants mentioned using web based solutions for PACS that implement PACS on the Internet and cloud. The Internet, cloud, web based solutions were frequently discussed in various posts (threads). The phrase cloud was clearly stated as a solution to PACS as follows:

> *"The cloud is a wonderful place to store data to be used between sites, manage backup and disaster recovery, and reduce capital expenditure. However, with the cloud comes a new worry, the stability of the vendor as a developer and as a business." (Discussion group 4, Discussion thread 3, # 4)*

Web/HTTP and Cloud

"I would like to add a few aspects that the Future PACS is all about Web/HTTP and should support:

- *Layer between RIS and PACS will get depleted and unified. Reports and images all part of the same archive.*
- *Easy integration with EMR, EHR and HIS using Rest API based standards.*
- *Multi-Tenant Primary workflow data on the Cloud at enterprise level and the images on local VNA / PACS at Hospital level. Some HTTP technologies that would need to make this happen are: Query using QIDO-RS, Download (retrieve) using WADO-RS, Upload (store) via STOW-RS, XDS-i (cross document exchange for imaging will use above 3 services), next version of HL7 some supporting links."* (D*iscussion group 1, Discussion thread 1, # 16)*

Medical Image Viewer

A number of participants discussed about medical image viewers, which is an application that needs to be uploaded on any computer to present medical images without any need for installation or modification.

"A … medical image viewer is just an application that doesn't need any installation to work. A zero footprint medical image viewer needs hardware (whatever it is) and a browser to work. This viewer is zero footprint because there is no modification of your computer. Electricity and computer are the minimal requirements." (D*iscussion group 1, Discussion thread 2, #2)*

Open source PACS

Participants also suggested the use of Open source PACS as a solution for the next generation PACS, which could add a new functionality to the traditional PACS.

> *"Using Open source PACS at each site and a custom Radiology Workflow solution we solved it with Virtual LAN zone and dropped the MPLS connection to 2-4 Mbps. This is how we solved with a huge cost saving...*
>
> - *Implement a Local PACS with dual IP, one is local/modality IP range and another is connected to ISP gateway.*
> - *Removed any direct DICOM Push to DICOM nodes outside the respective centers.*
> - *Unique IP Range for each center, so we avoided IP conflicts across enterprise.*
> - *The Modalities will Auto Push to studies to a local PACS.*
> - *A RIS Workflow solution deployed with a Meta data sync. It will perform a Study/Series level Q/R C-Find on the Local PACS and sync the information with central RIS workflow Database.*
> - *Rules engine at RIS Workflow will decide the Destination Radiologist workstation."* (*Discussion group 1, Discussion thread 5, # 24)*

5.3.1.4 Theme 4 - PACS on mobile phone

The theme of PACS on mobile phone comprised only one sub-theme i.e. DICOM for mobile phones (Table 5-11).

Table 5-11 Theme 4 - PACS on mobile phone: Sub-themes

Thematic Group and Sub-themes	
Thematic Group 4: PACS on mobile phones	
Sub-theme (1)	DICOM for mobile devices

The participants in many discussion groups mentioned uploading DICOM images on smart phones would be helpful in the future PACS. One thread titled “DICOM for mobile devices” stated “DICOM images on your smartphone: DHIR instead of FHIR”. The participant in this thread welcomed a DICOM Web solution and the use of mobile devices as a platform for presenting DICOM images:

> *“I have heard people that work on WG27 refer to these RESTful DICOM services as "DICOM Web". I like this term and suggest we rally around it rather than invent a new one. FHIR solves a different problem than DICOM Web, they are not in competition with one another.” (Discussion group 1, Discussion thread 7, # 3)*

5.3.1.5 Theme 5 - Vendor Neutral Archive

The theme of vendor neutral archive (VNA) also comprised one sub-theme i.e. Multi hospitals PACS (VNA) (Table 5-12). Many participants stated that sharing images rather than storing them will add extra features to PACS in the future and it will meet the clinicians’ preferences in using PACS. The participants referred to using multi-modality platforms with VNA as an enterprise solution for multi sharing.

"VNA & Enterprise solution to accommodate ever other clinical documentation. MULTI modalities platform. Sharing images rather than store them." (Discussion group 1, discussion thread 1, # 8)

In addition, participants argued that it was not reliable to share data among multiple institutions until it has been owned and stored at one facility with one general policy as can be done with the VNA.

"The big issue is access to shared data from multiple patients' episodes since that data is owned by different facilities with different policies. It is more an administrative and data format issue than a technological. Since EHR is a longitudinal record, potentially from cradle to grave, it is not yet clear what exactly we need to archive in the context of exploding imaging data volumes." (Discussion group 1, Discussion thread 3, # 4)

Table 5-12 Theme 5 - Vendor Neutral Archive: Sub-themes

Thematic Group and Sub-themes	
Thematic Group 3 Vendor Neutral Archive as a solutions for PACS	
Sub-theme (1)	Multi hospitals PACS (VNA)

5.3.1.6 Theme 6 – Full Integration of voice recognition in PACS

The theme of full integration of voice recognition in PACS included only one sub-theme i.e. full integration of voice recognition with PACS (Table 5-13).

Table 5-13 Theme 6 – Full integration of voice recognition in PACS: Sub-themes

Thematic Group and Sub-themes	
Thematic Group 3: Full integration of voice recognition in PACS	
Sub-theme (1)	Full integration of voice recognition with PACS

The findings showed that using voice recognition with PACS system would provide the radiologist with an improved way to undertake their job with the overwhelming support of the PACS stakeholders. This was stated in a thread as follows:

> *"In addition to above, we can also see a shift in how demographics of the patient can be queried in the work list. It will be more of voice based search thereby reducing the time of Technologist and Radiologist." (Discussion group 1, Discussion thread1, # 4)*

5.3.1.7 Theme 8 - Providing backup solutions for PACS

The theme of providing backup solutions for PACS also included one sub-theme i.e. backup solutions for both the short term and the long terms archives (Table 5-14). The participants raised the issue of PACS system backup and recovery as an important issue.

> *"Before you start backing up the data, you need to have restored plan. Since PACS data can grow to tens of terabytes within years, I feel, one should look for archive options and not backups for large discrete data sets. Also, synchronous replication of the storage can be a good option." (Discussion groups 4, Discussion thread 2, # 1)*

Table 5-14 Theme 8 - Providing backup solutions for PACS: Sub-themes

Thematic Group and Sub-themes	
Thematic Group 1: Providing backup solutions for PACS	
Sub-theme (6)	**Backup solution:** • Short term and long term archive

Some of the participants were concerned about the PACS system recovery and stated that it was not well developed and the PACS data can be lost in any accident. They discussed about the possibility of losing data if it was not backup due to some accident such as fire or water in the server room.

> *"One thing that enterprises both large and small need to realise is that Disaster Recovery is not back up.…True Disaster Recovery is a replica either online or offline of all your data in a different geographical location. That may be another rack in the server room, or an offsite location. Just remember a fire in the server room or burst water main above the server room that fills the server room with water, and you still have no data".* (Discussion group 1, Discussion thread 4**,** *# 3)*

> *"Disaster recovery, not many people see this important until you are hit with data-loss. I have seen hospitals don't invest on this, but spend thousands $$ when they get hit. Disaster recovery is not just storage - it includes Application and Database Servers. RAID, Server virtualisations are some of the key features of DR"* (Discussion group 1, Discussion thread 4, *#2)*

"Choice of storage media is not the priority. It is the process that needs to be automatic and completely reliable." (*Discussion group 4, discussion thread 2, # 2)*

5.3.1.8 Theme 7 – Training and development of PACS users

Findings showed that the theme of training and development of PACS users also comprised only one sub-theme: Providing continuous training to PACS users in both clinical and IT domains (Table 5-15).

Table 5-15 Theme 7 - Training and development of PACS users: Sub-themes

Thematic Group and Sub-themes	
Thematic Group 1: Training and development of PACS users	
Sub-theme (4)	**Providing continuous training to PACS Users** • Expertise in both clinical and IT domains

The participants discussed that the best way to improve PACS functionality was by providing sufficient and continuous training for PACS users. They suggested that PACS users must be well trained in using the current PACS system and their knowledge must be updated with any advances added to PACS technology. They suggested different categories of PACS training such as: general training for use of the applications, hardware, printer, network, and interface; training in speech recognition; and training for multimedia (video/3D applications) as under.

"As an aspiring RIS/PACS administrator who is trying to build up my experience and education I have found myself in the exact crossroads that this article describes. All of my research into higher education programs for getting my BA

degree have pushed me towards a BA in general CS, because I have been unable to find any program that merges general IT to Healthcare. This article has helped to confirm my suspicion that I will need to find alternate methods (PARCA cert and On the Job Training) in order to fulfil the clinical knowledge portion of my education." (Discussion group 2, discussion thread 3, # 4)

5.4 Summary

Analysis of three types of data obtained through semi structured interviews, questionnaire surveys and unstructured monitoring of professionals' online discussion groups on PACS through the LinkedIn network led to identification of eight themes on PACS. These themes included: Limitations in current PACS; features and requirements that can increase PACS functionality; web based solutions of PACS; PACS on mobile phones; adopting vendor neutral archive; integrating voice recognition in PACS; ensuring backup solution for the system; and providing continuous training to PACS users. The findings showed that apart from seven themes on technological issues, training of PACS users was also an important theme. These findings are discussed in the next chapter.

6 Chapter Six: Discussion

This chapter discusses the findings of this study in the light of previous published research. The discussion is based on eight themes: limitations in current PACS; features and requirements that can increase PACS functionality; Web based solutions of PACS; PACS on mobile phones; adopting vendor neutral archive (VNA); integrating voice recognition in PACS; ensuring backup solution for the system; and providing continuous training to PACS users (Table 6-1).

Table 6-1 Themes and types of data

#	Themes	Interviews	Questionnaire survey	Observation of online discussion groups (LinkedIn)
1	*Limitations in current PACS*	✓	✓	✓
2	*Features and requirements that can increase PACS functionality*	✓	✓	✓
3	*Using web based solutions for PACS*	✓	✓	✓
4	*PACS on mobile phones*	✓	✓	✓
5	*Vendor Neutral Archive*	X	X	✓
6	*Integration of voice recognition in PACS*	✓	X	✓
7	*Providing backup solutions for PACS*	X	X	✓
8	*Training and development of PACS users*	✓	X	✓
	✓ = Yes, X =No			

These themes were identified in the analysis of data, which were collected using mixed methods i.e. semi structured interviews (n= 6), questionnaire survey (n=120) and unstructured monitoring of professionals' online discussion groups on PACS (n=4) through the LinkedIn network (Table 6-1).

6.1 Limitations in current PACS

The theme of limitation in current PACS was identified in all three types of data (interviews, questionnaire survey and online discussion groups) collected and analysed in this study.

The findings of the interview data revealed that the main limitations of the PACS system included: restricted access to PACS; PACS acting as a single unit in each hospital with a minimum connection with other hospital systems; limited PACS connection between different hospitals; lack of training facilities to various types of PACS users; non-availability of PACS applications on mobile phones; and a limited number of accessible PACS stations in hospital. The results of the questionnaire survey data revealed additional PACS limitations such as: limited PACS connection between hospitals; limited search functionality of the PACS system; and restricted access to the PACS in the office. The findings of the data from the professionals' online group discussions on PACS identified further PACS limitations, which included: problems associated with implementing open source PACS; image transmission issues; network hardware issues; and difficulties in changing specific settings such as IP (internet protocol), hostname, AET (application entity title) and hardcoded DICOM attributes (data element).

These findings provide empirical evidence that the current PACS system has limitations and the findings of this study are in agreement with earlier studies that reported a number of limitations in the PACS. For example, limited connectivity between PACS and other hospital systems e.g. HIS, RIS and EPR, has been reported to be a factor limiting access to historical patient images and data within the system (Aryanto *et al.*, 2015; Huang, 2011). Therefore, PACS needs to be connected with other hospital systems such as the EPR from the perspective of enterprise wide PACS integration (van de Wetering and Batenburg, 2009).

The limitations in remotely accessing PACS images, despite the availability of faster and secure internet communication, was also identified as a major limitation of PACS. There are a number of issues that could lead to limited remote access to PACS images, for example, the remote login and access rights that are only given to the senior radiologist but not to a junior or trainee radiologist, or the lack of integration of PACS with the web and mobile applications. In addition, there might be data security and privacy issues limiting remote access to the PACS images. However the latest solutions such as adoption of web-based solutions (Godinho, Silva and Costa, 2015; Ross and Pohjonen, 2011) and mobile phone based solutions for PACS (Matar *et al.*, 2015; Choudhri *et al.*, 2013) could help in addressing the issues of remote access to PACS. Another limitation identified was restricted access of traditional PACS network due to the limited number local workstations, which could be due to technical, financial or organisational issues at the hospital level. However, the number of PACS workstations could be increased depending on the availability of funds, hardware and departmental needs, and

requirements at the local hospital or organisation level. The falling cost of hardware will have an impact. The other limitations identified in current PACS include: the non-availability of mobile medical image services; system communication speed; storage capability; and limited search functionality (Joshi *et al.*, 2014; Ivetic and Dragan, 2011; Joshi *et al.*, 2011; Santos *et al.*, 2011; Rosset, Rosset and Ratib, 2005; Tang *et al.*, 2004). These issues are discussed in the following sections.

Overall, these findings suggest further improvements in PACS functionality and implementation strategies and arrangements for PACS at hospital or organisational levels to meet the needs of various types of PACS users who include not only the radiologists but also the radiographers, technologists, administrators as well as other health professionals such as clinicians who might need to access the PACS with regard to medical decision making and providing medical care to patients.

6.2 Features and requirements that can increase PACS functionality

Features and requirements that can increase PACS functionality were also identified in all three types of data (interviews, questionnaire survey and online group discussion) collected and analysed in this study.

The findings of the interview data showed that the functionality of PACS could be enhanced by incorporation of a number of features. This included: connecting PACS with other departments in the same hospital; linking data with the hospital ID and civil ID of the patient; integrating PACS with all relevant hospital systems (RIS and HIS); increasing the storage capacity of PACS; and having multiple windows in PACS workstation.

The analysis of the questionnaire survey data revealed PACS functionality would be enhanced by providing: mobile PACS facility via the internet and mobile phones; connecting multi-site PACS; and availability and adoption of advanced Information and Communication Technology (ICT).

The findings of the data from the online discussion groups identified that PACS functionality of the PACS would be increased through features such as: multi-site PACS integration; connecting PACS systems between different hospitals; adopting open source PACS; and multimedia solutions.

From the perspective of the PACS users and administrators, the functionality of PACS has been reported as the second most important feature (the system continuity being the most important feature) for selecting the best PACS (Joshi *et al.*, 2014; Joshi *et al.*, 2011). Most of the earlier studies reported one or two features affecting the PACS functionality; however, this study has identified many more features which could increase the functionality of the PACS from the users' perspective.

For example, connecting PACS with other departments in the same hospital is important because it would help in providing access of the radiological and other associated images to and from other departments, such as in the emergency room, where this feature would help in improved and efficient clinical decision making and delivery of healthcare (Foord, 2005). In addition, the adoption of the cross enterprise Document Sharing profile (XDS) allows medical images to be shared even if they are from different PACS vendors and different hospitals (Fernandez-Bayó, 2011). Similarly, the feature of "integrating PACS with relevant hospital systems" such as

RIS, HIS and EMR would provide several benefits including paperless workflow, leading to improved treatment processes (Hecht, 2008). More importantly, integration of PACS with RIS could work as complementary to each other (Hecht, 2008) and integration of PACS with EMR could lead to integrating patients' electronic medical records with radiological images (Pechet, Girard and Walsh, 2010). However, integration of PACS with other hospital systems would need further developments such as increasing the number of workstations, which would require more funds (Maass and Suomi, 2004).

A further important feature identified for improving PACS functionality was 'increasing the storage capacity of PACS', which has been one of the main limitations of PACS (Rosset, Rosset and Ratib, 2005). The issue of the storage capacity of PACS could be resolved with the use of holographic PACS (that combines a single department through new storage technologies), enterprise PACS (that provides vertical and horizontal integration between specialities and departments) and virtual PACS (that works across the enterprise) (Faggioni *et al.*, 2011b). More importantly, the issue of increasing the storage capacity of PACS could be resolved by adopting cloud computing, which would help not only in increasing the storage capacity but also in sharing and presenting medical images and data offsite (Griebel *et al.*, 2015). However, adopting cloud computing for PACS and other health systems would have legal, social, technical and financial implications, which would be a significant challenge for many hospitals, especially in developing countries.

The feature of having ‘multiple windows in PACS’ was a further feature that could help improve the functionality of PACS through improved image visualisation and comparison as well as presentation of information. The need for this feature could be met by using the Rich Internet Application (RIA), which provides an interface based on browser technology and enables multiple forms of medical data, including both (DICOM) and non-(DICOM) images, and patient reports and data to be viewed (Hsiao *et al.*, 2011).

The next features identified were ‘connecting multi-site PACS’ and ‘connecting PACS systems between different hospitals. These are important because the future implementation of PACS will require medical images to be shared, not only between different sites of the same organisation / hospital, but also between different hospitals. Such cross-site and cross-organisational integration of PACS could be achieved with the adoption of ‘virtual PACS departments’, which could be achieved through the use of scalable GRID technology (Faggioni *et al.*, 2011a). The virtualisation of PACS would allow functions to cross organisational / hospital boundaries and connect various hospitals / enterprises and thereby enable medical images and other data to be shared and accessed across organisations. The implementation of virtual PACS would be enabled with the availability and use of advanced ICT, which was also identified as important to support other enhancements to PACS functionality. The use of advanced ICT in PACS could improve the speed and accessibility of PACS images, which would save time and improve workflow and productivity in the practices of PACS (Lee *et al.*, 2010). In

addition, advanced ICT could support the web-based PACS, which is discussed below.

6.3 Use of web based solutions for PACS

The theme of 'use of web based solutions for PACS' was identified in the interview data, questionnaire survey data and online group discussion data. The findings of the interview data revealed that all the interviewees were in agreement in supporting the use of web based solutions for PACS, such as the use of web to connect multi hospital PACS, which might solve a number of limitations in current PACS. This would include: the inability to share information and consultations between radiologists in different departments; having limited remote access to PACS; and the difficulty in reading the handwriting of some of the doctors.

The results of the questionnaire survey data and the findings of online discussion groups data also showed that using web based solutions for PACS would help in connecting multi-hospital PACS and connecting PACS with other hospital systems including RIS and HIS.

Literature shows that there are a number of implementations of web based PACS. These include; holographic PACS, enterprise PACS, virtual PACS (Faggioni *et al.*, 2011b; Sharma *et al.*, 2009), rich internet application (RIA) web pages for PACS (Hsiao *et al.*, 2011), multi departmental PACS (Bergh, 2006), super PACS (Benjamin, Aradi and Shreiber, 2010), regional PACS (Fernandez-Bayó, 2011), Web based DICOM (Aryanto *et al.*, 2015; Haak *et al.*, 2015; Liu *et al.*, 2015), electronic patient records (EPR) with PACS (Aryanto *et al.*, 2015; Huang, 2011), wireless LAN based PACS (Lee *et al.*, 2010), WIKI web-based DICOM with PACS (Nakata *et al.*,

2004), open source web based PACS (Iotti and Valazza, 2014), Dicoogle – search engine for PACS (Valente, Costa and Silva, 2013; Viana-Ferreira, Costa and Oliveira, 2012; Santos *et al.*, 2011; Costa *et al.*, 2011; Costa *et al.*, 2009; Muller *et al.*, 2004) and cloud based PACS (Philbin, Prior and Nagy, 2011).

These show that web based solutions for PACS can help; in optimisation of workflow (Kirrmann *et al.*, 2015), accessing images and report writing from home (Ranschaert and Binkhuysen, 2013), sharing images between radiologists and clinical teams, and accessing images in geographically distributed medial environments such as between organisations (hospitals) at local, regional, national and cross border levels (Godinho, Silva and Costa, 2015; Ross and Pohjonen, 2011). More importantly, web based solutions for PACS could save time, especially in emergency cases (Martinon *et al.*, 2014). Webs based solutions for PACS increase productivity and improve quality of medical services (Godinho, Silva and Costa, 2015).

However, the results of the questionnaire survey showed that radiologists were concerned that using web based solutions for PACS could be affected by a number of financial, social, technical, legal and practical factors, which included high costs, negative attitudes of staff involved, lack of suitable training in the use of system, perceived increase in workload, patient privacy and confidentiality, technical issues, lack of user friendly software, lack of perceived clinical usefulness, and lack of consultation with clinicians. These findings suggested that the above issues could be barriers in the implementation of web based solutions for PACS (Saliba *et al.*, 2012). Therefore, there is a need to address these issues prior to adopting and implementing web-based solutions to the PACS.

Overall, these findings suggested that web-based solutions could help in tackling some of the limitations, such as the issue of lack of integration of PACS between hospitals and lack of integration between PACS and other hospital systems at a hospital level. However, a number of factors that could affect the Implementation of web-based solutions for PACS must be considered prior to adoption.

6.4 PACS on mobile phones

The findings revealed that providing PACS on mobile phones was a major theme that was identified in all three types of data (interviews, questionnaire survey and online group discussions). PACS on mobile phones was found to be an important development in the future PACS technologies; however, mobile phone screen size and image resolution were reported to be potential limitations in using PACS on mobile phones.

The findings of the interview data and the results of the questionnaire survey showed that PACS on mobile phones would provide flexible access to medical images anywhere at any time (Ivetic and Dragan, 2011) and it would be helpful in emergency cases (Kim *et al.*, 2015; Matar *et al.*, 2015; Martinon *et al.*, 2014; Choudhri *et al.*, 2013). The findings of the online discussion groups' data also showed that PACS on mobile phones would be useful, especially for transferring DICOM images to the smart phone (Matar *et al.*, 2015; Choudhri *et al.*, 2013). In addition, PACS on smart mobile phones could enhance workflow in radiology practice through the notification messaging features provided on these devices (Chandratilleke and Honeybul, 2013).

Literature describes existing mobile phone based programs, such as OsiriX Mobile (Choudhri and Radvany, 2011), developed for iPhone and IPad (Matar *et al.*, 2015;

Choudhri *et al.*, 2013). Mobile phone based PACS can help in viewing medical images leading to; expedited diagnosis and medical treatment (Choudhri and Radvany, 2011); improved accessibility (Tang *et al.*, 2004); and help in retrieving and displaying medical images especially in the emergency cases (Martinon *et al.*, 2014), such as acute aortic emergencies (Matar *et al.*, 2015; Choudhri *et al.*, 2013) and acute appendicitis (Kim *et al.*, 2015).

However, a number of issues in mobile phone based PACS reported in the literature, such as image display resolution and clarity, and transfer speed, need to be addressed (Filip *et al.*, 2012). In addition new tools, such as search tools to identify the patient by name, age and ID as well as the date of procedure, would be required (Jeong *et al.*, 2014). However, it is imperative to ensure the security and safety of mobile phones based PACS data (Choudhri *et al.*, 2015).

Overall findings about the theme of PACS on mobile phones showed that PACS on mobile phones could provide a flexible and ubiquitous access to the PACS (Tang *et al.*, 2004) in real time (Lee *et al.*, 2008).

6.5 Vendor Neutral Archive (VNA)

The findings of this study revealed that vendor neutral archive was a major theme that emerged only from the data collected from online discussion groups on PACS. The finding showed that the vendor neutral archive would provide solutions to the problems of combining all radiological images and the patient record under one system, which can be under one control (Gray, 2014). Some researchers have even predicted that the VNA would provide storage and viewing of medical images and it would thus replace most of the medical image systems, including PACS, by 2018

(Dennison, 2014). Thus, the VNA has been suggested to be the future for delivering medical images but several issues, such as the definition of the standard, features, specifications, neutrality, interoperability and conformance to open standards and cost, need to be addressed as they could be significant barriers to its implementation (Cook, 2014). The VNA therefore needs time, money and expertise before it is widely adopted and implemented.

6.6 Full integration of voice recognition in PACS

The theme of full integration of voice recognition in PACS emerged in both the interview data and the data collected from the online group discussions on PACS. The findings of the interview data showed that the full integration and use of voice recognition in PACS would enhance the functionality of PACS but some radiologists, particularly the trainee radiologists, would need training in how it should be used.

The findings of the data from the online discussion groups revealed that full integration of voice recognition in PACS would support radiologists by saving their time for example through using voice based searches of the system. The importance of voice recognition in the PACS was reported as the 'third hand of a radiologist' by a senior radiologist and expert in PACS at the SPIE conference 2015 on the future of the PACS. Integration of voice recognition in PACS was reported as one of the important features in selecting the best PACS in two studies that involved radiologists (Joshi *et al.*, 2011) and PACS administrators in hospitals in the USA (Joshi *et al.*, 2014). In addition, voice recognition in PACS has been adopted by many hospitals, especially in the developed countries such as the USA (Torrieri, 2011).

Nevertheless, a number of drawbacks, such as errors in voice recognition transcriptions, distraction of the user and slowing down the productivity of the radiologists, are associated with the use of voice recognition in practice (Fox, Aschkenasi and Kalyanpur, 2013; Hayt and Alexander, 2001). In addition, the use of voice recognition is not common in hospitals in many developing countries such as Kuwait. It is also likely that despite the voice recognition tool being available it is not used in some radiology departments, which could be due to personal choice of radiologists as well as because of the lack of training and encouragement.

6.7 Providing backup solutions for PACS

The theme of backup solutions for the PACS was identified only in the data collected from online group discussions. The findings showed that backup solutions for PACS were important, especially for large amounts of data because PACS data could grow by tens of terabytes within years. In addition, the findings also revealed that some participants were apprehensive that PACS data could be lost in an incident, e.g. fire in a server room, because data recovery plans for PACS were not well developed. Moreover, the findings revealed that post disaster data recovery was not an actual and full back up. Earlier studies also reported that backup was an important feature in selection of PACS from the perspective of the radiologists and PACS administrators (Joshi *et al.*, 2014; Joshi *et al.*, 2011). These findings therefore suggested that PACS developers need to develop and PACS implementers need to adopt backup systems and solutions for the PACS.

6.8 Training and development of PACS Users

The theme of training and development of PACS users was identified in both the interview data and the online discussion groups' data. The findings of the interview data showed that there was a need to provide training on how to use the PACS because it was possible that some radiologists, such as trainee radiologists, might not be fully trained in using PACS. In addition, the findings of the interview data revealed that there was a need for training on the upcoming PACS applications. The findings of the online discussion groups' data revealed that training on the use of specific features, such as the voice recognition in the PACS, was required by some radiologists. In addition, the findings of the interview data identified a need for training on PACS on mobile phone.

These findings suggest providing training of on PACS is important because it would improve the competence of users in the use of PACS (Floyd *et al.*, 2015); thus, it would have a significant impact on the implementation of PACS and user productivity (Dubey *et al.*, 2009; Blado and Carr, 2004). Therefore, training of PACS users for effective utilisation of PACS (Watkins, 1999) should focus on various aspects of PACS, especially new features such as voice recognition (Bramson and Bramson, 2005) and PACS on mobile phones.

Training on PACS should begin before PACS implementation (Kalyanpur, Singh and Bedi, 2010). It is the case that the different types of PACS users have different needs and requirements vis-à-vis training on PACS (Paskins and Rai, 2006); therefore developing training programmes on PACS must consider users' requirements and competency levels (Floyd *et al.*, 2015). In addition, it also likely

that the PACS users might only receive one training session in the use of PACS but they will need refresher courses to keep up to date with the latest developments and features in the PACS (Kalyanpur, Singh and Bedi, 2010). These findings would suggest plans are developed and funds reserved for training on PACS as part of continuous professional development of the PACS users.

6.9 Findings and PACS pathways

6.9.1 Current PACS pathway

The findings of this study suggest changes should be made to the current PACS pathway. The current PACS pathway (Figure 6-1) is summarised in the following points:

a) Current PACS acts as a single, isolated unit in many hospitals with no connection with PACS systems in hospitals at local, regional, or national level.
b) There are many vendors providing PACS, which can be a barrier to connecting PACS between hospitals
c) There is minimal integration of PACS with other hospital systems such as HIS/RIS and not all hospitals have PACS connecting with HIS/RIS/EMR.
d) There is no full integration of voice recognition with PACS.
e) Access to PACS is restricted to the office for many radiologists and there are limitations in accessing and using PACS outside of the hospitals.
f) The use of PACS through ubiquitous devices and mobile phones is limited.
g) There are still no proper PACS applications that can be used on advanced smart mobile phones

h) There is no direct communication between the reading radiologists and the referring physicians through the PACS system.

The findings of this study have revealed that there are a number of limitations in current PACS practice, which have been described in section 6.1. In addition, this study has identified a number of new features that would increase the functionality of PACS (Section 6.2); and hence improve PACS practice. Moreover, new solutions for PACS, such as vendor neutral archive and PACS on mobile phones need to be adopted.

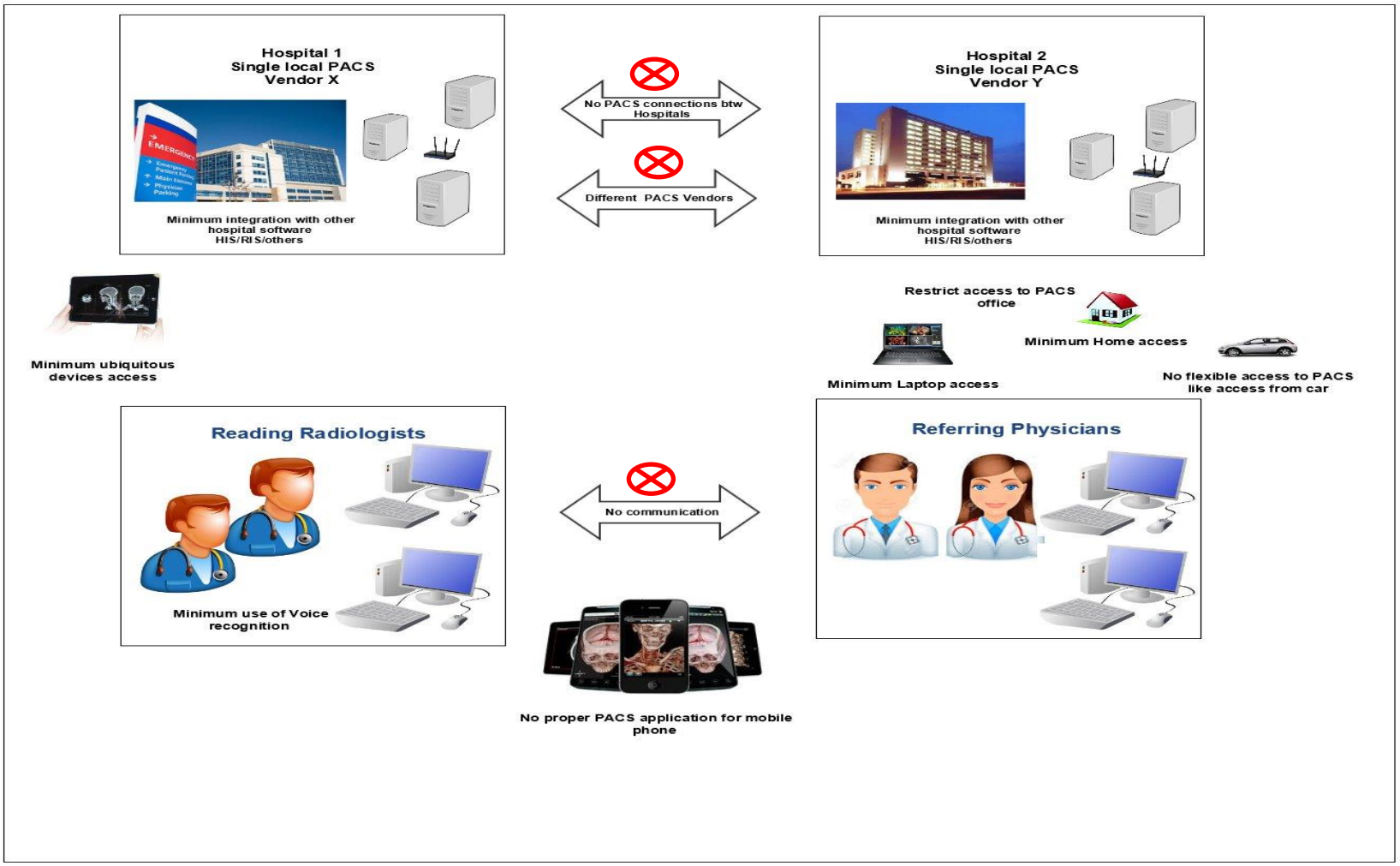


Figure 6-1 Current PACS pathway

6.9.2 Future PACS pathway

These findings suggest changes should be made to the current PACS pathway. A future PACS pathway has therefore been proposed (Figure 6-2). The salient features of the proposed future PACS pathway (Figure 6-2) are:

i. Connecting PACS systems between hospitals at local, regional and national level.

ii. Adopting the vendor neutral archive to provide a solution for connecting PACS from different vendors in different hospitals.

iii. Full integration of PACS with other hospital systems, especially with HIS, RIS and EMR systems.

iv. Full integration of voice recognition with PACS.

v. Adopting and maximising the use of latest solutions such as web-based PACS and PACS on ubiquitous devices and mobile phones

vi. Enabling and allowing flexible access to PACS on 24/7 basis from home or outside of workplace such as a conference, car etc.

vii. Adopting proper PACS applications that can be used on advanced smart mobile phone, which will be helpful in emergency cases and in seeking consultation between radiologists, and between radiologists and other clinicians

viii. Increasing direct communication between reading radiologists and referring physicians through the PACS systems.

6.9.3 Validation of future PACS pathway

The proposed future PACS pathway (Figure 6-2) was validated in the UK where there is more mature experience of PACS compared to developing countries such as Kuwait. The validation of the proposed future PACS pathway in the UK was helpful in identifying gaps and limitations in the suggested future PACS pathway. For validation, the researcher presented the proposed future PACS pathway to a focus group involving seven PACS users who were all radiologists including senior (n=2), junior (n=2) and trainee (n=3) radiologists. The focus group meeting was conducted at John Radcliffe Hospital, Oxford, UK and it lasted for an hour. The focus group participants discussed the PACS pathway and supported the proposed future PACS pathway (Figure 6-2) in general but they suggested some changes in it. The changes included inclusion of direct communication between reading radiologists and referring physicians through the PACS systems, which is shown as a circle in red colour in the future PACS pathway (Figure 6-2). The suggested change is included as a salient feature (bullet point viii above) of the proposed future PACS pathway (Figure 6-2). In addition, the participants of the focus group expressed their reservations with regard to PACS on mobile phones, especially regarding technical aspects and limitations including speed and screen size. They were in favour of some aspects of PACS solutions, including VNA and some of the advanced web based PACS technologies that were believed to increase the PACS maturity levels. These are discussed in the next section. There was no other data collected in the focus group meeting.

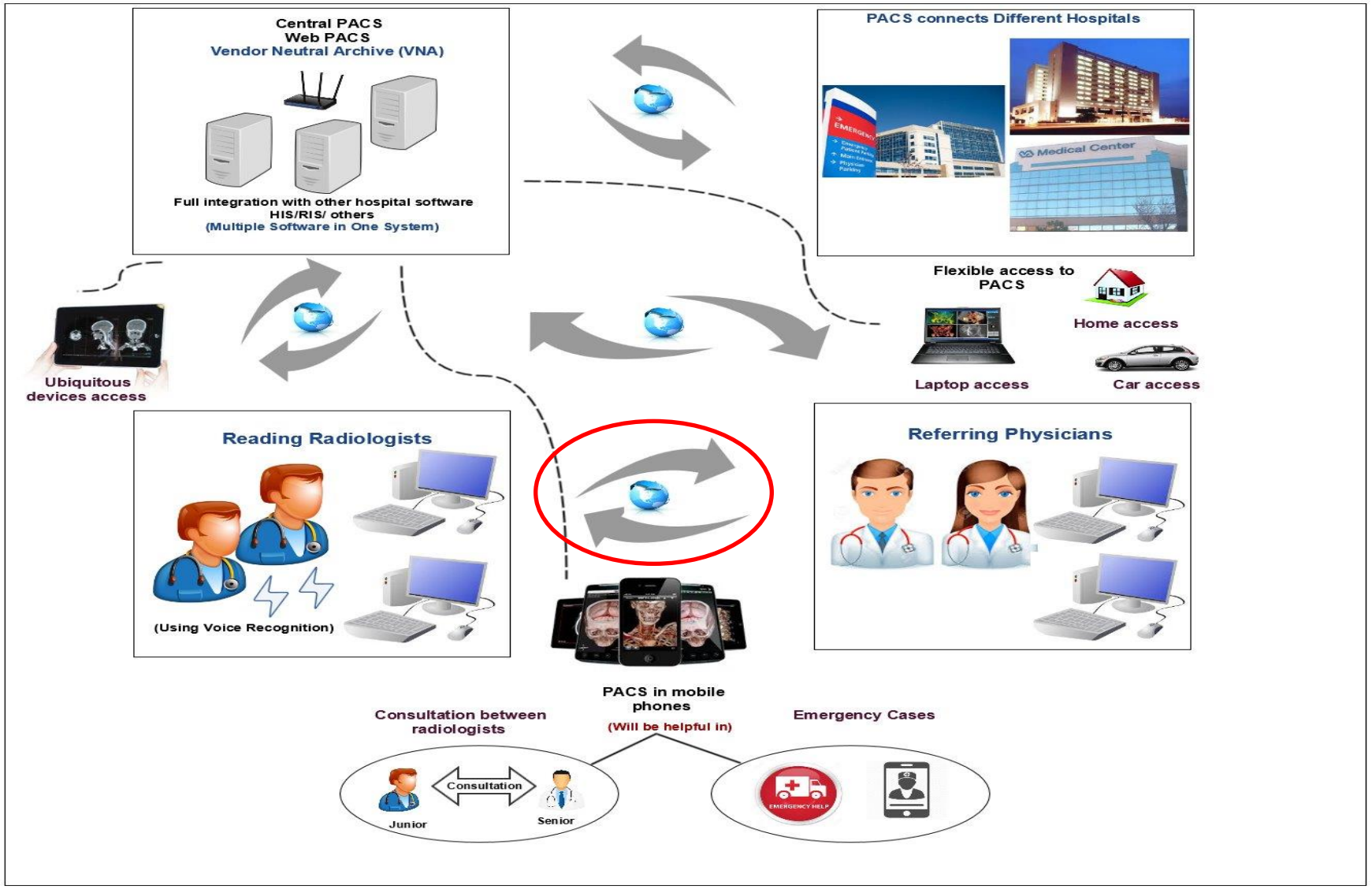


Figure 6-2 Proposed Future PACS pathway

The proposed future PACS pathway (Figure 6-2) is important because it addresses the limitations in the current PACS pathway and incorporates the latest solutions for PACS. It is therefore expected that adoption of the proposed future PACS pathway (Figure 6-2) would help in improving PACS practice. However, there is need for further research to evaluate the proposed future PACS pathway (Figure 6-2) in the field.

6.10 Findings and PACS Maturity levels update

The findings of this study showed that there have been a number of recent developments in the PACS domain. These developments have been in the following areas:

i. Development and adoption of Vendor Neutral Archive
ii. Implementation of Web based PACS
iii. Availability of PACS on ubiquitous devices and mobile phones
iv. Full integration of PACS with other hospital systems e.g. HIS/RIS/EMR (EPR)
v. Full integration of voice recognition with PACS
vi. Providing backup solutions for PACS
vii. Ensuring PACS storage capabilities

These developments in PACS suggest that PACS has reached maturity level six shown in yellow coloured box in Figure 6-3, which has been added to the PACS maturity model of van den Wetering and Batenburg (2009). Their model comprised only five levels.

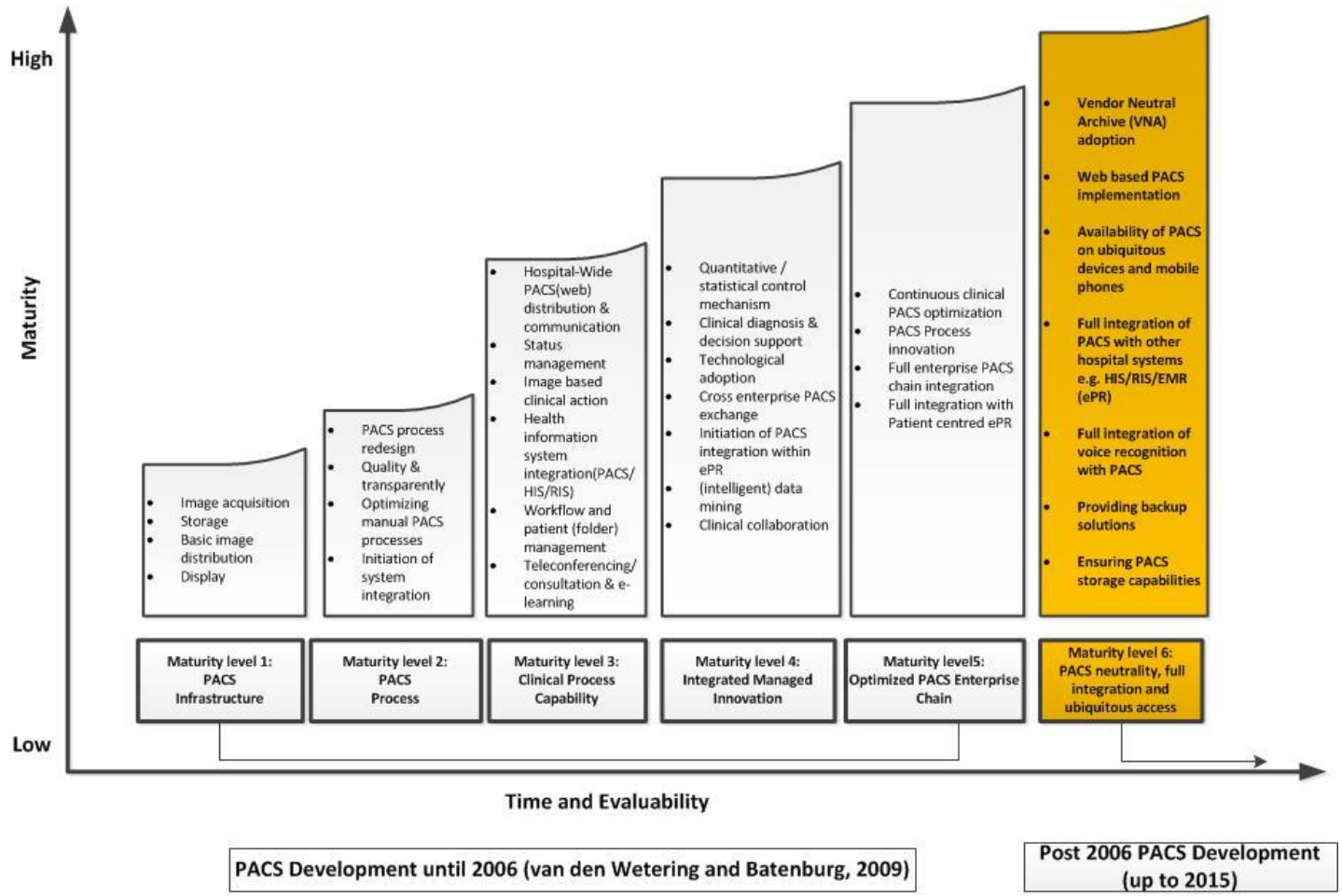


Figure 6-3 PACS maturity levels - update 2015

The maturity model of van den Wetering and Batenburg' model (2009) was based on literature published up to 2006 and was evaluated in various hospitals in the Netherlands during 2012-13 (van de Wetering and Batenburg, 2014). There are many recent developments in PACS, as described in this work, and it is clear that their model needs updating to include them. The present research has filled this gap by inclusion of PACS level six in the PACS maturity model (Figure 6-3). Level six in the PACS maturity includes the seven identified latest developments in the PACS domain. Nevertheless, literature shows that the PACS development process is continuous; hence, there will be new developments in the PACS domain, such as the demise of localised PACS and the adoption of the VNA and web-based solutions for PACS, leading to multi facility shared workflows (Dennison, 2014). Therefore, the updated PACS maturity model (Figure 6-3) will need further updating in the years to come. More importantly, the updated PACS maturity model presented in this research will also need evaluation through further research.

6.11 Summary

The findings of this study revealed eight themes, which included: limitations in current PACS; features and requirements that could increase PACS functionality: web based solutions of PACS; PACS on mobile phones; adopting vendor neutral archive; integrating voice recognition in PACS; ensuring backup solution for the PACS; and providing continuous training to PACS users (Table 6-1). The discussion provided in this chapter showed that addressing the limitations of current PACS and adopting and implementing the latest developments and solutions for PACS would need changes in the current PACS practice pathways (Figure 6-1). Based on these

findings, a pathway for future PACS practices was proposed (Figure 6-2), and was evaluated and approved by practicing radiologists. In addition, the findings of this study revealed that a number of technological developments have taken place in the PACS domain. These latest technological developments in the PACS domain have led to PACS attaining a higher maturity level, level six, in the PACS maturity model (Figure 6-3) of van de Wetering and Batenburg' model (2009). There is however need for further research for evaluating the updated PACS maturity model.

The next chapter presents the conclusions, contributions, implications, and limitations of this study and suggests recommendations for future research.

7 Chapter Seven: Conclusion and recommendations

This chapter provides the conclusion of the empirical study on the future developments and trends in the use of picture archiving and communication system, which is reported in this thesis. This is followed by consideration of the implications, contributions and limitations of this study. Finally, recommendations for further research in the PACS domain are presented.

7.1 Conclusion

PACS has been implemented in clinical practice over the last few decades and there has been continuous development in PACS technology aimed at improving functionality, leading to increasing the productivity of PACS users and expediting the clinical decision making based on studying and reporting clinical images through the PACS. However, limitations remain and there are barriers to effective implementation. There is therefore a need for research on how to improve the functionality of current PACS and to improve PACS practice and workflow.

The aim of this study was to determine how the functionality of PACS could be improved and to study PACS users' unmet needs vis-à-vis PACS functions and accessibility.

The study objectives were:

- To identify the limitations of current PACS
- To determine the future requirements of PACS users
- To identify state of the art technologies and solutions that can improve PACS functions and accessibility

This empirical study was undertaken using a cross sectional research design and adopting a mixed methods data collection approach, which involved: semi-structured interviews with six radiologists; self-completed questionnaire survey of 120 radiologists; and unstructured observation of four online discussion groups on PACS, which were accessed via the LinkedIn professionals' network.

The analysis of all three types of data led to the following key findings:

(a) Limitations of current PACS:

- Standalone single units of PACS from different vendors
- Minimal PACS connection between hospitals
- Minimal PACS integration with other hospital systems e.g. HIS, RIS and EMR (EPR)
- Limited ubiquitous access to PACS
- Limited storage capacity of PACS
- Limited number of windows in the PACS workstation

(b) Future requirements of PACS users

- Multi-site PACS integration
- Better search functionality in PACS
- Access PACS outside of the office
- Access medical images and data from anywhere and at any time
- Increased storage capacity of PACS
- Increased number of windows in PACS
- Training on PACS applications

(c) Technologies and solutions that can improve functions and accessibility of PACS:

- Using web based PACS
- Connecting PACS between different hospitals
- Connecting PACS with other hospital systems e.g. RIS, HIS, EMR (EPR)
- Accessing PACS on mobile phones
- Adopting vendor neutral archive for PACS
- Fully integrating voice recognition in PACS
- Ensuring backup solutions for PACS
- Increasing PACS storage capacity
- Providing training to PACS users

(d) Barriers to the adoption of web-based PACS:

- High cost
- Negative attitudes of staff involved
- Suitable training in the use of system
- Perceived increase in workload
- Patient privacy /confidentiality
- Technical concerns
- Lack of user-friendly software
- Lack of perceived clinical usefulness
- Lack of consultation with clinicians

The findings of this study have shown that the current generation of PACS has limitations and there are a number of unmet needs and requirements of PACS users. However, these limitations of PACS and the requirements of PACS users could be addressed with the adoption of state of the art ICT based solutions. In addition, highly developed PACS systems with advanced features will have a direct impact in changing and improving radiology workflow and providing better quality clinical practice. The findings from this empirical research can be used as recommendations to PACS vendors for developing technology and solutions and to healthcare institutions when undertaking implementation of PACS and providing training to current and future radiologists.

7.2 Implications

The findings of this study have implications for both the PACS technology developers (vendors) and PACS implementers (hospitals):

7.2.1 PACS technology developers (vendors)

- The findings of this study revealed that there are a number of limitations in the current generation of PACS. This includes: limited storage; limited windows in the PACS workstation; and standalone PACS units from different vendors that do not integrate with each other. Therefore, the PACS technology developers (vendors) need to address these issues in the future generation of PACS
- The findings of this study also showed that there a number of barriers in improving PACS functionality, integration and accessibility, particularly high cost. The PACS vendors need to develop and provide affordable solutions for implementers and users

7.2.2 PACS implementers (hospitals and users)

- The findings of this study showed that there are a number of limitations in using and accessing PACS including: non-integration of PACS units from different vendors; non-integration of PACS between hospitals; non-integration of PACS with other hospital systems; and access to PACs limited to the workplace. Therefore, these findings suggest that the hospital managers and PACS managers need to adopt the latest solutions to improve PACS functionality, integration and access
- The findings of this study have shown there was a need for initial and continuous training on PACS for different types of PACS users. Therefore there is a need to develop programmes for training on PACS and the latest applications for PACS
- The findings of this study have revealed that some of the potential users of PACS might have reservations for using the PACS; therefore, there is a need to involve / consult with PACS users prior to a PACS implementation
- The present study has also shown that adopting latest ICT based solutions for PACS, such as web-based PACS, could have implications for data security and data loss. Therefore, the PACS implementers / hospital managers need to ensure use of appropriate measures to ensure data backup and security solutions for the PACS

7.3 Contributions to the literature

The study has contributed to the body of knowledge as follows:

- Identification of the key limitations in the current generation of PACS

- Identification of the needs and requirements of PACS users
- Identification of the latest technological developments and solutions that can enhance PACS functionality
- Identification of the key barriers in the adoption of web based PACS
- Identification of the state of art ICT solutions for ubiquitous access and integration of PACS
- Development of a holistic future PACS pathway (Figure 6-2) to integrate the latest PACS developments and solutions to improve access, integration and communication in PACS practice
- Validation of proposed holistic future PACS pathway (Figure 6-2) through a focus group of radiologists
- Improvement and updating of the PACS maturity framework (van de Wetering and Batenburg, 2009) with the addition of level six - PACS neutrality, full integration and ubiquitous access
- Development, validation and application of a survey questionnaire to study the needs and requirements of PACS users to enhance the functionality and access of PACS to improve radiology workflow
- Collecting and presenting empirical evidence on the limitations of PACS, the requirements of PACS users and the latest technological developments and solutions for improving functionality, integration and access of PACS, based on a multi-method approach that involved semi-structured interviews, questionnaire survey and observation of online groups discussions on PACS

7.4 Research limitations

This empirical study has the following limitations:

7.4.1 Questionnaire survey

- No randomisation used in the selection of participants for the questionnaire survey
- Only 120 radiologists selected from six hospitals in Kuwait against the target of 200 participants
- Participants were from a single country so outcomes cannot be generalised directly to other contexts

7.4.2 Semi-structured interviews

- A limited sample size (n=6)
- Not all interviewees were aware of the latest developments in the PACS domain
- All interviewees were radiologists from one hospital in Kuwait so the perspectives of other types of PACS users and radiologists working at other hospitals were excluded

7.4.3 Accessing the LinkedIn online discussion groups

- Not all the PACS relevant groups accepted the researcher to access their group discussions even though some of them were important
- Most of the selected groups were not active and there were few comments on some trends
- The participants in the online discussion groups were self-selecting

- It was difficult to determine the type of each PACS user participating in the online discussion groups to determine the balance between the types of user. It could be the case that the majority of the participants in the groups were junior PACS users, e.g. trainee radiologists, and the representatives of PACS technology developers / vendors
- It is possible that the important stakeholders of PACS, such as senior radiologists, do not participate in social media technology such as LinkedIn and their opinions will not be observed
- There is no control on the topics of the group discussions. It is possible that topics were dominated with issues raised by representatives of the PACS vendors
- The issues identified through the online group discussions might not be representative of all types of PACS users due to the lack of randomisation in selecting the groups, threads / topics and comments

7.4.4 Mitigation against limitations

- The limited geographic location for collecting data was mitigated by using data collected from online discussion groups with participants from worldwide
- The limited sample size for interviews was mitigated by using data collected from the much larger online discussion groups
- The outcomes were validated with radiologists from a second country to increase generalisability
- The mixed method approach was used to compare and validate the outcomes from the separate methods

7.4.5 Research Focus

- The focus of this study was on the important features and solutions that can increase the functionality of PACS. The study did not address the technical aspects of next generation of PACS in detail.

7.5 Recommendations for future research

The findings of this study suggest further research on the following aspects of PACS:

7.5.1 PACS technology

- Future research should also focus on technical issues and solutions for next generation of PACS as the present research focused mainly on limitations of the current generation of PACS and solutions for PACS to provide recommendation for the important features that can increase PACS functionality.

7.5.2 PACS implementation

- Future research should study the barriers to implementing web based solutions for PACS and PACS on mobile phones
- Further research is also required to study the effect of the size of the hospital in implementing advanced solutions for PACS, such as web-based PACS, VNA for PACS and PACS on mobile phones

7.5.3 PACS access

- Further research should focus on using PACS on smart mobile phones and ubiquitous devices

7.5.4 PACS stakeholders

- Future research should investigate the needs and requirements of different types of PACS stakeholders such PACS administrators, radiology technicians, radiology staff, hospital administrators, clinicians, PACS engineers and the traditional PACS users.

7.5.5 PACS use outside of radiology departments

- Future research should study the use and impact of PACS outside of radiology departments, such as cardiology, real time surgery, and accident and emergency (A&E).

References

Aas, I. and Geitung, J. (2005) 'Teleradiology and picture archiving and communications systems: changed pattern of communication between clinicians and radiologists', Journal of Telemedicine and Telecare, 11(5), pp. 20-22.

Adair, C.E., Marcoux, G., Williams, A. and Reimer, M. (2006) 'The Internet as a Source of Data to Support the Development of a Quality-of-Life Measure for Eating Disorders', Qualitative Health Research, 16(4), pp. 538-546.

Albert, W. and Tullis, T. (2013) ‘Measuring the user experience: collecting, analyzing, and presenting usability metrics. Boston: Newnes.

Aldosari, B. (2012) 'User acceptance of a picture archiving and communication system', BMC Medical Informatics and Decision Making, 12, pp. 44.

Allan, B. (2010) Supporting research students. London: Facet.

Aryanto, K.Y.E., Broekema, A., Langenhuysen, R.G.A., Oudkerk, M. and van Ooijen, P.M.A. (2015) 'A Web-Based Institutional DICOM Distribution System with the Integration of the Clinical Trial Processor (CTP)', Journal of medical systems, 39(5), pp. 1-8.

Ayal, M. and Seidmann, A. (2009) 'On The Economic Role of RIS/PACS in Healthcare: An Empirical Study', IEEE, 1-10.

Bagozzi, R. P. (2007) ‘The Legacy of the Technology Acceptance Model and a Proposal for a Paradigm Shift’. Journal of the Association for Information Systems, 8(4), pp. 244-254.

Benjamin, M., Aradi, Y. and Shreiber, R. (2010) 'From shared data to sharing workflow: Merging PACS and teleradiology', European Journal of Radiology, 73(1), pp. 3-9.

Bergh, B. (2006) 'Enterprise imaging and multi-departmental PACS', European Radiology, 16(12), pp. 2775-2791.

Berlanga, R., P´erez, M., Museros, L. and and Forcada Rafael (2013) 'Semantic Discovery of Resources in Cloud-Based PACS/RIS Systems', In, Forner, P., Müller, H., Paredes, R., Rosso, P. and Stein, B. (eds.), nformation Access Evaluation. Multilinguality, Multimodality, and Visualization. Vol. 8138 of the series Lecture Notes in Computer Science Berlin Heidelberg: Springer, pp. 167-178.

Blado, M.E.E. and Carr, S.G. (2004) 'PACS training modules at Texas Children's Hospital', Journal of Digital Imaging, 17(2), pp. 124-133.

Bramson, R.T. and Bramson, R.A. (2005) 'Overcoming obstacles to work-changing technology such as PACS and voice recognition', American Journal of Roentgenology, 184(6), pp. 1727-1730.

Braun, V. and Clarke, V. (2006) 'Using thematic analysis in psychology', Qualitative Research in Psychology, 3(2), pp. 77-101.

Brown, S.A., Massey, A.P., Montoya-Weiss, M.M. and Burkman, J.R. (2002) ‘Do I really have to? User acceptance of mandated technology’. European Journal of Information Systems, 11(4), pp.283-295.

Bryman, A. (2004) Social research methods. 2nd edn. Oxford: Oxford University Press.

Buabbas, A. (2013) Investigation of the adoption of telemedicine technology in the Kuwaiti health system: Strategy and policy of implementation for overseas referral patients PhD Thesis. School of Information Systems, Computing and Mathematics, Brunel University London.

Burr, V. (2004) 'Constructivism', in 'Lewis-Beck, M.S., Bryman, A. and Liao, T.F.'. (eds.) The SAGE Encyclopedia of Social Science Research Methods. Thousand Oaks, CA.: Sage, pp. 186-187.

Button, G., Crabtree, A., Rouncefield, M. and Tolmie, P. (2015) Deconstructing Ethnography: Towards a Social Methodology for Ubiquitous Computing and Interactive Systems Design. Heidelberg: Springer.

Central Intelligence Agency, United States. (2014) The CIA World Factbook 2015. New York, NY.: Skyhorse Publishing.

Chandratilleke, M. and Honeybul, S. (2013) 'Modifying Clinicians Use of PACS Imaging', Journal of Digital Imaging, 26(6), pp. 1008-1012.

Chandratilleke, M. and Honeybul, S. (2013) 'Modifying Clinicians Use of PACS Imaging', Journal of Digital Imaging, 26(6), pp. 1008-1012.

Chen, W. and Hirschheim, R. (2004) 'A paradigmatic and methodological examination of information systems research from 1991 to 2001', Information Systems Journal, 14(3), pp. 197-235.

Choudhri, A.F. and Radvany, M.G. (2011) 'Initial Experience with a Handheld Device Digital Imaging and Communications in Medicine Viewer: OsiriX Mobile on the iPhone', Journal of Digital Imaging, 24(2), pp. 184-189.

Choudhri, A.F., Chatterjee, A.R., Javan, R., Radvany, M.G. and Shih, G. (2015) 'Security Issues for Mobile Medical Imaging: A Primer', RadioGraphics, 35(6), pp. 1814-1824.

Choudhri, A.F., Norton, P.T., Carr III, T.M., Stone, J.R., Hagspiel, K.D. and Dake, M.D. (2013) 'Diagnosis and treatment planning of acute aortic emergencies using a handheld DICOM viewer', Emergency Radiology, 20(4), pp. 267-272.

Chuttur M.Y. (2009). "Overview of the Technology Acceptance Model: Origins, Developments and Future Directions ," Indiana University, USA . Sprouts: Working Papers on Information Systems, 9(37). http://sprouts.aisnet.org/9-37.

Classen, S., Lopez, E.D., Winter, S., Awadzi, K.D., Ferree, N. and Garvan, C.W. (2007) ‘Population-based health promotion perspective for older driver safety: conceptual framework to intervention plan’. Clinical Interventions in Aging, 2(4), pp. 677-693.

Collis, J. and Hussey, R. (2009) Business research: a practical guide for undergraduate & postgraduate students. 3rd edn. Basingstoke; New York: Palgrave Macmillan.

Collis, J. and Hussey, R. (2014) Business research: a practical guide for undergraduate & postgraduate students. Fourth edn. Houndmills, Basingstoke, Hampshire: Palgrave Macmillan.

Collis, J., Hussey, R. and Hussey, J. (2003) Business research: a practical guide for undergraduate and postgraduate students. 2nd edn. Basingstoke: Palgrave Macmillan.

Connelly, L.M. (2009) 'Survey methods', Medsurg nursing : official journal of the Academy of Medical-Surgical Nurses, 18(2), pp. 114-133.

Cook, R. (2014) Is VNA the future of image delivery? A platform independent archival system has strong appeal. Available at: http://www.healthcareitnews.com/news/should-you-use-vna-whats-vna (Accessed: 03/2016 2016).

Costa, C., Ferreira, C., Bastião, L., Ribeiro, L., Silva, A. and Oliveira, J.L. (2011) 'Dicoogle - An open source peer-to-peer PACS', Journal of Digital Imaging, 24(5), pp. 848-856.

Costa, C., Oliveira, J.L., Silva, A., Ribeiro, V.G. and Ribeiro, J. (2009) 'Design, development, exploitation and assessment of a Cardiology Web PACS', Computer Methods and Programs in Biomedicine, 93(3), pp. 273-282.

Costantino, T. (2008) 'Constructivism', in Given, L.M. (ed.) SAGE encyclopedia of qualitative research methods. Thousand Oaks, CA.: SAGE, pp. 116-121.

Creswell, J.W. (2014) Research design: qualitative, quantitative, and mixed methods approaches. Fourth, International student edn. Los Angeles: SAGE.

da Cunha, J.V. and Orlikowski, W.J. (2008) 'Performing catharsis: The use of online discussion forums in organizational change', Information and Organization, 18(2), pp. 132-156.

Davis, F.D. (1986) A Technology Acceptance Model for Empirically Testing New End-User Information Systems: Theory and Results Doctoral dissertation. Sloan School of Management, Massachusetts Institute of Technology, Boston, MA., USA.

Davis, F.D. (1989) 'Perceived usefulness, perceived ease of use, and user acceptance of information technology', MIS Quarterly, 3(3), pp. 319-340.

Davis, F.D., Bagozzi, R.P. and Warshaw, P.R. (1989) 'User acceptance of computer technology: a comparison of two theoretical models. Management Science, 35(8), pp. 982-1003.

De Backer, A.I., Mortelé, K.J. and De Keulenaer, B.L. (2004) 'Picture archiving and communication system--part 2 cost-benefit considerations for picture archiving and communication system', JBR-BTR : organe de la Société royale belge de radiologie (SRBR) = orgaan van de Koninklijke Belgische Vereniging voor Radiologie (KBVR), 87(6), pp. 296.

DeLone, W.H. and McLean, E.R. (1992) 'Information Systems Success: The Quest for the Dependent Variable', Information Systems Research, 3(1), pp. 60-95.

DeLone, W.H. and McLean, E.R. (2003) 'The DeLone and McLean Model of Information Systems Success: A Ten-Year Update', Journal of Management Information Systems, 19(4), pp. 9-30.

Dennison, D. (2014) 'PACS in 2018: An Autopsy', Journal of Digital Imaging, 27(1), pp. 7-11.

Denzin, N.K. (1978) The Research Act. New York: McGraw-Hill.

Dubey, R.B., Hanmandlu, M., Gupta, S.K. and Singh, L. (2009) 'The Current CAD and PACS Technologies in Medical Imaging'. International Journal of Applied Engineering Research, 4(8), pp. 1439 -1456..

Duerinckx, A. (2003) 'Introduction to two PACS '82 panel discussions edited by Andre J. Duerinckx, MD, Ph.D.: "Equipment manufacturers' view on PACS" and "The medical community's view on PACS"', Journal of Digital Imaging, 16(1), pp. 29-31.

Duyck, P., Pynoo, B., Devolder, P., Voet, T., Adang, L. and Vercruysse, J. (2008) 'Do hospital physicians really want to go digital? Acceptance of a picture archiving and communication system in a university hospital', RoFo Fortschritte auf dem Gebiet der Rontgenstrahlen und der Bildgebenden Verfahren, 180(7), pp. 631-638.

Duyck, P., Pynoo, B., Devolder, P., Voet, T., Adang, L., Ovaere, D. and Vercruysse, J. (2010) 'Monitoring the PACS Implementation Process in a Large University Hospital—Discrepancies Between Radiologists and Physicians', Journal of Digital Imaging, 23(1), pp. 73-80.

Erzberger, C. and Kelle, U. (2003) 'Making Inferences in Mixed Methods: The Rules of Integration', in Tashakkori, A. and Teddlie, C. (eds.) Handbook of Mixed Methods in Social and Behavioral Research. Thousand Oaks, CA.: Sage, pp. 457-490.

Eysenbach, G. and Till, J.E. (2001) 'Ethical Issues In Qualitative Research On Internet Communities', BMJ: British Medical Journal, 323(7321), pp. 1103-1105.

Faggioni, L., Neri, E., Castellana, C., Caramella, D. and Bartolozzi, C. (2011a) 'The future of PACS in healthcare enterprises', European Journal of Radiology, 78(2), pp. 253-258.

Faggioni, L., Neri, E., Cerri, F., Turini, F. and Bartolozzi, C. (2011b) 'Integrating image processing in PACS', European Journal of Radiology, 78(2), pp. 210-224.

Fernandez-Bayó, J. (2011) 'IHE profiles applied to regional PACS', European Journal of Radiology, 78(2), pp. 250-252.

Fielding, N. and Fielding, J. (1986) Linking data: the articulation of qualitative and quantitative methods in social research. London: Sage.

Fielding, R.T. (2000) Architectural Styles and the Design of Network-based Software Architectures PhD Thesis. Information and Computer Science, University of California, Irvine, CA., USA. Available at: http://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm.

Filip, M., Linzer, P., Šámal, F., Tesar, J., Herzig, R. and Školoudík, D. (2012) 'Medical consultations and the sharing of medical images involving spinal injury over mobile phone networks', The American Journal of Emergency Medicine, 30(6), pp. 961-965.

Fink, A. (1995) The survey kit. Thousand Oaks, Calif; London: Sage Publications.

Floyd, D.M., Trepp, E.R., Ipaki, M. and Ng, C.K.C. (2015) 'Study of Radiologic Technologists' Perceptions of Picture Archiving and Communication System (PACS) Competence and Educational Issues in Western Australia', Journal of Digital Imaging, 28(3), pp. 315-322.

Foord, K. (2005) 'PACS outside radiology', International Congress Series, 1281, pp. 997-999.

Fox, M.A., Aschkenasi, C.J. and Kalyanpur, A. (2013) 'Voice recognition is here comma like it or not period', The Indian Journal of Radiology & Imaging, 23(3), pp. 191-194.

Fridell, K., Aspelin, P., Edgren, L., Lindsköld, L. and Lundberg, N. (2009) 'PACS influence the radiographer's work', Radiography, 15(2), pp. 121-133.

Fridell, K., Edgren, L., Lindsköld, L., Aspelin, P. and Lundberg, N. (2007) 'The impact of PACS on radiologists' work practice', Journal of Digital Imaging, 20(4), pp. 411-421.

Garland, R. (1991) 'The mid-point on a rating scale: Is it desirable'. Marketing Bulletin, 2(1), pp.66-70.

Godinho, T.M., Silva, L.M. and Costa, C. (2015) 'An automation framework for PACS workflows optimization in shared environments', In, Information Systems and Technologies (CISTI), 2015 10th Iberian Conference on. IEEE. pp. 1-7.

Gomez-Iturriaga, A., Bilbao, P., Casquero, F., Cacicedo, J. and Crook, J. (2012) 'Smartphones and tablets: Reshaping radiation oncologists' lives', Reports of Practical Oncology and Radiotherapy, 17(5), pp. 276-280.

Goodson, L. and Phillimore, J. (2004) Qualitative research in tourism: Ontologies, epistemologies and methodologies. Vol. 14, Abingdon, Oxon.: Psychology Press.

Gray, M. (2014) 'PACS Paradigm Shift: Moving control of the data from display applications to an enterprise access infrastructure. Context Magazine, (September), pp. 1-16. Available at: http://www.incontextmag.com/special-reports/pacs-paradigm-shift-moving-control-of-the-data-from-display-applications-to-an-enterprise-access-infrastructure.html.

Griebel, L., Prokosch, H., Kopcke, F., Toddenroth, D., Christoph, J., Leb, I., Engel, I. and Sedlmayr, M. (2015) 'A scoping review of cloud computing in healthcare', BMC Medical Informatics and Decision Making, 15(1), pp. 1-16.

Guest, G., Bunce, A. and Johnson, L. (2006) ‘How many interviews are enough? An experiment with data saturation and variability’. Field Methods, 18(1), pp.59-82.

Haak, D., Page, C., Reinartz, S., Kruger, T. and Deserno, T.M. (2015) 'DICOM for Clinical Research: PACS-Integrated Electronic Data Capture in Multi-Center Trials', Journal of Digital Imaging, 28(5), pp. 558-566.

Hayt, D.B. and Alexander, S. (2001) 'The pros and cons of implementing PACS and speech recognition systems', Journal of Digital Imaging, 14(3), pp. 149-157.

Hecht, M. (2008) PACS - Picture Archiving and Communication System. Vienna: University of Technology. Available at: https://www.cg.tuwien.ac.at/courses/Seminar/WS2009/PACS.pdf:

, .

Hoff, T.J. and Witt, L.C. (2000) 'Exploring the use of qualitative methods in published health services and management research', Medical Care Research and Review, 57(2), pp. 139-160.

Holden, R.J. and Karsh, B. (2010) 'The Technology Acceptance Model: Its past and its future in health care', Journal of Biomedical Informatics, 43(1), pp. 159-172.

Hsiao, C.-., Shiau, C.-., Liu, Y.-., Chao, M.M., Lien, C.-., Chen, C.-., Yen, S.-. and Tang, S.-. (2011) 'Use of a rich internet application solution to present medical images', Journal of Digital Imaging, 24(6), pp. 967-978.

Huang, H.K. (2010) PACS and imaging informatics: basic principles and applications. 2nd edn. Hoboken, N.J: Wiley-Blackwell.

Huang, H.K. (2011) 'From PACS to Web-based ePR system with image distribution for enterprise-level filmless healthcare delivery', Radiological Physics and Technology, 4(2), pp. 91-108.

Hussein, S.E. (2009) 'Picture Archiving and Communication System Analysis and Deployment', In: UKSim 2009: 11th International Conference on Computer Modelling and Simulation, pp. 520-525.

Iotti, B. and Valazza, A. (2014) 'A Reliable, Low-Cost Picture Archiving and Communications System for Small and Medium Veterinary Practices Built Using Open-Source Technology', Journal of Digital Imaging, 27(5), pp. 563-570.

Ivetic, D. and Dragan, D. (2011) 'Medical image on the Go!', Journal of Medical Systems, 35(4), pp. 499-516.

Ivankova, N.V., Creswell, J.W. and Stick, S.L. (2006) ‘Using mixed-methods sequential explanatory design: From theory to practice’. Field Methods, 18(1), pp.3-20.

Jackson, P.E. and Langlois, S.L. (2005) 'Introduction of picture archiving and communication system at the Townsville Hospital', Australasian Radiology, 49(4), pp. 278-282.

Jeong, C., Joo, S., Ryu, J., Lee, J., Kim, K. and Yoon, K. (2014) 'Development of a Mini-Mobile Digital Radiography System by Using Wireless Smart Devices', Journal of Digital Imaging, 27(4), pp. 443-448.

Jick, T.D. (1979) 'Mixing Qualitative and Quantitative Methods: Triangulation in Action', Administrative Science Quarterly, 24(4), pp. 602.

Johnson, J.K. and Barach, P. (2008) 'The Role of Qualitative Methods in Designing Health Care Organizations', Environment and Behavior, 40(2), pp. 191-204.

Joshi, V., Lee, K., Melson, D. and Narra, V.R. (2011) 'Empirical investigation of radiologists' priorities for PACS selection: An analytical hierarchy process approach', Journal of Digital Imaging, 24(4), pp. 700-708.

Joshi, V., Narra, V.R., Joshi, K., Lee, K. and Melson, D. (2014) 'PACS Administrators’ and Radiologists’ Perspective on the Importance of Features for PACS Selection', Journal of Digital Imaging, 27(4), pp. 486-495.

Kalyanpur, A., Singh, J. and Bedi, R. (2010) 'Practical issues in picture archiving and communication system and networking', Indian Journal of Radiology and Imaging, 20(1), pp. 2-5.

Kaplan, B. and Duchon, D. (1988) 'Combining Qualitative and Quantitative Methods in Information Systems Research: A Case Study', MIS Quarterly, 12(4), pp. 571-586.

Kharat, A.T., Safvi, A., Thind, S.S. and Singh, A. (2012) 'Cloud computing for radiologists', Indian Journal of Radiology & Imaging, 22(3), pp. 150-154 5p.

Kim, C., Kang, B., Choi, H.J. and Park, J.B. (2015) 'A Feasibility Study of Real-Time Remote CT Reading for Suspected Acute Appendicitis Using an iPhone', Journal of Digital Imaging, 28(4), pp. 399-406.

Kimberlin, C.L. and Winterstein, A.G. (2008) 'Validity and reliability of measurement instruments used in research', American Journal of Health-System Pharmacy, 65(23), pp. 2276-2284.

Kimchi, J., Polivka, B. and Stevenson, J.S. (1991) 'Triangulation: Operational Definitions', Nursing Research, 40(6), pp. 364-366.

Kinnunen, P. and Simon, B. (2012) 'Phenomenography and grounded theory as research methods in computing education research field', Computer Science Education, 22(2), pp. 199-218.

Kirrmann, S., Gainey, M., Rohner, F., Hall, M., Bruggmoser, G., Schmucker, M. and Heinemann, F. (2015) 'Visualization of data in radiotherapy using web services for optimization of workflow', Radiation Oncology, 10(1), pp. 22-22.

Kitchenham, B. and Pfleeger, S. (2002) 'Principles of survey research: part 3: constructing a survey instrument', ACM SIGSOFT Software Engineering Notes, 27(2), pp. 20-24.

Koshy, E., Waterman, H. and Koshy, V. (2011) Action research in healthcare. Los Angeles: Sage.

Kotter, E., Baumann, T., Jager, D. and Langer, M. (2006) 'Technologies for image distribution in hospitals', European Radiology, 16(6), pp. 1270-1279.

Kuzel, A. J. (1992) Sampling in qualitative inquiry. In, Crabtree, B. F. and Miller, W. L. (eds.), Doing Qualitative Research (Research Methods for Primary Care), Vol. 3, Newbury Park, CA: Sage, pp. 31–44.

Law, M.Y.Y. and Zhou, Z. (2003) 'New direction in PACS education and training', Computerized Medical Imaging and Graphics, 27(2), pp. 147-156.

Lee, H.J., Lee, K.H., Hwang, S.I., Kim, H.-., Seo, E.H., Kim, T.G. and Ha, K.-. (2010) 'The effect of wireless LAN-based PACS device for portable imaging modalities', Journal of Digital Imaging, 23(2), pp. 185-191.

Lee, S., Lee, T., Jin, G. and Hong, J. (2008) 'An implementation of wireless medical image transmission system on mobile devices', Journal of Medical Systems, 32(6), pp. 471-480.

Lee, Y., Kozar, K.A. and Larsen, K.R. (2003) ‘The technology acceptance model: Past, present, and future’. Communications of the Association for Information Systems, 12(1), Article 50. Available at: http://aisel.aisnet.org/cais/vol12/iss1/50

Liang, Z., Du, X., Guo, X., Rong, D., Kang, R., Mao, G., Liu, J. and Li, K. (2010) 'Comparison of dry laser printer versus paper printer in full-field digital mammography', Acta Radiologica, 51(3), pp. 235-239 5p.

Licklider, J.C.R. (1960) 'Man-Computer Symbiosis', IRE Transactions on Human Factors in Electronics, HFE-1(1), pp. 4-11.

Lienemann, B., Hodler, J., Luetolf, M. and Pfirrmann, C.W.A. (2005) 'Swiss teleradiology survey: present situation and future trends', European Radiology, 15(10), pp. 2157-2162.

Liu, B.J., Zhou, Z. and Huang, H.K. (2006) 'A HIPAA-compliant architecture for securing clinical images', Journal of Digital Imaging, 19(2), pp. 172-180.

Liu, L., Liu, L., Fu, X., Huang, Q., Zhang, Y., Luo, Q. and Xiong, X. (2015) 'SmartWADO: an Extensible WADO Middleware for Regional Medical Image Sharing', Journal of Digital Imaging, 28(5), pp. 547-557.

Lydeard, S. (1991) 'The questionnaire as a research tool', Family Practice, 8(1), pp. 84-91.

Maass, M.C. and Suomi, R. (2004) 'Adoption-related aspects of an information system in a health care setting', Proceedings of the Hawaii International Conference on System Sciences, 37, pp. 2267-2275.

Maglogiannis, I., Delakouridis, C. and Kazatzopoulos, L. (2006) 'Enabling Collaborative Medical Diagnosis over the Internet via Peer-to-Peer Distribution of Electronic Health Records', Journal of Medical Systems, 30(2), pp. 107-116.

Majid, S. and Misra, R.K. (2002) 'The Internet as a medium of training for picture archival and communication systems (PACS)', Library Review, 51(8/9), pp. 451-457.

Martinon, A., Le Pogam, M.A., Boublay, N., Ganne, C., Ben Cheikh, A., Buron, C., Thomson, V., Berthezène, Y. and Journé, C. (2014) 'Teleradiology saves times in cases of vital emergencies: A comparative study with on-call radiology in two urban medium-sized French hospitals', European Research in Telemedicine, 3(4), pp. 151-160.

Mata Miquel, C. (2015) Mata Miquel, C. (2015) *Web-based application for medical imaging management.* PhD Thesis. Institute for Research in Computer Vision and Robotics, Department of Computer Architecture and Technology, University of Girona. Girona, Spain. Available at: http://www.tdx.cat/handle/10803/323093.

Matar, R., Renapurkar, R., Obuchowski, N., Menon, V., Piraino, D. and Schoenhagen, P. (2015) 'Utility of hand-held devices in diagnosis and triage of cardiovascular emergencies. Observations during implementation of a PACS-based system in an acute aortic syndrome (AAS) network', Journal of Cardiovascular Computed Tomography, 9(6), pp. 524-533.

McCoy, S., Everard, A. and Jones, B.M. (2005) 'An Examination of the Technology Acceptance Model in Uruguay and the US: A Focus on Culture', Journal of Global Information Technology Management, 8(2), pp. 27-45.

Morgan, D.L. (2007) 'Paradigms Lost and Pragmatism Regained: Methodological Implications of Combining Qualitative and Quantitative Methods', Journal of Mixed Methods Research, 1(1), pp. 48-76.

Muller, H., Michoux, N., Bandon, D. and Geissbusher, A. (2004) A review of content-based image retrieval systems in medical applications clinical benefits and future directions', International Journal of Medical Informatics, 73 (1), pp. 1-23.

Nakata, N., Suzuki, N., Fukuda, K. and Fukuda, Y. (2004) Accessible web-based collaborative tools and wireless personal PACS: feasibility of group work for radiologists. International Congress Series, 1268 (June), pp. 260–264.

Norris, C. (2005) Epistemology. London: Continuum.

Oates, B.J. (2006) Researching information systems and computing. London: SAGE.

Onwuegbuzie, A.J. and Leech, N.L. (2005) 'On Becoming a Pragmatic Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies', International Journal of Social Research Methodology, 8(5), pp. 375-387.

Organisation for Economic Co-operation and Development, (2015) OECD Health Statistics 2015. Paris.

Orlikowski, W.J. and Baroudi, J.J. (1991) 'Studying Information Technology in Organizations: Research Approaches and Assumptions', Information Systems Research, 2(1), pp. 1-28.

Ortiz-Posadas, M., Ortiz-Posadas, M., Garcia-Porres, J., Garcia-Porres, J., Lemus-Martinez, C. and Lemus-Martinez, C. (2007) 'The Choice to Go Digital: A Guideline for Using PACS in Countries Receptive to Technology', in, Conf. Proc. IEEE Eng. Med. Biol. Soc., pp. 3601-4.

Östlund, U., Kidd, L., Wengström, Y. and Rowa-Dewar, N. (2011) 'Combining qualitative and quantitative research within mixed method research designs: A methodological review', International journal of nursing studies, International Journal of Nursing Studies, 48(3), pp. 369-383.

Paskins, Z. and Rai, A. (2006) 'The impact of Picture Archiving and Communication Systems (PACS) implementation in rheumatology', Rheumatology, 45(3), pp. 354-355.

Pechet, T., Girard, G. and Walsh, B. (2010) 'The value teleradiology represents for Europe: A study of lessons learned in the US', European Journal of Radiology, 73(1), pp. 36-39.

Philbin, J., Prior, F. and Nagy, P. (2011) 'Will the Next Generation of PACS Be Sitting on a Cloud?', Journal of Digital Imaging, 24(2), pp. 179-183.

Pope, C. and Mays, N. (2006) Qualitative research in health care. 3rd edn. Malden, Mass: Blackwell Pub./BMJ Books.

Pope, C., Ziebland, S. and Mays, N. (2000) 'Analysing qualitative data', British Medical Journal, 320(7227), pp. 114-116.

Ranschaert, E.R. and Binkhuysen, F.H.B. (2013) 'European Teleradiology now and in the future: results of an online survey', Insights into Imaging, 4(1), pp. 93-102.

Ratner, C. (2008) 'Objectivism', in Given, L.M. (ed.) The SAGE encyclopedia of qualitative research methods. Thousand Oaks, CA.: SAGE, pp. 568-73-573.

Reddington, M. and Francis, H. (2012) 'The Impact of Web 2.0 and Enterprise 2.0 Corporate Reputation: Benefits Problems and Prospects'. In: Martin, G., Cooper, C. L. and Burke, R. J. (eds.), Corporate Reputation: Managing Opportunities and Threats, Farnham: Gower publishing limited, pp. 217-244.

Ribeiro, L.S., Costa, C. and Oliveira, J.L. (2012) 'Clustering of distinct PACS archives using a cooperative peer-to-peer network', Computer Methods and Programs in Biomedicine, 108(3), pp. 1002-1011.

Ross, P. and Pohjonen, H. (2011) 'Images crossing borders: image and workflow sharing on multiple levels', Insights into Imaging, 2(2), pp. 141-148.

Rosset, C., Rosset, A. and Ratib, O. (2005) 'General Consumer Communication Tools for Improved Image Management and Communication in Medicine', Journal of Digital Imaging, 18(4), pp. 270-279.

Saliba, V., Legido-Quigley, H., Hallik, R., Aaviksoo, A., Car, J. and McKee, M. (2012) 'Telemedicine across borders: A systematic review of factors that hinder or support implementation', International Journal of Medical Informatics, 81(12), pp. 793-809.

Santos, M., Bastião, L., Costa, C., Silva, A. and Rocha, N. (2011) 'DICOM and clinical data mining in a small hospital PACS: A pilot study', In, ENTERprise Information Systems, Vol. 221 of the series Communications in Computer and Information Science, pp. 254-263.

Saunders, M. and Tosey, P. (2012) 'The Layers of Research Design', RAPPORT, (Winter), pp. 58-59. Available at: http://www.anlp.org/files/research-onion-layers_42_357.pdf.

Schwandt, T.A. (2001) SAGE Dictionary of Qualitative Inquiry. 2nd edn. Thousand Oaks, CA: SAGE Publications Inc.

Seale, C., Charteris-Black, J., MacFarlane, A. and McPherson, A. (2010) 'Interviews and Internet Forums: A Comparison of Two Sources of Qualitative Data', Qualitative Health Research, 20(5), pp. 595-606.

Sharma, A., Pan, T., Cambazoglu, B.B., Gurcan, M., Kurc, T. and Saltz, J. (2009) 'VirtualPACS - A federating gateway to access remote image data resources over the grid', Journal of Digital Imaging, 22(1), pp. 1-10.

Sicotte, C., Paré, G., Bini, K.K., Moreault, M. and Laverdure, G. (2010) 'Virtual Organization of Hospital Medical Imaging: A User Satisfaction Survey', Journal of Digital Imaging, 23(6), pp. 689-700 12p.

Siegel, E.L. (2003) 'Introduction to the Paper by Eliot Siegel and Bruce Reiner, “Work Flow Redesign: The Key to Success When Using PACS', Journal of Digital Imaging, 16(1), pp. 163-163.

Siegel, E.L. and Reiner, B. (2003) ‘Work flow redesign: the key to success when using PACS’. Journal of Digital Imaging, 16(1), pp.164-168.

Silva, L.A.B., Costa, C. and Oliveira, J.L. (2012) 'A PACS archive architecture supported on cloud services', International Journal of Computer Assisted Radiology and Surgery, 7(3), pp. 349-358.

Silva, L.A.B., Pinho, R., Ribeiro, L.S., Costa, C. and Oliveira, J.L. (2014) 'A Centralized Platform for Geo-Distributed PACS Management', Journal of Digital Imaging, 27(2), pp. 165-173.

Silva, L.B., Costa, C. and Oliveira, J. (2013) 'DICOM relay over the cloud', International Journal of Computer Assisted Radiology and Surgery, 8(3), pp. 323-333.

Sixsmith, J. and Murray, C.D. (2001) 'Ethical Issues in the Documentary Data Analysis of Internet Posts and Archives', Qualitative Health Research, 11(3), pp. 423-432.

Smith, H.,W. (1975) Strategies of Social Research: The Methodological Imagination. Englewood Cliffs, NJ.: Prentice Hall.

Sohier, R. (1988) 'Multiple Triangulation and Contemporary Nursing Research', Western Journal of Nursing Research, 10(6), pp. 732-742.

Tang, F.-., Law, M.Y.Y., Lee, A.C.H. and Chan, L.W.C. (2004) 'A mobile phone integrated health care delivery system of medical images', Journal of Digital Imaging, 17(3), pp. 217-225.

Tesoriero, J.A., Eddy, P. and Hasso, A.N. (2015) 'PACS Used While On-Call: A National Survey of Radiology Program Directors and Chief Residents', Journal of Digital Imaging, 28(2), pp. 205-212.

Thurmond, V.A. (2001) 'The Point of Triangulation', Journal of Nursing Scholarship, 33(3), pp. 253-258.

Torrieri, M. (2011) 'Talk vs Type: Taking another look at voice recognition.', Physician Practice, (July/August). Available at: http://www.physicianspractice.com/articles/talk-vs-type-taking-another-look-voice-recognition (Accessed: 20/03/2016).

Trochim, W.M.K. (2006) Research Methods Knowledge Base. Available at: http://www.socialresearchmethods.net/kb/survey.php (Accessed: 20/03/2016).

Twair, A.A., Torreggiani, W.C., Mahmud, S.M., Ramesh, N. and Hogan, B. (2000) 'Significant savings in radiologic report turnaround time after implementation of a complete picture archiving and communication system (PACS)', Journal of Digital Imaging, 13(4), pp. 175-177.

Tzeng, W.-., Kuo, K.-., Lin, H.-. and Chen, T.-. (2013) 'A Socio-technical assessment of the success of picture archiving and communication systems: The radiology technologist's perspective', BMC Medical Informatics and Decision Making, 13(1).

Valente, F., Costa, C. and Silva, A. (2013) 'Dicoogle, a Pacs Featuring Profiled Content Based Image Retrieval', PLoS ONE, 8(5), e61888.

Valente, F., Viana-Ferreira, C., Costa, C. and Oliveira, J.L. (2012) 'A RESTful Image Gateway for Multiple Medical Image Repositories', IEEE Transactions on Information Technology in Biomedicine, 16(3), pp. 356-364.

van de Wetering, R. and Batenburg, R. (2009) 'A PACS maturity model: A systematic meta-analytic review on maturation and evolvability of PACS in the hospital enterprise', International Journal of Medical Informatics, 78(2), pp. 127-140.

van de Wetering, R. and Batenburg, R. (2014) 'Towards a Theory of PACS Deployment: An Integrative PACS Maturity Framework', Journal of Digital Imaging, 27(3), pp. 337-350.

Venkatesh, V. and Bala, H. (2008) 'Technology Acceptance Model 3 and a Research Agenda on Interventions', Decision Sciences, 39(2), pp. 273-315.

Venkatesh, V., Morris, M.G., Davis, G.B. and and Davis, F.D. (2003) 'User Acceptance of Information Technology: Toward a Unified View', MIS Quarterly, 27(3), pp. 425-478.

Viana-Ferreira, C., Costa, C. and Oliveira, J.L. (2012) 'Dicoogle relay - a cloud communications bridge for medical imaging', 25th International Symposium on Computer-Based Medical Systems (CBMS). Rome, Italy, 20-22 June 2012. IEEE, pp. 1-6.

Watkins, J. (1999) 'A hospital-wide picture archiving and communication system (PACS): the views of users and providers of the radiology service at Hammersmith Hospital', European Journal of Radiology, 32(2), pp. 106-112.

Wisdom, J. and Creswell, J.W. (2013) Mixed Methods: Integrating Quantitative and Qualitative Data Collection and Analysis While Studying Patient-Centered Medical Home Models. Rockville, MD: Agency for Healthcare Research and Quality. February 2013. PCMH Research Methods Series, AHRQ Publication No. 13-0028-EF. Available at: https://pcmh.ahrq.gov/page/mixed-methods-integrating-quantitative-and-qualitative-data-collection-and-analysis-while

Wong, A. and Huang, H. (1996) 'Utilization of DICOM in PACS operation', Radiology, 201, pp. 515-515.

World Health Organization, (2014) Kuwait. Country cooperation strategy at a glance. Geneva: WHO

Xue, Y. and Liang, H. (2007) 'Understanding PACS development in context: The case of China', IEEE Transactions on Information Technology in Biomedicine, 11(1), pp. 14-16.

Zacharia, T.T., Sumner, J.E. and Saini, S. (2004) 'Picture archiving and communication systems applied to clinical trials: PACS promises to streamline image interpretation and accelerate the workflow in clinical settings', Applied Clinical Trials, 13(2), pp. S22.

Appendix-1 Ethics approval

School of Information Systems, Computing and Mathematics
David Gilbert, Head of School, Professor of Computing
Martin Shepperd, Head of Information Systems and Computing
Steven Noble, Head of Mathematical Science, Professor of Mathematics

Brunel UNIVERSITY LONDON

Brunel University, Uxbridge,
Middlesex UB8 3PH, UK
Telephone: +44(0) 1895 274000
Fax: +44(0) 1895 251686
Emails:
Yongmin.Li@brunel.ac.uk
Annette.Payne@brunel.ac.uk
Lampros.Stergioulas@brunel.ac.uk
Zidong.Wang@brunel.ac.uk

Date: 22/07/2014

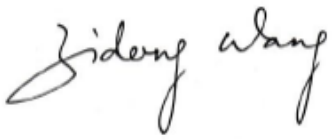
STATEMENT OF ETHICS APPROVAL

Proposer: Mona Al-Hajeri

Title: Future Trends in Picture Archiving and communication systems

The school's research ethics committee has considered the proposal recently submitted by you. Acting under delegated authority, the committee is satisfied that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that you will adhere to the terms agreed with participants and to inform the committee of any change of plans in relations to the information provided in the application form.

Yours sincerely,



Professor Zidong Wang
Chair of the Research Ethics Committee
SISCM

Appendix-2 Ethics approval (extended)

Brunel University London
Uxbridge UB8 3PH
United Kingdom

www.brunel.ac.uk

22 March 2016

STATEMENT OF ETHICS APPROVAL

Proposer: Mona Al-Hajeri

Dear Mona,

Project Title: Future Trends in Picture Archiving and Communication Systems

Extend Ethical Approval

Under delegated authority from the College Research Ethics Committee, I have considered the application recently submitted by you. I am satisfied that there is no objection on ethical grounds to the proposed study.

Approval is given on the understanding that you will adhere to the terms agreed with participants and to inform me of any change of plans in relation to the information provided in the application form.

In addition, please provide notification to the College Research Office when the study is complete, if it fails to start or is abandoned.

Yours sincerely,

John Park
College Research Mananger
T +44(0)1895 266057| **E** john.park@brunel.ac.uk

Brunel University London
College of Engineering, Design and Physical Sciences

Appendix-3 Support Letter from Ministry of Health, Kuwait

STATE OF KUWAIT
MINISTRY OF HEALTH

دولة الكويت
وزارة الصحة

Reference .....
Date..17/6/2014.....

قسم الطب النووي
مستشفى الفروانية
Nuclear Med. Department
Farwaniya Hospital

الرقم : .....
لتاريخ : .....

Dear / Dr. Malcolm Clarke
Supervisor
Reader in Telemedicine Systems

I have received your letter regarding Ms. Mona Al-Hajeri research.
I am ready to provide the help for her in conducting her work in Kuwait hospitals Radiology departments . I have already contacted the head of Radiology Council but she is out of town and will provide the letter you need soon .

Regards .

Dr. Iman Al-Shammeri
Head of Nuclear Med–icine Council
Head of Nuclear Medicine Department
Farwaniya Hospital
Ministry Of Health
imss6464@gmail.com

د. ايمان مطر الشمري
رئيس قسم الطب النووي

د. إيمان مطر الشمري
Dr. Iman Al-Shammeri
Nuclear Medicine Consultant

Cables : HEALTH KUWAIT
Admin. Financial Affairs Medical Stores
P.O.Box : 5 1519 22575
E-Mail : health @ moh. Gov. kw
Zip Code: 13001

برقيا : صحة الكويت
الوزارة المالية المستودعات
ص.ب : 5 1519 22575
الرمز البريدي للوزارة 13001

Appendix-4 Cover letter for interviews

This interview is aimed to identify and recommend enhanced information technologies and approaches to improve the functionality of current Picture Archiving and Communication System (PACS).

Date: Place: Time:

Interviewer:

Interviewee (Position):

All information will be **confidential** and will only be used for research purposes.

Appendix-5 Participant consent form

School of Computer Science
Brunel University, West London

Consent Form

Title of the project: Future Trends in Picture Archiving and Communication System (PACS).

Name of the researcher: Mona Al-hajeri

Please tick box

1	I confirm that I have read and understand the information sheet for the above study. I am fully aware about the purpose of this research.	
2	I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reasons.	
3	I agree to the interview being audio-recorded for purpose of transcription.	
4	I agree to take part in the above study.	

Name of participant **Date** **Signature**

Appendix-6 Participant Information Sheet

Brunel UNIVERSITY WEST LONDON

Important information

The name of the researcher: Mona Al-hajeri

This research project is a PhD thesis aims to identify and recommend enhanced information technologies and approaches to improve the functionality of current Picture Archiving and Communication Systems (PACS).

The aim of the questionnaire is to explore your opinion about the current limitations and future enhancement of PACS.

Completing this questionnaire is optional (not compulsory), and you can withdraw at any time without consequences.

All information will be confidential and will only be used for research purposes.

If you have any concerns or complaints regarding the ethical elements of this project please contact siscm.srec@brunel.ac.uk or Professor Zidong Wang (Chair of School Ethics Committee), Tel. No. 01895 266021.

Appendix-7 List of interview questions

Interview Questions

1. Educational level:

2. Years of experience:

(The current PACS usage)

3. How much do you use PACS in every day?

(The limitation of current PACS)

4. What are the current limitations of Picture Archiving and Communication system PACS?

(Additional features that can enhance functionality of PACS)

5. What feature do you think can increase the PACS functionality? How?

6. What do you need from PACS to reach maximum satisfaction in use?

(Expectation of the next generation PACS)

7. What advances in PACS have you heard of?

8. Do you think Web PACS solutions such as multi hospital PACS and PACS on mobile phones could be a solution for handling the previous issues?

9. What are your expectations of using mobile phones as a medium for retrieving and displaying medical images?

- Is it will be helpful especially in the emergency cases (on call)

10. What are your expectations of connecting hospitals with single multi-site PACS?

- It can improve PACS functionality and productivity. Not only Saving time and efforts but also provide better patient care.

-In term of having access to patients' medical images and data immediately after acquired.

-sending the medical images and report to the preferring physician through web design

- seeking consultation with radiologist in other institutions

-Providing consultation with smaller off site facilities

11. How would the next generation of PACS be different of traditional PACS?

12. Anything else you would like to add? Did I miss something important?

Many thanks for your participation making this interview successful

Appendix 8: Survey questionnaire

1. Dear Radiologist

Thank you for agreeing to complete this questionnaire on Future Trends in Picture Archiving and Communication

System (PACS)

Picture Archiving and Communication System (PACS) replaces hard copy based film with filmless environments. It acquires, stores, transmits, and archives medical images electronically. Because of rapid development in health care Information and Communication Technology (ICT) traditional PACS must be updated to follow the changes. The next generation of PACS must solve the existing problems of PACS and enhance its functionality to reach maximum potential. It must also incorporate modern technical developments to increase its productivity.

This survey seeks to explore your opinion about current limitations and future enhancements of PACS

Be assured that all data will be processed ANONYMOUSLY and responses will be treated with STRICT

CONFIDENTIALITY. No details related to any individual or organization will be available to any other party.This survey

should take 10 minutes to complete.

I am grateful for your help in this matter. If you require any further information or have questions about the survey,

Please call me on0096599801147or send an email to: <Mona.Alhajeri@brunel.ac.uk>

Copies of research detailing the full results of the survey, will be sent free of charge to participants.Should you

Like such a copy, please send your email address to the email mentioned above.

Yours sincerely;

Mona AlHajeri

School of Information Systems, Computing and Maths

Brunel University

1

Section One: Background Information

1. Indicate how much you use the following?

	Always	Often	Sometimes	Rarely	Never
PACS system?	○	○	○	○	○
Internet at work?	○	○	○	○	○
A smart phone for your work?	○	○	○	○	○

2. Indicate the level of SATISFACATION on the current Picture Archiving and Communication Systems

	Exteremely Satisfied	Slightly Satisfied	Slightly Dissatisfied	Extremely Dissatisfied
I am satisfied with current Picture Archiving and communication systems	○	○	○	○

3. I have concerns about the following in relation to PACS

	Strongly Agree	Agree	Disagree	Strongly Disagree
Limited search functionality	○	○	○	○
No connection between hospitals	○	○	○	○
Access restricted in my office	○	○	○	○

2

2.

4. Indicate your level of AGREEMENT with the following ststement

	Strongly Agree	Agree	Disagree	Strongly Disagree
Web PACS solutions such as multi hospital PACS and PACS in mobile phones could be a solution for handling the previous issues	○	○	○	○

Section Two:Preception next Generation PACS

5. Indicate the level of AGREEMENT on the following statements:

	Strongly Agree	Agree	Disagree	Strongly Disagree
There is a potential role for advanced Information and Communication Technology (ICT) in improving health care services	○	○	○	○
Providing PACS in mobile phones can provide flexible access to medical images anywhere at anytime	○	○	○	○
Providing PACS in mobile phones as an application can provide better patient services especially in emergency cases	○	○	○	○
Connecting hospitals with single multisite PACS can improve PACS functionality and productivity?	○	○	○	○

3

3. Section Three: Comfort with Technology

6. Indicate your level of AGREEMENT with the following:

	Strongly Agree	Agree	Disagree	Strongly Disagree
I can trust the technology at work	○	○	○	○
I am happy in using ICT/internet for the purpose of patient care	○	○	○	○
I would like to use ICT/Internet to communicate medical images and information with other health instituations	○	○	○	○
I would like to consult large centers in my specialty using patient medical images and information	○	○	○	○
I would like to have access to medical images and dataanywhere at any time	○	○	○	○
Web PACS solution can be integrated within our existing system	○	○	○	○

4

7. For the following issues indicate how you believe they will affect adoption of Web PACS solutions?

	Strongly Agree	Agree	Disagree	Strongley disagree
High cost	○	○	○	○
Negative attitudes of staff involved	○	○	○	○
Suitable training in the use of system	○	○	○	○
Perceived increase in workload	○	○	○	○
patient privacy /confidentiality	○	○	○	○
Technical concerns	○	○	○	○
Lack of user-friendly software	○	○	○	○
Lack of perceived clinical usefulness	○	○	○	○
Lack of consultation with clinicians	○	○	○	○

8. Any Other Comments

5

4. Section Four:Demographic and background characteristics

Your name:

9. What is your current position ?

- [ ] Senior radiologist
- [ ] Junior radiologist
- [ ] Trainee radiologist

10. Gender

- [ ] Female
- [ ] Male

11. Nationality

- ◯ Kuwaiti
- ◯ Non-Kuwaiti
- ◯ Other

Other (please specify)

12. Which category below includes your age?

- ◯ 21-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60 or older

13. What is your work experience in your present organization?

- ◯ less than 5 years
- ◯ Between 5-10
- ◯ More than 10 years

6

Appendix 9: Data extraction form for online discussion groups

S No.	Name	Position	Total No.	Comment S No.