An activity-based workload modelling approach for determining diagnostic radiographer staffing requirements within a diagnostic radiology practice.

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Declaration

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Abstract

Radiology is a medical speciality that uses imaging technologies to obtain and interpret medical images. Radiology forms a crucial part in the diagnosis and treatment of diseases, thus the quality of the reports and images, together with the quick turnaround time of the results, is paramount. The radiology team consists of radiologists, who are medical specialists that interpret images to appropriately advise on treatment, while radiographers operate the imaging equipment and ensure correct patient positioning.

The efficiency of a radiology department is influenced by effective integration of workflow and imaging technologies as well as by appropriately aligned staffing, amongst other factors. Furthermore, diagnostic radiographers are responsible for producing the medical images that form the basis for accurate diagnosis hence, ensuring that a diagnostic radiology practice is staffed by a sufficient number of diagnostic radiographers is a vital aspect in enabling effective service delivery. However, a review of existing radiology-specific staffing approaches reveals that radiology workload models focus mainly on diagnostic radiologists within tertiary hospital environments, while research into radiographers' workload and staffing only considers the radiation therapy practice field.

This research develops a framework that can be used to accurately determine diagnostic radiographer staffing requirements. The proposed framework is developed based on requirement specifications. These requirement specifications are formulated based on a body of literature that includes both general healthcare- and radiology-specific staffing approaches. A complete evaluation approach (verification and validation) is applied to the requirement specifications and the proposed framework. A self-verification of the requirement specifications to the proposed framework is done followed by a theoretical verification of both the underlying bodies of literature and the framework that involves subject matter experts. The validation process includes a case study application of the framework to a private diagnostic radiology practice. The results of the case study are validated with subject matter experts to confirm the framework's applicability and practicability. Insights from the case application confirm that the diagnostic radiographer staffing framework can be applied to both public and private diagnostic radiology environments.

Opsomming

Radiologie is ‘n mediese spesialiteit wat gebruik maak van beeldtegnologieë om mediese beelde te interpreteer. Radiologie speel ‘n fundamentele rol in die diagnose en behandeling van siektes en dus is die kwaliteit van verslae en beelde sowel as effektiewe omkeertyd van allerhoogste belang. Die radiologie span bestaan uit radioloë wie mediese spesialiste is en beelde interpreteer vir moontlike diagnose om behandeling te begin terwyl radiografiste die beeldtoerusting en patiënt samewerking behartig.

Die doeltreffendheid van ‘n radiologie departement word beinvloed deur die suksesvolle integrasie van die werksvloei en beeldtegnologieë beskikbaar sowel as die bekwaamheid en vaardigheid van personeel. Diagnostiese radiograwe is verantwoordelik om hoë kwaliteit mediese beelde te produseer wat die basis van ‘n akkurate diagnose vorm, daarom is dit noodsaaklikhed om ‘n diagnostiese radiologiese praktyk met genoegsame vaardige diagnostiese radiograwe te beman om doeltreffende dienslewering te bied. Huidige resensies van bestaande radiologie spesifieke personeel benaderings wys egter dat werkslading modelle in radiologie hoofsaaklik op diagnostiese radioloë in tersiêre hospitaal omgewings fokus, terwyl navorsing in radiograwe se werkslading en personeel vereistes alleenlik die bestralingsterapeutiese veld in ag neem.

Hierdie navorsing ontwikkel ‘n raamwerk wat met akkuraatheid die diagnostiese radiograaf personeelvoorsiening kan bepaal. Die voorgestelde raamwerk is saamgestel en gebaseer op vereiste spesifikasies. Die laasgenoemde is ontwikkel deur ‘n liggaam van literatuur wat beide algemene gesondheid- en radiologie spesifieke personeel benaderings insluit. ‘n Volledige evaluasie benadering (verifikasie en validasie) is aan die vereiste spesifikasies en voorgestelde raamwerk toegepas. ‘n Selfverifiëring van die vereiste spesifikasies aan die voorgestelde raamwerk is voltooi, gevolg deur ‘n teoretiese verifikasie van beide die onderliggende liggame van literatuur en die raamwerk met vakdeskundiges. Die valideringsproses sluit in ‘n gevallestudie toepassing van die raamwerk in ‘n privaat diagnostiese radiologiese praktyk. Die resultate van die gevallestudie is nagegaan met vakdeskundiges om die raamwerk se toepaslikheid en uitvoerbaarheid te bevestig. Insigte vanuit die gevallestudie bevestig dat die diagnostiese radiograaf personeelvoorsiening raamwerk toegepas kan word in beide publieke en privaat diagnostiese radiologiese omgewings.

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"For He will command His angels concerning you to guard you in all your ways;"

-Psalm 91:11

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Nomenclature

Acronyms and abbreviations

Abt	Abt Associates Inc.
COIDA	Compensations for Occupational Injuries and Diseases Act
CR	Computer photography and
CT	Computed Tomography
DR	Digital radiography
Fluoro	Fluoroscopy
GP	General practitioner
HHR	Healthcare human resources
HIS-RIS	Hospital Information System/ Radiology Information System
Mammo	Mammography
MRI	Magnetic Resonance Imaging
NHRPL	National Health Reference Price List
PACS	Picture archiving and communication system
PERT	Programme evaluation and review technique
PET	Positron emission tomography
RIS	Radiology information system
RTAT	Report turnaround time
RTs	Radiation therapists
RVU	Relative value unit (RVU)
US	Ultrasound
VR	Voice recognition
WHO	World Health Organisation

Greek symbols

σ = standard deviation.

Roman symbols

AWT	Total available working time
A	Number of possible working days in a year
B	Number of days off for public holidays in a year
C	Number of days off for annual leave in a year
CF	Conversion factor
D	Number of days off due to sick leave in a year
E	Number of days off due to other leave, such as training in a year
F	Number of working hours in one day
Total RVU	Total relative value unit
RVUPW	Physician work RVU
RVUPE	Practice expense RVU
RVUME	Malpractice expense RVU
GPCI	Geographic practice cost index
T_e	Mean of the beta distribution, the mean time estimate for the task
t_o	Optimistic time estimate
t_m	Most likely time estimate
t_p	Pessimistic time estimate

Terminology

Allied health professionals	Healthcare professionals that are not medical doctors but offer an array of diagnostic, therapeutic and support services concerning health care.

Demand based approaches	In the context of healthcare workforce planning, a healthcare staffing approach that seeks to predict future health workforce demand by focusing on the development or change of driving forces of the health services demand.
Diagnostic ultrasound	A non-invasive diagnostic imaging technique that use high frequency sound waves to produce real-time medical images.
Nuclear medicine	A discipline of radiology that uses radioactive material for the diagnosis and treatment of diseases.
Physicist	In the context of a radiology practice, this term refers to a medical physicist in radiation therapy responsible for managing and monitoring radiation safety and quality of all radiation equipment.
Radiation therapist	An allied health professional also known as a radiotherapist that works in the field of radiation therapy.
Radiation therapy	A cancer treatment discipline in radiology that uses large doses of radiation to kill cancer cells and shrink tumours.
Radiographer	A trained healthcare professional and radiation worker that can operate medical imaging equipment to develop medical imaging.
Radiologist	A medical doctor specialising in radiology.
Radiology	A medical speciality that uses medical imaging technologies to obtain medical images for the diagnosis and treatment of diseases.
Supply based approaches	In the context of healthcare workforce planning, a healthcare staffing approach that seeks to predict the future health workforce through the analysis of the factors that impact their movement into, through and exiting the health workforce.
Teleradiology	The application of several technologies in radiology to transfer clinical imaging information from the creator to the user and back.

Tertiary hospital	A specialised medical facility that offers tertiary care services (i.e. radiation therapy) and sustains a radiology training programme.
Workforce planning	A process of assessing the demand for labour.
Workload based approaches	In the context of healthcare workforce planning, a healthcare staffing approach that determines the staffing requirements based on the basic relationship between health care service activity and the workload involved in performing the activity.

Chapter 1: Introduction

This chapter starts with the background that consists of a summary of appropriate characteristics of the literature that aided in the formulation of the research problem. In addition, the research aims, and objectives are also described together with the scope of the study, its limitations and delimitations, appropriate research design and methodologies, evaluation approach, and how the chapter is structured.

1.1 Background

Radiology is a medical speciality that uses imaging technologies, such as x-ray (radiograph), computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, mammography, fluoroscopy, nuclear medicine, and positron emission tomography (PET) to obtain and interpret medical images. Radiology forms a crucial part in the diagnosis and treatment of diseases. The quality of the reports and images, together with the quick turnaround time of the results, is paramount in the effective and efficient treatment of patients.

Several steps are required, from capturing the patient's details, taking the x-rays until a report with results is provided to the referring physician. These tasks are performed by a variety of administrative, technical, and professional staff. The radiology team consists of radiologists, who are medical specialists that interpret x-rays and scans to appropriately advise other medical specialists on treatment, while radiographers operate the imaging equipment and produce x-rays and medical images. The administrative staff are responsible for capturing the patient's details, typing- and dispatching reports.

Technological changes, which include the introduction of filmless radiology and picture archiving and communication system (PACS), necessitate adaptation of the workflow within radiology departments, though this is not always implemented (Dreyer et al., 2006). Radiology managers are faced with many challenges ranging from increasing patient volumes, pressure to reduce reporting turnaround times, and improving utilization of imaging equipment, while maintaining focus on the patient and his or her needs. Often the aforementioned needs to be achieved with the same or a reduced number of staff (Aloisio & Winterfeldt, 2010). Therein lies an opportunity to address the staffing requirement challenges faced by radiology managers.

Workforce planning according to Reilly (1996, p.75) "*is a process in which an organisation attempts to estimate the demand for labour and evaluate the size, nature and resources of the supply which will be required to meet that demand*". This is typically a human resource management function within any organisation. The discipline of Industrial Engineering is also traditionally involved with workforce planning, primarily known as manpower planning or staffing, which forms part of work measurement. Staffing is concerned with determining the right number of people, with the right skill to meet the desired demand for services (Kachhal, 2001). In the healthcare industry, workforce planning is commonly applied to determine nursing staff requirements.

Radiology has also adopted the practice, with existing approaches focusing on determining staffing requirements for radiologists and for radiographers working specifically in a radiation therapy environment (commonly referred to as radiation therapists). However, there remains a need to consider approaches for determining staffing requirements for radiographers working in other radiology environments.

1.2 Problem statement

A radiology department's ability to provide the highest quality of care possible while either maximising income or minimising costs, depends largely on the execution of the workflow and how the department is staffed. Traditionally, research on radiology workload models focused primarily on diagnostic radiologists within a tertiary hospital environment, while research into radiographers' workload and staffing only considered the radiation therapy practice field. In addition, radiology experiences continuous changes from a technological perspective as well as changes in procedures which leads to role changes for both radiologists and radiographers. These role changes often render the traditional staffing models unreliable and outdated as such models do not take into consideration the changes to activities that resulted from the technology and procedural advances (Brady, 2011).

There is thus a need to develop an approach to accurately determine the required diagnostic radiographer staffing-levels for a radiology practice, based on the current technology and procedures in place.

1.3 Research aim and objectives

The aim of this research is to contribute towards increasingly efficient and effective radiology practices by developing a framework that can accurately (or with minimum bias) determine the diagnostic radiographer staffing requirements within a diagnostic radiology practice or department. To support the attainment of the stated research aim, a set of research objectives (ROs) have been defined. The objectives of this research are:

- **RO1:** To review literature affecting the radiological environment in terms of the general operations, workflow and the factors influencing workload and staffing requirements to formulate requirement specifications;

- **RO2:** To identify common healthcare and radiology staffing approaches through a literature review for the development of requirement specifications to formulate a radiology staffing framework;
- **RO3:** To develop a diagnostic radiographer staffing framework based on the requirement specifications and insights gathered from the first two objectives; and
- **RO4:** To verify and validate the framework using: self-verification; subject matter experts (SME) verification interviews; a case study application; and, finally, SME validation interviews.

1.4 Scope of study

Radiology, as depicted in Figure 1.1, consists of the following fields of study, namely: (i) diagnostic radiography; (ii) diagnostic ultrasound; (iii) nuclear medicine; and (iv) radiation therapy or therapeutic radiography (Etheredge, 2011). The first point of contact with radiology is either with diagnostic radiography or diagnostic ultrasound. This is considered the diagnostic radiology environment. Once a diagnosis is made in the diagnostic radiology environment, further interventions from nuclear medicine or radiation therapy might be required, as their operating environments are unique to the treatment required.

Radiologists are medical doctors that specialises in any of the four fields of study identified in Figure 1.1. The focus of his research is limited to the diagnostic radiology environment which includes diagnostic radiography and diagnostic ultrasound. Diagnostic radiographers work in the diagnostic radiology environment, while radiation therapists (the term used for radiographers that work in radiation therapy) and nuclear medicine radiographers work in the radiation therapy and nuclear medicine environment, respectively. Although the radiation therapy environment falls outside the scope of this research, their workflow is similar when considering the acquisition of medical images – radiographer use medical imaging equipment to obtain medical images. Thus, staffing approaches in the radiation therapy environment were considered when developing a diagnostic radiographer staffing framework. Furthermore, only the scope of work (activities) of the diagnostic radiographers will be considered, while other staff (i.e. administrative) that are also involved in the patient’s journey through radiology, is outside the scope of this study.

Diagnostic radiology is central to the accurate and timely diagnosis of diseases and illnesses. The radiology discipline relies on the skill of diagnostic radiographers to operate the technologically advanced imaging equipment that are used to obtain high quality medical images that are subsequently interpreted by radiologist to make an accurate diagnosis (Royal College of Radiologists, 2012b). Hence, the motivation to focus on radiographers in a diagnostic radiology context as they form part of a critical human resource team that not only ensures accurate and timely diagnosis, but also the efficacy of the functioning of a radiology department.

The initial scope of the research was limited to the private diagnostic radiology environment, but feedback from subject matter experts as part of the framework refinement, led to the realisation that, with a small adjustment, the framework can be suitable for both private and public sector diagnostic radiology environments.

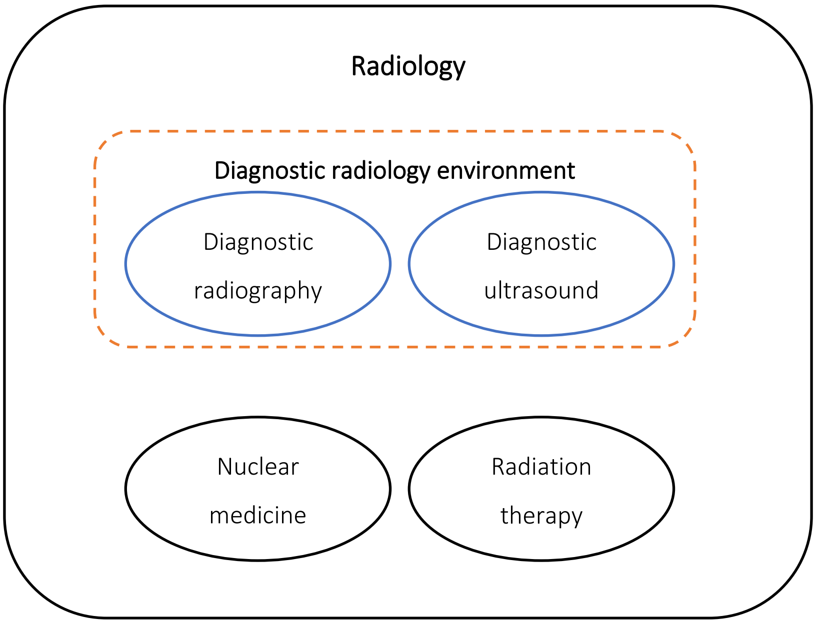

Figure 1.1: Schematic representation of radiology overview

1.5 Limitations and delimitations

This research is limited to the workload and staffing requirements of diagnostic radiographers in a diagnostic radiology context with the primary focus to establish the current number of diagnostic radiographers that are required to meet the existing demand.

Staffing, scheduling and reallocation are three core responsibilities of workload management (Ozcan, 2009). However, this research is limited to staffing only which focuses on determining the appropriate number of diagnostic radiographers.

1.6 Research design and methodology

In a qualitative research approach, the association between theory and research is mostly underlined by an inductive approach where the emphasis is on creating, rather than testing, theories (Bryman et al., 2014). In contrast, in a quantitative research approach the relationship between theory and research is based on deduction, with the importance being on testing of theories (Bryman et al., 2014). Both these two research approaches have strengths and weaknesses which Bryman et al. (2014) argue can be equalised with a mixed-method research approach.

This research will use a mixed-method research approach. Literature from secondary data sources pertaining to the radiology operating context, staffing and related challenges is reviewed to formulate and solve the research problem. In addressing the research problem, an inductive approach is applied to evaluate and synthesise the literature to formulate requirement specifications that inform the development of a diagnostic radiography staffing framework. The requirement specifications, derived from the literature review, are categorised based on the four categories of specifications as suggested by Van Aken et al. (2007). These categories provide a balanced approach to the design and formulation of a framework. The four categories of specifications, as defined by Van Aken et al. (2007), are as follows:

- Functional requirements (FR): the capabilities that the framework must provide to address the needs in the operating environment;
- User requirements (UR): specific or expressed need(s) or desired characteristic(s) from the perspective of the user;
- Boundary conditions (BC): requirements that must be met unconditionally; and
- Design restrictions (DR): requirements that describe a more desirable (*preferred*) solution space, considering any other constraints on the design of the framework.

The synthesis of the requirement specifications to build the framework will be done through a critical compatibility evaluation of the requirement specifications to the different staffing approaches from both radiology and healthcare.

1.7 Research artefact classification

The artefact that will be produced in this research is classified as a framework. Literature relevant to this research is reviewed and its findings (i.e. constructs, models and assumptions) are used to develop the staffing framework that addresses the research problem. The framework is used to illustrate or provide a step-by-step guide to determine the staffing needs in a diagnostic radiology environment, while a model represents an overview of a construct but does not contain the required detail to address the research problem.

When referring to existing methods for workforce modelling, the term ‘model(s)’ is uniformly used throughout this document. This represents the most appropriate description for the majority of artefacts from literature that are reviewed in the document and is used throughout the document to aid in disambiguation.

1.8 Evaluation approach

The intent of this research study is to develop a diagnostic radiographer staffing framework that can assist radiology managers to accurately determine the staffing requirements for diagnostic radiographers. To demonstrate the accuracy and usefulness of the framework, and the adequacy of the bodies of literature that guided the development of the requirement specification that underpins the framework, its intent must be evaluated.

The evaluation process is organised into two main categories, namely verification and validation, that are executed in four progressive phases. These phases build upon each other to enhance the reliability and validity of the developed diagnostic radiographer staffing framework. Figure 1.2 depicts an overview of the evaluation strategy deployed for this research.

The reliability of the requirement specification and diagnostic radiographer staffing framework will be assessed through the first main category of the evaluation approach namely, verification. Verification involves the process of determining whether the framework was developed consistent with the requirement specifications (Boehm, 1984). The first verification phase involves a self-verification to evaluate whether the staffing framework fulfils the requirement specification. Secondly, semi-structured interviews with SMEs are held to evaluate (verify): the adequacy of the requirement specification; and the accuracy of the development of the staffing framework to the requirements specification. This concludes the theoretical verification.

As shown in Figure 1.2, the theoretical verification is followed by a framework refinement process, where improvements are made to the framework in response to insights that were generated during the verification process.

The framework refinement is followed by the framework validation. Validation is concerned with evaluating the framework after development to ensure it is fit for purpose – i.e. that it addresses the research problem (Boehm, 1984). The refined framework is applied to a case environment to obtain comprehensive and functional insight into whether the proposed framework is fit for its intended use. Upon completion of the case study, the results are shared with SMEs that are working in the diagnostic radiology environment to ascertain the framework's applicability and operability within the diagnostic radiology environment.

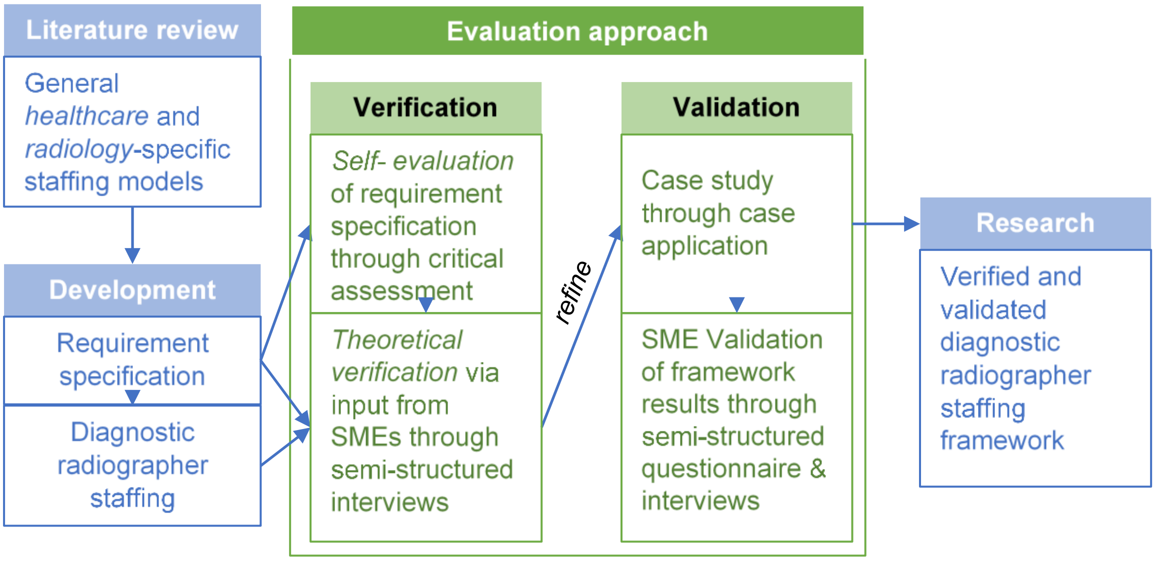

Figure 1.2: Overview of evaluation approach

1.9 Structure of the document

This document consists of six chapters. In Chapter 1 the context and an overview of the research is provided. The background to the problem statement is given, which then leads to the research aim and objectives, followed by the scope of the study, its limitations, and delimitations. The approach that is employed in the research is also outlined.

The first and second objectives of the research are jointly delivered in Chapters 2 and 3. In Chapter 2, literature on the radiology context pertaining to the clinical operating environment and the drivers of change in the radiology workload, are reviewed. In Chapter 3, literature on staffing models used in healthcare in general, and in radiology specifically, is presented, followed by a discussion on current radiology staffing approaches. Throughout these two chapters, requirement specifications are identified which form the basis upon which a solution to the research problem is developed.

In Chapter 4, the requirement specifications are consolidated, and the development and detail of the diagnostic radiographer staffing framework are described, thus fulfilling the third objective of the research. In Chapter 5, consideration is given to whether the framework is applicable and useable within the diagnostic radiology environment. A case study, as well as other components of the verification and validation, are presented. The fourth research objective is therefore achieved in this chapter.

The research is concluded in Chapter 6 and opportunities for future research are proposed.

1.10 Conclusion: Chapter 1

This chapter provided the background that led to the problem statement which described the ideal state against the setting of the current situation and propose a direction to move closer to the goal. The research aim and objectives were described, defining the scope of the study along with the limitations and delimitations. The research design and methodology to develop a suitable solution for the research problem, along with the evaluation approach and document structure are described.

Chapter 2: Radiology in Context

In Chapter 1 the research project was introduced, while in Chapter 2 the focus turns to providing a detailed introduction to the radiological environment by considering three themes, namely: (i) general overview of radiology; (ii) the clinical operating environment; and (iii) the drivers of change in radiology workload.

2.1 General overview of radiology

This subsection opens by briefly defining radiology and its key objectives, followed by the identification of key staff and the various imaging modalities that are used.

2.1.1 Defining radiology

Radiology is a medical speciality that deals with the use of radiant (or beaming) energy (i.e. x-rays), radioactive material (i.e. uranium) and high-energy radiation to examine the internal anatomical structure of the body for diagnosis and treatment of diseases (Royal College of Radiologists, 2012b). This definition highlights what radiology involves, the role it plays in the provision of medical care and how its achieved.

Soroosh, Mayo-Smith and Mollura (2019, p.7) define radiology as "*an organization either independent or within a larger medical facility, specialized for the delivery of medical imaging services, including diagnostic imaging and image-guided treatments*." This definition captures two important features such as (i) the possible location or practice environment of radiology; and (ii) divides radiology into two broad fields. The first being diagnostic and the second interventional radiology. In its basic form, diagnostic radiology deals with medical images to see structures inside the body, while interventional radiology performs minimally invasive treatments through the use of medical imaging to help guide medical procedures (Royal College of Radiologists, 2012b). Other areas of radiology include radiation therapy that uses high-energy radiation in the treatment cancer cells and nuclear medicine which involves the use of radioactive materials such as radiopharmaceuticals for the diagnosis and treatment of diseases (Royal College of Radiologists, 2012b).

Exact and timely diagnosis of patients mostly involves diagnostic radiology that might include the most basic chest x-ray to diagnose pneumonia, to the more complex examinations of CT and MRI to manage cancer, trauma, and stroke care (Royal College of Radiologists, 2012b). Efficient and effective diagnosis is dependent on the combination of both: radiological imaging technology and the skill of the radiographer producing the radiological image; and the radiologist making the diagnosis from the images (Royal College of Radiologists, 2012b).

The radiology environment's contact with other medical specialities usually starts with diagnostic radiology and, depending on the diagnosis, other sub-specialities of radiology may also be involved.

2.1.2 Key objectives of radiology

Radiology is primarily a referral-based practice, implying that patients are referred by general healthcare practitioners and specialists to radiology for medical images. Considering this, the key objectives of a radiology department are to provide the referring physician with high quality images and a radiographic imaging report within an acceptable turnaround time while, ensuring the patient feels safe, and is comfortable and informed about what procedure or examination will be performed.

Dutton et al. (2014) state that radiology departments are facing increasing demands to improve their quality of service and the accountability thereof. Dutton et al. (2014) refer to the contract between hospitals and radiology departments that incorporate important matters such as report turnaround time, patient and staff satisfaction measures and resource utilisation and efficiency. If radiologists are to adhere to the proposed standards, they must evaluate whether such standards are reasonable and whether they have the required resources in the form of infrastructure, information technology systems, and staffing. Dutton et al. (2014) also state that the efficiency of a radiology department is not only dependent on the radiologist, but that technologies such as PACS and high-quality voice recognition (VR) are vitally important in improving the efficient functioning of a department.

The crux is thus to deliver a high-quality imaging report with an acceptable report turnaround time (RTAT) to referring physicians, whilst adhering to ethical- and acceptable patient safety requirements, and ensuring financial sustainability of the department or practice (Dreyer et al., 2006).

2.1.3 Human resources involved in radiology

The effective functioning of a radiology imaging service is greatly dependent on a well-organised group of personnel (Malkin & Teninty, 2014). The roles that stakeholders in an advanced healthcare institution fulfil for the delivery of imaging services are summarised in Table 2.1 (Malkin & Teninty, 2014). As the radiology technology advanced, so too has the intertwining practices and personnel changed. Traditionally the workflow within radiology focused on the printing and storage of images as films. Later, it transitioned to computer photography (CR) and digital radiography (DR). These advances required personnel with different responsibilities and skill sets. Depending on the local conditions of the radiology department, the roles outlined are executed by a smaller number of personnel that are also less specialised (Malkin & Teninty, 2014). These roles must, however, be fulfilled either by specialised- or multiskilled individuals, as these roles are critical for safe and effective imaging (Malkin & Teninty, 2014).

Table 2.1: Stakeholders and their key responsibilities in diagnostic radiology services (adapted from Malkin and Teninty, (2014))

Stakeholder	Responsibility
Administration (i.e. Front desk staff, accounting, human resources)	• Schedule patients • Document insurance • Record payments • Manage human resources • Manage quality inspection • Run the business economic aspects of the unit
Diagnostic radiographer	• Operate radiographic imaging hardware and equipment to capture radiographic images • Ensure optimal and efficient equipment use • Transmit images (print or electronic) to radiologists • Explain procedures and examinations to patients
Physicists	• Manage safety (radiation dose) of imaging hardware • Manage quality (resolution, calibrations) of imaging hardware and software • Monitor continuing safety and quality of all equipment
Information technology	• Manage saving/ sending of imaging studies • Use formats like DICOM • Manage specialised servers (PACS) to conduct high-volume traffic from radiographers to radiologist
Radiologists	• Interpret and report on images for diagnosis • Perform specific specialised interventional examinations • Work alongside radiographers as complimentary imaging professionals

Radiographers obtain a professional qualification through a tertiary educational institution that takes up to four years. They have the option of selecting one of four categories of radiography namely: diagnostic; therapeutic; nuclear medicine; or ultrasound.(Etheredge, 2011). It is worth noting that there is a key difference between nuclear medicine radiographers and diagnostic radiographer. Nuclear medicine radiographers assist nuclear medicine physicians and work with nuclear medicine isotopes. They support the nuclear medicine physician with the injection of isotopes and scanning of patients after injection to detect changes in the body because of diseases processes.

The radiology profession is vast with many sub-professions and sub-specialities for both radiologists and radiographers. However, this research aims to only focus on diagnostic radiographers as this forms the basis which also underpins the others sub-specialities, and the scope of work of diagnostic radiographers is more general in the radiology context.

The requirement specifications set out in Table 2.2 are formulated based on the information presented in this section.

Table 2.2: Requirements based on human resource perspective

RS Category	Description
UR 1	Framework must be able to allow the capturing of the number of qualified diagnostic radiographers (e.g. *Identify the current number of qualified radiographers).*
UR 2	The competency level of the qualified diagnostic radiographers must be captured (e.g. *Identify the current competency of diagnostic radiographers in the different modalities).*
UR 3	Activities performed by an appropriately qualified radiographer or under the supervision of qualified radiologists must be identified and listed (e.g. *Create an activity list of the qualified radiographer*).
DR 1	Framework will be constrained to the diagnostic radiology profession only.
DR 2	Framework will be constrained to appropriately qualified diagnostic radiographers only.

2.1.4 Diagnostic radiography as an allied health labour category

According to Ridoutt, Schoo and Santos (2006), there appears to be little consensus on a grouping of labour and a definition for the allied health workforce and profession. After a review of literature and focus group discussions, however, they settled on a possible taxonomy of allied health labour categories or types as a departure for their study to develop workload capacity measures for use in allied heath workforce planning. This taxonomy is in part derived from the four main categories of medical specialities of the Medical Training and Education Council of New South Wales (MTEC NSW) that includes (Ridoutt, Schoo and Santos, 2006):

i. *Procedural* specialities including surgical training, obstetrics and gynaecology and ophthalmology;
ii. *Medical* specialities including physician training (adult and paediatric);
iii. *Critical care* specialities including emergency medicine, anaesthetics, and intensive care medicine; and

iv. *Consultative* and *diagnostic* specialities including psychiatry, dermatology, radiology, pathology and general practice.

The broad allied health workforce was subclassified into similar categories which included (Ridoutt, Schoo and Santos, 2006):

i. *Diagnostics* specialities, such as diagnostic radiography, medical imaging technology;
ii. *Procedural* (or therapeutic) specialities, such as physiotherapy, speech pathology, audiology, optometry, chiropractics, podiatry;
iii. *Consultative* specialities, such as psychology, social work, occupational therapy, dietetics;
iv. *Dispensing* specialities, such as pharmacy, radiation therapy, prosthetics and orthotics; and
v. *Preventative* specialities, such as nutrition, dental hygiene, environmental health, health promotion, public health.

The authors have succeeded to classify the allied health workforce based on the four main categories of medical specialities, and diagnostic radiographers are part of the broad allied health workforce. The significance of this will be further explored in Chapter 3.

2.1.5 Imaging modalities

Imaging modalities such as x-ray imaging, MRI, CT, fluoroscopy, angiography, mammography, ultrasound, and nuclear medicine are used to produce diagnostic images which aid in the diagnosis and treatment of diseases. The correct diagnosis and treatment of patients is highly dependent on effective medical decision making which relies upon diagnostic imaging for proper assessment and confirmation of disease identification and treatment. Radiology is now considered to be a primary diagnostic tool for various diseases and plays a critical part in monitoring intervention and predicting outcomes (European Society of Radiology, 2010).

2.1.5.1 X-rays

X-rays are the most widely used imaging modality and is usually the first modality for evaluating bone fractures or breaks, bone tumours and pulmonary diseases, to mention a few. Radiography has developed greatly since X-rays were first discovered in 1895 by Wilhelm Conrad Roentegen, a German physicist (Sanghvi & Harisinghani, 2010). Digital radiography (DR) equipment replaced most conventional radiography systems because they change X-ray images to electronic data that can be viewed on a monitoring device and archived on a computer disk (Sanghvi & Harisinghani, 2010). These digital techniques make instantaneous viewing of radiographs possible and allow for manipulation of the images to deliver greater visibility of the abnormality (Sanghvi & Harisinghani, 2010).

A study on the "*analysis of licensed South African diagnostic imaging equipment"* done by Kabongo, Nel and Pitcher (2015) found that there are 34.8 general radiography units per million population in South Africa, which makes it the most accessible and equitably distributed modality.

2.1.5.2 Computed Tomography

CT, also known as a computerized axial tomography or CAT scan, is an imaging modality that is employed for non-invasive medical procedures or examinations. It uses x-ray photons to produce cross-sectional images of the body. These images are initially captured two-dimensionally and reconstructed by the CT machine to three-dimensional images. CT images capture more detailed information of the internal body than traditional x-rays which makes it a popular alternative for imaging of soft tissue (Sanghvi & Harisinghani, 2010). Furthermore, the use of contrast media in CT studies enhances abnormalities by differentiating structures of similar density in the body (Sanghvi & Harisinghani, 2010).

Technology advances in CT machines made it possible to produce more images or 'slices' in lesser time with the use of the new multi-slice CT or multidetector CT scanner. These advances produced better resolution CT images that require more time for interpretation – CT interpretation becomes more complex depending on the anatomical region – which, in turn, impacts on radiologists' capacity and ultimately their workload (Brady, 2011).

South Africa's has 5.0 CT units per million population which is lower than the OECD average of 13.3 (Kabongo, Nel and Pitcher, 2015).

2.1.5.3 Positron Emission Tomography

PET is a type of nuclear medicine examination or scan that applies radioactive materials called tracers in small quantities to evaluate the body's organ and tissue functioning (Sanghvi & Harisinghani, 2010). A very sensitive PET camera captures pictures of the radiotracers that are attracted by abnormal tissues or disease areas within the body, and using computer analysis, a 3D image of the disease areas is generated. A PET scan does not precisely locate the abnormal tissue in the body (as it creates a blurry picture), it only detects it (the abnormal tissue) whilst a CT scan is used to clearly define the anatomy of the body. When used together, PET and CT scans form a PET/CT scan, that provides a precise image of a patient's disease.

2.1.5.4 Magnetic Resonance Imaging

MRI is superior to other imaging modalities, because it offers spatial and soft tissue contrast resolution (Sanghvi & Harisinghani, 2010). Its ability to image in several planes, caused MRI to be viewed as the problem-solving modality for evaluating pathologies in various anatomical locations and, when combined with intravenous contrast agent gadolinium, MRI allows for the assessment of enhanced characteristics (Sanghvi & Harisinghani, 2010). Developments in MRI brought about the ability to not just indicate *anatomical* information but also information relating to *physiology*, which includes, amongst others, MR spectroscopy and tractography (Sanghvi & Harisinghani, 2010). The RCR states that advances in imaging technology causes clinical radiologists' workload to increase (Royal College of Radiologists, 2012b).

2.1.5.5 Mammography

Mammography is an imaging modality that applies low energy dose x-rays for imaging of breast tissue. It is used as a screening tool for the discovery of premature breast cancer in asymptomatic women.

Digital mammography (alias full-field digital mammography), computer-aided detection and breast tomosynthesis (otherwise known as three-dimensional mammography) are three of the improvements in mammography (World Health Organization, 2011).

According to a study done by Kabongo, Nel and Pitcher, (2015) South Africa has 4.96 mammography units per million population. This is lower than the OECD average of 26.46 mammography units per million population (Kabongo, Nel and Pitcher, 2015).

2.1.5.6 Conclusion: Imaging modalities

The requirement specifications set out in Table 2.3 are formulated based on the information presented in this section.

Table 2.3: Requirements based on imaging modalities

RS Category	Description
UR 4	The framework must be adjustable to allow the capturing of the number of equipment and modalities that are available and in use.
UR 5	The framework must be adjustable to enter the number of procedures and / or techniques that are being used in each modality.
DR 3	The framework must be restricted to diagnostic radiology equipment, modalities, and procedures (and / or techniques).

2.1.6 Different radiology practice environments

Dutton et al. (2014) identified six different radiology practice environments namely (i) private practice; (ii) hospital-based practice; (iii) academic or medical school; (iv) multispecialty or academic clinic; (v) corporate employees; and (vi) government. These practicing environments present a variety of options to radiologists when deciding on the type of environment to work in. However, Dutton et al. (2014) point out that there are key differences among the practice environments such as (i) physician autonomy, (ii) efficiency, (iii) productivity, and (iv) subspecialty versus general practice, which impact on operational aspects of the practice environment, such as workload and personal career development. Physician autonomy is a key issue in the various radiology practice locations and private practice tends to afford physicians the greatest degree of autonomy, whilst physicians that are government employees tend to have the lowest degrees of autonomy. Higher degrees of physician autonomy tend to be associated with higher workloads, both for physicians and for radiologists (Dutton et al., 2014). The requirement specifications set out in Table 2.4 are formulated based on the information presented in this section.

Table 2.4: Requirements based on radiology practices environments

RS Category	Description
DR 4	The framework will be constrained to the private practice radiology environment.
UR 6	The framework must allow the user to specify the number of radiology practices within the group.

2.2 The clinical operating environment

In this section, various attributes of the radiology environment will be discussed with specific focus on characteristics of the clinical operating environment and how they may affect staffing requirements within radiology.

2.2.1 Radiology value chain

Mariani et al. (2006, p.18) define *"a radiological workflow as the procedure of analysing individual steps necessary to carry out the whole process in a radiology department*." This process contains all the necessary steps to produce both medical images and the ultimate work product, namely a finalised radiology report for diagnostic or therapeutic purposes. Although radiology departments differ greatly, there is some commonality in the basic process for obtaining images. In its basic form, the process is initiated by a request form from a referring physician requesting radiographic images and a report. This request is acknowledged by administrative staff who enter the patient's details on a radiology information system (RIS) that will allocate an appointment for the appropriate test (examination) to the patient. The radiographer (or radiologic technologist) then performs the necessary diagnostic imaging procedures, with or without the assistance of the radiologists, using medical imaging technologies. The images are captured and stored in a PACS from where the radiologists can view, interpret, and report on them. The radiologist uses VR technology to convert spoken words (based on the interpretation of images) to digital text (radiology report). Hereafter the report is ready to be delivered to the requesting physician.

Since the report and medical images will be used for prognosis and treatment of a patient, the effective and efficient management of the workflow within a radiology department is paramount. Any improvement in the workflow management of a radiology department that reduces the turnaround time of reports, can have a positive impact on the diagnosis and treatment of a patient.

The requirement specifications set out in Table 2.5 are formulated based on the information presented in this section.

Table 2.5: Requirements based on radiology value chain

RS Category	Description
UR 7	The framework must allow the user to specify local conditions that are of significance and will impact on the workload of the department or unit (e.g. the physical layout of the department, its organisational structure, the key medical processes, patient flow and procedures related to the specific department). Thus, an analysis of the clinical flow and identification of all the professional roles associated with the activities along the workflow, must be accommodated.

2.2.2 The role of a radiology department

Diagnostic radiology has become an integral part of any aspect of medicine and it is almost impossible to imagine practicing medicine without it (Patti et al., 2008). Patti et al. (2008) reference personal communication with a subject matter expert who conservatively estimates that about "*40% of patient encounters result in the ordering, reviewing, or use of imaging examinations*". In addition, approximately 50% to 60% of cancer patients will encounter service from radiation oncology at some point during their illness (Patti et al., 2008). Furthermore, Rahman (2014) agrees that radiology has become a major diagnostic aid for many diseases and plays a critical role in monitoring treatment and predicting results.

A finalised radiology (or imaging) report is viewed as the definitive work product of a radiology department (Boland et al., 2008). As described in the previous section, the radiology value chain starts with the referring doctor and ends with the referring doctor. The imaging report together with the radiological images allow medical specialists to diagnose and treat patients effectively.

Larson et al*.* (2014) refer to radiology as a centre that generates (or acquires) information – thus radiology is in the business of information. The authors argue that, as patients go through the radiology department, information is acquired. Referring clinicians pass on image order information and patients' clinical history to radiology; in their turn, the radiology department generates information from the patient's body in the form of images. More information is generated when the images are interpreted and communicated back to the referring clinician. Larson et al. (2014) continue by stating that value is added throughout the imaging process as information and patients flow through the imaging process.

The value of a radiology department is also associated with the speed (quantified as the RTAT) and the quality of the report (Boland et al., 2008). The demand for quicker report turnarounds increased significantly and any interruptions in the delivery of reports negatively impact the perceived '*value'* of a radiology department (Boland et al., 2008). In some cases, poor performance in terms of RTAT can be partially attributed to inadequate staffing levels and the lack of adequate information systems, such as radiology information system (RIS), PACS, and VR (Boland et al., 2008).

2.3 Drivers of change in radiology workload

Radiology workload has changed rapidly. This can, at least partially, be attributed to following drivers of change that are discussed in the succeeding sections.

2.3.1 Workflow management

Radiology departments, like many other areas of healthcare provision, are facing a growing demand for more efficient and higher quality services. These demands have been partially met with the introduction of new and evolving workflow management technologies (Zhang et al., 2009). Moreover, workflow management was made easier through the introduction of technologies such as PACS, RIS, VR and physician extenders (Dubinsky, 2013).

Traditionally, radiology departments operated a system that was based on paper and printed film, which was labour intensive and potentially inefficient (Boland et al., 2008). Generally, such a paper-and-film-based system did not facilitate quick RTAT to referring doctors. However the development of information technology in health care, especially radiology, has seen radiology departments adopting some of these workflow management technologies to improve efficiencies, quality and patient care (Morgan et al., 2014). In a case study, Mariani et al. (2006) demonstrated that the introduction of new technologies can have a significant positive impact on the radiology workflow. As an example of the potential scale of the impact of these technologies, Mariani et al. (2006) recorded an 85% reduction in the number of process steps and a reduction of between 35% and 57% in the turnaround time of cases following the introduction of PACS and RIS technology. It is evident that the introduction of these technologies would also have an impact on staffing requirements.

McEnery (2013) argue that the optimal efficiency for imaging departments occur when the RIS and PACS (all systems) integration enables seamless information sharing amongst all systems. While each of these systems in isolation contribute greatly to improve the workflow within the radiology department, they contribute significantly to the speed, quality and cost-efficient patient care, which includes the speedy delivery of high-quality imaging and reports, when integrated (Boland et al., 2008). Proper integration can ensure that the radiology department upholds it value by delivering reports to referring doctors as quickly as possible – improving on RTAT.

A failure to meet the demand for faster RTAT rests at least partially on inadequate staffing since the radiology department functions as a complete system of equipment, technology, radiology staff and other health professionals, and patients. MacDonald et al. (2013) state that managing radiologists' workload within a radiology department is desirable for managing workflow and advising staffing requirements within a radiology department.

The requirement specifications set out in Table 2.6 are formulated based on the information presented in this section.

Table 2.6: Requirements based on workflow management

RS Category	Description
UR 8	The framework should allow the analysis of data obtained from the integrated workflow management technologies such as PACS, RIS and VR as data relating to the workflow and duration can be collected from these systems.

2.3.2 Role of radiologist

Dutton et al. (2014) state that, with the increase in demand for radiological imaging, the complexity of determining radiologist's productivity also grew rapidly. Historically, radiologists' workload was determined by the number of reports that were generated. As technology within radiology advanced, so has procedures and imaging quality, and consequently the role of radiologist changed to such an extent that traditional measures of their workload in the department is no longer adequate (Dutton et al., 2014).

Traditionally radiologists' work entailed reporting plain films and cross-sectional imaging studies, but radiologists are now centrally involved in patient management through multidisciplinary teams (Brady, 2011). Though activities will undoubtedly vary significantly between individuals, the core clinical role of the radiologist can be summarised as included in the following functions (Royal College of Radiologists, 2008):

i. Image acquisition through direct methods such as ultrasound and fluoroscopy and image-guided treatment (i.e. both vascular and non-vascular interventional radiology);
ii. Interpreting images such as plain films, MRIs and CTs that were produced by other people;
iii. Provide consultation and case discussion with non-radiological practitioners in various forms and through various means of communication; and
iv. Non-clinical duties that include management and supervision of departments, teaching and research.

The radiologists' role in patient management is crucial for patient diagnosis and treatment as many decisions are based on the imaging findings (Royal College of Radiologists, 2012b). This demonstrates the pivotal role which radiologists play and motivates why their input in multidisciplinary team meetings becomes mandatory. Traditional measures of radiologists' workload do not make provision for these patient management activities that are executed as part of multidisciplinary teams.

The requirement specifications set out in Table 2.7 are formulated based on the information presented in this section.

Table 2.7: Requirements based on type of work performed

RS Category	Description
UR 9	Framework must make provision for both clinical and non-clinical activities.

2.3.3 The impact of technology advances on the role of radiology personnel

This section starts with a general discussion on the impact of technology on radiologists' workload and the demand for radiology services. This is followed by a more detailed discussion of the impact of selected technologies on radiology staffing and workflow. The technologies that have been selected for more in-depth discussion, are PACS, Hospital Information System/ Radiology Information System (HIS-RIS), and teleradiology. These are technologies that have been shown to have a significant systemic influence on workflow and / or workload. Evidence from various case studies that are concerned with the impact of technology on the operations within radiology departments are included in the discussion. The requirement specification set out in Table 2.8 is formulated based on the information presented in the sub-section that follow.

Table 2.8: Requirements based on technology advances

RS Category	Description
UR 10	Framework must make provision for adjustments relating to technological advances – must be easily adaptable when the clinical environment changes.

2.3.3.1 The influence of PACS and HIS-RIS

Dreyer et al. (2006) studied the introduction of HIS-RIS and PACS at Baltimore Veterans Affairs Medical Centre. Key findings from this detailed case study are summarised here to provide insight on the likely impact of the introduction of these technologies in a radiology practice.

Dreyer et al. (2006) state that, before the introduction of PACS, the largest percentage of activities in a radiology department's workflow process were of a clerical nature. The activities included the entire imaging requisition process – completion, submission, handling, processing and communication between clerical staff and radiographer. In addition, the authors mention other key activities that involved the handling and movement of films to and from the film library or any other areas within the medical centre. Part of the clerical functions of the film library staff were delivering the "*report dictation audiotapes from the reading room to the report transcription area*" (Dreyer et al., 2006).

Dreyer et al. (2006) also describe how the working method for clerical staff and the workflow in the radiology department changed significantly with the introduction of a HIS-RIS and PACS. According to Dreyer et al. (2006), the technology drastically improved the workflow in the clerical areas of the radiology department. The authors mention that the transition from manual systems to the use of the computer systems led to a substantial decrease both in the number of steps involved in clerical activities and time required to perform these clerical activities. A key improvement identified by the authors include the transformation of the imaging request process to a much quicker and streamlined process whereby the referring clinician completes the imaging request online (using a computer workstation with a graphical user interface), with all the relevant patient information, including the exam details being provided as part of the online request.

In this case study, the use of the computer systems (specifically the Hospital Information System – HIS) made patient information available to the radiographer or receptionist to schedule patient examinations which previously (before PACS & HIS) was gathered manually, using a paper-based-method. The time-consuming process of manually retrieving patients' imaging (film) folders, matching them, and transporting folders back, was thus replaced by the PACS. This system creates an electronic file in its database with the previous examinations to be used for comparisons. The authors mentioned that as a result of the integration of the PACS with the HIS-RIS and elimination of films and paper request forms, the film file personnel became obsolete and other clerical personnel was reduced by 56%. According to Dreyer et al. (2006), prior to the introduction of PACS and the HIS-RIS, there was some overlap in the activities performed by radiographers and clerical and film library personnel. Some of the routine manual processes they identified include the welcoming of patients, the hanging of films for interpretation, and entering patient information from the paper image request form into a computer.

Dreyer et al. (2006) mention that significant improvements in the workflow of radiographers were achieved through filmless operations and the switch to the PACS and HIS-RIS. More specifically, the authors report the removal of a significant number of activities that previously formed part of the duties in the CT room, including the setting up of various editions of medical images in different windows, and managing of films. The time it took a CT radiographer to do a CT examination was reduced by 45% through the removal of these steps (Dreyer et al., 2006). In addition to a reduction in the number of workflow steps, the authors state that the integration of an imaging modality such as CT with a worklist feature, and with HIS-RIS and PACS, improved accuracy. The modality worklist feature allows the radiographer to view and select all related examinations that are to be performed, and this allows for speedy entry of patient information and increases the accuracy of data (Dreyer et al., 2006).

2.3.3.2 Impact of technology on radiologists' workload and demand for radiology services

Traditionally, interaction between the radiologist and the patient and the radiologist and the referring doctor was minimal (European Society of Radiology, 2010). However, this changed significantly with technological advances in imaging techniques and non-clinical duties like multidisciplinary meetings where the diagnosis and treatment of patients are discussed (Royal College of Radiologists, 2012b).

This change in role was influenced by the advances in technology. Due to technological advances in imaging, radiologists are more involved in complex and time-consuming diagnostic procedures (Royal College of Radiologists, 2012a). The imaging advances lead to an increase in diagnostics information being available to the radiologist (European Society of Radiology, 2010). In turn, this makes interpretation more time-consuming, as the radiological images are more complex. This has a negative effect on the radiologist's output (in terms of number of reports produced) and consequently impacts staffing requirements.

The aforementioned led to an increase in demand for radiological services. This increase is evident in various forms (Royal College of Radiologists, 2012b) :

i. The variety of examinations increased, and the biggest percentage increase is in the more complex examinations or the ones that are more labour intensive, namely CTs and MRIs;
ii. The complexity of imaging studies increased, and this has a direct impact on the clinical radiology workload. (This complexity can be understood as more diagnostic information, including in the form of the number of images, being available per examination, thus generating an increased interpretation workload to ensure precise and accurate diagnosis.);
iii. Twenty-four-hour access to radiological service for rapid diagnosis;
iv. An increased incidence of radiology sub-specialisations providing inputs to multidisciplinary teams, due to the increase complexity of medicine; and
v. An increased need for interventional radiology that could lead to reduced hospital stays and less major complications for patients.

In summary, therefore, clinical radiologists have experienced a significant increase in workload that is driven by an increase in the need for radiological services, the increased variety of imaging techniques that produces more images for interpretation, and the inherent complexity of the investigations.

2.3.3.3 The influence of teleradiology

Teleradiology branched out of telemedicine which is the application of several technologies for the transfer of clinical information from the creator to the user and back (Burute & Jankharia, 2009). Teleradiology refers to the ability to obtain radiologic images transmitted from one location to another – over a distance – for viewing and interpretation by a radiologist (Khetrapal, 2018). The high quality and speed of image transmission made teleradiology a key component in the delivery of radiological services and, through the use of teleradiology, subspecialist opinion is instantly accessible (European Society of Radiology, 2010).

According to the European Society of Radiology (2010) more than 70% of US radiological practices around the world provide on-call emergency reporting via teleradiology. Teleradiology is also in use to provide radiological services to remote rural communities (Burute & Jankharia, 2009). Although teleradiology adds value, it also has a downside to it since the interaction between the radiologists and the clinician or referrer is lost when it is used extensively (European Society of Radiology, 2010). However, it does address two current issues caused by the increased demand for diagnostic imaging interpretation, which are the deficiency of adequate staff to service the interpretation needs and the lack of speciality expertise (Burute & Jankharia, 2009).

2.4 Conclusion: Chapter 2

In this chapter, the radiology environment was contextualised through a general overview of the radiology environment, including definitions of radiology and the various imaging modalities. The key objectives of a radiology department or practice as well as the key stakeholders and their main responsibilities, were defined. Radiology's clinical operating environment was discussed by defining the radiology value chain and the role of a radiology department. The chapter concluded with a brief overview of the drivers of change in radiology workload. This created the context for the next chapter, where general healthcare and radiology specific staffing models will be addressed.

Chapter 3: General healthcare and radiology-specific staffing models

In this chapter, the most prominent general healthcare staffing approaches are introduced. The three most prominent approaches are: supply-based approaches, based on the supply of healthcare providers; demand-based approaches, based on the demand for healthcare services; and workload-based approaches, based on the workload generated by each healthcare activity that is performed. Furthermore, a selection of models that have been specifically developed for determining radiologist and radiation therapist workload are also discussed. The chapter concludes with a presentation of challenges that have been identified in terms of existing radiology staffing approaches to determine radiology staffing needs.

3.1 Introduction to healthcare staff modelling approaches

The healthcare market, according to Lopes, Almeida and Almada-Lobo (2015), consists of two components, the one being the supply side or the suppliers of health services, and the other the demand side or the patients needing or requiring health services. The supply side refers to the healthcare workforce qualified, skilled, and ready to assist those in need whereas population size, demographics, epidemiology, and socioeconomic factors are amongst the primary determinates of the demand side (Lopes et al., 2015).

Furthermore, supply and demand can be viewed from two perspectives. One being the micro perspective, such as when a patient visits a healthcare provider, and the other a macro perspective, which entails healthcare provision throughout a province or a country, for example. Lopes et al. (2015) reviewed 60 years' historic healthcare human resources (HHR) planning literature to better understand its development and identify the methodologies that have endured over time. The authors found that there is no general agreement on a preferred methodology for HHR planning, but identified two broad approaches, namely supply-based, and demand-based. In the context of supply-based approaches, Lopes et al. (2015) conclude that there are four commonly used models, namely: (i) training (entries and losses); (ii) productivity; (iii) skill mix; and (iv) worker-to-population ratios. In terms of demand-based approaches on the other hand, the authors identified three models, namely: (i) needs (or potential demand); (ii) economic (or effective demand); and (iii) service targets. Supply-based approaches to determining healthcare staffing are introduced in more detail in Section 3.2 with a discussion of each of the four commonly used models in Section 3.3. Demand-based approaches are introduced in more detail in Section 3.4 with a discussion of each of the three commonly used models in Section 3.5.

Lopes et al.'s (2015) study referred to HHR planning at the national and regional level (macro) only and not at the local (meso and micro) level (hospital and medical centre). Planning at the meso and micro level is conceptually different to planning at a macro level, and consequently different methods and tools are required to achieve such planning. Workload-based approaches are commonly used for planning at the meso and micro level. Schoo et al. (2008) identified five workload-based models for HHR planning, namely: (i) ratio-based-; (ii) procedure-based-; (iii) categories of care-based; (iv) diagnostic or case mix-based models; and (v) a combination of the aforementioned four models. Workload-based approaches are introduced in more detail in Section 3.6, with a discussion of each of the five commonly used models in Section 3.7.

3.2 Supply-based approaches

The first general approach to healthcare staff modelling that is discussed as part of this thesis, is supply-based. Supply models seek to predict the future health workforce through the analysis of the factors that impact their movement into, through and exiting the health workforce (Cruz-Gomes et al., 2018). Dreesch et al. (2005) state that the supply side signifies, based on assumptions of health care personnel's inflow, losses and employment, the accessibility and features of health care personnel at the current instant or at some future instant in time.

The supply model of Laurence and Karnon (2016), takes into account the transfer of the current general practitioner (GP) stock, between employment status (part- or full-time), their location (rural or urban) and the entry and exit of GPs from the current stock. Similarly, a study by Lopes et al. (2015) estimates the required supply of physicians (supply side), by accounting for inflows, exits, newcomers and population growth, using stock-and-flow models. Correspondingly, the stock of individuals and the flow of their activities are two key factors that Birch et al. (2009) consider when determining the supply of health care workers. According to Dreesch et al. (2005, p. 268) the method applied for the supply side "*is to assess the availability of human resources ('active supply') as the difference between future increments (from new graduates, transfers from other occupations, immigration) and projected losses (through deaths, retirements, emigration, transfer to other occupations, and 'inactive supply', usually unemployed health workers)*." These are typical factors that are considered when determining the supply side of the staffing requirements.

The requirement specifications set out in Table 3.1 are formulated based on the information presented in this section.

Table 3.1: Requirements based on supply-based approaches

RS Category	Description
FR 1	The framework should be able to calculate the healthcare professionals required based on supply type data.
UR 11	The framework should make provision for capturing the current available staff, their competency, skill set and employment status (i.e. part- or full time).

3.3 Supply-based models

Supply-based models focus on the supply of medical professionals with the appropriate skill and expertise to execute the healthcare service to meet the demand (Lopes et al., 2015). Such models consider: the number of new entrants entering the healthcare workforce; the institutional capacity to train the adequate number of different types of health professionals for the future and their recruitment into the industry; and the loss rate through activities such as retirement, early retirement, emigration, and death (Dal Poz et al., 2010). Prominent supply-based models (discussed in more detail in the subsections that follow), are:

1. *Workforce-to-population ratio* (Lopes et al., 2015; Dreesch et al., 2005)
2. *Skill mix* (Lopes et al., 2015);
3. *Productivity* (Lopes et al., 2015; Laurence & Karnon, 2016); and
4. *Training* (Lopes et al., 2015; Laurence & Karnon, 2016).

3.3.1 Worker-to-population ratio

The workforce-to-population ratio method is a basic forecast of prospective quantities of required health care workers that is established on nominated thresholds, for example, healthcare workers per 10 000 population (Dal Poz et al., 2010). Thus, worker-to-population ratio models determine a desired ratio for the number of doctors and nurses per unit of population and compares this to the actual ratios (Lopes et al., 2015).

The data requirements include records of the existing workforce to population ratios, the amount of active and employed physicians and nurses as well as population demographics (Lopes et al., 2015). Dreesch et al. (2005) on the other hand identifies the desired worker-to-population ratio based on existing best region ratios or benchmark against a country with a comparable but supposedly more advanced health sector.

These models are simple and easy to apply (Lopes et al., 2015), and is the least demanding of all the supply-based models in terms of data collection (Dal Poz et al., 2010), The models do, however, omits key variables, aside from population growth, which could impact on the type and magnitude of future healthcare services to be offered, including the accompanying staffing needs (Dal Poz et al., 2010). Other limitations include that these models ignores elements such as needs, demand and the efficiency of the available workforce (Lopes et al., 2015).

3.3.2 Skill mix

Skill mix refers to the allocation of certain tasks to other health specialists, either through horizontal- (amongst medical specialists) or vertical (amongst doctors and nurses) substitution (Lopes et al., 2015).

3.3.3 Productivity

Lopes et al. (2015) define productivity in its most basic form as the ratio of output per unit of input. It is possible to improve the productivity when assuming the input variable (health workforce) remains constant and improvement techniques such as lean and operations research is implemented, to improve the output and outcome of the health workforce (Lopes et al., 2015). Laurence and Karnon (2016), on the other hand, use productivity in their planning model as a standard to translate the mean estimated quantity of consultations per annum (output) to the required quantity of full-time equivalents (FTEs) (input) that can provide the health services needs of the population. The productivity standard is 1760 consulting hours per FTE that is based on a 40-hour work week (Laurence & Karnon, 2016). Both these authors use the productivity element, but in different ways: Lopes et al. (2015) view it as an improvement approach; while Laurence and Karnon (2016) applies it as a standard to determine the number of FTEs.

3.3.4 Training

Training models, as viewed by Lopes et al. (2015), forecast the availability of healthcare personnel based on the existing staff complement while considering the number of new entrants, those exiting, migrating, and retiring. This approach differs slightly from Birch et al. (2009), who state that provider supply (supply side) is the result of two factors; namely ‘the stock of individuals’ and ‘the flow of activities’. The ‘stock of individuals’ refers to the quantity of qualified healthcare workers that are potentially available for the provision of healthcare services (Birch et al., 2009). The authors identify two factors upon which the flow of activities relies namely, the participation rate and the activity rate. The latter represents the hours spent (or degree of activity) in supplying healthcare services by those active in the delivery of healthcare services, while the former refers to the quantity of ‘current stock’ that is participating in the delivery of healthcare (Birch et al., 2009). The authors then concluded that one way of quantifying the supply of providers are in labour hours. Although their approach differs slight, the fundamental concept of using available healthcare providers are similar and the slight difference arise with the concept of ‘flow of activities’. Laurence and Karnon (2016) on the other hand, identify training as a module in their GP workforce planning model with graduates as parameter. The authors use the same stock and flow concept as identified by Birch et al. (2009).

3.3.5 Conclusion: Supply-based models

The requirements specifications set out in Table 3.2, are formulated based on the preceding information on supply-based models.

Table 3.2: Requirements based on supply-based models

RS Category	Description
FR 2	The framework should be able to accommodate productivity measures as part of the staffing requirements.

3.4 Demand-based approaches

The second general approach to healthcare staff modelling that is discussed as part of this thesis, is demand-based. According to Lopes et al. (2015), healthcare demand is an inferred demand affected by the socioeconomic conditions of a country, and the factors of total demand for health care services are population size, income and preferences. If patients are to pay for health services then the demand (for health services) is constrained by their ability to pay and the need for health care will not translate into effective demand (Lopes et al., 2015). Demand approaches, according to Cruz-Gomes et al. (2018), seek to forecast the health workforce demand for the future by focusing on the development or change of the driving forces of the health services demand. These forces strongly relate to demographic, socioeconomic and epidemiological factors (Lopes et al., 2015).

The demand or need model of Laurence and Karnon (2016) combines health needs that include disease incidence and prevalence data, population data that is age- and gender specific, and level of service (described as utilisation or use of available services). These variables are used to estimate the total level of services needed for the entire population including the required number of GPs that will provide the desired level of services (Laurence & Karnon, 2016). The needs element attempts to cover the epidemiological conditions, based on the assessment of diseases (morbidity) and mortality rates or on experts' opinions, and converts this data into a given quantity of required healthcare service demand (Lopes et al., 2015). Moreover, the emphasis is on the medical conditions that may contribute to the need for health care, originating from the development of chronic diseases, prevalence rates and overall morbidity patterns (Lopes et al., 2015). The actual observed demand, through service utilisation ratios, such as bed occupancy rates and number of inpatients, is considered economic or effective demand (Lopes et al., 2015). The majority of demand-based approaches build on the descriptions of needs and actual demand with some overlay in their scope of application (Lopes et al., 2015).

The requirement specifications set out in Table 3.3 are formulated based on the preceding information on demand-based approaches.

Table 3.3: Requirements based on demand-based models

RS Category	Description
FR 3	The framework should be able to calculate the healthcare professionals required based on demand type data that accommodates changes.
UR 12	The framework must make provision for capturing demand-related information.

3.5 Demand-based models

Dreesch et al. (2005) state that the demand-based models (needs-, utilisation or demand-based and target-setting approaches) attempt to convert the required quantity and types of healthcare services to time estimates. These time estimates are then converted to full-time equivalents (FTEs) that represent the health workforce through the application of norms and standards on the actual productive time (Dreesch et al., 2005). The demand methods differ in the manner which the health care services are obtained. Al-Sawai and Al-Shishtawy (2015) agree and state that the differences amongst the demand models rely upon the means of identifying the required health care services that are based on the following approaches:

i. The health needs of the population;
ii. Current technology in use at the health facilities;
iii. A population's demand for certain services;
iv. The existing health services provided;
v. Meeting the existing health needs of the population; and
vi. Considering changes in the population structure when forecasting future requirements.

Three demand-based models are discussed in the sections that follow.

3.5.1 Needs-based models

Lopes et al. (2015), Dreesch et al. (2005) and Dal Poz et al. (2010) all developed needs-based models with slight variations in definition, description and identification. However, all the authors consider similar elements for determining the staffing requirements. The needs (or potential demand) method of Lopes et al. (2015) determines the consequence of diseases, by considering epidemiological trends, mortality and morbidity rates, on the demand for health services with the purpose of estimating the quantity of personnel hours required to cover the needs that arise as a result of a disease. Epidemiology experts normally assess the needs of the population and the data requirements are high and include incidence and prevalence rates, health patterns of the population and epidemiology. Dreesch et al. (2005) on the other hand in their needs-based model*,* used the populations' health needs to estimate the quantity and type of health services that are to be provided for different age and gender groups. This is usually established from service norms and morbidity trends (Dreesch et al., 2005). The authors' needs-based models translate those service needs to healthcare workforce requirements while applying productivity standards and expert's judgement.

Fakhri et al. (2014) refer to the work of Dreesch et al. (2005) and O'Brien-Pallas et al. 2001 when defining their needs-based model that estimates the required health workforce based on the anticipated health service needs of a given population after adjusting for age and gender. Fakhri et al. (2014, p.108) stated that the quantity of health care workers that are needed are determined by "*the number of services that should be provided to a given population yearly*' divided by '*the number of services that a person is able to provide yearly"*. Dal Poz et al. (2010) agree with the above-mentioned authors when describing their health needs method as being more exhaustive, as it explores potential changes in the populations' health services needs which are based on changes in patterns of epidemiology, impairments and traumas. Included are the quantity and types of services needed to respond to these outcomes. For this approach, an array of epidemiological, sociocultural, and demographic data is collected and analysed.

Laurence and Karnon (2016) and Birch et al. (2009) have a slightly different approach to the previous authors, as they have identified variables that their models consider, which are a combination of both supply and demand. In contrast, the aforementioned authors only described demand methodologies.

Laurence and Karnon (2016) in their demand or need model combine health needs that include disease incidence and prevalence data, population data that is age- and gender specific, and level of service (described as utilisation or use of available services). These variables are used to estimate the total level of services needed for the entire population including the required number of GPs that will provide the desired level of services (Laurence & Karnon, 2016). Birch et al. (2009) define 'provider requirement' as a measurement of the number of suppliers required to ensure adequate 'flow' of healthcare services to satisfy the needs of the population. The provider requirement component of the authors' needs-based health human resources planning framework, has four determining factors. The first being demography, that represents the population size, age distribution (including any changes to the distribution relating to the aging of the population), migration, and birth and death rates. The second determining factor, epidemiology, accounts for the degree and distribution of the needs in the population and various levels of need are accommodated by the model as part of the estimation. The third factor is the level of service which refers to the quantity and variety of services that are suitable to address the health needs of the population. Any changes in the level of service will impact the requirements for providers. Finally, the fourth determining factor of the provider requirement is productivity which the authors defined as the 'inverse of the mean level of productivity of providers' which is represented by the number of providers per service. In addition, Birch et al. (2009, p.59) state that productivity depends on several components such as the *"intensity of work (proportion of paid hours devoted to patient care), how work is organized, technological inputs, and inputs of other types of professionals".*

3.5.2 Utilisation-based models

The utilisation-based models have been recognised by several authors as a demand approach with differing identification but similar definition and considerations.

Economic (or effective) demand refers to the actual services rendered to the population while considering socio-economic factors (Lopes et al., 2015). In addition, Lopes et al. (2015, p.5) state that economic or effective demand interprets the "*actual, observed demand, usually measured in terms of service utilisation ratios (such as bed occupancy rates, number of inpatients).*" According to the authors, the data requirements for this method are high and generally includes data on socio-economic variables, disposable income, GDP growth projections and ethnic factors. Similarly, the service demand method as defined by Dal Poz et al. (2010) determines the range and type of anticipated demands for services by applying the 'observed health services utilisation rates' for various population groups to the future population profile. Additionally, proven productivity standards or norms together with the expected demands are used to calculate the required health personnel. Dreesch et al. (2005, p.269) state that the utilization-based approach "*estimates the future health workforce requirements based on the current level of service utilization in relation to future projections of demographic profiles.*" Generally, in the utilisation-based models, the current level of health services usage is assumed to be suitable to satisfy the health needs. Thus, future health workforce requirements are determined by taking changes to the characteristics of the population into account (Dreesch et al., 2005).

Fakhri et al. (2014) report that utilisation-based models forecast the required health service requirements based on current health service utilisation, factoring in changes to demographic trends. The authors specify a basic formula that is practised generally for the utilisation-based models when calculating the quantity of expected health staff, as the quantity of the supplied service (utilisation) divided by the quantity of service that a person is able to offer yearly (Fakhri et al., 2014).

Daviaud and Chopra (2008, p.46) describe the utilisation-based models as "*the actual level of use over a year (i.e. the expressed demand) as the basis for calculation of staff requirements"*. They also refer to the *utilisation-based models* as a workload-based model**.** The authors conducted a case study that focused on determining the staffing requirements for primary health care in South Africa. Daviaud & Chopra (2008) critiqued three possible approaches that could be used to assess the appropriate allocation of health professionals namely, needs-, population- and utilisation-based models. They decided on the workload indicators of staffing needs (WSIN) method, which is closely linked to the utilisation-based models and adapted it to reflect the South African challenges and policy options. Due to the limitations of the utilisation-based models, the authors adopted a consolidation of the utilisation-based models with the population-based models (also known as workforce-to-population ratio which is classified by several authors as a supply methodology), to address the South African challenges. The adapted WISN model used various local condition assumptions to produce, as an output, a tabular comparison of expected (estimated) staffing with actual staffing "gaps and excesses" (Daviaud & Chopra, 2008).

In general, the authors agree that the utilisation-based models consider the actual, observed level of health services rendered to the population while considering changes to the characteristics of the population.

3.5.3 Service target-based models

Several authors have described the service target-based models and agreed on its definition and the use of set targets for the delivery of health services which in turn are used to determine staffing requirements.

Lopes et al. (2015) state that service targets broaden a needs-based model by integrating different criterions, for instance consumer needs, to build service target ratios. Service targets outline normative (prescriptive) targets for the provision of health care services, which are then changed to staffing requirements. Descriptions of the data requirement for this method in literature vary from low to high, and indicators on which data must be gathered include: the number of occupied beds; number of inpatients and outpatients; and the number of surgeries / screenings / consultations performed.

According to Dal Poz et al. (2010) the service target-based models assign targets for the delivery of different types of health services and their associated institutions, based on a set of assumptions and specify how they should develop in quantity, size and staffing that conform with productivity standards. Dreesch et al. (2005) state that, for the target-setting approach, specific targets are set for the quantity and type of services at the different stages of care based on considerations such as: the existing technology; services already offered; and the populations' demand for certain services. Moreover, the authors define service target-based models as establishing goals for the provision and execution of specific result-oriented health services. These targets are then translated into healthcare workforce requirements using staffing and productivity standards. Fakhri et al. (2014) agree by stating that the service target-based models stipulate targets for specific health services delivery that are based on existing services, existing technologies, and other planning considerations. The authors recognize that this approach is based on the assumption that both needs in all circumstances, and productivity of all providers, are similar (Fakhri et al., 2014).

3.5.4 Conclusion: Demand-based models

The requirement specifications set out in Table 3.4 are formulated based on the preceding discussion of demand-based models.

Table 3.4: Requirements based on demand-based models

RS Category	Description
FR 4	The framework should be able to use activity times to determine workload.
FR 5	The framework should be able to translate workload to FTEs.

3.6 Workload-based approaches

The third and final general approach to healthcare staff modelling that is discussed as part of this thesis, is workload-based. As mentioned in Section 3.1, one way in which workload-based approaches differ from supply-based and demand-based approaches, is that workload-based approaches can also be employed at a meso and a micro level.

Ridoutt, Schoo and Santos, (2006) considered literature in the study of workload capacity measurement and found no consistency in the use or definition of workload measurement. Consequently, the authors proposed that it be thought of as a basic connection between health care service activity, the work or workload performance involved in the activity, and the required labour to bear the workload. This relationship, as illustrated in Figure 3.1, is also relevant in the health economic and workforce planning literature as a relationship between 'service demand' and inferred 'labour demand' (Ridoutt et al., 2006). Furthermore, this relationship can be viewed at an organisational level (meso) or at a unit or department (micro) level where the relationship is between 'service activity' and 'staffing requirements' (Ridoutt et al., 2006).

Figure 3.1: Relationship between health service activity and labour (adapted from (Ridoutt et al., 2006))

The health care activity or service measured by the admissions, surgical operations, bed days, outpatients treated and laboratory tests conducted, are provided by the health care workforce through executing various tasks, functions, interventions and units of care (Ridoutt et al., 2006). The degree of service activity demanded and the amount of work or effort involved (workload) to provide the activity is used to determine the amount of required labour (Ridoutt et al., 2006).

3.7 Workload-based models

Schoo et al. (2008), through an extensive literature search and review, interviews and focus group consultations, produced a typology of workload capacity measurement models namely: (i) ratio-based-; (ii) procedure-based-; (iii) categories of care-based; (iv) diagnostic or case mix-based models; and (v) a combination of all four models.

The relationship as illustrated in Figure 3.1, is at the centre of a conversion from service demand to labour demand (at the macro level) and in theory the methods of calculation are similar to that of the micro level.

In practice, however, when the relationship, as depicted in Figure 3.1 is defined, from a macro level, then ratio-based models are frequently employed (Ridoutt, Schoo and Santos, 2006). When this is done, aggregate estimates of demand and units of labour are assumed from average performance levels (Ridoutt, Schoo and Santos, 2006). Alternatively, by adding the estimates derived from the micro level (workload measurement) activity calculations, a more comprehensive representation of the wider labour requirements throughout a healthcare system can be constructed (Ridoutt, Schoo and Santos, 2006). Although the aforementioned macro level approach is acceptable, one could argue that it does not reflect reality sufficiently accurately as workload measures vary between health services contexts. When such an approach is applied, however, it is assumed that the variation will be absorbed within a wider health care system throughout a sufficiently large population of service delivery units (Ridoutt, Schoo and Santos, 2006).

The diagnostic or case mix-based models make no distinction between macro and micro level estimates, since all units of service activity are treated equally in these models (Ridoutt et al., 2006). Ridoutt et al., (2006) advise concentrating on labour's work performance to create a view of labour demand and the procedure-based approach presents a near match to actual work performed, which makes it most suitable for compiling a bottom-up realisation of the system-wide labour requirements.

3.7.1 Ratio-based models

Ratio-based models employ a comparatively basic ratio of personnel to activity, where the activity variable refers to measures such as the number of beds, number of ‘bed days’ or number of patients. Adams (2004) developed a basic ratio-based method of physiotherapist to population, physiotherapist to beds and physiotherapist to surgeons. In Ridoutt et al.'s (2006) view, Adam’s (2004) method is easy to use and, the only data necessary is the ‘*measure of activity*’. Although the ratios can be developed at the micro level, they are generally referenced externally, for example, a set of professional standards and make no reference to local conditions since ‘average’ requirements are applied (Ridoutt et al., 2006). This method is best applicable in environments where the activity level and type is relatively stable, such as a nursing home (Ridoutt et al., 2006).

3.7.2 Procedure-based models

Procedure-based models consider the work executed – directly and indirectly – to deliver the healthcare service such as, procedures, functions, and broader areas of work or tasks. This method uses facility-specific studies or set standard practices to estimate the labour needed to execute the procedures (in time units). Wright et al. (1993) use a task list to identify procedures and mean time requirements that were either researched or obtained through focus groups. Ridoutt et al. (2006) states that Wright et al.’s (1993) method is best applied where the activities are relatively repetitive and routine. Data collection for procedure time estimates can be costly and contentious if based on expert opinion (Ridoutt et al., 2006).

3.7.3 Categories of care models

Categories of care or patient acuity-based models apply a ratio of personnel to patients where various patient conditions such as, basic care needs and / or therapeutic treatment requirements are considered. These models are primarily intended for quick staffing changes in response to frequent fluctuations in patient numbers and conditions, which makes the models suitable for environments where patient throughput is high and variable, such as general surgical or medical wards (Ridoutt et al., 2006). Data collection for these models is normally resource intensive and Ridoutt et al. (2006) highlight that the application of these models in their current form for determining staffing requirements at the macro level, is difficult to realize.

3.7.4 Diagnostic models

Diagnostic or case mix-based models are linked to diagnostic sub-groups. Schoo et al. (2008, p.18) state that “*cost weights in the form of hours of professional care to appropriately treat /*

serve each diagnostic sub-group are established, and total staff requirements calculated by multiplying the hour per diagnostic group and anticipated case mix." Data collection is highly resource intensive, though the required data could potentially be extracted from the financial system.

3.7.5 Combination or mix models

The final approach is a combination or mix of more than two of the abovementioned models. Ridoutt et al. (2006) report from the literature a hospital pharmacy case applied a mixed approach and divided their work into three primary functional areas, namely (i) clinical work; (ii) distribution services work; and (iii) management services work. Each of these functional areas adopted a slightly different methodological approach, that included for the clinical services a simple pharmacist to bed ratio which is a ratio-based approach; for the distribution services a procedure-based approach were followed and for the management services a fixed ratio of management personnel to clinical personnel was applied (Ridoutt, Schoo and Santos, 2006).

3.8 Comparison of general healthcare staff modelling approaches

In summary, the three most widely used approaches for determining healthcare staffing requirements are demand-based, supply-based, and *workload-based*. Sections 3.2 – 3.7 have comprised a detailed discussion of these approaches to determining staffing needs in healthcare. Table 3.5 provides a high-level summary of the aforementioned discussion, indicating the types of models identified in a select group of comprehensive publications.

As an example of how to interpret the table, supply-based approaches comprise four main model types, namely training models, productivity models, skill mix models, and workforce-to-population ratio models. (The terminology defined by Lopes, Almeida and Almada-Lobo, (2015) has been adopted in the aforementioned list.) Furthermore, 'training models', as defined by Lopes, Almeida and Almada-Lobo, (2015) incorporate both 'training models' and 'supply models', as defined by Laurence and Karnon (2016), and are equivalent to 'stock of individuals models' as defined by Birch et al. (2009).

Table 3.5: High level summary of most widely used staffing approaches in healthcare

Approach category		Lopes, Almeida and Almada-Lobo (2015)	Dreesch et al. (2005)	Schoo et al. (2008)	Laurence and Karnon (2016)	Birch et al. (2009)
Approach category	**Supply or provider supply approaches**	• Training (entries and losses)	-	-	• Training • Supply	• Stock of individuals
		• Productivity	-	-	• Productivity	• Flow of activities
		• Skill mix	-	-	-	-
		• Workforce-to-population ratios	• Health workforce to population ratio	-	-	-
	Demand or provider requirement approaches	• Needs (or potential demand)	• Needs-based	-	• Health needs	• Epidemiology
		• Economic (or effective demand)	• Utilization or demand	-	• Service utilisation rates	• Level of service
		• Service targets	• Service target-setting • Adjusted service target	-	-	-
		-	-	-	• Population size	• Demographic
		-	-	-	• Productivity	• Productivity
	Workload measures approaches	-	-	• Ratio (*staff-to-activity*) • Procedure • Categories of care or patient acuity • Diagnostic or case mix	-	-

3.9 Radiology staffing models

There is limited literature on diagnostic radiographers' staffing models. Literature searches of the Scopus and Web Science databases, with search lines such as ((radiographer w/5 workforce) OR (radiographer w/5 workload) OR (radiographer w/5 staffing requirements)) did not uncover literature related to diagnostic radiographer staffing requirements. However, literature pertaining to radiographers in the radiation therapy environment is uncovered and will be discussed in the following subsections.

Consequently, though this research focuses on developing a staffing requirements framework for diagnostic radiographers, literature on radiologists and radiation therapists' (RTs) staffing models is also reviewed to gain insight on: the challenges associated with these models; and elements of these models that can contribute to the development of the diagnostic radiographer staffing framework.

3.9.1 Radiation therapy linear accelerator staffing approach

Traditionally RT staffing models were founded only on the number of linear accelerator (linac) machines available at a cancer facility (Patel & Mitera, 2011). The RT staffing models calculated the number of RTs required per linac-hour[1]. However, according to Griffiths (2000, p.168) "*radiographer staffing has a complex inter-relationship with workload, equipment, technology, specialist practice, range of practice and roles*." Moreover, the size of the institution, its equipment base and case mix may also affect the staffing model and the basic conceptualisation of the radiation therapy model should make provision for all the activities required to achieve workload demands, including patient care needs (Griffiths, 2000). RT staffing models will have to consider more variables than just the number of linac machines to stay effective and ensure quality of care for patients when determining RT staffing requirements, given the increasing complexity of radiation therapy practices.

Griffiths et al. (2006) developed a staffing framework and formula that is based on a factor for core service activities led by the radiation therapist and delivered within the available linac-hours (machine hours) per day. The core services factor, as established by the survey data, is 1.33 whole time equivalents (WTE) per linac-hour; thus, assuming a 7-hour-day on a single linac, equates to 9.31 staff (7 x 1.33) that are needed to perform all the core activities (Griffiths et al., 2006). It includes all other resources that contribute to the core services, i.e., radiographers, assistants, helpers, etc. Inclusive of the staff required, is a provision of 25% for all leave types, continued professional development (CPD) activities, etc. (Griffiths et al., 2006). This formula can be used to determine the staffing requirements of an entire radiation therapy department with an average workload, variety of equipment, technologies, technique complexities, and for departmental working arrangements (Griffiths et al., 2006). However, small adjustments must be made to account for local operating conditions (Griffiths et al., 2006). In this study the authors also made provision for non-core services by suggesting staffing estimates for each of those non-core service, in order to present an all-

[1] Linac-hour refers to the hourly run time of a linear accelerator machine (Routsis et al., 2006).

inclusive departmental staffing solution or guideline that might be staffed separately or form part of RT's duties, such as patient information and support, research, education and staff development support.

In anticipation of a shortage in RT's supply and an increase in demand for radiation therapy services, Routsis, Thomas and Head (2006) explored different working hour patterns for radiation therapy linear accelerators use to optimise RT time. The authors approached this by reviewing the RT's activities that constitute their workload to consider whether it is possible to remove ancillary responsibilities from primary treatment responsibilities to redistribute to suitably trained medical assistants (non-RTs). They claim that this is possible when the working pattern of the linac machines are a 7-hour day (during core service hours) as it requires the least RTs per linac-hour, or for an 8-hour day given that part-time RTs are available to cover lunch time. This staff modelling approach by Routsis et al. (2006), only considered RT tasks directly related to treatment delivery activities, while provision for annual leave, sick leave, training, planned maintenance and quality assurance procedures were excluded. The authors do, however, mention the study done by Griffiths (2000), that indicates an additional 20-25% cover for annual leave, sick leave, and training.

3.9.2 Radiation therapy workload-based staffing approach

Continuous advancements in radiation treatment practices, new techniques and technology have rendered the traditional RT staffing models, that did not account for these changes in the radiation therapy environment, outdated (Smoke & Ho, 2015; Smith et al., 2016). The challenges with radiation therapy staffing models are discussed in more detail in Sections 3.10.1 - 3.10.2. Given these advancements in radiation therapy treatments, several authors made improvements to the traditional RT staffing models.

Smoke and Ho (2015) developed a model that used the number of equipment and related clinical activities to determine staffing levels. Time allocated to clinical activities and the identification of other key areas of responsibilities for radiation therapists (which were previously omitted in other RT staffing models), were determined by an expert panel (with more than 10 years of clinical experience) using the Simplex Process Creativity Tool (Smoke & Ho, 2015). The proposed model accounted for the staffing needs of all clinical activities including additional essential areas of responsibility that supported clinical activities, such as brachytherapy, quality assurance, orthovoltage, radiation oncology systems, administration, technology development and / or implementation, education, and staff time off (Smoke & Ho, 2015). Moreover, an additional 20% FTEs is provisioned for annual-, sick-, maternity- and other leave types (Smoke & Ho, 2015). The authors posited that this staffing model is more appropriate for modern radiation therapy practices as it accounts for all activities within the RT's role and responsibility.

Klein (2010) applied a workload-driven methodology to develop a staffing justification grid which matches the clinical needs of a radiation oncology department with the required number and quality of staff. The author determined the total annual hours required by customising the activity times from the Abt Associates Inc. (Abt) study reports[2] to suit the local clinical environment. The total annual hours were derived from multiplying the activity times with the anticipated activity frequency in a given year (Klein, 2010). Klein (2010) did not consider time for vacation, sick leave and meetings, but allowed time for personal development (such as education) and administration. Klein (2010) determined the total number of FTE by dividing the total time per task by the total available time per year. Subsequently, the author applied a technique called experience mapping which maps the task or assignment of a post to the appropriate level of skill or experience required. Tasks could be mapped to faculty appointment levels, considering a variety of different personnel to perform a particular task. These tasks ranged from technically challenging tasks that require a high level of experience and expertise to more routine tasks that can be performed by experienced staff. For example, the efforts of a post assisting a physicist such as, a Clinical Physics Assistant, were scaled to 50% (as they are funded at approximately half the level) of the physics faculty FTEs (Klein, 2010).

Tobergte and Curtis (2013) followed a similar approach, termed an activity-based algorithm, that forecasts staffing levels to address the need for a guide that proposes suitable staffing levels when new services, expansions or upgrades of current services within a radiation therapy environment are required. It seeks to account for all the activities along the whole radiation therapy workflow, such as: patient- and, equipment-related activities; specific complex techniques; educational activities; and non-clinical activities (Tobergte & Curtis, 2013). According to the authors, staffing levels are determined by several factors, including: the number of and intricacy of equipment; the number of patients; the types of procedures, their complexity and activities; and the number of students and trainees. A prerequisite for the quantitative staffing algorithm is an analysis of the clinical workflow and the identification of all the professional roles associated with the activities along the workflow (Tobergte & Curtis, 2013). The authors do acknowledge that the best input data would come from detailed timekeeping of all activities, however this would not be practical in the highly dynamic radiation therapy environment where techniques are constantly refined in response to rapid technological changes. Hence the activity-based staffing levels discussed, are based on benchmarking and expert consensus where evidence is lacking.

The revised radiation therapy staffing model by Smith et al. (2016, p. 209), maintained its fundamental operating principle which is "*full-time equivalent (FTE) radiation therapists (RTs) per linear accelerator hours*". The guiding principles upon which Smith et al. (2016) model is based are as follows:

i. Only qualified radiation therapists are considered;

[2] Standards from external sources.

ii. The hours in a day (taken as 8h) and a week, including all leave types per year, are considered to determine the available time for 1 FTE per year. The number of leave days per year are expressed as a percentage of the total available time;

iii. Both clinical or direct activities and non-clinical or indirect activities are accounted for;

iv. For clinical or direct activities, mean time per case and the number of cases per annum are used to determine the total time per case, while non-clinical or indirect activities are based on suggested numbers from a literature review;

v. The required FTE for clinical or direct activities is determined by dividing the sum of all the total times for the cases by the total available time per year;

vi. Once the base FTE, which includes both clinical or direct activities and non-clinical or indirect activities, is calculated, a leave relief factor is applied to calculate the total number of required FTEs (which accounts for when the different leave types are taken up by the radiation therapists);

vii. Since the model is based on the number of linac machines and their operating hours to determine the number of radiation therapists (RTs), the number of *RTs per linac operating hour* is then calculated by dividing the FTE (that includes the leave relief factor) by the number of linac machines and their related operating hours (established as 8h); and

viii. The number of *RTs per linac operating hour* is subsequently used as a guideline to determine the base RT staffing requirements by considering the number of linac machines, their operating hours, and the number of RTs per linac operating hour.

The new model is based on data, modern practice, and provides better overall flexibility and utility relating to workforce planning and individual service delivery profiles (Smith et al., 2016). The authors concluded that this revised RT staffing model is non-prescriptive and offers sufficient flexibility for radiation oncology services to adequately develop RT staffing requirements that consider their unique needs and operating conditions (Smith et al., 2016).

3.9.3 Conclusion: Existing radiation therapy staffing models

The requirement specifications set out in Table 3.6 are formulated based on the information on existing radiation therapy staffing models presented in the preceding sections.

Table 3.6: Requirements based on radiation therapy workload-based approaches

RS Category	Description
BC 1	The framework should consider the various leave allowances as stipulated by law and company policies.
FR 6	The framework should be able to calculate the total available time per year for a suitably qualified diagnostic radiographer.
UR 13	The framework should make provision for capturing the current available staff information relating to age and gender.
UR 15	The framework should consider the maximum allowable working hours per week when determining the workload
FR 7	The framework should be able to calculate the workload for the post under review.
FR 8	The framework should allow the calculation translating workload to FTE required to be transparent and reproducible.

3.9.4 Radiologist staffing models: Brief history of relative value units

As mentioned in the introduction to Section 3.9, there is limited literature on radiation therapy staffing models specifically, and literature on radiologist staffing models is therefore also reviewed as this may also serve to inform efforts to develop a framework for determining staffing requirements for diagnostic radiographers. Workforce models in radiology, especially for radiologists, are dominated by the relative value unit (RVU) system or an adaptation thereof. Consequently, the concept of RVUs is introduced in this section. In terms of the three approaches to general healthcare workload modelling, models that use RVUs can be classified as workload-based approaches.

According to Baadh et al. (2016), RVUs is an essential measurement tool which is used for calculating reimbursement of physician services. It forms part of the resource-based relative value scale that was developed by Dr Hsiao and adapted by the United States of America's Centres for Medicaid and Medicare Services "*to value physician services*" and to aid in determining reimbursement (Baadh et al. 2016). In the adapted version of the resource-based relative value scale, procedures were allocated 'Current Procedure Terminology' codes and several RVUs. The latter represent the total relative amount of work required to execute a procedure and were based on the RVUs of: physician work (RVUPW), practise expense (RVUPE), and malpractice expense (RVUME). The relationship is expressed as follows:

$$Total\ RVU = RVUPW + RVUPE + RVUME \qquad (3.1)$$

In order to determine the total payment amount, each of the RVUs must be multiplied by a geographic practice cost index (GPCI) and then multiplied by a conversion factor (CF) that converts the RVU into a monetary value. Thus, according to Baadh et al. (2016)

$$Total\ RVU = (RVUPW \times GPCI) + (RVUPE \times GPCI) + (RVUME \times GPCI) \qquad (3.2)$$

Whereas

$$Payment = Total\ RVU\ \times CF. \tag{3.3}$$

RVUPW is regarded as the most significant component of the equation and describes both the time and intensity of a physician's effort towards the delivery of a service (Duszak & Muroff, 2010).

3.9.5 Development of the radiologist's workload models

The concept of RVUs, which tends to underpin radiologist's workload models, was introduced in the previous section. In this section, an overview of specific staffing models that have been developed for radiologists is presented.

The use of RVUs to determine the amount of work and resources required to perform procedures, allows for productivity comparison among physicians (Duszak & Muroff, 2010). Thus, the RVU system has been adopted to address the need to benchmark the workload of radiologists to peers. Pitman and Jones, on request from the Royal Australian and New Zealand College of Radiologists' (RANZCR) working group, reviewed several radiologist workload measurement methods, including the resource-based relative value scale, to develop the RANZCR relative value unit model (Pitman & Jones, 2006).The authors proposed a pragmatic and uncomplicated workload measurement technique that uses RVUs. Their technique uses two primary measurements namely (i) 'crude reporting RVU' and 'net reporting RVU' per annum per radiologists FTE. These methods do not account for any leave types or academic nonclinical activities, such as teaching, research, and administration (Pitman & Jones, 2006).

Over the years, the RANZCR RVU model was further developed and applied both inside and outside of the Australian context. When applied within the Australian context, the original recommendation of 40 000 crude RVU per FTE was increased by 12,5% to 45 000 crude RVU per FTE (Pitman et al., 2009). Moreover, several weaknesses remain, and the model is becoming outdated, particularly in CT as it does not account for newer, more time-consuming CT examinations (Pitman et al., 2009). Outside of the Australian context, Brady (2011) applied the RANZCR RVU model to determine the crude reporting and net reporting RVU to calculate the workload of consultant radiologists in Ireland. The author made some small adjustments, such as assigning RVUs to an intravenous procedure and changing descriptions of non-countable activity categories to reflect the Irish radiology context. It was concluded that the Irish Consultant Radiologist staffing levels are lower than suitable international standards (of 45 000 crude and net RVU/ FTE) for the existing workload (Brady, 2011). According to the author, non-countable activities constitute approximately one-third of a radiologist's time. Similarly Khan and Hedges (2013) applied the RAZCR RVU model with slight changes in the classification of some investigations and how to include non-reporting activities (such as teaching, administration and multidisciplinary team meetings) to reflect the UK context and for ease of data collection. Khan and Hedges (2013) found that non-reporting activities constitute 42.5% of radiologists' time and that their workloads are far above comparative international benchmarks.

Cowan et al. (2013) set out to produce a list of standard times ('*absolute times'*) and RVUs for diagnostic examinations with reduced subjective input. The authors briefly evaluated and combined two methods: (i) simplest reporting measurement that uses raw examination numbers or number of reports dictated per year (such as the RANZCR RVU); and (ii) using a RIS to measure radiologists' reporting time. The latter being more accurate less subjective than the former which uses only raw examination numbers (Cowan et al., 2013). Cowan et al. (2013, p. 558) claim that "*relative value units (RVUs), using the ratio of time taken for each category of report to that of a defined report such as a chest X-ray, offer more accuracy*." In this study, reporting constituted approximately fifty percent of all radiologist activity. The outcome of the retrospective study was a list of standard times ('*absolute times'*) and RVUs for diagnostic examinations with reduced subjective input (Cowan et al., 2013).

One of the limitations of the RANZCR RVU model is that it does not capture non-clinical or non-reporting activities such as procedural work, teaching, multidisciplinary team (MDT) meetings, or administration which, as mentioned previously, has been found to constitute 42.5% of radiologists' time (Khan & Hedges, 2013). MacDonald et al. (2013) applied a workload measurement approach to create a clinical radiologists activity list that also includes both clinical and non-clinical activities. The authors' list includes six broad classifications namely: reporting; procedures; trainee supervision; clinical conferences and teaching; informal case discussions; and administration related to referral forms. Mean radiological image reporting times were taken from the RIS while the frequency and times of each activity were obtained through observation, timing of radiologist's activities and consensus (MacDonald et al., 2013). All the data collected through the activity list was used to calculate total clinical hours required to meet radiological service demands (MacDonald et al., 2013). The recorded study results revealed that radiologists spent approximately 35% of their time on diagnostic reporting and 65% on non-reporting activities, including: 23% on procedures; 15% on trainee supervision; 14% of conferences and tutorials; 10% on informal case discussions; and 3% on referral-related administration (MacDonald et al., 2013). This non-reporting result of 65% is notably higher than the result of 42,5% obtained by Khan and Hedges (2013).

Several investigations, as mentioned above, have built (or improved) upon the RVU system to include both reporting and non-reporting activities to determine the workload of radiologists. MacDonald et al., (2013) went further and applied tools from the manufacturing industry such as lean, theory of constraints and production planning to the radiology context to reduce the impact of radiologists' capacity limitations on delivering radiographic images and reports. Steps that were taken include: setting report and imaging turnaround targets; setting up production planning tools for direct scheduling; and reducing waste and variation in radiologist's workflow and working environment (MacDonald et al., 2013). This permitted the true understanding of service demand, capacity and the effect of demand or capacity changes on service delivery (MacDonald et al., 2013).

The user requirement set out in Table 3.7: Requirements based on radiologists' workload-based models is formulated, based on the information presented in this section.

Table 3.7: Requirements based on radiologists' workload-based models

RS Category	Description
UR 14	The framework should be able to minimise subjectivity of the results (and activity times) by utilising activity or procedure times from the RIS

3.9.6 Beyond radiologist workload models

As an alternative to approaches that utilise RVUs, an activity-based approach to determining staffing requirements within radiology has also been proposed.

Van Der Merwe et al. (2013) developed staffing requirement models for three of the main disciplines in radiology (namely diagnostic radiology, nuclear medicine, and radiation therapy). The authors' models are based on task analysis of the functions and activities, task duration and the clinical workload that include the number of examinations, procedures and techniques used within each discipline. The local working conditions, workload estimation, number of equipment and modalities, and the quantity of procedures for all three models are user-defined (Van Der Merwe et al., 2013). The models also include patient numbers that are based on available statistics, such as number of procedures in nuclear medicine and radiology, while in radiation therapy the number of patients treated per year was considered (Van Der Merwe et al., 2013). The required number of diagnostic radiology equipment is based on the number of procedures, the task duration, the working hours and the machine time (Van Der Merwe et al., 2013). The number of 'full time equivalent (FTE) medical physics services' is based on the number of diagnostic radiology equipment. The authors highlight that the nuclear medicine staffing requirements model is similar to the diagnostic radiology model, in that it is task- and time-based, and does not include provision for radiation protection services, involvement in education (i.e. teaching) activities, or research. Whereas the radiation therapy model includes all activities along the entire radiation therapy process including management, administration, education, and research, amongst others, which the authors classify as an activity-based approach. At the time the article was published, the authors were in the process of validating the models.

3.10 Challenges with existing approaches to determining radiology staffing needs

Specific challenges to the radiation therapy and radiologist staffing approaches were identified during the literature review of radiology specific staffing approaches. The challenges are grouped according to radiation therapy and radiologist staffing models of which each will be discussed in the following sections.

3.10.1 Challenges with radiation therapists staffing models

Literature referring to radiographers staffing models is limited to the field of radiation therapy and RTs.

Smoke and Ho (2015), from Canada's Radiation Therapy Professional Advisory Committee, were tasked by the Cancer Care Ontario's Radiation Program Leadership to improve their RT staffing model. The model in use was outdated and did not make provision for modern radiation therapy practice. More specifically key limitations of the RT model were: consideration for advancements in treatment planning and / or delivery procedures were not kept abreast of; and staffing for clinical activities such as brachytherapy and orthovoltage, as well as for critical patient safety activities, were excluded. A similar situation occurred when the Australian Society of Medical Imaging and Radiation Therapy tasked Smith et al. (2016) to revise the 2001 RT staffing model to incorporate the existing radiation oncology practice, technology and service organisation. The 2001 RT model did not account for new techniques, such as intensity-modulated radiation therapy which is more resource intensive since its preparation time is relatively longer (Smith et al., 2016).

Moreover, technology advances increased the complexity of radiation oncology services as they are now applying the most advanced information technology infrastructure. Griffiths (2000) highlights that radiation therapy has progressed from using an uncomplicated process and technology, with limited success in disease treatments, to applying multifaceted technologies with improved success. This significantly influences staffing and skill mix demands in addition to the need for information technology, patient care and technical skills (Griffiths, 2000).

Smith et al. (2016, p. 210) stated that a requirement for the revision of the 2001 RT model of the Australian Society of Medical Imaging and Radiation Therapy is that it should be established upon the "*operating hours of megavoltage external beam treatment units as this remains the core business of all radiation oncology centres*". Griffiths (2000) states that a suitable staffing model that allows radiation therapists training time is needed given factors such as: the continuous advancements of technology and treatments; the broadened scope of RTs' role in both patient care and technical capacities; and maximising treatment throughputs.

Klein (2010) identified that it is challenging to match the radiation therapy needs with the required staffing and skill in a radiation therapy environment. The process itself is overwhelming and requires constant revisiting as new technologies are implemented. The author argues that, although the available staffing suggestions from the American College of Radiology and Abt studies make provision for staffing levels in all departments in a radiation therapy environment, these are too basic and misunderstood. Moreover, Klein (2010, p. 263) argues that these approaches neglect to address the 'level of quality of staff' needed and physicist still raise the question of "*how to fairly derive the time it takes to perform tasks*".

Van Der Merwe et al. (2013) state that there is a lack of evidence-based documentation that describes staffing models which accurately calculates the number and category of radiology professionals to deliver radiation services. There are very few documented radiology staffing models that account for direct patient related workload; technology advances; and differing infrastructures (Van Der Merwe et al., 2013). They recognise that a staffing method is needed that is transparent and flexible to accommodate changes in services, modalities and technologies, while maintaining quality patient care and safety. The models which the authors described are still to be validated. The authors identified many reasons why staffing levels are important in the medical environment referring to patient safety, 'practice accreditation' purposes and 'professional credentialing' amongst others. These staffing levels have often been based on retrospective subjective estimates and crude 'population size, equipment availability, and disease incidence' (Van Der Merwe et al., 2013).

Patel and Mitera (2011) in their systematic scoping literature review, refer to a total quality culture that should be incorporated into radiation therapy (RT) staffing models. As discussed, RT staffing models are traditionally based on the number of linear accelerators used at cancer centres and outdated "recommendations on international standards". The authors refer to RT staffing models as being task-focused (i.e., the number of linear accelerators) while total quality culture strategies promote process-focused performance or process-oriented results using a patient-centred approach. Patel and Mitera (2011, p. 84) suggest that "*an RT staffing structure is patient-centred, process driven, incorporates the complexity involved for each treated case, and can accommodate continuous improvement strategies rather than a model designed around equipment and task*."

3.10.2 Challenges with radiologists staffing models

Research into radiology staffing models primarily focussed on radiologists in public and tertiary hospitals, rather than in private institutions. Medical advances, more specifically in radiology imaging equipment and techniques, have seen the roles of staff within radiology change and this impacts on staffing requirement methodologies.

Khan and Hedges (2013) state that because of the rapid technological and procedural advances within the radiology discipline, the role of radiologist has also changed drastically. Yet, the methods for measuring radiologist workload does not account for the diverse activities performed by the radiologists. Brady (2011) agrees and argues that although the role of radiologist changed significantly (from only reporting on "plain films and cross-sectional images" to being part of a multidisciplinary team involved in patient care) over the past years, the methods for measuring their workload did not change. The outdated workload measurement techniques for radiologists use crude numbers of investigations reported per radiologists as basis for measurement. Furthermore, Cowan, MacDonald and Floyd (2013) are in agreement and state that the current method of measuring radiologists' workload is based on the number of examinations done per year (raw estimation method) which is a very limited view of the workload. The authors explain that this method allocates the same amount of radiologist time to single plain x-ray as to a 4000 image CT x-ray and this is a noticeable shortcoming. Brady (2011, p. 248) concurs, commenting on the principles that underpin the RANZCR RVU model that "*complex, large data-volume examinations with multiple images take a longer time to report, and consume more mental effort than studies with only a handful of images, such as a CXR. Another cardinal feature…is that the value of an examination depends on the number of regions covered; this is particularly so for CT, where a 'chest/ abdomen/pelvis' clearly takes more time and effort than a 'chest'*". Not all examinations and images are of the same complexity as some examinations have more images and cover a greater region. Such examinations require more mental effort and take longer to report on. The complexities of radiologist's work and the variation among workplaces complicates the measurement of radiologists' workload.

A report by the Faculty of Radiologists of the Royal College of Surgeons in Ireland that was quoted by Brady (2011, p. 247), argues that "(*t)he use of crude study numbers to determine radiologist workload and throughput is an old-fashioned, discredited and inappropriate misuse of data. Although the introduction of PACS/RIS technology in many Radiology departments makes it possible to acquire this data, it should not be used in an unfiltered and un-weighted manner..."* Any method that wishes to calculate the workload of radiologists should take into account the numerous variables associated with the acquisition and reporting of images, bearing in mind the local circumstances and clinical demand (Brady 2011). Currently there are neither a globally applicable or globally weighting system in practice (Brady 2011). Those that are available were mostly designed for medical aid reimbursement or other purposes not directly related to the workload of radiologists (Brady 2011). Brady (2011, p. 248) suggest that if radiologists' workload should be determined that it *"be done through the medium of an agreed, robust system of measuring the relative values of different studies, procedures and activities, which is adaptable to new professional and technical developments in the future*".

The Royal College of Radiologist in the United Kingdom have published a document ("*Clinical radiology: Guidance on radiologists' reporting figures*") that provides some standards for radiologist reporting activities that can aid in calculating the workload and staffing levels of radiologists. However, the Royal College of Radiologists (2012a) does caution in the use of these figures without considering departmental and personal variables that will affect the workload, such as: work output standards; human-, capital-, and equipment resources; service location; and work practices. The authors highlight that there is a need for a meaningful and accurate measure of radiological workload to address the increasing demand for radiological services. Royal College of Radiologists (2012a) identifies three healthcare levels throughout the United Kingdom where there is a need for measuring radiologist workload. The needs at the various levels include the desire to know whether the current staffing level will match the demand in both healthcare services and competencies and whether the workload will reflect all clinical activities.

A comprehensive review of the limitations of the RVU measurement model conducted by Dubinsky (2013), states that to depend on RVU models for workload and staffing alone would be incomplete and insufficient as it neglects to account for non-RVU producing work. The author proposes that a methodology that combines RVUPW and the assessment of nontangible contributions is needed to address the challenge of radiologist's workload, productivity, job satisfaction and staffing.

3.11 Summary of radiology staffing model challenges

Table 3.8 summarises the literature that was reviewed in the previous sections, and that which was considered in the compilation of the requirement specifications, to identify the main features that contribute to the challenges that are currently being experienced with both radiologists and RTs staffing models. It reveals that the most significant challenges that are identified in literature is that staffing models are outdated and do not account for all the activities the post under review is performing. The second most frequently identified challenge is that the staffing models do not consider all the variables that are impacting on the acquisition and reporting of images. The third most frequently identified challenge is that the staffing models make use of crude data such as the number of radiological reports.

Table 3.8: High level summary of the challenges of both radiologist and radiation therapy staffing models

		Khan & Hedges (2013)	Brady (2011)	Royal College of Radiologists (2012b)	Royal College of Radiologists (2012c)	Dubinsky (2013)	Dutton et al. (2014)	Smoke & Ho (2015)	Smith et al. (2016)	Griffiths (2000)	Klein (2010)	Van Der Merwe et al. (2013)	**Total**
Radiology (both radiologists and radiation therapist) staffing model challenges by theme	Staffing models are outdated – does not account for all the activities performed	X	X	X	X	X	X	X	X				**8**
	Methods for measuring workload are outdated – use crude numbers	X	X			X						X	**4**
	Staffing models does not consider all the variables related to the acquisition and reporting of images	X	X	X	X				X	X			**6**
	No universally applicable and universally accepted weighting system		X										**1**
	Process of staffing is overwhelming and complex										X		**1**
	Challenging to match clinical physics needs with required staffing and skill										X		**1**
	Lack time for training									X			**1**
	Current staffing standards too basic and misunderstood										X		**1**
	Neglect to address the "level of quality of staff"										X		**1**
	Need to know how to fairly derive the time it takes to perform tasks										X		**1**
	Lack evidence-based documentation describing models which accurately quantifies the number and type of professionals											X	**1**
	Lack models that directly relate to patient workload, technology, technique and infrastructure											X	**1**
	Need to be transparent and flexible to accommodate changes to service, modalities and technologies											X	**1**
	Models are based on retrospective, subjective estimates and crude population size, equipment availability, and disease incidence											X	**1**

3.12 Conclusion: Chapter 3

Three approaches to determining general healthcare staffing needs were introduced, namely supply-based, demand-based and workload-based approaches. The supply- and demand-based models tend to represent the macro environment (i.e. regional and national or country) better for human healthcare planning, whereas workload-based models represent the meso and microenvironment (i.e. organisational and departmental or unit) more favourably.

Radiology staffing models were introduced by presenting and overview of existing radiologist and radiation therapists' staffing models. The latter forming part of a branch of specialities in radiography. There is limited literature on diagnostic radiographers' staffing models. Consequently, though this research focuses on developing a staffing requirements framework for diagnostic radiographers, literature on radiologists and radiation therapists' staffing models was also reviewed to gain insight on: the challenges associated with these models; and elements of these models that can contribute to the development of the diagnostic radiographer staffing framework.

The next chapter will consolidate the requirements specifications that were formulated throughout this and the previous chapter, and describe the diagnostic radiographer staffing framework that is developed based on the requirement specifications.

Chapter 4: Diagnostic radiographer staffing framework development

In the previous chapter, staffing models in the general healthcare environment as well as radiology staffing models specifically, were discussed. The models identified in the healthcare environment were generally more suited to health workforce planning at a macro level, while the models identified for the radiology environment, followed a workload measurement approach and were therefore more suited to planning at a meso- or micro level.

In this chapter, a framework to determine staffing requirements for diagnostic radiographers in the radiology environment will be develop, based on the requirement specifications that were developed throughout the literature reviews presented in previous chapters. This chapter starts by introducing a consolidated table of all the requirement specifications developed in the preceding chapters. This is followed by an evaluation of the various staffing approaches against the requirement specifications to identify the most suitable existing approach to determining staffing requirements. The existing staffing requirement model that is identified based on this evaluation, is closely aligned to the requirement specifications and can be used as a base model for the development of a diagnostic radiographer staffing requirement framework. The development of the diagnostic radiographer staffing framework is discussed in detail and a diagram summarising the framework is presented.

Moreover, the final diagnostic radiographer staffing framework is discussed here and includes the relevant proposed enhancements from the SMEs that were obtained during the theoretical verification process (discussed in Chapter 5). To maintain the flow of the thesis and to avoid duplicating the framework in the main document, the preliminary diagnostic radiographer staffing framework is included in the verification pre-read document in Appendix A.

4.1 Summary: Requirement specifications

The requirement specification categories that are employed in this research were described in Section 1.6. The requirement specifications, identified throughout the previous chapters, are summarised in Table 4.1 – 4.4. This gives the reader a consolidated view of all the functional- and user requirements, boundary conditions, and restrictions against which the design of a framework for radiology staffing should be evaluated.

Table 4.1: Summarised functional requirements for the diagnostic radiographer staffing framework

Functional requirements: Refers to the capabilities that the framework must provide to address the existing radiology staffing framework challenges	
RS category	**Description**
FR 1	The framework should be able to calculate the healthcare professionals required based on supply type data.
FR 2	The framework should be able to accommodate productivity measures as part of the staffing requirements.
FR 3	The framework should be able to calculate the healthcare professionals required based on demand type data that accommodates changes.
FR 4	The framework should be able to use activity times to determine workload.
FR 5	The framework should be able to translate workload to FTEs.
FR 6	The framework should be able to calculate the total available time per year for a suitably qualified diagnostic radiographer.
FR 7	The framework should be able to calculate the workload for the post under review.
FR 8	The calculation translating workload to FTE requirements in the framework should be transparent and reproducible.

Table 4.2: Summarised user requirements for the diagnostic radiographer staffing framework

User requirements: Specific or expressed need(s) or desired characteristic(s) from the perspective of the user	
RS category	**Description**
UR 1	The framework must be able to allow the capturing of the number of qualified diagnostic radiographers. (e.g. *Identify the current number of qualified radiographers.)*
UR 2	The competency level of the qualified diagnostic radiographers must be captured. (e.g. *Identify the current competency of diagnostic radiographers in the different modalities.)*
UR 3	Activities performed by an appropriately qualified radiographer or under the supervision of qualified radiologists must be identified and listed. (e.g. *Create an activity list of the qualified radiographer.*)
UR 4	The framework must be adjustable to allow the capturing of the number of equipment and modalities that are available and in use
UR 5	The framework must be adjustable to enter the number of procedures and / or techniques that are being used in each modality
UR 6	The framework must allow the user to specify the number of radiology practices within the group (in other words it must allow for more than one practice to be indicated).
UR 7	The framework must allow the user to specify local conditions that are of significance and will impact on the workload of the department or unit (e.g. the physical layout of the department, its organisational structure, the key medical processes, patient flow and procedures related to the specific department). Thus, an analysis of the clinical flow and identification of all the professional roles associated with the activities along the workflow, must be accommodated
UR 8	The framework should allow the analysis of data obtained from the integrated workflow management technologies such as PACS, RIS and VR as data relating to the workflow and duration can be collected from these systems
UR 9	The framework must make provision for both clinical and non-clinical activities
UR 10	The framework must make provision for adjustments relating to technological advances (i.e. it must be easily adaptable when the clinical environment changes).
UR 11	The framework should make provision for capturing the current available staff, their competency, skill set and employment status (i.e. part- or full time).
UR 12	The framework must make provision for capturing demand-related information.
UR 13	The framework should make provision for capturing the current available staff information relating to age and gender.
UR 14	The framework should be able to minimise subjectivity of the results (and activity times) by utilising activity or procedure times from the RIS
UR 15	The framework should consider the maximum allowable working hours per week when determining the workload.

Table 4.3: Summarised design restrictions for the diagnostic radiographer staffing framework

Design restrictions: Refer to a more desirable (*preferred*) solution space, considering any other constraints on the design of the framework	
RS category	**Description**
DR 1	The framework will be constrained to the diagnostic radiology profession only.
DR 2	The framework will be constrained to appropriately qualified diagnostic radiographers only.
DR 3	The framework must be restricted to diagnostic radiology equipment, modalities, and procedures (and / or techniques)
DR 4	The framework will be constrained to the private practice radiology environment.

Table 4.4: Summarised boundary conditions for the diagnostic radiographer staffing framework

Boundary conditions: The framework should conform to legal requirements and existing business policies, while blending in with the current company culture.	
RS category	**Description**
BC 1	The framework should consider the various leave allowances as stipulated by law and company policies.

4.2 Compatibility of existing staffing models

The various approaches to determining healthcare staffing needs in general, as well as the specific radiation therapist and radiologist staffing models that were discussed in Chapter 3, are subjected to evaluation against the requirement specifications to identify the most suitable approach that will serve as basis for the development of a diagnostic radiography staffing framework. The compatibility evaluation is summarised in tabular form in Table 4.5, where a '1' indicates compatibility with the criteria and a '-1' indicates incompatibility.

In this compatibility evaluation, five groups of staffing models, as discussed throughout Chapter 3, are evaluated against the requirement specification. These groups are:

i. *Supply based approaches*, which predominantly predict future health workforce through the analysis of factors that impact their movement from one state to another, as discussed in Section 3.2;
ii. *Demand based approaches* that seek to predict the future health workforce demand by focusing on the changes to the driving forces that affect the health service demand, as discussed in Section 3.4;
iii. *Workload-based approaches* that use the relationship between health service activity and the work or effort involved (or workload) to determine the required labour, as discussed in Section 3.6;

iv. *Radiation therapist staffing models*, that were initially primarily based on the number of radiation therapists per linac hour (the number of hours that a machine is available in a day) but has since evolved into workload-driven and activity-based models, as described in Sections 3.9.1 and 3.9.2; and

v. *Radiologist staffing models* which developed from a crude reporting RVU measurement to a workload measurement approach that considers both clinical and non-clinical activities, as discussed in Sections 3.9.4 to 3.9.6.

These groups of staffing models represent healthcare workforce modelling in general and radiology staffing models specifically. As discussed, however, this research focuses on a staffing requirement framework for diagnostic radiographers, a staffing category of radiographers (defined in Section 2.1.3). Though there are a limited number of research articles on radiographer staffing models, and those found primarily focus on radiation therapist, radiologist staffing requirement models were considered to draw some insights from. This was considered appropriate since radiographers' work alongside radiologists. Both the existing radiation therapist and radiologist staffing models do, however, have several challenges as outlined and discussed in Sections 3.10.1 and 3.10.2 .

In Table 4.5, the various staffing models that were presented in Chapter 3: are evaluated against the requirement specifications that have been developed for the diagnostic radiographer staffing framework to identify the most suitable staffing requirement approach.

Table 4.5: Compatibility evaluation of requirement specifications to staffing approach

	Supply-based approaches				**Demand-based approaches**			**Workload capacity measurement approaches**				**Radiation therapist staffing models**						**Radiologist staffing models**		
	Training and supply (*incl. stock of individuals*)	Productivity (*incl. flow of activities*)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Routsis et al., 2006)	(Griffiths et al., 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (A. G. Pitman & Jones, 2006); (A. Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(MacDonald et al., 2013); (Cowan et al., 2013)
Functional requirements																				
FR1: Calculate the number of healthcare professional required based on *supply type data*	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1
FR 2: Accommodate productivity measures as part of the staffing requirements	-1	1	-1	-1	-1	1	1	-1	1	1	1	1	-1	-1	-1	-1	-1	1	1	1
FR 3: Calculate the number of healthcare professional required based on *demand type data*	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	-1	1	1	1	-1	-1	-1
FR 4: Apply activity times to calculate workload	-1	1	1	-1	-1	-1	1	1	1	1	-1	-1	-1	1	1	1	1	-1	1	-1
FR 5: Translate workload to full-time-equivalents (FTE)	-1	-1	-1	-1	-1	-1	1	-1	1	1	1	-1	-1	-1	1	1	1	-1	1	1

Continued on next page

	Supply-based approaches				Demand-based approaches			Workload capacity measurement approaches				Radiation therapist staffing models						Radiologist staffing models		
	Training and supply (*incl. stock of individuals*)	Productivity (*incl. flow of activities*)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Routsis et al., 2006)	(Griffiths et al., 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (A. G. Pitman & Jones, 2006); (A. Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(MacDonald et al., 2013); (Cowan et al., 2013)
FR 6: Calculate the total available time per year	-1	-1	-1	-1	-1	-1	1	-1	1	-1	-1	-1	-1	-1	1	1	1	1-	-1	1
FR 7: Calculate the workload of the post/ position under review (*not for the activity*)	-1	-1	-1	-1	-1	-1	1	-1	1	-1	1	-1	-1	-1	1	1	1	-1	-1	1
FR 8: The calculation translating workload to FTEs required should be *transparent* (easily understood) and *reproducible*	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1
User requirements																				
UR 1: Capture the number of qualified diagnostic radiographers	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

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	Supply-based approaches				Demand-based approaches			Workload capacity measurement approaches				Radiation therapist staffing models						Radiologist staffing models		
	Training and supply (*incl. stock of individuals*)	Productivity (*incl. flow of activities*)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Routsis et al., 2006)	(Griffiths et al., 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (A. G. Pitman & Jones, 2006); (A. Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(MacDonald et al., 2013); (Cowan et al., 2013)
UR 2: Capture the competency of qualified diagnostic radiographers in the various modalities	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1
UR 3: All activities performed by an appropriately qualified diagnostic radiographer must be identified and listed	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	-1
UR 4: Identify the number of equipment and modalities that are available and in use	-1	-1	-1	-1	-1	1	1	-1	-1	-1	-1	1	1	1	-1	1	1	-1	-1	-1
UR 5: Identify the number of procedures and or techniques that are being used in each modality (procedure & technique list)	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	1	1	1	1	1	1

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	Supply-based approaches				Demand-based approaches			Workload capacity measurement approaches				Radiation therapist staffing models						Radiologist staffing models		
	Training and supply (*incl. stock of individuals*)	Productivity (*incl. flow of activities*)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Routsis et al., 2006)	(Griffiths et al., 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (A. G. Pitman & Jones, 2006); (A. Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(MacDonald et al., 2013); (Cowan et al., 2013)
UR 6: Specify the number of radiology practices	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
UR 7: Specify any significant local conditions	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	1	-1	-1	1	-1	-1	-1	-1
UR 8: Use data from the integrated workflow management technologies (e.g. PACS, RIS, VR)	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1
UR 9: Make provision for clinical and non-clinical activities	-1	1	1	-1	-1	-1	1	1	1	1	-1	-1	1	1	-1	1	1	-1	1	1
UR 10: Be able to adapt to technology advances	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	-1	-1	-1	-1
UR 11: Capture current *available staff*, their *competency level*, *skill set* and *employment status* (part- and full-time)	1	1	1	1	-1	-1	1	1	-1	1	-1	1	1	-1	-1	1	-1	-1	-1	-1

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	Supply-based approaches				**Demand-based approaches**			**Workload capacity measurement approaches**				**Radiation therapist staffing models**						**Radiologist staffing models**		
	Training and supply (*incl. stock of individuals*)	Productivity (*incl. flow of activities*)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Routsis et al., 2006)	(Griffiths et al., 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (A. G. Pitman & Jones, 2006); (A. Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(MacDonald et al., 2013); (Cowan et al., 2013)
UR 12: Capture demand related information	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	-1	1	1	1	1	1	1
UR 13: Capture current available staff information relating to age and gender	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
UR 14: Minimise subjectivity of the results (and activity times) by utilising activity and procedure times from RIS (*or other work measurement techniques*)	-1	1	-1	-1	-1	-1	1	-1	1	1	1	-1	-1	1	1	1	1	-1	-1	1
UR 15: Consider the maximum allowable **working hours** per week when determining the workload	-1	1	-1	-1	-1	-1	1	-1	1	1	1	1	1	1	1	1	1	-1	-1	1

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	Supply-based approaches				Demand-based approaches			Workload capacity measurement approaches				Radiation therapist staffing models						Radiologist staffing models		
	Training and supply (*incl. stock of individuals*)	Productivity (*incl. flow of activities*)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Routsis et al., 2006)	(Griffiths et al., 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (A. G. Pitman & Jones, 2006); (A. Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(MacDonald et al., 2013); (Cowan et al., 2013)
Design restrictions																				
DR 1: Constraint to the diagnostic radiology profession only	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
DR 2: Constraint to appropriately qualified diagnostic radiographers only	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
DR 3: Restricted to diagnostic radiology equipment, modalities, and procedures (and/ or techniques)	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
DR 4: Constraint to the private practice radiology environment	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

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	Supply-based approaches				**Demand-based approaches**			**Workload capacity measurement approaches**				**Radiation therapist staffing models**						**Radiologist staffing models**		
	Training and supply (*incl. stock of individuals*)	Productivity (*incl. flow of activities*)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Routsis et al., 2006)	(Griffiths et al., 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (A. G. Pitman & Jones, 2006); (A. Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(MacDonald et al., 2013); (Cowan et al., 2013)
Boundary conditions																				
BC 1: Consider the different leave allowances as stipulated by law and company policies	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	1	1	1	-1	1	1	-1	-1	1
Total compatibility score	**-20**	**-12**	**-18**	**-24**	**-22**	**-18**	**2**	**-14**	**-2**	**-6**	**-10**	**-14**	**-10**	**-14**	**-4**	**6**	**0**	**-22**	**-16**	**-4**

Legend: ‘1’ if the criteria are supported by the methodology and ‘-1’ if it is not supported or incompatible.

A review of how the staffing requirement models under evaluation performed against the requirement specification categories reveals the following:

i. The specifications in the *functional requirement* category refer to the capabilities and results the framework must provide. The service targeted-based models (that employ demand-based approach), and the procedure-based models (that employ a workload-based approach) score the highest in the *functional requirement* category, while Tobergte and Curtis' (2013) radiation therapy staffing model scores the second highest. The primary difference amongst these models is their fulfilment of FR 2, which refers to the functionality of making provision for productivity measures. Since both the model from Tobergte and Curtis (2013) and the procedure-based model take micro- and meso approaches to determining staffing requirement (discussed in Section 3.6 and 3.7), the manner in which procedure-based models incorporate productivity measures can be considered when designing a diagnostic radiography staffing framework.
ii. Tobergte and Curtis' (2013) radiation therapy staffing model scored the highest in terms of fulfilling the *user requirements*, indicating that this model best addressed the specific need(s) or desired characteristics for the framework, as defined from the perspective of the likely users. The requirements that were not addressed by the aforementioned model were also not addressed by any of the other models under evaluation. These requirements are very specific to diagnostic radiographers and their specific environment and, since no diagnostic radiographer staffing requirement model was found in literature, these requirements could not be fulfilled by the models under evaluation. However, these requirements are essential and will be considered when developing a diagnostic radiography staffing framework.
iii. The *design restrictions* for the development of the diagnostic radiographer's staffing requirement framework were not met by any of the models under evaluation. Since these restrictions refer to the preferred solution space, their consideration in the development of a diagnostic radiography staffing framework is critical.
iv. The *boundary conditions*, which are the requirements that the framework must meet unconditionally, are fulfilled by the staffing model with the highest overall evaluation score, namely Tobergte and Curtis' (2013) radiation therapy staffing model.

The staffing model approach by Tobergte and Curtis (2013), that forms part of the radiation therapy staffing model group, achieved the highest compatibility score, indicating that these authors' approach to determining staffing requirements is the most closely aligned to the needs of the diagnostic radiology environment of all of the models under investigation. However, their approach is developed for the radiation therapy environment and not a diagnostic radiology environment. As discussed in Section 2.1.3, these two environments do differ in a few important ways. The shortcomings of Tobergte and Curtis' (2013) radiation therapy staffing model in terms of the diagnostic radiology environment relate to: FR1 and FR5; UR1, UR2, UR8 and UR13; and all four design requirements. Given the scope of the shortcomings, a simple modification or adjustment to the Tobergte and Curtis (2013) model will not suffice. However, the principles and approaches of their model align closely to the requirement specification and will therefore be utilised as a starting point when developing a diagnostic radiography staffing framework.

4.3 Diagnostic radiographer staffing framework

The final diagnostic radiographer staffing framework that has been designed in line with the requirements summarised in Section 4.1 and that incorporates the minor enhancements, consists of seven steps. In order to provide an overview of the framework, a short description of the input, process, and output for each of the seven steps in the framework is presented in Table 4.6. A detailed description of each of the seven steps in the framework is presented in the remainder of this section.

Table 4.6: Input, process, output summary of the diagnostic radiographer staffing framework

Steps	Description	Input	Process	Output
1. Establish staffing purpose and focus	Define the purpose and focus of the staffing assessment or review.	Identification of the staffing objectives and challenges.	Interviews with key stakeholders to identify objectives and challenges. Review of performance reports.	An agreed set of staffing objective(s) and defined challenges.
2. Collect basic data	Collect basic data related to the objective(s) and challenges identified.	Data related to staffing numbers; leave, statutory and regulatory policies; demographic (age & gender); type and quantity of procedures, modalities, and equipment; patient numbers per procedure and intervention; roles and organisation, working hours.	Collect all the relevant information using a structured approach; analyse the information to ensure a good understanding of the operating context of the facility or organisation where the staffing assessment will be performed including the operating context of the post(s) to be reviewed.	Data sheet containing all the relevant information pertaining to the organisation; staffing objectives; challenges and post(s) to be assessed.

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3. Determine available working time	Establish the available time per FTE for the period under review and the leave factor.	The various time allowances are accounted for such as personal breaks, statutory and regulatory breaks.	The total available working days in a year is subtracted from the total leave provision days in a year and then multiplied by the number of working hours in a day to reach the total hours available per year.	The total available hours per year represents the time that one fulltime employee (or FTE) has available in a year to perform the activities of the post being occupied. Calculated leave factor.
4. Develop a task/ activity list	Develop a task list that identify all the activities that constitute the workers daily time	An understanding of the activities of the post to be analysed together with the operating context within which the post functions. In addition, job descriptions or job profiles and interviews with the incumbents in the post that needs to be assessed	Use all the relevant documents (e.g. interview responses) and information system(s) e.g. RIS to gather information that can be used by the appropriately experienced radiology staff to create an all-inclusive activity list. Validate the list with the appropriately experienced and qualified radiology staff	An all-inclusive activity list; a good understanding of the operating environment and other activity related (raw) data such as procedure types, frequency and some activity times (from the RIS)
5. Assign activity time & frequency of occurrence	Each activity performed by the incumbent is assigned both an activity duration and frequency of occurrence (how often the activity is performed)	The primary input document is the activity list from the previous step and the RIS data or any other activity times collected through various other methods such as direct observations, log sheets, questionnaires, and expert opinions	Several approaches exist for obtaining activity times and frequencies which could involve direct observations, interviews, questionnaires, self-monitoring, expert opinions, and the use of external sources for standards amongst others	An all-inclusive activity list with activity times and frequency for each activity performed by the incumbent

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6. Determine required* full-time equivalents (*FTE)	Calculating how many FTEs are required to execute a particular workload for a set period considering the most critical variables	All outputs from the previous steps are used	Calculate the total quantity of workload divided by the total available time for one FTE for a set period considering critical variables that impact the staffing requirements	The number of FTE's (or workers) to execute a particular workload for a specified period
7. Analyse and interpret the results	Analyse the results and consider their likely consequences	The number of FTE's that is calculated and that is required for a specified workload. The agreed staffing objectives and challenges defined	Interpret the difference between the existing and required staffing level; ratio of existing staffing level to the required staffing level (assessing the daily work pressure) and analyse activity proportion to total workload for improvements	Staffing strategies that addressed the staffing needs

4.3.1 Step 1: Establish the staffing purpose and focus

The first step of the framework involves defining the purpose and focus of the staffing assessment or review. As shown in Table 4.6, the input to this step is staffing objectives and challenges; the process followed is interviews with key stakeholders and reviews of performance reports; and the output is an agreed set of staffing objective(s) and definition of relevant challenges.

Any staffing endeavour should be led by a purpose or an objective for the pursuit. Many of the pursuits are initiated (or driven) by the challenges with existing staffing models (as discussed in Sections 3.10.1 and 3.10.2). Increases in demand, technological advances, and challenges in delivering a safe and premium service could trigger the evaluation of the workforce's workload and capacity to deliver a high quality and safe radiological service.

The World Health Organization (2010) highly recommends defining the need for introducing a staffing endeavour and what decisions need answers as it determines the focus for the staffing requirement process. The World Health Organization (2010), present the following key questions as possible reasons for initiating a staffing endeavour:

i. How many of a particular staffing category or categories are required at a particular health care facility (location) to cope with the existing workload?
ii. Is a comparison of workload amongst existing staffing categories needed?
iii. Which staffing category or categories at which health care facility (location) endure the highest workload pressure?
iv. When planning a new health service facility, will the new functions be performed by the existing staff category or categories or by a new staffing category?

The World Health Organization (2010) refers to the following questions when making decisions regarding which staffing group and facility should be prioritised for workload and staffing assessment within a health care setting:

i. Which staff category is in shortest supply in relation to the need for staff?
ii. In which type of health facility is the staffing shortage worst?
iii. For which cadres is staffing distribution likely to be most inequitable?
iv. Where (between what types of facilities) is the distribution of main staff categories most imbalanced?
v. Which of these staffing problems have affected the quality of care most?
vi. Which of them are likely to affect the quality of care soon?
vii. Are any of the staff cadres or health facility types particularly important for planned future health programmes?

Adapting these questions to a radiology setting and considering other questions based on the challenges within existing radiology staffing models (as discussed in Sections 3.10.1 and 3.10.2), it is proposed that the following questions be used as a guideline to establish the diagnostic radiographer staffing purpose within radiology:

1. Are any alarming or concerning changes, either increasing or decreasing, in radiographic imaging requests being experienced?
2. Do these changes in radiographic imaging requests occur at any specific radiology site?
3. Do these changes in radiographic imaging requests occur for any specific imaging modality?
4. Are acquisitions of any new facility or expansions of existing facilities being considered?
5. Are any new radiographic imaging technology, techniques or procedures being introduced?
6. Which staff category, such as general diagnostic radiographers including CT and MRI radiographers, sonographers and mammographers, are in shortest supply?
7. Do staffing shortages affect multiple or specific radiology sites?
8. Do staffing shortages affect multiple or specific radiological services?
9. For which staffing category is staffing distribution likely to be most unbalanced or inequitable?

10. Where (multiple or specific radiology sites) is the distribution of staff categories most unbalanced or inequitable?
11. Is the quality of radiology service affected by staffing challenges? Examples include the following;
    a. Do any of the radiology sites experience long waiting times and queues?
    b. Are radiological imaging requests completed within agreed standards?
    c. Are RTATs met?

The output of this step builds a high-level understanding of the key staffing requirement purpose and focus relating to the staffing category (diagnostic radiographer) and location (modality and site) that will be addressed by the staffing requirement assessment.

4.3.2 Step 2: Collect basic data

The second step of the framework involves collecting data associated with the objective(s) and challenges identified in Step 1. As indicated in Table 4.6, the input to this step involves data related to current staffing numbers, demographics (age and gender), type and number of leave days allocated per year, type and quantity of examinations and/or procedures per modality completed per year, type of modalities and number of imaging modalities, roles and organisation, and working hours. The process involved is a structured data collection approach followed by a basic analysis of the information to ensure a good understanding of the operating context of the diagnostic radiology environment. The output to this step is a data sheet containing all the relevant information pertaining to the organisation, staffing and possible challenges facing the diagnostic radiographers.

Given the purpose of the staffing endeavour which will inform the collection of basic data to address the key questions or objectives that the staffing endeavour addresses. This basic data should also be related to the local conditions where the staffing initiatives are planned. Isambert *et al*. (2015) consider the following basic data when determining staffing requirements of medical physics personnel:

i. The department's scope of activity, including its organization and management;
ii. The number and complexity of the equipment and procedures used;
iii. The number of patients cared for and the complexity of their treatments;
iv. The involvement in training and teaching; and
v. The level of participation in research and development.

Considering these basic data requirements and adapting it to a diagnostic radiology environment, the following list can serve as a guide to collect the appropriate data to address the purpose and focus of the staffing endeavour. The list of basic data for collection include:

1. Create a list with all the radiology sites.

2. Create a list of all services at each radiology site.
3. Create a list with all the examinations and procedures offered according to their modalities.
4. Create a list with all the examinations and procedures completed.
5. If any staff is involved in training, teaching, research, and development, please provide the number of staff involved and the time spent (hours or minutes).
6. Create a list of all qualified diagnostic radiographers including skill, employment status, gender, and age group.
7. List all the equipment available and in use.
8. Is procedure and examination times available from the radiology information system (RIS)? If yes, please add times to the examination and procedure list.
9. Consider the leave and any statutory and regulatory policies that guide or prescribe how leave allocation are done and how many. Create a list of all leave types and the days available per leave type.
10. List the operating hours at each of the radiology sites and staff schedules.
11. Consider local conditions relevant to the workload of the radiology department or unit such as, physical layout of the department, organisational structure, and key clinical and non-clinical processes.

Once this data is collected, analysed, and logically arranged it will create a clear picture of the current situation within the diagnostic radiology environment and set a solid foundation for the staffing requirement.

4.3.3 Step 3: Determine available working time

The third step of the framework involves establishing the available time per FTE for the period under review. As shown in Table 4.6, the input involves the various time allowances (i.e. leave types); the process followed is the total available working days in a year is subtracted from the total leave provision days in a year and then multiplied by the number of working hours in a day to reach the total hours available per year. The output is the total available hours per year that represents the time that one fulltime employee (or FTE) has available in a year to perform their activities.

Determining the available working time is a key component in the formula for determining the staffing requirements. This is the total working time available per FTE for the period under review (normally a year or a month). The available time considers the time allowed for breaks (such as tea and rest breaks). It also includes the allowances for statutory and regulatory breaks (such as sick days, public holidays, family responsibility leave and annual leave).

To convert total activity hours to FTE's, the average available hours in a year (or month) for an FTE needs to be calculated. The following formula, proposed by the World Health Organization (2010), is to be used for estimating the available time per year:

$$AWT = [A - (B + C + D + E)] \times F \tag{4.1}$$

where:

i. AWT is the total available working time;
ii. A is the number of possible working days in a year;
iii. B is the number of days off for public holidays in a year;
iv. C is the number of days off for annual leave in a year;
v. D is the number of days off due to sick leave in a year;
vi. E is the number of days off due to other leave, such as training, etc., in a year; and
vii. F is the number of working hours in one day.

MacDonald et al. (2013); Tobergte and Curtis (2013); Smoke and Ho (2015); and Smith et al. (2016) are amongst several radiology researchers that have used this approach when determining the available working time in their staffing models.

In addition to the total available working time, Smith et al. (2016) calculate a *leave relieve factor* using the following equation

$$Leave\ relieve = \frac{Working\ hours\ per\ day\ \times total\ unavailable\ days\ per\ year}{Available\ working\ hours\ per\ year}. \tag{4.2}$$

Relief refers to when a position or post is temporarily occupied by another skilled person when the primary employee assigned to the post is not available to work. The leave relieve factor is multiplied with the total required FTE to make provision for when the post under review takes leave and the activities of the post must continue.

4.3.4 Step 4: Develop a task or activity list

The fourth step of the framework involves developing an activity list that identifies all the activities that constitute the diagnostic radiographer's daily workload. As shown in Table 4.6, the input involves an understanding of the activities of the diagnostic radiographer and their operating context. The process followed is: a review of the job description; interviews with the diagnostic radiographer(s); and an analysis of the RIS data. The output is a validated activity list summarising all activities, both clinical and non-clinical, performed by a qualified diagnostic radiographer.

Compiling an activity list is a key step in determining staffing levels as all the tasks or activities associated with the position under review should be considered. These are the activities that consume most of the position's daily working time. Various existing models for both radiation therapists (Smith et al., 2016; Klein, 2010; Tobergte & Curtis, 2013; Smoke & Ho, 2015) and radiologists (MacDonald et al., 2013; Dhanoa et al., 2013), use activity lists to first establish all the activities performed by the position or post to be reviewed before the activity times are determined.

MacDonald et al. (2013) use three methods namely, observation, measurement, and consensus to create an activity list with associated time requirements. Alternative methods for establishing an activity list include through the use of manpower evaluation documents such as the Abt studies (used by Klein (2010)), and through the use of an assigned panel of experts to review and elaborate on existing activity lists (used by Smoke and Ho (2015)).

Klein (2010) used *Current Procedural Terminology* ® codes[3] from the Abt study and customised it to their clinical situation to create an activity list. Similarly Smith et al. (2016) used Medicare Benefits Schedule (MBS) codes as a basis for an activity list in their radiation therapy staffing model. The radiology environment and other medical professionals in South Africa similarly use uniform codes namely the National Health Reference Price List (NHRPL) and the Compensations for Occupational Injuries and Diseases Act (COIDA) as reference for reimbursement from medical aids. These codes are also referred to as medical aid tariff codes. The NHRPL reference uniform codes for examinations and procedures in radiology. Hence these codes can be used as basis to develop an activity list for diagnostic radiographers since it includes all the examinations and procedures performed by these professionals. Table 4.7 represents a basic template approach for developing an activity list for diagnostic radiographers from these codes, with a number of activities entered as examples. When identifying the activities, care should be taken to ensure that activities do not overlap and that all activities, both clinical and non-clinical, are accounted for. If a task is not listed, then no time will be allocated to it and neither will time be associated with it towards staffing (Martin-Vega, 2004).

The tasks are typically classified either as clinical or non-clinical tasks and as variable or fixed (constant) tasks. Martin-Vega (2004) defines all the tasks that are not directly related to the output of a department as *fixed tasks*, while all the tasks that are directly related to the output of the department are classified as *variable tasks*. The author gives the example of cleaning a machine daily as a fixed or constant task, whereas the actual operation of the machine to produce a product is a variable task. In the healthcare environment, particularly in radiology, clinical activities refer to tasks that are directly related to- or involve an interaction with a patient, whereas non-clinical activities are those that do not involve patients.

[3] *Current Procedural Terminology*® codes are formulated by the American Medical Association (AMA) as a uniform language that assigns numbers to every task and medical service that doctors, and health care professional provide to patients such as surgical, medical and diagnostic services. https://www.ama-assn.org/practice-management/cpt/cpt-overview-and-code-approval

Table 4.7: Template for an activity list with examination description, codes, modality and activity type, selected examples of activities are included

Examination description	Modality name	Exam code	Activity type
Doppler hep, spleen, IVC - portal hypertension / thrombosis (41210)	Ultrasound	41210	Clinical
U/S Abdomen (41200)	Ultrasound	41200	Clinical
U/S Abdomen + Pelvis (40210)	Ultrasound	40210	Clinical
U/S Abdominal wall (40200)	Ultrasound	40200	Clinical
U/S Bilateral lower limb, pulse & doppler, compress & reflux, all veins (70240)	Ultrasound	70240	Clinical
Cleaning of examination room	Ultrasound	Not applicable	Non-clinical
Staff meeting	Ultrasound	Not applicable	Non-clinical
Abdomen multiple views (40105)	Radiography	40105	Clinical
Abdomen multiple views plus Chest (40110)	Radiography	40110	Clinical
Abdomen single view (40100)	Radiography	40100	Clinical
AC Joints plus Stress Bilateral (61128)	Radiography	61128	Clinical
Both Feet standing single view (74140)	Radiography	74140	Clinical
Quality assurance: Department of Health radiation control requirements	Radiography	Not applicable	Non-clinical
Staff meeting	Radiography	Not applicable	Non-clinical

The output of this step is a comprehensive task list that outlines the nature of each task. This serves then as an input to the measurement step.

4.3.5 Step 5: Assign an activity time and frequency of occurrence to each activity

The fifth step of the framework involves assigning each activity performed by a diagnostic radiographer an activity time (or duration) and frequency. As shown in Table 4.6, the input to this step is the validated activity list, RIS data, and any other activity times not recorded on the RIS. The process that is to be followed varies based on the availability of the information but can include methods such as direct observations, log sheets, questionnaires, and expert opinions. The output is a comprehensive activity list with an activity time and frequency for each activity performed by the diagnostic radiographers.

In the previous two steps (Sections 4.3.3 and 4.3.4) the available time per year of the post under review was determined and the work performed (activity list) was defined. Next, an activity time is assigned to each of the tasks/ activities identified and the associated frequency of occurrence (number of events) or activity volume. Several methods for determining staffing requirements were identified in the literature. Ozcan & Hornby (1999) propose five primary methods of collecting the data that underpins the analysis to determine activity times:

i. Direct observation of staff activities;
ii. Self-monitoring using a log or a diary;
iii. Questionnaires;
iv. Interviewing relevant staff; and
v. Expert opinion.

In the same vein, Kolehmainen-Aitken (1993) offers a partially overlapping list of approaches and they are:

i. Standards obtained from external sources;
ii. Standards based on expert opinion;
iii. Standards based on experience;
iv. Standards based on functional and task analysis; and
v. Indicators of staffing needs.

Kolehmainen-Aitken (1993) argues that no single best method exists, though Ridoutt et al. (2006) point out that instead, each approach has its strengths and weaknesses, which pertains to its accuracy, cost and time to complete. It could be added that the purpose of the analysis, the industry, availability of quantitative data, and the local conditions of the environment where the assessment is conducted, will influence the choice of method. Ridoutt et al. (2006) claim that in the allied health workforce planning work environment it is common practice to rely in part or in whole on 'expert advice' when identifying tasks/ activities and activity times. The authors argue that this approach is uncomplicated, comparatively low cost and has high levels of adoption amongst practitioners. In the radiology environment where workflow and patient information are being captured on a radiology information system, procedure information such as procedure type, frequency and time can be extracted to determine staffing requirements of radiologists (MacDonald et al., 2013). A study done by Klein (2010) in the radiation therapy environment used a combination of methods for obtaining activity times, one being the Abt study, which is an external source, and the other consensus opinion from clinical staff in their environment. Another study, also in the radiation therapy environment, done by Tobergte and Curtis (2013) used consensus from experts, and best obtainable evidence of a realistic time frame within which an activity can be safely performed, to assign time to an activity or task.

Estimation is one of three main work measurement methods (the other two are direct observation with three subcategories such as time study, work sampling and physiological work measurement and standard data systems with two sub categories namely macroscopic- and microscopic standard data) to develop standard work which can be achieved in either of two ways namely, expert opinion (knowledgeable worker) or using historical data (Martin-Vega, 2004). Estimation is considered the least accurate method, but it also demands the least amount of time to establish time standards (Martin-Vega, 2004). The limitation of accuracy can be mitigated through the application of a process frequently applied in critical path scheduling, namely the programme evaluation and review technique (PERT) (Martin-Vega, 2004). This model makes use of judgement estimation to determine the time values of each task (activity). Three estimates are done for each activity instead of one and they are an optimistic time, a pessimistic time, and a most likely time. When estimating the pessimistic and optimistic times, all major factors that might cause variation in the task completion should be considered to establish a mental minimum and maximum boundary (Martin-Vega, 2004). The time estimates conform to the beta distribution and uses the following equation (Martin-Vega, 2004)

$$T_e = \frac{t_o + 4t_m + t_p}{6} \tag{4.3}$$

where:

T_e = mean of the beta distribution, the mean time estimate for the task;

t_o = optimistic time estimate;

t_m = most likely time estimate; and

t_p = pessimistic time estimate.

A template for the use in Step 5 is provided in Table 4.8 and depicts the examination code and description, modality, activity type and the application of the PERT concept with the different time estimates.

The application of standard deviation of the activity time is optional and is illustrated by the following formula (Martin-Vega, 2004):

$$\sigma = \left(\frac{t_p - t_o}{6}\right)^2 \tag{4.4}$$

where σ = standard deviation.

PERT can also be applied to determine the frequency of occurrence of the activity if the frequency information is not readily available. Moreover, Klein (2010) used billable activities to account for the number of occurrences for most of the tasks.

Table 4.8: A template for logging activity data, populated with selected examples

Examination description	Modality name	Exam code	Activity name	Examination frequency	Optimistic Time (To) (min)	Most likely time (Tm) (min)	Pessimistic Time (Tp) (min)	Mean Time Estimate for Examination (Te) (min)
U/S Abdomen (41200)	Ultrasound	41200	Clinical	97	20,61	25,67	28,67	25,33
U/S Abdomen + Pelvis (40210)	Ultrasound	40210	Clinical	27	21,56	28,82	32,01	28,14
U/S Abdominal wall (40200)	Ultrasound	40200	Clinical	2	10,70	13,49	15,61	13,38
Cleaning of examination room	Ultrasound	Not applicable	Non-clinical	21,7	2	3	5	3,17
Staff meeting	Ultrasound	Not applicable	Non-clinical	4	20	30	60	33,33
Abdomen multiple views plus Chest (40110)	Radiography	40110	Clinical	17	8,20	9,12	12,4	9,51
Abdomen single view (40100)	Radiography	40100	Clinical	73	4,62	4,87	5,6	4,95

Once the accumulated activity time, which comprises all the activities (both clinical and non-clinical) performed by the post under review, is calculated, the various allowances are added to determine a total activity time (in hours). This denotes the total workload for the post being assessed, which will serve as an input for the next step.

4.3.6 Step 6: Determine the (workload and) required FTEs

The sixth step of the framework involves calculating how many FTEs are required to execute a particular workload for a set period. As shown in Table 4.6: the input to this step is all the outputs (i.e. activity list with activity times and frequencies) from the previous steps; the process followed is to calculate the total quantity of workload divided by the total available time for one FTE for a set period considering critical variables that impact the staffing requirements; and the output is the required number of FTEs to execute a particular workload for a specified period.

The outputs generated in Steps 4 and 5 (Sections 4.3.4 and 4.3.5) are a comprehensive activity list, that includes all activities associated with the post under review, and their associated activity times and frequency of occurrence (or activity volume). The mathematical product of the activity time and frequency of occurrence is the workload which is depicted by the following formula (Disselkamp, 2013):

$$Workload\ = Business\ volume\ \times Labour\ standard. \tag{4.5}$$

The frequency of occurrence or activity volume denotes the business volume in this formula and the activity time denotes the labour standard. The significance of both these elements, frequency of occurrence and activity time, which can be related to this formula, were discussed in Section 4.3.5.

In the radiation therapy environment Battista et al. (2012), utilised the following formula to determine the total demand for FTEs, where *P* refers to the type or category of personnel; *T* refers to a specified task or procedure type and *N* refers to the actual procedures completed:

$$FTE(P,N,T) = \frac{N\ procedures\ of\ type\ T\ per\ year\ \times time\ required\ per\ procedure}{Paid\ worktime\ per\ year}. \tag{4.6}$$

In (4.6), the numerator represents the workload as depicted in formula 4.5 and the denominator represent available working time as discussed in Section 4.3.3. Similarly Martin-Vega (2004) proposes the following theoretical formula for determining the number of FTEs that are required:

$$Theoretical\ FTEs\ = \frac{T}{Hours\ available\ per\ FTE\ per\ time\ period} \tag{4.7}$$

where *T* = total workload in standard hours for a specific time period.

The required FTE is often a fraction and needs to be rounded to a whole number. Rounding the number up or down has a much greater impact on departments with fewer staff than those that are generously staffed (World Health Organization, 2010a). The World Health Organization (2010a) therefore advises being more generous in rounding up small FTE required results (i.e. one or two) than a large FTE result. More specifically, the following rounding guidelines are provided (World Health Organization, 2010a):

- 1,0 – 1,1 is rounded down to 1 and > 1,1 – 1,9 is rounded up to 2;
- 2,0 – 2,2 is rounded down to 2 and > 2,2 – 2,9 is rounded up to 3;
- 3,0 – 3,3 is rounded down to 3 and > 3,3 – 3,9 is rounded up to 4;
- 4,0 – 4,4 is rounded down to 4 and > 4,4 – 4,9 is rounded up to 5; and
- 5,0 – 5,5 is rounded down to 5 and > 5,5 – 5,9 is rounded up to 6.

Equation (4.7) assumes that staff are 100 percent utilised, which is unrealistic as factors such as demand variability, skill level requirements, and scheduling constraints will affect the actual required number of FTEs (Martin-Vega, 2004). When considering these types of factors, a utilisation standard can be added to the denominator in (4.7) as follows (Martin-Vega, 2004):

$$FTE\ needed\ = \frac{T}{Hours\ available\ per\ FTE\ per\ time\ period\ \times utilisation\ standard} \tag{4.8}$$

A comparable approach of adjusting the formula with a utilisation standard was adopted in a radiation therapy environment by Battista et al. (2012) where the authors applied FTE weights for each task or procedure type (T) and type of personnel (P). The authors defined an FTE weight as the fulfilment of a defined standardised number '*n*' of clinical procedures (e.g. 0.8 FTE physicists per 1000 treatment plans). In other words, it is a rate of working which is similar to the utilisation standard in (4.8). Battista et al. (2012) rationalised the FTE demand formula (4.6) as follows:

$$FTE\ Weight\ (P, n, T) = FTE\ (P, N, T) \tag{4.9}$$

In this formula, the required time per procedure determines the standardised number '*n*' and the FTE demand formula (4.6) for N procedures actually completed within a work year is then attained by adjusting (Battista et al., 2012):

$$FTE\ (P, N, T) = FTE\ Weight\ (P, n, T)\ \times \frac{N}{n} \tag{4.10}$$

The template to be used in Step 6 is given in Table 4.9 and depicts the total workload per examination code with the required FTE at various utilisation percentages. (4.5) is used to calculate the workload, while the required FTEs, at the various utilisation percentages, is calculated using (4.8).

Table 4.9: A template indicating the total workload hours and the required FTE at various utilisation %, populated with selected examples

Examination description	Modality name	Exam code	Activity name	Exam freq.	Optimistic Time (To) (min)	Most likely time (Tm) (min)	Pessimistic Time (Tp) (min)	Mean Time Estimate for Examination (Te) (min)	Workload (hrs) per month	FTEs at 100% utilisation	Rounded FTEs at various utilisation percentages			
											100%	90%	80%	70%
U/S Abdomen (41200)	Ultrasound	41200	Clinical	97	20,61	25,67	28,67	25,33	41,09	0,31	0,5	0,0	0,0	0,0
U/S Abdomen + Pelvis (40210)	Ultrasound	40210	Clinical	27	21,56	28,82	32,01	28,14	12,59	0,10	0,0	0,0	0,0	0,0
U/S Abdominal wall (40200)	Ultrasound	40200	Clinical	2	10,70	13,49	15,61	13,38	0,48	0,00	0,0	0,0	0,0	0,0
Cleaning of examination room	Ultrasound	Not applicable	Non-clinical	21,7	2	3	5	3,17	11,44	0,09	0,0	0,0	0,0	0,0
Staff meeting	Ultrasound	Not applicable	Non-clinical	4	20	30	60	33,33	2,22	0,02	0,0	0,0	0,0	0,0
Abdomen multiple views plus Chest (40110)	Radiography	40110	Clinical	17	8,20	9,12	12,4	9,51	2,72	0,02	0,0	0,0	0,0	0,0
Abdomen single view (40100)	Radiography	40100	Clinical	73	4,62	4,87	5,6	4,95	6,04	0,05	0,0	0,0	0,0	0,0

4.3.7 Step 7: Analyse and interpret the results

The seventh and last step of the framework involves the analysis and interpretation of the results within the context of the local conditions. As shown in Table 4.6, the input to this step is the number of FTEs calculated as required for a specified workload as well as the agreed staffing objectives and challenges (as determined in Step 1).

After determining the required FTEs to cover the total workload, the following step is to analyse the results and consider their likely consequences. The results can be scrutinised in the following ways as described by the World Health Organization (2010a):

i. Drawing a comparison of the existing staffing level to the calculated or required staffing level will indicate where there is an overstaffing or understaffing issue that requires management's attention. This can be computed by the following:

$$Difference = Existing\ staffing\ level - Required\ staffing\ level. \tag{4.11}$$

If the existing staffing level is greater than the required staffing level, the result (difference) will be a positive value. This does not necessarily indicate that the excess of diagnostic radiographers is idling, but rather that the quality of the service delivery could be of a higher standard than elsewhere where no excess exists. Or if the required staffing level is greater than the existing staffing level the difference will be negative. This would indicate that the diagnostic radiographers work under some pressure to meet the workload. Moreover, the results of the difference between the existing staffing level and the required staffing level should always be considered within the context of the local conditions at the radiology environment where the staffing requirement assessment was performed.

ii. The ratio of the existing staffing level to the required staffing level indicates the degree of pressure or strain under which the diagnostic radiographers are working to manage the annual or daily workload, since the staffing requirement calculations are based on actual examinations and work being performed and not on theoretical estimates. The workload strain ratio, which is used as an indirect or proxy measure, is calculated as follows:

$$Workload\ strain = \frac{Existing\ staffing\ level}{Required\ staffing\ level} \tag{4.12}$$

A workload strain result, greater than 1.0, indicates that there are sufficient diagnostic radiographers to meet the required workload and that the staffing level and workload are in balance. For example, if the existing staffing level is 14 diagnostic radiographers and the required staffing level is 12, then the workload strain will be 14/12 = 1.17 or 117%, which shows a surplus of 17% of diagnostic radiographers above the level required to meet the workload.

When the workload strain is less than 1.0, it shows that the existing diagnostic radiographers is not enough to service the workload demand and a shortage of diagnostic radiographers exist. By way of an example, if the existing staffing level is 10 diagnostic radiographers and the required staffing level is 14, then the workload strain value will be 10/14 = 0.71 or 71%, which indicates that only 71% of the required diagnostic radiographers are available. Alternatively, only 71% of the workload can be accomplished. Moreover, the smaller the workload strain ratio, the greater the workload pressure or strain.

The template to be used in Step 7 is illustrated in Table 4.10 and depicts the results table of the current and required FTE's per radiology site, including its interpretation (staffing analysis) and workload strain.

Table 4.10: Screenshot of results table depicting the current and required FTE including its interpretation and workload strain (adapted from the World Health Organization (2010)*)*

Radiology site	Current number of Diagnostic radiographers	Required FTE	Difference (*current vs required*)	Staffing analysis	Workload strain	Workload strain analysis
MMC	16	18	-2	Shortage	89%	High
RMC	15	12	3	Excess	125%	Low
KRM	17	16	1	Excess	106%	Low
VP	8	8	0	Sufficient	100%	None

An alternative analysis and interpretation employed by MacDonald et al. (2013), demonstrates an analysis of the proportion of time each activity constitutes to the total (clinical) time for the purpose of planning and controlling workload.

The required staffing level can be further examined by separating the job title group into general diagnostic radiographers and sonographers. This can be accomplished by only considering the workload of the activities performed by either the general diagnostic radiographer or the sonographers. Since these are two unique skillsets, staffing issues related to either one should be considered separately.

When drawing conclusions based on and attributing meaning to the numerical results, a thorough understanding of the local radiology operating environment should be borne in mind. The World Health Organization (2010) suggest that the following questions be considered when examining the staffing requirements output, it is proposed that this same list should be used in a concluding interpretive analysis as part of the framework:

i. Do the results portray an accurate representation of the staffing status at the radiology site or location?
ii. If any discrepancy exists, consider what might the cause be between the calculated staffing requirements and what the current reality portrays;
iii. Was the activity (and examination) times used in the workload calculation realistic?

iv. Is there any need to validate the activity times? If yes, by whom?
v. Were all the activities, both clinical and non-clinical, considered when determining the workload?
vi. Are all the activities suitable for the post under review or should some be performed by someone else? If yes, by whom and what should the requirements of such a post be?

When the outcomes and interpretation of the results after examination are questionable (or do not accurately reflecting the local conditions of the radiology site or location), it can be improved. The accuracy of the results is most affected by the activity times which can be refined depending on the method used, as discussed in Step 5. However, this higher accuracy most certainly comes with additional effort and cost which should be considered in the light of the objectives, as identified in Step 1, and whether it will substantially change the decision outcome of the staffing requirement. Alternatively, a review of the actual activities performed, by the post under review, and an interview with the incumbent in the post, might also provide some insight into the workload as activities which do not form part of the job description could have been included. This could also have impacted on the staffing requirement outcome and requires further investigation.

Examining and interpreting the staffing requirement results within the context of the local conditions is vital to ensure that it is representative of the staffing requirements and within an acceptable level of accuracy, since the results will inform future staffing decisions.

4.3.8 Visual summary of the diagnostic radiographer staffing framework

Figure 4.1 illustrates the input, process, and output flow diagram of the diagnostic radiographer staffing framework. Moreover, Figure 4.1 illustrates the dependency of certain inputs to certain outputs for initiating the process to deliver the required output at a particular step. This sequence continues throughout the flow diagram resulting in the staffing requirement. All the inputs to the staffing requirement process as well as the different outputs at the different steps along the process, are identified in Figure 4.1.

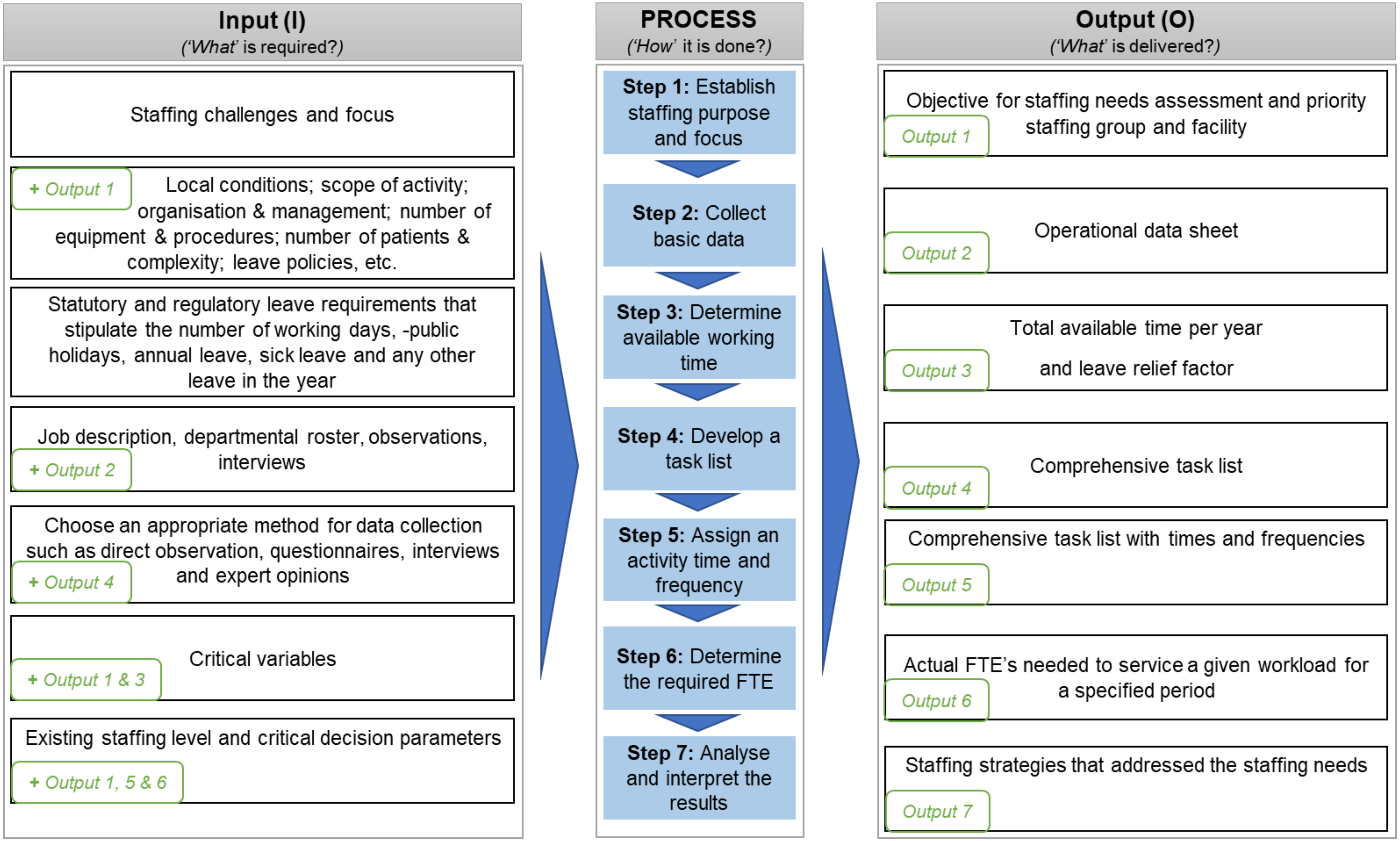

Figure 4.1: Visual summary of the diagnostic radiographer staffing framework

4.4 Conclusion: Chapter 4

This chapter produced a diagnostic radiographer staffing framework that was underpinned by a requirement specification. The requirement specification served as basis against which the most prominent general healthcare and specific radiology staffing approaches were evaluated for compatibility to the requirement specifications. The staffing approach with the highest compatibility score served as basis and starting point for the development of the diagnostic radiographer staffing framework.

Chapter 5: Evaluation of the diagnostic radiographer staffing framework

In the previous chapter the diagnostic radiography staffing framework was developed based on the requirement specifications that were developed and discussed throughout Chapters 2 and 3. This chapter focuses on the evaluation of the framework, thus the verification and validation of the diagnostic radiography staffing framework. First the evaluation approach that is employed will be discussed in the context of relevant literature. Then the verification process, that ensures the staffing framework was developed according to the requirement specifications, is presented. This is followed by a presentation of the validation process that evaluates whether the staffing framework is fit for purpose.

5.1 Evaluation approach

The evaluation approach that is employed in this research was introduced in Section 1.8. In summary, two verification and two validation steps are followed. The two verification steps involve a self-assessment against the requirement specifications, and theoretical verification via input from SMEs through semi-structured interviews. As described in Section 1.8, the verification process is followed by a framework refinement step. The first step in the validation process involves the application of the refined framework to a case study. The final step of the validation process comprises SME validation of the case study results. The verification and validation approaches are described in more detail in the remainder of this section.

5.1.1 Verification approach

The aim of this research study is to develop a diagnostic radiographer staffing framework that can aid radiology managers to accurately determine the number of diagnostic radiographers needed for the efficient and effective execution of radiological services. To demonstrate the accuracy and usefulness of the framework, and the adequacy of the bodies of literature that guided the development of the requirement specification that underpins the diagnostic radiographer staffing framework, its aim must be evaluated. According to Leedy & Ormrod (2016) this can be achieved by evaluating the *validity* and *reliability* of the research output which affects the degree to which the researcher can learn something about the research being conducted and the extent to which meaningful conclusions can be drawn from the results of the framework.

Reliability refers to the degree of consistency of the results over time and the accurate presentation of the population being researched (Golfashani, 2003). In this research, the reliability of the requirement specification and diagnostic radiographer staffing framework will be assessed through verification. Verification involves the process of determining whether the framework was developed consistent with the requirement specifications (Boehm, 1984). In addition, Morse et al. (2002) state that verification relates to the strategies used throughout the framework development process to gradually contribute to ensuring reliability and validity which, consequently, proves the rigor of the development process.

Researchers such as Kennon (2017), Ungerer (2015), and Kleynhans (2020) adopted similar methods for the verification of their research as the verification process used for this research. The verification methods employed in this research are:

i. Requirement specification content verification: Verifying the bodies of literature used to formulate and create the diagnostic radiographer staffing framework; and
ii. Framework construct verification: Verifying to what degree the framework was built to specifications and is fit for purpose.

For both methods, subject matter experts from the healthcare and radiology field of study are consulted to obtain their opinions and insight. In addition, a self-evaluation to gauge the degree to which the framework addresses the requirement specification is also performed. These approaches namely theoretical verification and self-evaluation respectively, constitute the verification process for this research.

5.1.2 Validation approach

According to Bryman et al. (2014) validity is vital in research as it affects the integrity of the conclusions that can be drawn and ensures that the output of the research is relevant to the concept under investigation. Hence, validation is determining whether the right system is built and refers to the process of evaluating the framework after development to ensure it is fit for purpose – i.e. that it addresses the research problem (Boehm, 1984).

In considering the validity of the research methodology two concepts should be defined, namely internal and external validity. According to Kothari (2004), internal validity refers to the ability of a research approach to delivery on its objectives and external validity refers to the degree to which the solution generated by a study can be generalised, considering its significance to a greater population.

Leedy and Ormrod (2016) identified the following four ways to establish validity:

i. *Face validity* is the degree to which the results appears to be valid according to the investigated concept;
ii. *Content validity* refers to the extent to which the solution reflects adequate coverage of the research topic;
iii. *Criterion validity* refers to the degree to which related features of the solution can be accurately predicted by the theoretical concept; and
iv. *Construct validity* refers to the extent to which a solution effectively addresses the concept that it aimed to address and does not include irrelevant attributes.

Three common validation strategies as identified by Mouton (2001) are summarised in Table 5.1. The strengths and weaknesses of each of the strategies, as described by Mouton (2001), are also summarised in the table.

Table 5.1: Various validation strategies, their definition, strengths, and weaknesses by (Mouton, 2001)

Validation strategy	Definition	Strength	Weakness
Interviews with subject matter experts (SMEs)	Using interviews allow the researcher to obtain the opinions and knowledge from experts in the field of study to validate or disprove claims made by the researcher. Interviews can primarily be structured, semi structured or unstructured.	It creates an opportunity for the researcher to acquire knowledge from relevant experts that can either contest or endorse the research findings.	Responses from interviewees are only based on their personal experiences and knowledge within their context therefore special consideration is required in interviewee selection.
Case study application	It is an elaborate investigation of an existing case with the objective of rendering descriptive, informative, and exploratory results.	It introduces a different view or position from which practical challenges and prerequisites are better realized because of a resemblance between the case study and real-world.	Case studies are sensitive to manipulation and deep-rooted in the context where it takes place. Hence a lack of generalisability of the outcomes.
Implementation	This represents the complete implementation of a framework in an appropriate setting to evaluation and validate its accuracy.	The outcomes of the application of the framework are holistic and definitive.	The framework implementation is characterised as a resource-intensive process and time-consuming.

Considering the nature and context of the research problem and aim, the validation process for this research involves the application of the verified staffing framework to a real-life environment. This is done through a case study application to obtain comprehensive and functional insights into whether the proposed framework is fit for its intended use. Upon completion of the case study, the results are presented to SMEs that are working in the diagnostic radiology environment to ascertain the framework's applicability and operability within the diagnostic radiology environment.

5.2 Self-verification of the diagnostic radiographer staffing framework

As discussed in the previous section, the first step in the verification and validation strategy employed in this research, is self-verification to gauge the degree to which the framework addresses the requirement specification.

As mentioned previously, verification is concerned with determining whether the staffing framework was developed consistent with the design specification (Boehm, 1984). Twenty-eight requirement specifications, as summarised in Section 4.1, were defined throughout Chapters 2 and 3, based on reviews of relevant topics in literature.

To evaluate whether the staffing framework was developed consistent with the requirement specification, Table 5.2 indicates in which framework step (rows) the specific requirement specification (column) was addressed. The allocation of at least one "✓" for each requirement against a framework step, verifies that the requirement is addressed in the framework, though this does not give an indication to what extent the requirement is addressed.

Table 5.2: Self-verification of the requirement specification to the diagnostic radiographer framework

Requirement specification		**Framework process steps**						
Requirements category	**Requirements** *(summarised)*	**1. Establish staffing purpose or need**	**2. Collect basic data**	**3. Determine available working time**	**4. Develop a task list**	**5. Assign an activity time & frequency**	**6. Determine the workload required FTE**	**7. Analyse and interpret the results**
FR 1	Use supply type data (e.g. *current staffing*)		✓					
FR 2	Accommodate productivity measures						✓	
FR 3	Use demand type data (e.g. *age & gender*)		✓					
FR 4	Apply activity times					✓		
FR 5	Translate workload to FTE						✓	
FR 6	Calculate total available time			✓				
FR 7	Calculate workload						✓	
FR 8	Calculation must be transparent and reproducible	✓	✓	✓	✓	✓	✓	✓
UR 1	Capture qualified radiographers		✓					
UR 2	Capture competency in each modality		✓					
UR 3	List all activities performed		✓		✓			
UR 4	List all equipment and modalities		✓					
UR 5	List all procedures in use in each modality		✓		✓			
UR 6	Specify the number of radiology practices		✓					
UR 7	Specify any local conditions	✓	✓		✓			

Continued on next page

Requirement specification		Framework process steps						
Requirements category	**Requirements** *(summarised)*	**1. Establish staffing purpose or need**	**2. Collect basic data**	**3. Determine available working time**	**4. Develop a task list**	**5. Assign an activity time & frequency**	**6. Determine the workload required FTE**	**7. Analyse and interpret the results**
UR 8	Use data from integrated workflow management technologies (e.g. PACS,RIS)		✓		✓	✓		
UR 9	Included clinical & non-clinical activities				✓			
UR 10	Be able to adapt to technology advances	✓	✓		✓	✓		
UR 11	Capture staff information re competency level, skill set and employment status		✓					
UR 12	Capture demand related information		✓					
UR 13	Capture staff's age and gender		✓					
UR 14	Minimise subjectivity of results				✓	✓	✓	
UR 15	Consider maximum allowable working hours per week for workload determination		✓	✓				
DR 1	Diagnostic radiology profession only	✓	✓		✓			
DR 2	Appropriately qualified diagnostic radiographers only		✓		✓			
DR 3	Restricted to diagnostic radiology equipment, modalities and procedures	✓	✓		✓	✓		
DR 4	Constraint to the private practice radiology environment	✓						
BC 1	Consider the different leave allowances as stipulated by law and compay policies		✓					

In continuation of the self-verification process, Table 5.3 verifies to what extent – *fulfilled* or *fulfilled with restrictions* – the diagnostic radiographer staffing framework addresses the requirement specifications. Given the analysis captured in Table 5.2, each RS category is verified to the staffing framework as a whole and does not only refer to a specific step in the framework but to what extent each requirement is met by the staffing framework as a whole.

Table 5.3: Self-verification of the degree to which the staffing framework addresses the requirement specifications

RS category	**Satisfaction criterion**	**Description/ Motivation**
Functional requirements		
FR 1	Fulfilled with restrictions	Supply type data relating to '*stock of individuals*' and '*flow of activities*' (*as outlined in Section 3.2*) is not accounted for in its entirety. However, the current available diagnostic radiographers (which refers to the '*stock of individuals*') and their associated activities (which refers to the '*flow of activities')* forms part of the computation for the staffing requirements. This does, to some degree, account for the supply-related factors.
FR 2	Fulfilled	Provision for productivity measures in the form of a utilisation standard is made in the formula when computing FTEs.
FR 3	Fulfilled with restrictions	Demand data relating to demographic, socioeconomic and epidemiological factors (as outlined in Section 3.4) are not directly accounted for in the framework. However, the retrospective number of procedures and imaging data, obtained from the workflow management technologies, are entered for use in the FTE calculation. This does, to some degree, account for the demand-related factors.
FR 4	Fulfilled	The framework makes provision for the development of an activity list as a step, followed by another step to assign activity times for the computation of workload.
FR 5	Fulfilled	Provision is made in the framework for the translation of workload into FTEs.
FR 6	Fulfilled	The total available time per year forms a critical part of the FTE computation within the framework.
FR 7	Fulfilled	The framework is designed in such a way to allow the identification of the post under review including its activities, duration and frequency which enables the computation of the post's / position's workload.
FR 8	Fulfilled	The procedure for computing workload and translating it to FTE requirements is stipulated explicitly in the framework, which also allows it to be reproduced.
User requirements		
UR 1	Fulfilled	The framework allows for the capturing of the number of qualified diagnostic radiographers as part of the needs analysis (establish the staffing purpose or need) and data collection steps.
UR 2	Fulfilled	Identification of the current competency of the diagnostic radiographer in various modalities forms part of the basic data collection step in the framework.

RS category	Satisfaction criterion	Description/ Motivation
UR 3	Fulfilled	The development of an activity list forms an integral part of the framework.
UR 4	Fulfilled	The framework allows for the capturing of the number of equipment and modalities that are available and in use, as part of the data collection step.
UR 5	Fulfilled	The framework allows for entering the number of procedures and / or techniques that are being used in each modality and this data as part of the data collection step.
UR 6	Fulfilled	The data collection step within the framework makes provision for the number of practices to be stated.
UR 7	Fulfilled	The framework makes provision for the user to specify local conditions under the data collection step.
UR 8	Fulfilled	Provision for using data from workflow management technologies such as, RIS, PACS and VR are made when assigning activity times and frequency of occurrences to activities.
UR 9	Fulfilled	Provision for clinical activities are made using data from workflow management technology, non-clinical activity data is obtained using the data collection methods described in Section 4.3.5.
UR 10	Fulfilled	Any changes to technology, procedures, or workflow will be accounted for when compiling an activity list and the associated activity times.
UR 11	Fulfilled	Basic data related to the number of diagnostic radiographers available, their competency, skill set, and employment status, are entered during the basic data collection step.
UR 12	Fulfilled with restrictions	Demand data relating to demographic, socioeconomic and epidemiological factors (as outlined in Section 3.4) are not directly captured. However, the number of procedures, retrospectively obtained from the workflow management technologies, are collected during the basic data collection step. This does, to some degree, account for the demand-related factors.
UR 13	Fulfilled	Provision is made for entering staff information relating to age and gender during the basic data collection step.
UR 14	Fulfilled	The subjectivity of results is minimised using data from the workflow management technologies and through the collection of activity times using the data collection methods described in Section 4.3.5.
UR 15	Fulfilled	The framework makes provision for the computation of available working time as part of the FTE calculation.
Design restrictions		
DR 1	Fulfilled	The primary focus domain of the staffing framework is the diagnostic radiology environment. However, the basic elements that constitute the framework (such as the activity list, activity times, etc.) allows for the application of the framework to the broader
DR 2	Fulfilled	

RS category	Satisfaction criterion	Description/ Motivation
DR 3	Fulfilled	radiology profession and even the healthcare environment in general. Due consideration of the workflow within the staffing requirement context, local conditions, equipment, availability of appropriate staffing and procedure data will be required when adapting the framework for broader application.
DR 4	Fulfilled	All though the framework in this research endeavours its application within a private practice radiology environment, it can be applied elsewhere in the broader radiology environment. Due consideration to the comments mentioned in the other design restrictions (DR 1 to DR 3) should be given prior to a broader application.
Boundary conditions		
BC 1	Fulfilled	The framework makes provision for the computation of available working time in which instance the various leave allowances as stipulated by law and company policies are considered. Documents describing these allowances are collected during the basic data collection step of the framework.

This concludes the verification of the diagnostic radiographer staffing framework, which indicates that most of the requirement specifications were met, and some were explained.

5.3 Theoretical verification

As described in Section 5.1, the second component of the verification and validation strategy employed in this research is theoretical verification, via SME interviews.

The interaction with the SME's for data collection is in the form of semi-structured interviews, conducted via the Microsoft Teams platform as in person interactions were restricted by COVID-19 regulations. However, this method of interaction is not uncommon. Engagement with SMEs can be achieved in the following four interview methods as posited by Mouton (2001): (i) structured questionnaires; (ii) semi-structured interviews; (iii) free attitude interviews; and (iv) telephone interviews. Moreover, the concept of online personal interviews is supported by Bryman et al. (2014) and can be applied to semi-structured interviews. Hence, semi-structured online interviews were used in the interaction with SMEs.

The SMEs are provided with a pre-read document prior to the online interview to familiarise themselves with the content that is addressed in the verification questions. This pre-read document, which contains a summary of the relevant bodies of literature, design requirement specifications, diagnostic radiographer staffing framework and verification questions, is included in Appendix A.

The verification process first required from the SMEs to familiarise themselves with the pre-read document which highlighted the context and focus of the research study, in order to enable meaningful contribution to the verification of the design requirements and the diagnostic radiographer staffing framework. During the semi-structured interview, the SME was again presented with the pre-read verification document; given an opportunity to ask clarification questions; and requested to answer the verification questions which are further addressed in Section 5.3.3. Subsequent to the verification sessions with all the SMEs, the relevant proposed improvements were incorporated to the preliminary diagnostic radiographer staffing framework to create the final framework. The final framework that is presented in Chapter 4 was used in the validation of the staffing framework though a case study application. The SMEs who participated in the semi-structured verification interviews were from different fields of expertise, as described in the subsequent section.

5.3.1 Selection and background of SMEs for verification

The SMEs who participated in the verification process through semi-structured interviews had either healthcare workforce planning knowledge and experience or were from the diagnostic radiology environment and had staffing experience and knowledge of the diagnostic radiology environment. Thus the SMEs were purposively sampled individuals, rather than randomly sample individuals, with the sampling criteria being based on merit (Palinkas et al., 2015). The SMEs' practical application and research experience in staffing and workforce planning in either a healthcare or a diagnostic radiology environment warrant their selection to best assist the researcher in verifying the requirement specification and diagnostic radiographer staffing framework.

To obtain insightful feedback from the evaluation process, five SMEs from the diagnostic radiology environment in either public or private and applied research in health human resource planning and general workforce planning were identified. Table 5.4 briefly describes the selected SME's background and reason for inclusion.

Table 5.4: Selected SME's background and reason for inclusion

Sector	SME ref.	Occupational background	Rationale for inclusion
Public diagnostic radiology	SME-ref A	A registered diagnostic radiographer with more than 25 years' experience, that has an MSc Diagnostic Radiography qualification. Holds the position of Assistant Director Diagnostic Radiography at a large public and tertiary academic hospital. Managing the day-to-day functions of the imaging department of more than 120 staff of which 65 are radiographers, 27 radiologists and the remainder are administrative staff.	Extensive practical experience in the operational functions of a public diagnostic radiography department's planning and scheduling of human resources for optimal workflow, service coverage and ensuring patient safety. This hands-on and in-depth understanding of the human resource requirements is beneficial for the verification of the requirement specification and practicability and usability of the staffing framework in a public diagnostic radiology environment.
Private diagnostic radiology	SME-ref B	A registered diagnostic radiographer with more than 15 years' experience, that has a BTech: Diagnostic Radiography, Magnetic Resonance Imaging postgraduate qualification, and Human Resource qualification. Holds the position of Branch Service Manager at a large (12 practices) private radiology business. Oversees the operational functioning and planning of the human resource requirements of all 12 practices, employing approximately 200 radiographers.	Knowledge of the operational functioning of a large private diagnostic radiology department and in-depth, practical experience of human resource requirement planning and scheduling of diagnostic radiographers. This knowledge is essential for verifying the development of the requirement specifications and diagnostic radiology staffing framework's applicability and usability in a large private diagnostic radiology business.

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Consulting: Workforce planning	SME-ref C	A professional industrial engineer with more than 10 years' experience in the development and implementation of workforce planning models in both pathology laboratories and retail in South Africa, Namibia, and the United Kingdom.	Knowledge and practical experience in the development of workforce planning models which is vital for the verification of the requirement specification and the development of the staffing framework.
Medical research	SME-ref D	Health economist and senior specialist scientist. Focuses on economic evaluation and human resources planning in South Africa and across Africa. Developed a Human Resource Planning model for primary healthcare (PHC) re-engineering in South-Africa.	Knowledge of human resource planning in healthcare and extensive experience in the development of a healthcare workload model. This knowledge is useful in verifying the relevancy of the bodies of literature for the development of the requirement specification and staffing framework.
Medical research	SME-ref E	Health economist and senior research scientist. Ph.D. candidate in health systems with extensive experience in health human resource requirements and the various health human resource staffing requirement models and approaches.	Knowledge of the different HHR models and approaches is useful in verify the bodies of literature that were reviewed for determining the requirements specifications and verifying the logic of the staffing framework.

5.3.2 Evaluation criteria of the semi-structured interview questions

Semi-structured interviews were held with purposively selected SMEs to obtain their inputs as part of the verification process on the requirement specification and the diagnostic radiographer staffing framework. The open-ended verification questions were formulated to verify: the relevance of the bodies of literature; purpose of the framework; framework development process; and the strengths and weakness of the framework. This semi-structured method builds on the advantages of unstructured interviews, for example allowing for probing conversations and spontaneous responses that provide depth and detail, while benefiting from the clarity and guidance that the arrangement of questions in structured interviews offer (Bryman et al., 2014). The open-ended verification questions are presented in Table 5.5

Table 5.5: SME semi-structured, open-ended interview questions

Classification	Code	Questions
Relevant bodies of literature	R1	Were the relevant bodies of literature considered in the development process of the requirement specification and framework?
	R2	Are you aware of any other literature that should be included?
Purpose of the framework	P1	Will the diagnostic radiographer staffing framework achieve its stated purpose – is it fit for purpose?
	P2	Do you know of any other radiology staffing framework that can determine the required number of diagnostic radiographers?
Framework development process	D1	Did the requirement specifications adequately capture the staffing needs of a diagnostic radiographer's environment?
	D2	Are there any other requirements that should be considered or included?
	D3	Did the diagnostic radiographers staffing framework (the solution) adequately address the requirement specification?
Framework strengths	S1	What would you describe as the key strengths of the proposed framework?
	S2	Where do you think can the framework's strengths assist with its implementation that relates to practicability and usability?
Framework weakness	W1	What would you consider as the key weakness of the proposed framework?

5.3.3 SME verification interview feedback

The verification interview feedback from the SMEs, is discussed in this section.

5.3.3.1 Relevant bodies of literature

Questions R1 and R2 (see Table 5.5) seek to determine whether the relevant bodies of literature were consulted for the development of the requirement specification which formed the basis for the development of the diagnostic radiographer staffing framework. Based on their experience and exposure to the relevant literature, all SMEs agreed that the relevant literature was consulted, and that the literature study was both comprehensive and relevant for the purpose of developing the requirement specifications. Hence, all said that they are not aware of any additional literature to included. SME-ref C indicated that it was challenging to find relevant scientific workforce planning literature while SME-ref D indicated that experience with healthcare staffing models revealed that there are very few people, especially in South Africa, that are working in this field (workforce modelling or staffing requirements).

5.3.3.2 Purpose of the framework

This group of questions (P1 and P2) considers whether the diagnostic radiographer staffing framework will achieve its stated purpose and whether the SMEs are aware of any other diagnostic radiographer staffing framework. All the SMEs agreed that the framework will achieve its stated purpose. SME-refs C and A agreed '*from a theoretical point of view*' and SME-ref E commented "*Certainly, for current utilisation…it will determine the (staffing) requirements based on current utilisation.*" None of the SMEs were aware of any other diagnostic radiographer staffing framework.

5.3.3.3 Framework development process

This group of questions (D1 and D2) relate to whether the requirement specifications adequately capture the staffing needs of a diagnostic radiographer's environment and enquire about any additional requirements that should be considered or included. All SMEs agree that the requirement specifications adequately capture the staffing needs of a diagnostic radiographer's environment. Responding to question D2, which refers to whether any additional requirements should be considered, SME-ref C commented that consideration should be given to "*the functionality to 'run' different scenarios*", while SME-ref A responded that the "*framework should be adaptable to both private and public sector*" diagnostic radiology environments and "*include on-call and on-site duties, in other words a 24 hour coverage*". In addition, consideration should be given to "*softer issues, such as a pregnant radiographer that can only do certain activities to limit exposure to radiation*". SME-ref D thought it "*useful to explicitly state under the boundary conditions that diagnostic radiographers' activities within their scope of practice will be considered*". SME-ref E's response was "*no, I think it is sufficient*".

The staffing framework's primary focus is to establish the current number of diagnostic radiographers required as a starting point that is based on the existing demand and future research could be conducted on the functionality to 'run' different scenarios as it falls outside the scope of this study. SME-ref D's response can be accommodated, while SME-ref A's request can be accommodated in the framework by defining the activities (i.e. training) not captured by the RIS that differentiates the private from the public tertiary radiology environment, as more time is devoted to training in the public tertiary environment. Provision is made in the framework to accommodate all activities that are performed for a said period (i.e. 24 hours or per annum) in both calculating the available time and the workload. The '*softer issues*', for example pregnant radiographers that perform limited activities can be justified by the concluding interpretive analysis in Step 7 of the diagnostic radiology staffing framework.

Question D3 seeks to determine whether the diagnostic radiographer staffing framework adequately addressed the requirement specifications. All the SMEs concurred that the staffing framework adequately addressed the requirement specifications. Some additional comments to D3 were "*the requirements appear to be comprehensive*" and "*the requirement specifications are appropriate, relevant and well structured*".

5.3.3.4 Frameworks strengths

This group of questions (S1 and S2) seek to identify from the SMEs what they consider to be the key strengths of the proposed diagnostic radiographer staffing framework and how the strengths can aid in the implementation of the proposed solution relating to practicability and usability. The feedback from the SMEs covered various aspects of the framework and requirement specification.

SME-ref C identified the input data (i.e. activity list or procedure codes, time, and duration) as a strength since it can be easily accessed from the RIS and this could increase the sustainability of the framework. Furthermore, "*An activity-based staffing framework can be very accurate if the input times are correct*". SME-ref B also identified the input data from RIS as a strength since all patient and examination related information is processed on digital systems such as RIS. In addition, SME-ref B pointed out that "*the RIS, if used consistently*, *can become the source data set for establishing the framework*".

SME-ref B suggested that "*with training, managers could become the drivers of determining staffing needs through this framework as well as having a better understanding of workload and productivity of radiographers.*" SME-ref D referred to the framework as "*very systematic and practical … which can facilitate its implementation*". It was essential and very useful for SME-ref D that the final step included a "*basic analysis of what the results are saying*".

SME-ref D highlighted that the use of the framework is "*more than just a HR planning tool and can evaluate whether the current staffing is vastly under or vastly overstaffed"*. SME-ref A is also of the opinion that the framework *"can aid to create a standard for the number of diagnostic radiographers needed and be used as a standard approach for determining radiographer staffing requirements"*. Additionally, it can be beneficial to use it as a standard approach for determining radiographer staffing requirements in the absence ("… *or at least that I am aware …"*) of an existing staffing framework for diagnostic radiographers.

Two of the SMEs (ref D and E) found the evaluation of the different workload and staffing models to the requirement specification very methodical and valuable for the development of the framework.

5.3.3.5 Frameworks weakness

This question (W1) seeks to obtain from the SMEs any weakness of the framework.

Three of the SMEs (ref A, B and C) referred to the input as a possible weakness. SME-ref A responded that "*it appears that the data input can be complicated, so I would like to see from a practical point of view how that would work*" and hence must be "*user-friendly and easy to maintain*". SME-ref B mentioned that inconsistent data input could affect the results. SME-ref C referred to "*the demand input (procedure frequency) might be a weakness*". Explaining that "*one will most probably never know how many patients balked, i.e. did not contact the department for radiological services due to the department being too busy or having long waiting queues*". This relates to the response from SME-ref E that "*The patient flow through the system will affect how many patients a radiographer is able to see and I think that will help you to look at efficiency within the radiology system in terms of how many people / patients coming in or how many is (sick) seen within a day. Also, how many patients the radiographer is able to see, is not only just a product of how long it takes her to do those specific activities but how long it takes for that patient to come into the radiology department*". These are fair comments; however, it does not fall within the scope of this research and should be considered for future research on this topic.

SME-ref D found no weakness and responded, "*I must say I am very impressed with the framework*".

5.3.4 Theoretical verification conclusion

Generally, the responses during the semi-structured interviews with SMEs, were favourable and they agreed that the relevant bodies of literature were consulted, and that the literature review was adequate for the purpose of the research. There was consensus that the diagnostic radiographer staffing framework is fit for purpose and will achieve its stated goal. The requirement specification was received favourably, and all agreed that it adequately captured the staffing needs of the diagnostic radiographers' environment to enable the development of the staffing framework. In addition, there was sufficient agreement that the framework was developed consistent with the requirement specification, which renders the research output verified.

The comments and inputs from the SMEs were address in Section 5.3.3. The requests made by the SMEs were accommodated in the method of capturing the data (i.e. activities) and did not require an adjustment in the functioning of the framework. However, critical reflection based on the theoretical verification process resulted in minor refinements to the framework as indicated below.

i. In Step 3 a leave factor has been incorporated which is based on the ratio of total unavailable hours per year to available hours per year. This leave factor then makes provision for coverage when the FTE is on leave.
ii. In Step 4 the activity list for the different modalities and types of activities (i.e. clinical and non-clinical) was managed separately, but the principle of using examination codes remained the same.
iii. In Step 5 the assigning of an activity or examination duration for clinical and non-clinical times was calculated differently due to the format of the RIS data. Clinical activities (i.e. examination times) were obtained from RIS and here the mean or average examination duration was used, whereas for non-clinical activities (i.e. meetings) the PERT (discussed in Section 4.3.5) approach was followed by estimating the optimistic, pessimistic and mostly like time to determine a mean time estimate. The minor adjustment in determining the activity duration highlighted that an alternative method to the PERT method can be applied to determine activity duration.

This concludes the theoretical verification, and the explanation of the minor refinements to the diagnostic radiographer staffing framework that were made in response to the insights that were generated as part of the verification process.

5.4 Validation of staffing framework

As mentioned previously, validation refers to the process of evaluation of the system (or framework) after development to ensure it is fit for purpose and addresses the research problem (Boehm, 1984). As stated in Section 5.1, the first part of the validation strategy employed in this research comprises a case study application.

A case study application is defined by Mouton (2001) as an elaborate investigation of an existing case with the objective of rendering descriptive, informative, and exploratory results. According to Bryman et al. (2014), a case can be a: single organisation; a single location; and / or a single event. Moreover, Yin (2018) gives four types of case study research designs based on a 2 x 2 matrix, namely: single-case and holistic, or single-case and embedded; and multiple-case and holistic, or multiple-case and embedded.

This study adopted a single-case holistic design approach. This choice is based on two rationales, namely critical case and representative or typical case. Critical case because the diagnostic radiographer staffing framework is built on a clear set of requirement specifications from specific literature that is verified and needs to be tested in a real-life environment to confirm, challenge, or extend its construct. The second rationale is a representative or typical case approach with the objective of capturing the circumstances and context of a single diagnostic radiology department from a single radiology organisation. The lessons learned from applying the framework to the case environment can be informative about its applicability and operability and, to strengthen this, the results of the framework will be further validated with selected SMEs working in the diagnostic radiology environment.

5.4.1 Selection of case study

A private diagnostic radiology practice was selected for the case study application. This choice was guided by the main criteria for selecting cases by Yin (2018) that include: convenience; access; and geographical proximity. The identification of the case site materialised because of the researcher's acquaintance with the private radiology practice. Moreover, internet searches indicated that the case site has a wide variety of radiological services and is one of the largest private radiology practices in the geographical proximity of the researcher. This fits the research and makes accessibility for data gathering convenient.

5.4.2 Holistic single-case study background information

The case site is one of twelve diagnostic radiology practices that forms part of the private radiology organisation. The case site is considered the largest diagnostic radiology practice because of the number of diagnostic radiological examinations conducted at the practice and has all the primary diagnostic radiological services (i.e. MRI, CT and PET-CT, X-ray, ultrasound, mammography; and interventional radiology). The diagnostic radiology case site is located within a private hospital that offers a wide variety of 48 medical services and 157 doctors and allied healthcare workers. RIS data were obtain from the case site that only contains procedure or exam information, without any personal, sensitive, or patient details.

5.4.3 Holistic single-case study: Framework validation

In this section, the seven-step diagnostic radiology staffing framework is applied to the case study environment to illustrate the applicability and practicability of the framework.

5.4.3.1 Step 1: Establishing the staffing focus and purpose

During this step, the purpose and focus of the staffing endeavour is determined and the template in Table 5.6 was completed with the head of department of the diagnostic radiology case site.

Table 5.6: Staffing focus and purpose template (completed)

No.	Description	Response
1	Are any alarming or concerning change, either increasing or decreasing, in radiographic imaging requests being experienced?	No, not as far as I know.
2	Do these changes in radiographic imaging requests occur at any specific radiology site?	Not applicable
3	Do these changes in radiographic imaging requests occur at any specific modality(ies)?	Not sure, need to establish.
4	Are acquisitions of any new facility or expansions of existing facilities being considered?	No
5	Are any new radiographic imaging technology, techniques or procedures being introduced?	No
6	Which staff category, such as general diagnostic radiographers including CT and MRI radiographers, sonographers and mammographers, are in shortest supply?	Not sure, need to establish.
7	Do staffing shortages affect multiple or specific radiology *sites*?	Not applicable (only use one site for case application)
8	Do staffing shortages affect multiple or specific radiological *services*?	No sure, need to establish
9	For which staffing category is staffing distribution likely to be most unbalanced or inequitable?	Diagnostic radiographer
10	Where (multiple or specific radiology sites) is the distribution of staff categories most unbalanced or inequitable?	Not applicable (only use one site for case application)
11	Is the quality of radiology service affected by staffing challenges? Examples include the following: • Does any of the radiology sites experiencing long waiting times and queues? • Are radiological imaging requests completed within agreed standards? • Are RTATs met?	No • No, not that I am aware of • Yes, as far as I know • Yes, as far as I know
12	Establishing the diagnostic radiographer staffing baseline.	Yes

The head of department is not aware of any major challenges with their services and indicated that the focus for the staffing assessment should be to establish the current diagnostic radiographer staffing baseline. This will aid in determine whether the current staff is in oversupply, undersupply or just sufficient to cope with the current demand for radiological services. Once the staffing assessment's purpose and focus have been established, the basic data that supports the staffing assessment is gathered.

5.4.3.2 Step 2: Collect basic data

The collection of the basic data is informed by the purpose and focus of the staffing endeavour which was established in the previous step. Table 5.7 and Table 5.8 are used as basic data collection templates and were completed with the head of department.

Table 5.7: Basic data collection template (completed)

No.	Description	Check or comment
1	Create a list with all the radiology sites.	This assessment will only focus on one radiology practice which is **VP.**
2	Create a list of all *services or modalities* at each *radiology site.*	*See list Table 5.8*
3	Create a list with all the *examinations* and *procedures offered* according to their modalities.	Please refer to *Step 4 Exam list*
4	Create a list with all the examinations and procedures *completed* (*demand data*).	Please refer to *Step 4*
5	If any staff is involved in *training, teaching, research, and development*, please provide the number of *staff involved* and the *time spent* (hours or minutes).	None
6	Create a list of all *qualified diagnostic radiographers* including *skill*, *employment status*, *gender,* and *age group.*	*It was sensitive information*: only total diagnostic radiographers and skill is provided.
7	List all the *equipment available* and in *use*	*See Table 5.8*
8	Is procedure and examination *times available* from the radiology information system (*RIS*)? If yes, please add times to the examination and procedure list.	Yes, please refer to *Step 5 & 6*
9	Consider the leave and any statutory and regulatory policies that guide or prescribe how leave allocation are done and how many. *Create a list of all leave types and the days available per leave type.*	Please refer to Step 3 Working time. *Annual leave* = 22 days per year *Sick leave* = 12 days per year *Compassionate leave* = 3 days per year *Public holidays* = 13 per year
10	How many hours does a radiographer work in a day and how many days in a week does a radiographer work?	7,5 hours a day; and 5 days in a week
11	Consider local conditions relevant to the workload of the radiology department or unit such as, *physical layout* of the department; *organisational structure*, and *key clinical* and *non-clinical* processes.	The department is managed by a head of department (HOD) that is a diagnostic radiographer. Diagnostic radiographers working in the different modalities report to the HOD. Each modality has a senior radiographer known as the head of modality. The key clinical processes are the procedures and examinations as identified in Step 5. The major non-clinical processes are meetings, quality assurance and cleaning of the examination room. The physical layout is favourable to allow the diagnostic radiographer easy access to patients in the waiting room.

Table 5.8: VP modality and equipment list

Modalities		**Equipment**
General radiography	X-rays	1
	Fluoroscopy	1
	BMD (Bone mineral density)	1
	Panoramic radiography or x-ray	1
	Portables	1
	Theatre (MSK & Vascular)	5
Computerised Tomography (CT)		1
Magnetic Resonance Imaging (MRI) 3 Tesla		1
Ultrasound		3
Mammography		1

By completing the basic data collection template, the related basic data (i.e. examination list, duration, and frequency of occurrence, type of modalities and number of units / equipment that are available and in use) serves as input to the framework and sets the context within which the staffing requirements are determined. Moreover, this data can help to explain any differences in the calculated staffing results and actual staffing numbers.

5.4.3.3 Step 3: Determine available working time

The available working time is a key input for the FTE calculation. Data collected in the previous step, relating to statutory and regulatory leave requirements, was used to calculate the total available working time, using (4.1), given in Section 4.3.3.

The result of applying the total available time formula to the case site is shown in Table 5.9. The total available hours per month for the case site equates to 131 hours. This represents the total available hours per month for a full-time equivalent (FTE) and this value will be used in determining the required number of FTEs for a given workload.

Next, the leave relief factor is calculated using equation (4.2), given in Section 4.3.3. The inputs for this formula are given in Table 5.9 and equates to 23,8% or rounded to 24%. The leave relieve factor of 24% is multiplied by the total required FTE to make provision for when diagnostic radiographers take leave and the activities in the modality must continue.

In this instance, diagnostic radiographers were not obligated to work on public holidays, but the radiological services are required and therefore provision for staff must be made. If they were required to work on public holidays, the number of public holidays must be excluded from the leave relief factor.

Table 5.9: Total available working time and leave factor

Key	Description	Qty
F	Working week Working hours per day	5 7,5
	Weeks in a year	52
A	Total available days per year	260
C D E E B	Ave. # of vacation days per year Ave. # of sick days per year Ave. # of compassionate leave days per year Ave. # of training days per year Public holidays	22 12 3 0 13
	Total unavailable days per year	*50*
	Available working days per year	210
	Available working hours per year	1575
AWT	**Total available hours per month**	**131**
Leave factor is added to the required FTE		
	Total hours per year on leave (7,5 * 50)	375
	Leave Factor (375 / 1575)	23,8%

5.4.3.4 Step 4 Develop a task or activity list

The activity list is created from the RIS data and encompasses all the examinations that are performed per modality by the diagnostic radiographers. Moreover, it represents the clinical activities done by the diagnostic radiographers.

The modalities included in the activity list are identified in Table 5.8. Table 5.10 is an extract from the activity list and depicts the different mammogram examinations. The entire list of examinations can be viewed in the Appendix B. The examinations are identified by standard uniform codes from the National Health Reference Price List (NHRPL) and Compensations for Occupational Injuries and Diseases Act (COIDA). These standard codes are used by all radiology environments and other medical professionals in South Africa for reimbursements from medical aids. Since these codes are standard and used by all health professional and medical aids, it allows for universal use in any diagnostic radiology context (i.e. private or public) to generate an activity list of radiological imaging examinations.

Table 5.10: Extract from the activity (clinical) list representing the different examinations for mammography

Examination description	Exam Code	Activity type	Modality name
Mammogram (34100)	34100	Clinical	Mammography
Mammogram unilateral (34101)	34101	Clinical	Mammography
Mammogram unilateral (34101)	34101	Clinical	Mammography
MVT601-3101 - Mammogram (T917330 - 34100)	T9173	Clinical	Mammography
Biopsy specimen of the Mamma (34140)	34140	Clinical	Mammography
Stereotactic Mammogram Biopsy (34130)	34130	Clinical	Mammography
Stereotactic Mammography localisation (34120)	34120	Clinical	Mammography

Non-clinical activities were identified through consensus between the head of department and the head of modality. These activities can be viewed in Table 5.11. The comprehensive activity list generated from the RIS and consensus among diagnostic radiographers, serves an input to Step 5.

Table 5.11: Non-clinical activity list for mammography

Activity description	Modality	Activity type
Meetings (monthly)	Mammography	Non-clinical
Meetings (weekly)	Mammography	Non-clinical
Quality assurance: Department of Health radiation control requirements	Mammography	Non-clinical
Cleaning of x-ray room	Mammography	Non-clinical

5.4.3.5 Step 5: Assign an activity time and frequency to each activity

An activity time and frequency of occurrence is assigned to each activity on the activity list generated in Step 4. Different methods of collecting activity times and frequency of occurrence for the activities can be used, as discussed in Section 4.3.5. In this case study, RIS data were used to assign activity times and frequency of occurrence to the clinical activities. The RIS data were imported to Microsoft Excel, cleaned and pivot tables were used to manipulate and analyse the data. Average activity times (durations) and the sum of frequency of occurrence for a month were allocated to the examinations. Table 5.12 is an extract from the activity list and depicts the mammography modality with the different examinations, frequencies per month per examination and their associated average activity duration.

Table 5.12: Mammography (clinical) activity list with frequencies per month and average durations (activity time)

Examination description	Modality name	Exam code	Frequency per month	Average duration in minutes
Mammogram (34100)	Mammography	34100	211,9	21,54
Mammogram unilateral (34101)	Mammography	34101	13,2	21,05
MVT601-3101 - Mammogram (T917330 - 34100)	Mammography	T9173	0,4	7,75
Biopsy specimen of the Mamma (34140)	Mammography	34140	0,1	0,00
Stereotactic Mammogram Biopsy (34130)	Mammography	34130	1,5	49,71
Stereotactic Mammography localisation (34120)	Mammography	34120	0,1	65,83

Non-clinical activity duration was determined by expert opinion which included the head of department and senior radiographers from the respective modalities. (4.3), defined in Section 4.3.5 was used to allocate the mean time estimate to each non-clinical activity. As an example, a summary of the variables and calculated estimates for non-clinical mammography activities is provided in Table 5.13.

Table 5.13: Mammography non-clinical activity list with frequencies per month and mean time estimate per activity

Activity description	Modality	Frequency per month	Optimistic Time (To) (min)	Most likely time (Tm) (min)	Pessimistic Time (Tp) (min)	Mean Time Estimate per activity (Te) (min)
Meetings (monthly)	Mammography	4	45	60	90	62,50
Meetings (weekly)	Mammography	4	20	30	60	33,33
Quality assurance: Department of Health radiation control requirements	Mammography	22	1	2	5	2,33
Cleaning of x-ray room	Mammography	217	2	3	4	3,00

5.4.3.6 Step 6: Determine the workload and required FTE

The workload for each examination within a modality were calculate using (4.5), defined in Section 4.3.6.

The frequency of occurrence or activity volume denotes the business volume in this formula and the activity time denotes the labour standard. Table 5.14 is an extract from the activity list and depicts the mammography modality with the different examinations, frequencies per month per examination, their associated average activity duration and calculated workload hours per examination. In addition, as shown in the table, the total workload for the mammography modality is calculated at a mean of 82 hours per month and the mean total number of mammography examinations per month is 227.

Table 5.14: Mammography (clinical) activity list with frequencies per month, average durations (activity time) and workload.

Examination description	Modality name	Exam code	Frequency per month	Average duration in minutes	Workload hours	FTE at 100%
Mammogram (34100)	Mammography	34100	211,9	21,54	76,08	0,58
Mammogram unilateral (34101)	Mammography	34101	13,2	21,05	4,63	0,04
MVT601-3101 - Mammogram (T917330 - 34100)	Mammography	T9173	0,4	7,75	0,05	0,00
Biopsy specimen of the Mamma (34140)	Mammography	34140	0,1	0,00	0,00	0,00
Stereotactic Mammogram Biopsy (34130)	Mammography	34130	1,5	49,71	1,24	0,01
Stereotactic Mammography localisation (34120)	Mammography	34120	0,1	65,83	0,09	0,00
TOTAL			**227**		**82**	**0,626**

Table 5.15: Mammography (non-clinical) activity list with frequencies per month, average durations (activity time) and workload.

Activity description	Modality	Frequency per month	Optimistic Time (To) (min)	Most likely time (Tm) (min)	Pessimistic Time (Tp) (min)	Mean Time Estimate (Te) (min)	Workload (hrs) per month
Meetings (monthly)	Mammography	1	45	60	90	62,50	1,04
Meetings (weekly)	Mammography	4	20	30	60	33,33	2,22
Quality assurance: Department of Health radiation control requirements	Mammography	22	1	2	5	2,33	0,84
Cleaning of x-ray room	Mammography	217	2	3	4	3,00	10,84
Total *non-clinical* workload hours per month			**14,94**				

Next, the number of full-time equivalents required to service the demand of 227 mammography examinations at 82 hours and non-clinical activities (see Table 5.15) at approximately 15 hours per month, are calculated using (4.7), defined in Section 4.3.6. In this instance, the total workload in standard hours for a specific period (T) is calculated as 96.94 hours per month.

The available hours per FTE was calculated in Step 3, and as shown in Table 5.9 this was found to be 131 hours. When both the total workload and available hours per FTE are substituted into (4.7), defined in Section 4.3.6, the required FTE for the mammography modality is found to be 0.74.

When applying the WHO guideline for rounding the required number of FTEs, as given in Section 4.3.6, the FTE required (Table 5.16) for mammography is rounded up to 1 FTE which is at 100 percent utilisation.

However, working at a 100 percent utilisation is prevented by operational factors that are either controllable or uncontrollable (Ozcan, 2009). Controllable factors that affect the utilisation include scheduling of staff and vacations; and reducing employee idle time by allowing them to leave work when the workload permits (Ozcan, 2009). Ozcan (2009) identifies uncontrollable factors as significant demand fluctuations, referencing doctors' imaging request patterns, sick leave, and the unavailability of part-time staff. Given these operational factors that affect the FTE utilisation, this case study adopted three utilisation levels that is, 90, 80 and 70 percent. (4.8), as defined in Section 4.3.6, was applied to account for the utilisation percentage and the results of this application to the mammography modality is depicted in Table 5.16.

Table 5.16: FTE required for mammography at various utilisation percentages

Modality	**FTE required (at 100%)**	**FTE required (rounded)**			
		100%	**90%**	**80%**	**70%**
Mammography	0,74	1,0	1,0	1,0	1,0

When applying the same steps and principles to the other modalities within the diagnostic radiology environment, the results displayed in Table 5.17 are determined.

Table 5.17: FTE required for all modalities at various utilisation percentages

Modality	**FTE required (at 100%)**	**FTE required at (rounded)**			
		100%	**90%**	**80%**	**70%**
Ultrasound	1,20	2	2	2	2
Radiography[4]	2,64	3	3	4	4
Mammography	0,74	1	1	1	1
Magnetic resonance	1,30	2	2	2	2
Computer tomography	1,13	1	2	2	2
Theatre	1,01	1	1	2	2
Total FTE required	**8,03**	**10**	**11**	**13**	**13**
FTE with leave factor (23,8%)	***9,9***	***12,4***	***13,6***	***16,1***	***16,1***

The leave factor is added to the total required FTE to make provision for when diagnostic radiographers take leave and the activities in the modality must continue. The FTE leave factor was calculated in Step 3 and is depicted in Table 5.9.

[4] Radiography include general and mobile x-rays, bone mineral density (BMD), and dental cephalometric x-rays.

The required FTE for the various modalities at different utilisation percentages, must be analysed and interpreted in respect of the current staffing level. This is executed in the seventh and final step of the framework.

5.4.3.7 Step 7: Analyse and interpret the results

The required FTEs obtained from the previous step was determined at different utilisation level. After considering the results and the operational factors that might affect the utilisation percentage, the head of department from the case environment indicated that the analysis should be done based on an 80 percent utilisation rate. The FTE results will be subjected to three stages of analysis and interpretation. Firstly, a comparison of the difference between the existing staffing (FTE) level and the required FTE. Secondly, a ratio analysis of existing staffing (FTE) level to the required FTE and finally a concluding interpretive analysis.

Firstly, a comparison between the existing FTE level and the required FTE level is done to indicate whether there is an overstaffing or understaffing issue. The results of applying (4.11), defined in Section 4.3.7, and the associated interpretation of the required FTEs for the various modalities at an 80 percent utilisation rate is displayed in Table 5.18

Table 5.18: Required FTE results analysis and interpretation

Modality	**Existing Diagnostic Radiographers**	**FTE required at 80% (rounded)**	**Difference at 80%**	**Staffing analysis**
Ultrasound	2	*2*	0	Sufficient
Radiography	6	*4*	2	Excess
Mammography	1	*1*	0	Sufficient
Magnetic resonance	2	*2*	0	Sufficient
Computer tomography	2	*2*	0	Sufficient
Theatre	3	*2*	1	Excess
Total FTE required	**16**	**13**	**3**	
FTE with leave factor (23,8%)	_	**16**		

Secondly, the ratio between the existing and the required FTE (staffing level) can be analysed to assess the degree of pressure or strain under which the diagnostic radiographers are working to manage the monthly workload. The workload strain ratio, which acts as an indirect or proxy measure, is calculated according to (4.12), defined in Section 4.3.7. The associated interpretation (workload strain) of the required FTE for the various modalities at an 80 percent utilisation rate is displayed in Table 5.19

Table 5.19: Required diagnostic radiographer (FTE) results analysis and interpretation (adapted from World Health Organization (2010b)*)*

Modality	**Existing Diagnostic Radiographers**	**FTE required at 80% (rounded)**	**Difference at 80%**	**Staffing analysis**	**Workload strain**	**Workload strain analysis**
Ultrasound	2	*2*	0	Sufficient	1,0	None
Radiography	6	*4*	2	Excess	1,5	Low
Mammography	1	*1*	0	Sufficient	1,0	None
Magnetic resonance	2	*2*	0	Sufficient	1,0	None
Computer tomography	2	*2*	0	Sufficient	1,0	None
Theatre	3	*2*	1	Excess	1,5	Low
Total FTE required	**16**	**13**	**3**			
FTE with leave factor (23,8%)	_	**16**				

Lastly, as discussed in Section 4.3.7, a thorough understanding of the local radiology operating environment should be borne in mind when drawing conclusions based on and attributing meaning to the numerical results. In Section 4.3.7, a list of questions were proposed as a guideline for this concluding interpretive analysis, and only relevant questions are applied to the required FTE results of the case study environment as part of the analysis presented in Table 5.20.

Table 5.20: Concluding interpretive analysis

Question	**Response**
1. Do the results portray an accurate representation of the staffing level at the radiology department?	The required FTEs for six modalities at VP (case study site) were calculated and there were discrepancies with two of the six modalities. The modalities that had discrepancies were radiography with a difference of 2 FTEs in excess and theatre with a difference of 1 FTE, also in excess. This caused the total required FTEs to differ with the existing FTEs by 3 diagnostic radiographers in excess or overstaffed.

Question	Response
2. If any discrepancy exists, consider what might the cause be between the calculated or required FTE results and what the existing reality portray?	The difference with the theatre FTE can possibly be attributed to the method in how the activity duration is logged on the radiology information system (RIS). The theatre activity requires the diagnostic radiographer to leave the radiology department and provide diagnostic radiology service to surgical operations in theatre. The activity duration starts when the diagnostic radiographer leaves the department to attend to theatre and ends when back in the department after capturing the patient and examination details. However, this method of logging time for theatre does not happen consistently and it is suspected that the activity is started on returning from theatre and ends after the relevant details are captured. Hence the current duration for the theatre activity is shorter and reflects less workload which results in the difference between the required FTE and existing staffing levels. The same principle holds true for the radiography modality where activity durations are not started and ended in sync with the physical start and end of the activity. This inconsistency in logging start and end times causes the workload to reflect lower and results in discrepancies between the required FTE for radiography and the existing staffing level of radiography. An example of this is mobile (or portable) x-rays, which forms part of the radiography modality, are like the theatre activity in that the diagnostic radiographer leaves the radiology department to render diagnostic radiology services elsewhere in the hospital. The activity stop and start time is treated the same as in the case of the theatre modality.
3. Were the activity (and examination) times used in the workload calculation realistic?	For most of the modalities the examinations times (duration) were realistic as the source of the data is an established radiology information system. However, on closer scrutiny after comparing the required FTE with the existing staffing level, the theatre modality and mobile x-ray (which forms part of the radiography modality) times became questionable. The most likely cause for this is discussed in the previous question (number 2).
4. Were all the activities both clinical and non-clinical considered when determining the workload?	Both clinical and non-clinical activities, suitable for the diagnostic radiographer, for the different modalities were considered when the workload and required FTE were calculated.
5. Does the required FTE match the existing number of diagnostic radiographers?	Yes, the overall FTE required match the existing number of diagnostic radiographers. This is achieved when the leave factor is applied to the total require FTE. Although the overall counts match, there are difference at the modality level which have been discussed earlier in this table.

5.4.4 External validation of case study results

Once the case study is completed and the results explained in the context of the case environment, the final step in determining the applicability and usability of the diagnostic radiology staffing framework, is to validate the results of the framework. This is in line with the evaluation approach as discussed in Sections 1.8 and 5.1.

5.4.4.1 Selection and background of SMEs for validation

To validate the diagnostic radiology staffing framework, various closed and open-ended questions were asked to a select few SMEs which formed part of the theoretical verification process (refer to Table 5.4 SME-ref A and B) and who were exposed to the framework in its entirety; understanding the staffing framework's development process and how it functions. The SMEs represent both public and private diagnostic radiology environments. A third SME from a private diagnostic radiology environment was invited to participate in the validation process but had to cancel on short notice due to urgent work-related matters.

5.4.4.2 Validation criteria of SME questionnaire

The validation questionnaire was sent to the SMEs to complete, but only after a presentation that explained each of the framework steps, as applied to the case environment. This presentation was done via Microsoft Teams. The closed and open-ended questions were designed to: validate the accuracy of the results; validate the ability of the framework to achieve its stated purposes; and confirm the framework's strengths and weaknesses.

The response of the SMEs to the closed ended questions was gauged using a 5-point Likert scale as this offered more insights than a straightforward 'yes or no'. The options on the Likert scale ranged from 'strongly agree' to 'strongly disagree'. If the interviewee selected 'disagree' to any of the questions, they were asked a follow-up open-ended question requesting more information on the reason for this choice. Other open-ended questions related to the strengths and weaknesses of the framework and whether the interviewee would recommend the framework for use in a diagnostic radiology environment. The SME validation questionnaire template with the closed and open-ended questions is reproduced in Appendix B.

5.4.4.3 SME validation feedback and results

A summary of the response to the closed-ended questions (Questions 1 – 4) from the SMEs is provided in Figure 5.1 The open-ended responses (Questions 5 – 9) of the validation questionnaire are summarised in Table 5.21.

The four closed-ended questions that were posed to the SMEs were:

- Question 1: To what extent do you agree that the results (required FTE per modality) accurately reflect the staffing level per modality? If you disagree, please explain why;

- Question 2: To what extent do you agree that interpreting the results are valid (i.e. reasonable and sensible) and can be used to inform staffing decisions? If you disagree, please explain why;
- Question 3: To what extend do you agree that interpreting the results are enabled by the results interpretation table in Step 7 of the framework? If you disagree, please explain why;
- Question 4: To what extend do you agree that the diagnostic radiographer staffing framework can be used for determining staffing requirements in a diagnostic radiology environment? If you disagree, please explain why.

It is evident from Figure 5.1 that the SMEs responded positively to the closed-ended questions, thereby reaching consensus that the diagnostic radiographer staffing framework succeeded in achieving its stated purpose, that the results reflect a reasonable degree of accuracy and that the results are valid and useful.

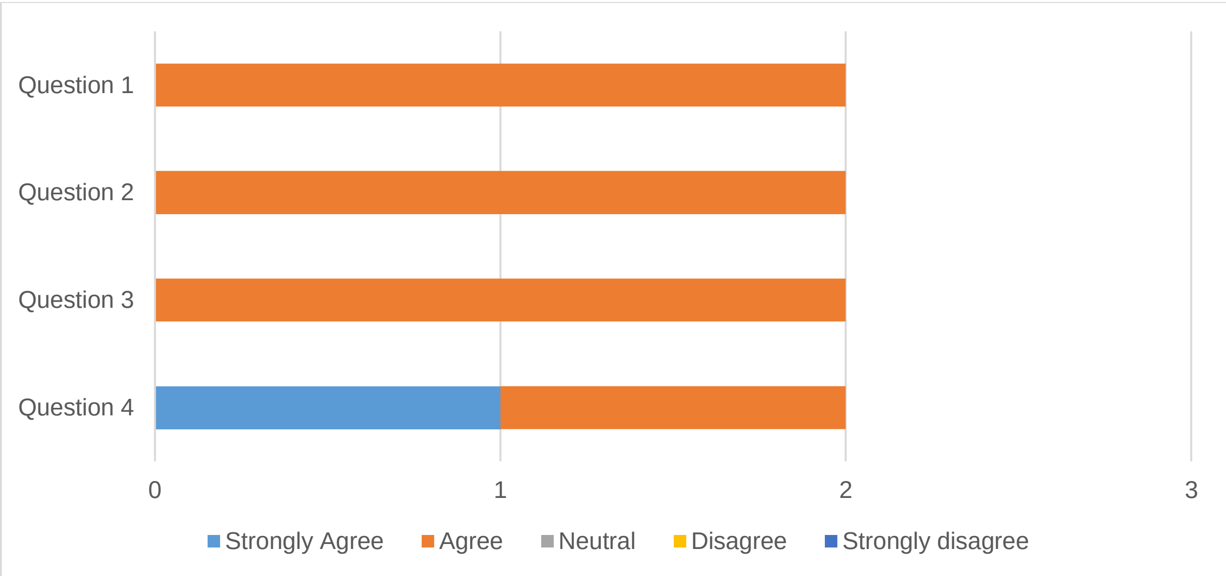


Figure 5.1: SME validation questionnaire (closed-ended) feedback score

Table 5.21: SME validation responses to open-ended questions

Questions (open-ended)	SME responses
5. Are you aware of any other scientific approach that has been proposed which is better suited to determine staffing requirements, specifically in a diagnostic radiology environment?	Both SMEs were not aware of any scientific approach to determine staffing requirements within a diagnostic radiology environment.
6. What do you view as the *key strengths* of the framework?	*SME-ref A:* The framework follows a structured and logical approach for determining workload and required FTEs. "*It can help to build a solid case, based on actual data, for staffing decisions. People want to make decisions based on facts! And this framework can give it!*" *SME-ref B*: "*The foundation on which this framework is based is validated by existing models as discussed in the literature review.*" "*The examination duration is based on actual time from the RIS and not some theoretical standard*"
7. What do you view as the *key weaknesses* of the framework?	*SME-ref A* indicated that it appears as if a certain level of proficiency in Microsoft Excel is needed to input the data from RIS and this could pose a weakness as not all diagnostic radiographer managers would necessarily have a high degree of proficiency in Microsoft Excel. *SME-ref B*: "*Possible a lack in discipline of RIS inputs which might affect the workload.*"
8. Would you recommend the diagnostic radiographer staffing framework for determining staffing requirements in a diagnostic radiology environment?	*SME-ref A*: "*Yes, most definitely*" *SME-ref B*:" *Absolutely. This initially can assist in initial workforce planning. If data is reliable and user friendly, the timeous staffing estimate exercise can become much more efficient.*"
9. Are there any other additional comments and feedback?	*SME-ref A*:"*When we can standardise approaches like this - staffing requirements - it would actually do the profession good*" *SME-ref B*:"*There has been little research done in the diagnostic radiography staffing requirements in South Africa as can be seen from the literature review. With this as a baseline in the private sector in South Africa, much more streamlined models could be established and shared internationally to improve efficiencies, staffing requirements and quality improvements.*"

5.5 Validation conclusion

The application of the diagnostic radiographer staffing framework to a real-life case study of a diagnostic radiology environment indicates and confirms the staffing framework's usability and applicability within the diagnostic radiology environment. Moreover, the conclusion of applicability is strengthened by the overall positive feedback received, both from an SME working in the case environment (private diagnostic radiology) and from an SME working in a public diagnostic radiology environment. The SMEs agree that they are not aware of any other tool within the diagnostic radiology environment that is suitable for determining staffing requirements.

5.6 Conclusion: Chapter 5

This chapter consists of two primary parts, namely verification and validation. A self-verification of the requirement specification to the diagnostic radiographer staffing framework was performed to evaluate whether the staffing framework was developed consistent with the requirement specification. In addition, a self-verification of the degree to which the staffing framework addresses the requirement specification was done. SMEs were consulted as part of the theoretical verification of the requirement specification and the diagnostic radiographer staffing framework and this concluded the verification process that contribute to the reliability and validity of the research.

For the validation section, a case study application was done. The results of the case study and the feedback from the SMEs, as part of the external validation, indicated that the diagnostic radiology staffing framework is applicable and usable in both the private and public diagnostic radiology environment.

Chapter 6: Conclusions

In this final chapter a summary of the research findings of all chapters are presented. The limitations and contributions of the research is discussed alongside recommendations for future research that builds on this study.

6.1 Research summary

Chapter 1 of this research started with the background to the study, research question and problem definition, followed by the aim and objectives, research design and methodology, requirement specification and the verification and validation approach. The background to the research identified that radiology staffing models did not keep up with the technological advances in the field and that research into diagnostic radiology staffing models were primarily done for radiologists and radiation therapists and not for diagnostic radiographers. To address the need for a diagnostic radiographer staffing framework that can be adapted to account for all the activities performed, both clinical and non-clinical, a mixed-method research approach was adopted. Requirement specifications were developed from literature and grouped into four categories, based on Van Aken et al. (2007), that included functional requirements, user requirements, boundary conditions and design requirements.

Chapter 2, provided the context of a radiology environment by creating a general overview of radiology by defining what it is, why it is important, who is involved, what imaging modalities are, and established that diagnostic radiographers are part of the allied health professionals. The clinical operating environment was discussed with specific focus on the radiology value chain and the importance or value of radiology in healthcare provision. The drivers of change in the radiology workload were identified through changes in the workflow management, and the impact of technological advances on the role of radiology personnel. Throughout the chapter, requirement specifications were identified. This chapter addressed the first objective of the research.

Chapter 3 explored literature most prominent to general healthcare staffing models, as well as a selection of staffing models specifically developed for determining radiologist and radiation therapist workload. Three categories of general healthcare staffing models were introduced, namely supply-based, demand-based and workload-based approaches. The supply and demand models tend to represent the macro environment (i.e. regional and national or country) better for healthcare human resource planning, whereas workload-based models represent the meso- and micro environment (i.e. organisational and departmental or unit) more favourably. Workload and staffing requirement models for diagnostic radiographers are limited and by reviewing radiologist and radiation therapist staffing models, the chapter aimed at deriving insights from these models that could assist in the development of a diagnostic radiographer staffing framework. Staffing models in radiology were representative of workload-based models which are at the meso- and micro level. The chapter concluded with a discussion of the challenges that are associated with current staffing models for both radiologist and radiation therapists. Requirement specifications were identified throughout the chapter. This chapter addressed the second objective of the research.

The requirement specifications were consolidated at the beginning of Chapter 4 which set the basis for the evaluation of existing healthcare and radiology staffing models against the requirement specifications. This evaluation highlighted the staffing model that was most compatible with the requirement specifications and hence most suitable for adaptation to the diagnostic radiology environment. The staffing model that scored the highest is a radiation therapist staffing model that employs a workload-based approach. The principles of the radiation therapy activity-based (i.e. workload-based) approach from Tobergte and Curtis (2013) served very useful for developing a diagnostic radiographer staffing framework. Next, the diagnostic radiographer staffing framework overview was presented followed by a detailed discussion of the seven framework steps. This chapter addressed the third objective of the research, namely, to formulate and evaluate a diagnostic radiographer staffing framework.

The validation and verification of the requirement specification and diagnostic radiographer staffing framework was presented in Chapter 5. Verification consisted of self-verification and theoretical verification by SMEs, while validation consisted of a case study application and SME validation. The theoretical verification of the requirement specifications and diagnostic radiographer framework was done using semi-structured interviews with SMEs. Feedback from SMEs indicated that the requirements specifications were accurate, and the framework was developed consistent with the requirement specification, thereby confirming its validity. Some enhancements to the requirement specifications and staffing framework were proposed, and after critically evaluating the information that was uncovered during the theoretical verification process, minor changes to the approach for calculating time estimates for clinical and nonclinical activities was made and a leave factor was incorporated. These refinements were applied to the framework before the case application. During the case study, RIS data from a private diagnostic radiology practice was used to determine the required number of diagnostic radiographers. On completion of the case application, the results were validated with SMEs in the field of diagnostic radiology. The purpose of the case application was to test practicability and applicability of the diagnostic radiographer staffing framework. This was affirmed. This chapter addressed the fourth objective of the research.

6.2 Contributions

This research adds to both the academic literature and to diagnostic radiology workforce planning. The body of literature is contributed to through an example of how a mixed-methods approach can be used to formulate a diagnostic radiographer staffing framework. This research outcome is a requirement specification and a diagnostic radiographer staffing framework which satisfies this requirement specification. Since no diagnostic radiographer staffing framework could be found in the literature, the framework itself is a contribution to the literature.

Contributions to practice are made by the implementation of the diagnostic radiographer staffing framework to a private diagnostic radiology practice as a case study and validating the results from both a private and public diagnostic radiology perspective.

6.3 Limitations of the research

Diagnostic radiology is a 24-hour, 7-days a week, 365 days in a year service with core operating hours from 7 am till 5 pm, Monday to Friday and Saturday 9 am to 1 pm. After-hours are considered any time outside of core operating hours. Due to varying work schedules outside of core hours and on weekends in the case study environment, this research only focused on the staffing requirements during the core operating hours of 7 am till 5 pm, Mondays till Fridays.

Another limitation highlighted in the validation of the case study results (as mentioned in Section 5.4.4.3), was that one SME was unavailable for this process. The SME input step of the validation strategy therefore only included feedback from two individuals. Though this is acknowledged as a limitation of the research, this part of the validation strategy is still considered to have been successfully concluded as the two SMEs that did participate have significant, relevant expertise and responsibility in the public and private sector, respectively.

6.4 Recommendations and future work

Throughout the research, and especially with the case application, opportunities for future research were highlighted. These are discussed in the subsequent sections.

6.4.1 Recommendations

During the case application, while working with the actual RIS data, it became apparent that the examination duration can be statistically analysed to set standards for most commonly used examinations.

6.4.2 Proposed future work

This research focused on determining the required diagnostic radiographer FTEs only and did not focus on the scheduling of the FTEs once determined. This staffing framework will determine the required number of FTEs for a given workload over a given period, but it will not indicate how these FTEs should be scheduled for the given period. Suggested future research might include the scheduling of the diagnostic radiographers to cover both the core hours and after-hours requirements.

During the theoretical verification, it was suggested that the diagnostic radiographer staffing framework should make provision for different staffing scenarios that could aid workforce scenario planning which could add additional value to diagnostic radiology managers.

A typical staffing scenario could be that radiology managers anticipate the demand for a modality to increase with a certain percentage and would like to know how it will impact the current staffing requirements. Alternatively, at which percentage increase in demand will additional staff be required.

Finally, although the diagnostic radiographer staffing framework was designed for determining the staffing requirements of diagnostic radiographers only, it is possible that it could be expanded (and adapted) to include the staffing requirement of the entire diagnostic radiology department, as outlined in Table 2.1.

6.5 Conclusion: Chapter 6

This chapter concluded the research study by introducing a summary of each chapter and how it contributed to the development of the diagnostic radiographer staffing framework. It also highlighted the contribution that the research made to the academic literature and to diagnostic radiology workforce planning. This was followed by a discussion of the limitations of the research. In conclusion, opportunities for future work was highlighted, together with a brief discussion of how such future work could enhance the diagnostic radiographer staffing framework.

References

Adams, R. (2004). *Progress in the development of recommended staffing levels for rural physiotherapy services*. 1–5.

Al-Sawai, A., & Al-Shishtawy, M. M. (2015). Health workforce planning: An overview and suggested approach in Oman. *Sultan Qaboos University Medical Journal*, *15*(February), 27–33.

Aloisio, J. J., & Winterfeldt, C. G. (2010). Rethinking traditional staffing models. *Radiology Management*, *32*(6).

Baadh, A., Peterkin, Y., Wegener, M., Flug, J., Katz, D., & Hoffmann, J. C. (2016). The Relative Value Unit: History, Current Use, and Controversies. *Current Problems in Diagnostic Radiology*, *45*(2), 128–132. https://doi.org/10.1067/j.cpradiol.2015.09.006

Battista, J. J., Clark, B. G., Patterson, M. S., Beaulieu, L., Sharpe, M. B., Schreiner, L. J., MacPherson, M. S., & Dyk, J. Van. (2012). Medical physics staffing for radiation oncology: A decade of experience in Ontario, Canada. *Journal of Applied Clinical Medical Physics*, *13*(1), 93–110. https://doi.org/10.1120/jacmp.v13i1.3704

Birch, S., Kephart, G., Murphy, G. T., Brien-pallas, L. O., Alder, R., & Mackenzie, A. (2009). *Health Human Resources Planning and the Production of Health: Development of an Extended Analytical Framework for Needs-Based Health Human Resources Planning*. 56–61.

Birch, S., Kephart, G., Murphy, G. T., O'Brien-Pallas, L., Alder, R., & MacKenzie, A. (2013). Health Human Resources Planning and the Production of Health. *Journal of Public Health Management and Practice*, *15*(Supplement), S56–S61. https://doi.org/10.1097/phh.0b013e3181b1ec0e

Boehm, B. W. (1984). Verifying and Validating Software Requirements and Design Specifications. *IEEE Software*, *1*(1), 75–88. https://doi.org/10.1109/MS.1984.233702

Boland, G. W. L., Guimaraes, A. S., & Mueller, P. R. (2008). Radiology report turnaround: Expectations and solutions. *European Radiology*, *18*(7), 1326–1328. https://doi.org/10.1007/s00330-008-0905-1

Brady, A. P. (2011). Measuring Consultant Radiologist workload: method and results from a national survey. *Insights into Imaging*, *2*(3), 247–260. https://doi.org/10.1007/s13244-011-0094-3

Bryman, A., Bell, E., Hirschsohn, P., Santos, A. dos, Toit, J. du, & Masenge, A. (2014). *Research Methodology: Business and Management Contexts*. Oxford University Press.

Burute, N., & Jankharia, B. (2009). Teleradiology: The Indian perspective. *Indian J Radiol Imaging*, *19*(1), 16–18. https://doi.org/10.4103/0971-3026.45337

Cowan, I. A., MacDonald, S. L. S., & Floyd, R. A. (2013). Measuring and managing radiologist workload: Measuring radiologist reporting times using data from a Radiology Information System. *Journal of Medical Imaging and Radiation Oncology*, *57*(5), 558–566. https://doi.org/10.1111/1754-9485.12092

Cruz-Gomes, S., Amorim-Lopes, M., & Almada-Lobo, B. (2018). A labor requirements function for sizing the health workforce. *Human Resources for Health*, *16*(1), 1–12. https://doi.org/10.1186/s12960-018-0334-4

Dal Poz, M., Dreesch, N., Fletcher, S., Gedik, G., Gupta, N., Hornby, P., & Schofield, D. (2010). Models and tools for health workforce planning and projections. *Human Resources for Health Observer*, *3*, 1–19.

Daviaud, E., & Chopra, M. (2008). How much is not enough? Human resources requirements for primary health care: a case study from South Africa. *World Health Organization. Bulletin of the World Health Organization*, *86*(1), 46–51. https://doi.org/10.1136 bmj.331.7519.750

Dhanoa, D., Dhesi, T. S., Burton, K. R., Nicolaou, S., & Liang, T. (2013). The evolving role of the radiologist: The Vancouver workload utilization evaluation study. *Journal of the American College of Radiology*, *10*(10), 764–769. https://doi.org/10.1016/j.jacr.2013.04.001

Disselkamp, L. (2013). “Workforce Asset Management Book of knowledge.” In *Notes and Queries* (Vols. s2-II, Issue 31). https://doi.org/10.1093/nq/s2-II.31.90-a

Dreesch, N., Dolea, C., Dal Poz, M. R., Goubarev, A., Adams, O., Aregawi, M., Bergstrom, K., Fogstad, H., Sheratt, D., Linkins, J., Scherpbier, R., & Youssef-Fox, M. (2005). An approach to estimating human resource requirements to achieve the Millennium Development Goals. *Health Policy and Planning*, *20*(5), 267–276. https://doi.org/10.1093/heapol/czi036

Dreyer, K. J., Hirschorn, D. S., Thrall, J. H., & Mehta, A. (2006). PACS: A guide to the digital revolution. In *Atlas of the Deep-Water Seabed: Ireland* (2nd ed.). Springer-Verlag New York. https://doi.org/10.1007/0-387-31070-3

Dubinsky, T. J. (2013). Comprehensive review of the limitations of relative value unit measurements of productivity in academic departments. *Ultrasound Quarterly*, *29*(2), 97–102. https://doi.org/10.1097/RUQ.0b013e3182915931

Duszak, R., & Muroff, L. R. (2010). Measuring and Managing Radiologist Productivity, Part 1: Clinical Metrics and Benchmarks. *Journal of the American College of Radiology*, *7*(6), 452–458. https://doi.org/10.1016/j.jacr.2010.01.026

Dutton, S. C., Sze, G. K., Lund, P. L., & Bluth, E. I. (2014). Radiology practice environment: Options, variations, and differences - A report of the ACR commission on human resources. *Journal of the American College of Radiology*, *11*(4), 352–358. https://doi.org/10.1016/j.jacr.2013.12.025

Etheredge, H. R. (2011). An opinion on radiography, ethics and the law in South Africa. *South African Radiographer*, *49*(1), 9–12. http://ezproxy.umsl.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=61059490&site=ehost-live&scope=site

European Society of Radiology. (2010). The future role of radiology in healthcare. *Insights into Imaging*, *1*(1), 2–11. https://doi.org/10.1007/s13244-009-0007-x

Fakhri, A., Seyedin, H., & Daviaud, E. (2014). A Combined Approach for Estimating Health Staff Requirements. *Iranian Journal of Public Health*, *43*(1), 107–115. internal-pdf://59.184.45.143/Fakhri-2014-A combined approach for estimating.pdf%5Cnhttp://www.scopus.com/inward/record.url?eid=2-s2.0-84893103149&partnerID=40&md5=1a7d4fa4685aa1b450663472da2cea3d http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4454024/pdf/IJP

Golfashani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*, *8*(4), 597–607. http://nsuworks.nova.edu/tqr%0Ahttp://nsuworks.nova.edu/tqr/vol8/iss4/6%0Ahttps://nsuworks.nova.edu/tqr/vol8/iss4/6

Griffiths, S. (2000). Therapy radiographer staffing for the treatment and care of cancer patients. *Journal of Radiotherapy in Practice*, *1*(4), 161–169.

Griffiths, S. E., Craig, A., & Abraham, M. (2006). Radiographer roles and risk management in radiotherapy, and a UK survey. *Journal of Radiotherapy in Practice*, *5*(3), 137–146. https://doi.org/10.1017/S1460396906000197

Isambert, A., Du, D. Le, Valéro, M., Guilhem, M. T., Rousse, C., Dieudonné, A., Blanchard, V., Pierrat, N., & Salvat, C. (2015). Medical physics personnel for medical imaging: Requirements, conditions of involvement and staffing levels-french recommendations. *Radiation Protection Dosimetry*, *164*(1–2), 130–133. https://doi.org/10.1093/rpd/ncu312

Kabongo, J. M., Nel, S., & Pitcher, R. D. (2015). Analysis of licensed South African diagnostic imaging equipment. *Pan African Medical Journal*, *22*, 1–9. https://doi.org/10.11604/pamj.2015.22.57.7016

Kachhal, S. K. (2001). Industrial Engineering Applications in Health Care Systems. In *Handbook of Industrial Engineering* (pp. 737–750). John Wiley & Sons, Ltd. https://doi.org/https://doi.org/10.1002/9780470172339.ch27

Kennon, D. (2017). Towards an Antifragile South African SME. *PhD*. thesis, Stellenbosch:

Stellenbosch University.

Khan, S. H. M., & Hedges, W. P. (2013). Workload of consultant radiologists in a large DGH and how it compares to international benchmarks. *Clinical Radiology*, *68*(5), e239–e244. https://doi.org/10.1016/j.crad.2012.10.016

Khetrapal, A. (2018). *What is Teleradiology*. News Medical Life Sciences. https://www.news-medical.net/health/What-is-Teleradiology.aspx

Klein, E. E. (2010). A grid to facilitate physics staffing justification. *Journal of Applied Clinical Medical Physics*, *11*(1), 263–273. https://doi.org/10.1120/jacmp.v11i1.2987

Kleynhans, E. (2020). *The Development of a Policy Analysis Logic Model to Support Public Medicine Availability Initiatives in the Context of VAN*. Ph.D. thesis, Stellenbosch: Stellenbosch University.

Kolehmainen-Aitken, R.-L. (1993). Human resources planning : issues and methods. In *Data for Decision Making Project*. http://sphweb.sph.harvard.edu/ihsg/publications/pdf/No-1.PDF

Kothari, C. . (2004). *Research Methodology: Methods and Techniques* (2nd ed.). New Age International Pty.

Larson, D. B., Froehle, C. M., Johnson, N. D., & Towbin, A. J. (2014). Communication in diagnostic radiology: Meeting the challenges of complexity. *American Journal of Roentgenology*, *203*(5), 957–964. https://doi.org/10.2214/AJR.14.12949

Laurence, C. O., & Karnon, J. (2016). Improving the planning of the GP workforce in Australia: a simulation model incorporating work transitions, health need and service usage. *Human Resources for Health*, *14*(1), 13. https://doi.org/10.1186/s12960-016-0110-2

Leedy, P. D., & Ormrod, J. E. (2016). *Practical Research: Planning and Design* (11th ed.). Pearson Education, Inc.

Lopes, M. A., Almeida, Á. S., & Almada-Lobo, B. (2015). Handling Healthcare Workforce Planning With Care: Where Do We Stand? *Human Resources for Health*, *13*(1), 38. https://doi.org/10.1186/s12960-015-0028-0

MacDonald, S. L., Cowan, I. A., Floyd, R., MacKintosh, S., Graham, R., Jenkins, E., & Hamilton, R. (2013). Measuring and managing radiologist workload: Application of lean and constraint theories and production planning principles to planning radiology services in a major tertiary hospital. *Journal of Medical Imaging and Radiation Oncology*, *57*(5), 544–550. https://doi.org/10.1111/1754-9485.12090

MacDonald, S. L. S., Cowan, I. A., Floyd, R. A., & Graham, R. (2013). Measuring and managing radiologist workload: A method for quantifying radiologist activities and calculating the full-time equivalents required to operate a service. *Journal of Medical Imaging and Radiation Oncology*, *57*(5), 551–557. https://doi.org/10.1111/1754-9485.12091

Malkin, R., & Teninty, B. (2014). *Radiology in Global Health* (pp. 7–12). https://doi.org/10.1007/978-1-4614-0604-4

Mariani, C., Tronchi, A., Oncini, L., Pirani, O., & Murri, R. (2006). Analysis of the X-ray work flow in two diagnostic imaging departments with and without a RIS/PACS system. *Journal of Digital Imaging*, *19*(1 SUPPL.), 18–28. https://doi.org/10.1007/s10278-006-0858-3

Martin-Vega, L. A. (2004). Industrial Engineering: Past, Present, and Future. In *McGraw Hill*.

McEnery, K. W. (2013). Radiology Information Systems and Electronic Medical Records. *Journal of the American College of Radiology*, 1–14.

Morgan, M. B., Meenan, C. D., Safdar, N. M., Nagy, P., & Flanders, A. E. (2014). Informatics leaders in radiology: Who they are and why you need them. *Journal of the American College of Radiology*, *11*(12), 1241–1250. https://doi.org/10.1016/j.jacr.2014.09.007

Morse, J. M., Barrett, M., Mayan, M., Olson, K., & Spiers, J. (2002). Verification Strategies for Establishing Reliability and Validity in Qualitative Research. In *International Journal of Qualitative Methods* (Vol. 1, Issue 2).

Mouton, J. (2001). *How to succeed in your master's and doctoral studies : a South African guide and resource book*. Van Schaik.

Ozcan, S., & Hornby, P. (1999). Determining Hospital Workforce Requirements: A Case Study. *Human Resources for Health Development Journal (HRDJ)*, *3*(3), 210–220.

Ozcan, Y. A. (2009). *Quantitative Methods in Health Care Management: Techniques and applications*. San Francisco: Jossey-Bass.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., Hoagwood, K., Angeles, L., & Northwest, K. P. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Dental Survey*, *44*(12), 73. https://doi.org/10.1007/s10488-013-0528-y.Purposeful

Patel, P., & Mitera, G. (2011). A systematic scoping literature review of incorporating a total quality culture within radiotherapy staffing models: A management strategy to improve patient safety and quality of care in radiation therapy departments. *Journal of Medical Imaging and Radiation Sciences*, *42*(2), 81–85. https://doi.org/10.1016/j.jmir.2011.03.001

Patti, J. A., Berlin, J. W., Blumberg, A. L., Bryan, R. N., Gaschen, F., Izzi, B. M., Larson, P. A., Lewin, J. S., & Liebscher, L. A. (2008). ACR White Paper: The Value Added That Radiologists Provide to the Health Care Enterprise. *Journal of the American College of Radiology*, *5*(10), 1041–1053.

https://doi.org/10.1016/j.jacr.2008.06.003

Pitman, A. G., & Jones, D. N. (2006). Radiologist workloads in teaching hospital departments: Measuring the workload. *Australasian Radiology*, *50*(1), 12–20. https://doi.org/10.1111/j.1440-1673.2005.01524.x

Pitman, A., Jones, D. N., Stuart, D., Lloydhope, K., Mallitt, K., & O'Rourke, P. (2009). The Royal Australian and New Zealand College of Radiologists (RANZCR) relative value unit workload model, its limitations and the evolution to a safety, quality and performance framework. *Journal of Medical Imaging and Radiation Oncology*, *53*(5), 450–458. https://doi.org/10.1111/j.1754-9485.2009.02094.x

Rahman, K. (2014). *Editorial Radiology – Changing Role in Healthcare*. *2*(1), 1–2.

Reilly, P. (1996). *Human Resource Planning: An Introduction*. http://www.employment-studies.co.uk/pubs/summary.php?id=312

Ridoutt, L., Schoo, A. M., & Santos, T. (2006). *Workload Capacity Measures for Use in Allied Health Workforce Planning*.

Routsis, D., Thomas, S., & Head, J. (2006). Are extended working days sustainable in radiotherapy? *Journal of Radiotherapy in Practice*, *5*(2), 77–85. https://doi.org/10.1017/S1460396906000112

Royal College of Radiologists. (2008). *How many radiologists do we need ? A guide to planning hospital radiology services Board of the Faculty of Clinical Radiology*.

Royal College of Radiologists. (2012a). *Clinical radiology workload : guidance on radiologists ' reporting figures*. https://www.rcr.ac.uk/publication/clinical-radiology-workload-guidance-radiologists'-reporting-figures

Royal College of Radiologists. (2012b). *Investing in the Clinical Radiology Workforce – The Quality and Efficiency Case* (Issue June).

Sanghvi, D., & Harisinghani, M. G. (2010). Modalities in modern radiology: a synopsis. *Journal of Postgraduate Medicine*, *56*(2), 85–87. https://doi.org/10.4103/0022-3859.65282

Schoo, A. M., A Boyce, R., Ridoutt, L., & Santos, T. (2008). Workload capacity measures for estimating allied health staffing requirements. *Australian Health Review: A Publication of the Australian Hospital Association*, *32*(3), 548–558. https://doi.org/10.1071/AH080548

Smith, L. J., Kearvell, R., Arnold, A. J., Choma, K., Cooper, A., Young, M. R., Matthews, D. L., Hilder, B., Howson, D., Fox, K., & Churcher, K. (2016). Radiation therapy staffing model 2014. *Journal of Medical Radiation Sciences*, *63*(4), 209–216. https://doi.org/10.1002/jmrs.198

Smoke, M., & Ho, P. H. E. (2015). Staffing Model for Radiation Therapists in Ontario. *Journal of Medical Imaging and Radiation Sciences*, *46*(4), 388–395.

https://doi.org/10.1016/j.jmir.2015.08.004

Soroosh, G. P., Mayo-Smith, W. W., & Mollura, D. J. (2019). Radiology Overview: Defining Radiology and Stakeholders in the Radiology Enterprise. In D. J. Mollura, M. P. Culp, & M. P. Lungren (Eds.), *Radiology in Global Health: Strategies, Implementation, and Applications* (pp. 9–13). Springer International Publishing. https://doi.org/10.1007/978-3-319-98485-8_2

Tobergte, D. R., & Curtis, S. (2013). Staffing in radiotherapy: an activity based approach. In *Journal of Chemical Information and Modeling* (Vol. 53, Issue 9). https://doi.org/10.1017/CBO9781107415324.004

Ungerer, G. D. (2015). *A Competitive Strategy Framework for E-Business Start-Ups*. Ph.D. thesis, Stellenbosch: Stellenbosch University.

Van Aken, J. E., Berends, H., & Van Der Bij, H. (2007). *Problem-solving in organizations: A methodological handbook for business students*. Cambridge University Press. https://doi.org/10.1017/CBO9780511618413

Van Der Merwe, D., Palm, S., & Van Der Putten, W. J. (2013). Staffing requirements in radiation medicine. *IFMBE Proceedings*, *39 IFMBE*, 2268–2271. https://doi.org/10.1007/978-3-642-29305-4_595

World Health Organization. (2010a). Workload Indicators of Staffing Need: USER'S MANUAL. In *World Health Organization*. http://www.who.int/hrh/resources/WISN_Eng_UsersManual.pdf?ua=1

World Health Organization. (2010b). Workload Indicators of Staffing Need: USER'S MANUAL. *World Health Organization*.

World Health Organization. (2011). Mammography Unit Core medical Equipment - Information. *ECRI Institute, GMDN Agency*, *2011*(1), 1.

Wright, M., Scott, E., & Cockerill, R. (1993). Surviving the Management Game: Workload Measurement Systems in a Cost-Conscious Environment. *Canadian Journal of Occupational Therapy*, *60*(1). https://doi.org/10.1177/000841749306000106

Yin, R. K. (2018). *Case Study Research and Applications: Design and Methods*.

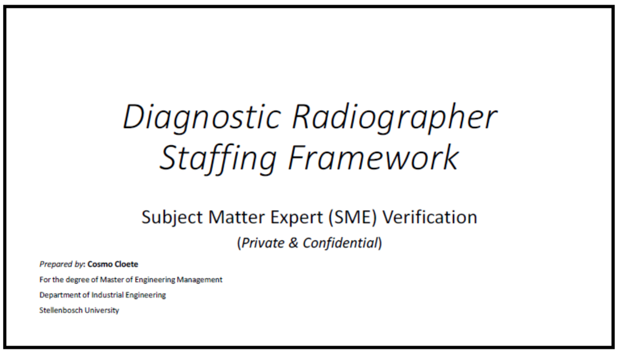
Zhang, J., Lu, X., Nie, H., Huang, Z., & Van Aalst, W. M. P. (2009). Radiology information system: A workflow-based approach. *International Journal of Computer Assisted Radiology and Surgery*, *4*(5), 509–516. https://doi.org/10.1007/s11548-009-0362-6

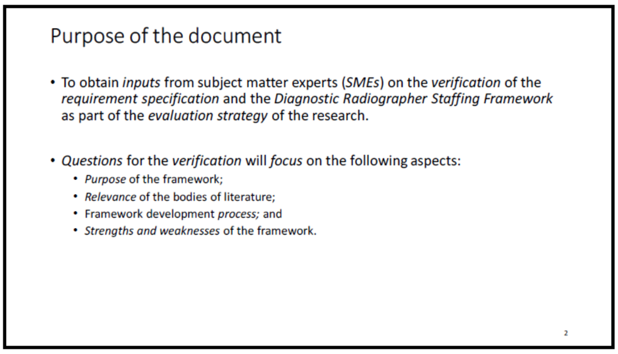
Appendix A: **SME verification document**

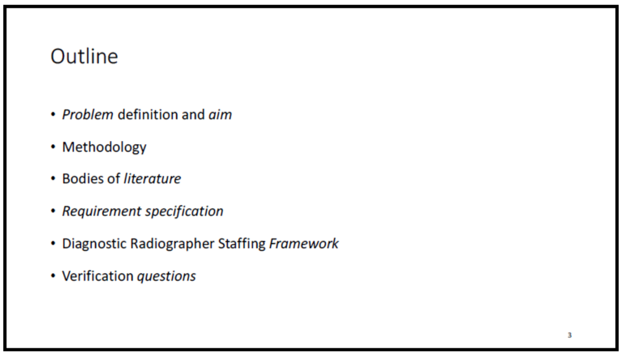
This appendix contains the verification document in the form of a PowerPoint which was presented to the SMEs prior to verification interview.

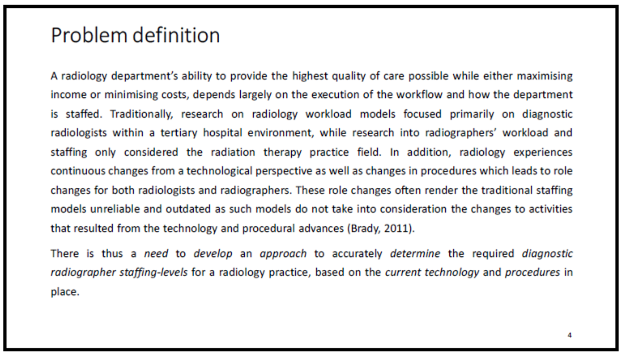
A.1 Diagnostic radiographer staffing framework verification document

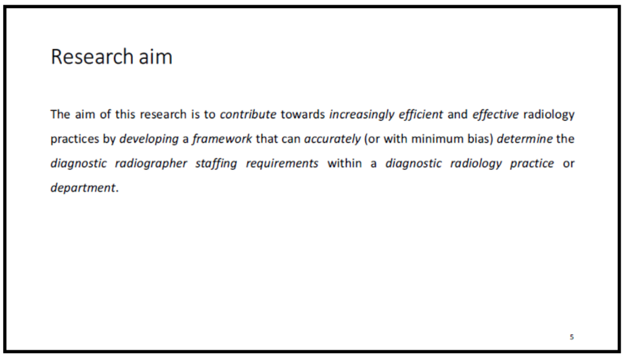
Subject matter experts (SMEs) formed part of the theoretical verification process as outlined in Sections 1.8 and 5.1. They were consulted for the verification of the proposed framework; relevance of the bodies of literature; framework development process; and strength and weakness of the framework. Prior to the semi-structured interviews, a "pre-read" document in the form of a Microsoft PowerPoint was provided and presented during the online interview via Microsoft Teams.

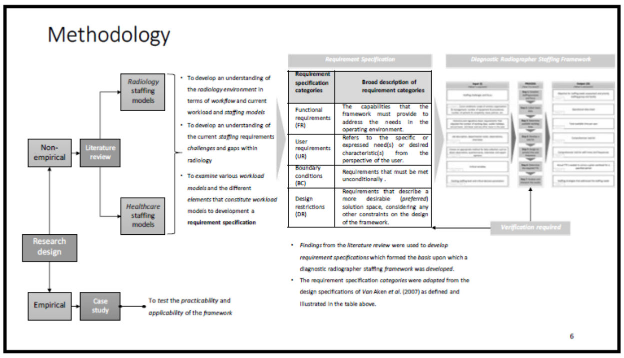








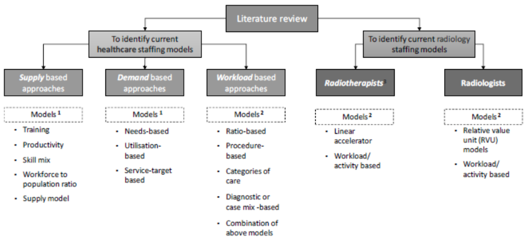




Literature overview

7

Literature overview – Staffing models



1 These models provide staffing needs on a *macro* or national and regional healthcare level
2 *Micro* and *meso* level models provide staffing needs on department or organisational level
3 Radiographers form part of the *allied health* workers(AHW). AH professionals are involved with the delivery of health or related services pertaining to the identification, evaluation and prevention of diseases and disorders; dietary and nutrition services; rehabilitation and health systems management, among others. AH professionals include, amongst others dental hygienists, diagnostic medical sonographers, dietitians, medical technologists, occupational therapists, physical therapists, radiographers, respiratory therapists, and speech language pathologists. https://www.asahp.org/

8

Literature overview – Healthcare staffing models

Supply based approaches

Supply based models seek to *predict the future healthcare workforce* based on the *analysis* of *factors* that impact their *movement* into, through and exiting the health workforce pool (Cruz-Gomes et al., 2018). Dreesch *et al.* (2005) agrees with the previous authors and state that the supply side signifies, based on assumptions of health care personnel's inflow, losses and employment, the accessibility and features of healthcare personnel at the current instant or at some future instant in time.

Models	Brief description
• *Training*	• *Forecasts* the availability of healthcare personnel based on the *existing staff complement* while *considering* the number of *new entrants*, those *existing*, *migrating* and *retiring* (Lopes et al., 2015; Laurence and Karnon, 2016). • Birch *et al.* (2013), which states that provider supply (supply side) is the result of two factors; namely *'the stock of individuals' and 'the flow of activities'* (e.g. time spent in the executing the services)
• *Productivity*	• Laurence and Karnon (2016) use productivity as a *parameter* of *consulting hours per full-time equivalent (FTE)*, as part of their productivity (and work) module, to *determine* the '*headcount* of base year General Practitioner (GP) stock'. The latter is changed to FTEs by *multiplying* the *headcount* by part-time or full-time *hours per week divided* by a standard full-time *clinical working week* (Laurence and Karnon, 2016).
• *Skill mix*	• Refers to the *allocation* of *certain tasks* to other health specialists, either through *horizontal*- (amongst medical specialists) or *vertical* (amongst doctors and nurses) *substitution* (Lopes et al., 2015).
• *Workforce to population ratio*	• Is a basic *forecast* of *prospective quantities* of needed *healthcare workers* based on *established* or *nominated* (suggested/advised) *thresholds* for example, healthcare *workers per 10000 population* (Dal Poz *et al.* 2010). • Determines a *desired ratio* for the number of doctors and nurses *per unit of population* and *compares* it to the *actual ratios* (Lopes et al., 2015).
• *Supply model*	• Consisting of two *sub-models* namely a *supply*- and a *need (demand)* sub-model, which has *three components (training, supply* and *productivity)* and *four components (population size, health needs, service utilisation* and *productivity)* respectively. (Laurence and Karnon, 2016). The authors used the *productivity component* as a *parameter* of the *number of consulting hours per FTE* (which was based on 40 hours of clinical work per week) in both the supply- and needs sub-models *to determine the number of FTEs.*

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Literature overview – Healthcare staffing models

Demand based approaches

Healthcare demand is an inferred demand *affected* by the *socioeconomic conditions* of a *country* and the *factors* of *total demand* for healthcare services are *population size*, *income* and *preferences* (Lopes et al., 2015). *Demand* approaches, according to Cruz-Gomes et al. (2018), *seek to forecast the future health workforce demand* by focusing on the development or *change* of the *driving forces* of the health services demand. These *forces* strongly relate to *demographic*, *socioeconomic* and *epidemiological* factors (Lopes et al., 2015). The demand model of Laurence and Karnon, (2016) *combines health needs* that include disease incidence and prevalence data, population data that is age- and gender specific, and level of service. These *variables* are *used* to *estimate* the *total level of services needed* for the *entire population* including the required number of GPs that will provide the desired level of services (Laurence and Karnon, 2016). The *majority* of *demand-based* approaches *build on* the descriptions of *needs* and *actual demand* with some *overlay* in their *scope of application* (Lopes et al., 2015).

Models	Brief description
• *Needs-based*	• *Determines* the *consequence of diseases*, by considering epidemiological trends, mortality and morbidity rates, *on* the *demand* for *health services* with the purpose of *estimating* the *quantity* of *personnel hours required* to *cover* the *needs* that arise as a result of a disease. (Lopes et al., 2015) • Dreesch *et al.* (2005), used the *populations' health needs* to *estimate* the *quantity* and *type* of *health services* that are to be provided for different age and gender groups which is usually established from service norms and morbidity trends. The authors' models *translate* the *service needs* to healthcare *workforce requirements* while *applying productivity standards* and *expert's judgement*.
• *Utilisation-based*	• Recognised by several authors as a demand approach. Economic (or effective) *demand refers* to the *actual services rendered* to the *population* while *considering socio-economic factors* (Lopes et al., 2015). Economic demand interprets the "*actual, observed demand, usually measured in terms of service utilisation ratios (such as bed occupancy rates, number of inpatients)*" • "*estimates the future health workforce requirements based on the current level of service utilization in relation to future projections of demographic profiles.*" (Dreesch *et al.*, 2005) • The current level of health services usage becomes the baseline for the health needs; and future health workforce requirements are determined by taking changes to the characteristics of the population into account. (Dreesch *et al.*, 2005)
• *Service-target based*	• *Specific targets* are *set* for the *quantity* and *type* of *services* at the different stages of care; *considering* existing *technology*, *services* already offered and the populations' demand for certain services (Dreesch *et al.*, 2005). These *targets* are then *translated* into *healthcare workforce requirements* using staffing and productivity *standards*.

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Literature overview – Healthcare staffing models

Workload based approaches

Workload measurement can be thought of as a basic *connection* between *healthcare service activity*, the work or *workload* performance involved in this activity, and the *required labour* to bear this workload (Ridoutt et al., 2006). The *relationship* between health service activity, workload, and labour requirements (demand) are illustrated in figure 1 which is at the *centre* of a *conversion* from *service demand* to *labour demand;* in theory the methods of calculation is similar to that of the *micro level or organisational level operations*. The degree of service activity demanded and the amount of work or effort involved (workload) to provide the activity, is used to determine the amount of required labour (Ridoutt et al., 2006).

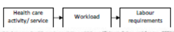

Figure 1: Relationship between health service activity and labour (Ridoutt, Schoo and Santos, 2006)

Models	Brief description
• *Ratio-based*	• Employs a *comparatively basic ratio* of *personnel* to *activity*, where the activity variable refer to measures such as the number of beds, number of 'bed days' or number of patients (Schoo *et al.*, 2008).
• *Procedure-based*	• Considers the *work executed* – directly and indirectly – to *deliver* the *healthcare service* such as, procedures, functions and broader areas of work or tasks. This method *uses* facility *specific studies* or *set standard practices* to *estimate* the *labour needed* to execute the procedures (in time units) and are best *applied* where *activities* are relatively *repetitive* and *routine* (Schoo *et al.*, 2008).
• *Categories of care or patient acuity*	• Apply a *ratio* of *personnel to patients* where various patient conditions such as, basic care needs and/ or therapeutic treatment requirements are considered. This method is primarily *intended* for *quick staffing changes* in reply to frequent *fluctuations* in *patient numbers* and *conditions*, which makes it suitable for environments where *patient throughput* is *high* and *variable*, such as general surgical or medical wards (Ridoutt et al., 2006).
• *Diagnostic or case mix-based*	• Schoo *et al.* (2008), states that "*cost weights in the form of hours of professional care to appropriately treat/ serve each diagnostic sub-group are established, and total staff requirements calculated by multiplying the hour per diagnostic group and anticipated case mix.*"
• *Combinations of above models*	• A combination or *mix* of *more* than *two* of the abovementioned methodologies. Schoo *et al.* (2008), reports from the literature a hospital pharmacy case applied a *mixed approach* and *divided* their *work* into three primary *functional areas*, namely (i) *clinical work*; (ii) *distribution services* work; and (iii) *management services* work. Each of these functional areas adopted a slightly *different methodological approach*.

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Literature overview – Radiology staffing models

Radiotherapy staffing approaches

Traditionally radiation therapists (RT) staffing models were founded only on the *number of linear accelerator* (linac) *machines available* at a cancer facility (Patel and Mitera, 2011). The RT staffing models *calculated the number of RTs required per linac-hour* . However, according to Griffiths (2000), "*radiographer staffing has a complex inter-relationship with workload, equipment, technology, specialist practice, range of practice and roles.*" Moreover, the size of the institution, its equipment base and case mix may also affect the staffing model and the *basic conceptualisation* of the radiation therapy *model* should *make provision* for *all* the *activities required* to achieve *workload* demands, including patient care needs (Griffiths, 2000).

Models	Brief description
• *Linear accelerator*	• Griffiths et al. (2006) developed a *staffing framework* and *formula* that is *based* on a *factor* for *core service activities* led by the radiotherapist and delivered within the available linac-hours[1] (machine hours) per day. • The *core services factor*, as established by the *survey* data, is *1.33 whole time equivalents (WTE) per linac-hour*; thus, assuming a 7-hour-day on a single linac, equates to 9.31 staff (7 x 1.33) that are needed to perform all the core activities (Griffiths et al., 2006). • It *includes all* other *resources* that contribute to the core services, i.e., radiographers, assistants, helpers, etc. Inclusive of the staff required, is a provision of *25%* for all *leave types*, continued professional development (*CPD*) activities, etc. (Griffiths et al., 2006).
• *Workload & activity based*	• The *revised* radiation therapy *staffing model* by Smith et al. (2016), *maintained* its fundamental operating principle which is "*full-time equivalent (FTE) radiation therapists (RTs) per linear accelerator hours*". The *new model* is based on *data*, *modern practice*, and provides better overall flexibility and utility relating to workforce planning and individual service delivery profiles (Smith et al., 2016). • Smoke and Ho. (2015), developed a *model* that used the *number* of *equipment* and *related clinical activities* to determine staffing levels. Time allocated to clinical activities and the identification of other key areas of responsibilities for radiation therapists (which were previously omitted in other RT staffing models), were determined by an expert panel using the Simplex Process Creativity Tool (Smoke and Ho, 2015). The *proposed model accounted* for the staffing needs of *all clinical activities* including additional essential areas of responsibility that supported clinical activities, such as brachytherapy, quality assurance, orthovoltage, radiation oncology systems, administration, technology development and / or implementation, education, and staff time off (Smoke and Ho, 2015). Moreover, an additional *20%* FTEs of the total is provisioned for *annual-*, *sick-*, *maternity-* and other *leave types* (Smoke and Ho, 2015).

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1 Linac-hour refers to the hourly run time of a linear accelerator machine (Routsis, Thomas and Head, 2006).

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Literature overview – Radiology staffing models

Radiotherapy staffing approaches

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Models	Brief description
• Linear accelerator	• Griffiths, Craig and Abraham, (2006) developed a staffing framework and formula that is based on a factor for core service activities led by the radiotherapist and delivered within the available linac-hours[1] (machine hours) per day. • The core services factor, as established by the survey data, is 1.33 whole time equivalents (WTE) per linac-hour; thus, assuming a 7-hour-day on a single linac, equates to 9.31 staff (7 x 1.33) that are needed to perform all the core activities (Griffiths, Craig and Abraham, 2006). • It includes all other resources that contribute to the core services, i.e., radiographers, assistants, helpers, etc. Inclusive of the staff required, is a provision of 25% for all leave types, continued professional development (CPD) activities, etc. (Griffiths, Craig and Abraham, 2006).
• *Workload & activity based*	• Tobergte and Curtis (2013), followed a similar approach termed an *activity-based algorithm* that *forecasts staffing levels* to address the need for a guide that *proposes* suitable *staffing levels* when *new services*, *expansions* or *upgrades* of current services within a *radiotherapy* environment are required. It seeks to *account* for *all* the *activities* along the whole radiotherapy workflow, such as patient- and, equipment-related activities; specific complex techniques; educational activities; and non-clinical activities. According to the authors, staffing levels are determined by several factors, including: the number of and intricacy of equipment; the number of patients; the types of procedures, their complexity and activities; and the number of students and trainees (Tobergte and Curtis, 2013). • Klein (2010), applied a *workload-driven methodology* to develop a staffing justification grid which matches the clinical needs of a radiation oncology department with the required number and quality of staff. The author *determined* the *total annual hours required* by *customising* the *activity times* from the Abt Associates Inc. (*Abt*) *study reports* to suit the local clinical environment. The *total annual hours* were *derived* from *multiplying* the *activity times* with the *anticipated activity frequency* in a given year.

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Literature overview – Radiology staffing models

Radiologist staffing approaches

Initially workforce *models* in radiology, especially for radiologists, were *dominated* by the *relative value unit (RVU)* system or an adaptation thereof. *RVUs* is an essential *measurement tool* which is used for *calculating reimbursement* of *physician services* and later was used to *determine radiologist workload* (Baadh et al. 2016). The *RVU method* had several *weaknesses* and did *not keep up* with *technology* and *procedural* advances and become *outdated* (Pitman et al., 2009). *Further development* in radiologist staffing *led* to the development of *workload* based or *activity* based *models* that *considered all* the *activities* performed by radiologists.

Models	Brief description
• *Relative value unit (RVU)*	• Pitman & Jones developed the Royal Australian and New Zealand College of Radiologists (*RANZCR*) relative value unit (*RVU*) *model*. Their technique uses *two* primary *measurements* namely (i) *'crude reporting RVU'* and *'net reporting RVU'* per annum per radiologists FTE (Pitman and Jones, 2006). Several *weaknesses* were identified and the model became *outdated*, particularly in computed tomography (*CT*) as it did *not account* for *newer, more time-consuming* CT *examinations* (Pitman et al., 2009). • Brady (2011) applied the *RANZCR RVU model* to determine the *crude reporting* and *net reporting RVU* to calculate the workload of consultant radiologists in Ireland. The author *made* some small *adjustments*, such as *assigning RVUs* to an *intravenous procedure* and changing descriptions of non-countable activity categories to reflect the Irish radiology context. Similarly Khan and Hedges (2013), applied the RAZCR RVU model with slight changes to the classification of some studies and *included non-reporting activities*.
• *Workload & activity based*	• Cowan et al. (2013), evaluated and *combined* two *methods*; (i) *simplest reporting measurement* that *uses raw examination numbers* or number of *reports* dictated per year (such as the RANZCR RVU) and (ii) using a Radiology Information System (*RIS*) to *measure radiologist reporting time*. The *latter* being *more accurate* and reducing the subjective component while the *former* is *flawed* as it uses *only raw examination numbers* (Cowan et al., 2013) • MacDonald et al. (2013) applied a *workload measurement approach* to *create* a clinical radiologists *activity list* that *includes* both *clinical* and *non-clinical* activities. Radiological image *reporting times* were *taken* from the radiology information system (*RIS*) while the *frequency* and *times* of each *activity* were *obtained* through *observation*, *timing* of radiologist's *activities* and *consensus* (MacDonald et al., 2013).

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Top 3 radiology staffing model challenges

Radiology (both radiologists & radiation therapists) staffing model challenges by theme	Khan & Hedges (2013)	Brady (2011)	Royal College of Radiologists (2012a)	Royal College of Radiologists (2012b)	Dubinsky (2013)	Dutton et al. (2014)	Smoke and Ho (2015)	Smith et al. (2016)	Griffiths (2000)	Klein (2010)	Van der Merwe et al. (2013)	Total
Staffing models are ***outdated*** – does not account for all the activities performed	x	x	x	x	x	x	x	x				8
Methods for measuring workload are ***outdated*** – use crude numbers	x	x			x						x	4
Staffing models does ***not*** consider ***all*** the ***variables*** related to the acquisition and reporting of images	x	x	x	x				x	x			6
No universally applicable and universally accepted weighting system		x										1
Process of staffing is overwhelming and complex										x		1
Challenging to match clinical physics needs with required staffing and skill										x		1
Lack time for training									x			1
Current staffing standards too basic and misunderstood										x		1
Neglect to address the "level of quality of staff"										x		1
Need to know how to fairly derive the time it takes to perform tasks										x		1
Lack evidence-based documentation describing models which accurately quantifies the number and type of professionals											x	1
Lack models that directly relate to patient workload, technology, technique and infrastructure											x	1
Need to be transparent and flexible to accommodate changes to service, modalities and technologies											x	1
Models are based on retrospective, subjective estimates and crude population size, equipment availability, and disease incidence											x	1

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Requirement Specification

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Broad category description of the requirement specification

Throughout the *literature review* and through *synthesis requirements specifications* were *identified* and grouped into *functional requirements, user requirements, design requirements* and *boundary conditions*. These *groupings are* based on the *categorisation* of Van Aken *et al*. (2007) and can be viewed in the table below.

Requirement specification categories, adapted from Van Aken *et al.,* (2007)

Requirement specification categories	Broad description of requirement categories
Functional requirements (FR)	Refers to the *capabilities* that the *framework* must *provide* to *address* the *needs* in the *operating* environment.
User requirements (UR)	Refer to the specific or expressed *need(s)* or desired *characteristic(s)* from the perspective of the *user*.
Boundary conditions (BC)	*Requirements* that must be *met unconditionally*.
Design restrictions (DR)	Requirements that describe a more desirable (*preferred*) *solution space*, considering any other *constraints* on the design of the framework.

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Requirement specification – *Functional* requirements

Functional Requirements (FR):
Refers to the *capabilities* that the framework must provide to *address* the existing radiology staffing framework challenges

RS Category	Description
FR 1	The framework should be able to *calculate* the *number* of *radiographers* required based on *supply* type *data*.
FR 2	The framework should be able to *calculate* the *number* of *radiographers* required based on *demand* type *data* that accommodates *changes*.
FR 3	The framework should be able to use *activity times* to determine workload.
FR 4	The framework should be able to *translate workload* to FTEs.
FR 5	The framework should be able to accommodate *productivity measures* as part of the staffing requirements.
FR 6	The framework should be able to calculate the *total available time per year* for a suitably qualified diagnostic radiographer.
FR 7	The framework should be able to *calculate* the *workload* for the post under review.
FR 8	The calculation translating workload to FTE requirements in the framework should be *transparent* and *reproducible*.

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Requirement specification – *User* requirements

User Requirements (UR): Specific or expressed *need*(s) or desired *characteristic*(s) from the perspective of the *user*	
RS Category	**Description**
UR 1	The framework must be able to allow the *capturing* of the *number* of *qualified diagnostic radiographers*. (e.g. *Identify the current number of qualified radiographers.)*
UR 2	The *competency level* of the qualified diagnostic radiographers must be captured. (e.g. *Identify the current competency of diagnostic radiographers in the different modalities.)*
UR 3	*Activities* performed by an appropriately qualified radiographer or under the supervision of qualified radiologists must be identified and listed. (e.g. *Create an activity list of the qualified radiographer.*)
UR 4	The framework must be *adjustable* to allow the capturing of the *number* of *equipment* and *modalities* that are *available* and in *use*.
UR 5	The framework must be *adjustable* to enter the *number* of *procedures* and/or techniques that are being used in *each modality*.
UR 6	The framework must allow the user to specify the number of *radiology practices* within the group (in other words it must allow for more than one practice to be indicated).
UR 7	The framework must allow the user to *specify local conditions* that are of significance and will impact on the workload of the department or unit. (e.g. *The physical layout of the department, its organisational structure, the key medical processes, patient flow and procedures related to the specific department.*) The model must incorporate an analysis of the *clinical flow* & identification of all the professional roles associated with the activities along the workflow.
UR 8	The framework should allow the *analysis* of *data* obtained from the integrated workflow management technologies (*IWMT*) such as PACS, RIS and VR as data relating to the *workflow* and *duration* can be collected from these systems.
UR 9	Framework must make provision for both *clinical* and *non-clinical activities*
UR 10	Framework must make provision for *adjustments* relating to *technological advances* (i.e. it must be easily adaptable when the clinical environment changes).
UR 11	The framework should make provision for capturing the current *available staff*, their *competency, skill set* and *employment status* (i.e. part- or full time).
UR 12	The framework should make provision for capturing the current available staff information relating to *age* and *gender*.
UR 13	The framework must make provision for capturing *demand-related* information.
UR 14	The framework should be able to *minimise subjectivity* of the *results* (and activity times) by utilising activity or procedure times from the radiology information system (RIS).
UR 15	The framework should consider the *maximum allowable working hours* per week when determining the workload.

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Requirement specification – Design Restrictions & Boundary Conditions

Design Restrictions (DR): Refer to a more desirable (*preferred*) *solution space*, considering any other *constraints* on the design of the framework	
RS Category	**Description**
DR 1	The framework will be constrained to the *diagnostic radiology* profession only.
DR 2	The framework will be constrained to appropriately *qualified diagnostic radiographers* only.
DR 3	The framework must be restricted to *diagnostic radiology equipment*, *modalities* and *procedures* (and/or techniques).
DR 4	The framework will be constrained to the private practice radiology environment.

Boundary Conditions (BC): The framework should conform to legal requirements and existing business policies, while blending in with the current company culture	
RS Category	**Description**
BC 1	The framework should consider the various *leave* allowances as stipulated by *law* and *company policies*.

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Compatibility evaluation – Summary table

The various approaches to determining *healthcare staffing* needs in general *(such as supply, demand* and *workload*-based approaches*)*, as well as the specific *radiotherapy* and *radiologist staffing* approaches that were discussed in previous slides, are *subjected* to *evaluation* against the *requirement specifications* to *identify* the *most suitable approach* that will serve as *basis* for the *development* of a *diagnostic radiographer staffing framework*.

The compatibility evaluation is summarised in tabular form in the table below, where a *'1'* indicates *compatibility* with the criteria and a *'-1'* indicates *incompatibility*.

	Supply-based approaches				**Demand-based approaches**				**Workload-based approaches**				**Radiotherapy staffing approaches**					**Radiologist staffing approaches**		
Criteria (Legend: '1' if the criteria is supported by the methodology and "-1" if it is not supported or incompatible.	Training and supply (incl. stock of individuals)	Productivity (incl. flow of activities)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of service	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Roudsis, Thomas & Head, 2006)	(Griffiths, Craig & Abraham, 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (Pitman & Jones, 2006); (Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(S. L. S. MacDonald et al., 2013); (Cowan, MacDonald & Floyd, 2013)
***Functional** Requirements*	-4	0	-2	-6	-4	-2	6	-2	6	2	2	-4	-4	-4	4	4	4	-6	-2	2
***User** Requirements*	-11	-7	-11	-13	-13	-11	1	-7	-5	-3	-7	-7	-3	-7	-3	5	-1	-11	-9	-3
Design Restrictions	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Boundary Conditions	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	1	1	1	-1	1	1	-1	-1	1
Grand Totals	**-20**	**-12**	**-18**	**-24**	**-22**	**-18**	**2**	**-14**	**-2**	**-6**	**-10**	**-14**	**-10**	**-14**	**-4**	**6**	**0**	**-22**	**-16**	**-4**

A **detailed account** of the **compatibility evaluation** can be viewed here

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Compatibility evaluation – Summary table

Staffing approaches	**Brief summary**
Supply based	Predominantly predict future *health workforce* through the analysis of factors that impact their *movement* as discussed in previous slides.
Demand based	Seek to predict the future health workforce demand by focusing on the *changes* of the driving *forces* that affect the *health service demand* as discussed in previous slides.
Workload-based	Use the *relationship* between health service *activity* and the work or effort involved (or *workload*) to determine the *required labour*. (Discussed in previous slides)
Radiotherapy staffing	Primarily based on the *number* of radiation therapists per *linac hour* (the number of hours that a machine was available in a day) but *evolved* into *workload-driven* and *activity-based* models as discussed in previous slides.
Radiologist staffing	Developed from a crude reporting relative value unit (*RVU*) measurement to a *workload measurement* approach that considers both *clinical* and *non-clinical* activities when determining radiologist staffing requirements. (Discussed in previous slides)

	Supply-based approaches				***Demand-based approaches***				***Workload-based approaches***				***Radiotherapy staffing approaches***					***Radiologist staffing approaches***		
Criteria (Legend: '1' if the criteria is supported by the methodology and "-1" if it is not supported or incompatible.	Training and supply (incl. stock of individuals)	Productivity (incl. flow of activities)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of service	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Roudsis, Thomas & Head, 2006)	(Griffiths, Craig & Abraham, 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (Pitman & Jones, 2006); (Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(S. L. S. MacDonald et al., 2013); (Cowan, MacDonald & Floyd, 2013)
***Functional** Requirements*	-4	0	-2	-6	-4	-2	6	-2	6	2	2	-4	-4	-4	4	4	4	-6	-2	2
***User** Requirements*	-11	-7	-11	-13	-13	-11	1	-7	-5	-3	-7	-7	-3	-7	-3	5	-1	-11	-9	-3
Design Restrictions	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Boundary Conditions	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	1	1	1	-1	1	1	-1	-1	1
Grand Totals	-20	-12	-18	-24	-22	-18	2	-14	-2	-6	-10	-14	-10	-14	-4	6	0	-22	-16	-4

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Compatibility evaluation – Staffing approaches against RS

	Supply-based approaches				**Demand-based approaches**				**Workload-based approaches**				**Radiotherapy staffing approaches**					**Radiologist staffing approaches**		
Criteria (Legend: '1' if the criteria is supported by the methodology and "-1" if it is not supported or incompatible.	Training and supply (incl. stock of individuals)	Productivity (incl. flow of activities)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of service	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Roudsis, Thomas & Head, 2006)	(Griffiths, Craig & Abraham, 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (Pitman & Jones, 2006); (Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(S. L. S. MacDonald et al., 2013); (Cowan, MacDonald & Floyd, 2013)
***Functional** Requirements*	-4	0	-2	-6	-4	-2	***6***	-2	***6***	2	2	-4	-4	-4	***4***	***4***	***4***	-6	-2	2
User Requirements	-11	-7	-11	-13	-13	-11	1	-7	-5	-3	-7	-7	-3	-7	-3	5	-1	-11	-9	-3
Design Restrictions	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Boundary Conditions	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	1	1	1	-1	1	1	-1	-1	1
Grand Totals	-20	-12	-18	-24	-22	-18	2	-14	-2	-6	-10	-14	-10	-14	-4	6	0	-22	-16	-4

Requirement specification (RS)	**Brief results summary**
Functional requirement (A detailed account can be viewed here)	• Tobergte & Curtis (2013), model scored the *second highest* in this category (together with Klein, 2010; Smith et al. 2016) after *service targeted* (and adjusted service targets) from the *demand-based approach*, and the *procedure-based* approach from the workload –based approach; which both scored the same amount. • The *primary difference* amongst these models is the *FR 5* which refers to the functionality of making provision for *productivity measures*. Since both the model from Tobergte and Curtis (2013), and the *procedure-based approach* are micro and meso staffing requirement approaches (as discussed in previous slides), the characteristics of how the *procedure-based model* incorporates productivity measures can be considered for the diagnostic radiographers staffing framework.
Design restrictions (A detailed account can be viewed here)	• The *design restrictions* for the development of the diagnostic radiographer's staffing requirement model were *not met* by *any* of the *models* under evaluation. Since these restrictions refer to the desirable (preferred) solution space, their consideration in the development of the radiographer staffing requirement framework is critical.

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Compatibility evaluation – Staffing approaches against RS

	Supply-based approaches				**Demand-based approaches**				**Workload-based approaches**				**Radiotherapy staffing approaches**					**Radiologist staffing approaches**		
Criteria (Legend: '1' if the criteria is supported by the methodology and "-1" if it is not supported or incompatible.	Training and supply (incl. stock of individuals)	Productivity (incl. flow of activities)	Skill mix	Worker to population ratios	Economic, utilisation, service utilisation rates and level of service	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff-to-activity)	Procedure	Category of care or patient acuity	Diagnostic or case mix	(Roudsis, Thomas & Head, 2006)	(Griffiths, Craig & Abraham, 2006)	(Smoke & Ho, 2015)	(Klein, 2010)	(Tobergte & Curtis, 2013)	(Smith et al., 2016)	RANZCR RVU; (Pitman & Jones, 2006); (Pitman et al., 2009)	Adjusted RANZCR RVU; (Brady, 2011); (Khan & Hedges, 2013)	(S. L. S. MacDonald et al., 2013); (Cowan, MacDonald & Floyd, 2013)
Functional Requirements	-4	0	-2	-6	-4	-2	6	-2	6	2	2	-4	-4	-4	4	4	4	-6	-2	2
User Requirements	-11	-7	-11	-13	-13	-11	1	-7	-5	-3	-7	-7	-3	-7	-3	**5**	-1	-11	-9	-3
Design Restrictions	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
Boundary Conditions	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	1	1	1	-1	**1**	1	-1	-1	1
Grand Totals	-20	-12	-18	-24	-22	-18	2	-14	-2	-6	-10	-14	-10	-14	-4	6	0	-22	-16	-4

Requirement specification (RS)	**Brief results summary**
User requirement (A detailed account can be viewed here)	• These specifications are from the viewpoint of the users and reflects their specific need(s) or desired characteristics for the framework. Tobergte and Curtis (2013), *scored* the *highest* in this category implying that the authors' model addressed most of the user requirements. • The *requirements* that were *not addressed* by the model were *also not addressed* by any of the *other models* under evaluation. These *requirements* are very *specific* to *diagnostic radiographers* and *their* specific *environment* and since no diagnostic radiographer staffing requirement model could be found these requirements could not be fulfilled by the models under evaluation. However, these requirements are essential and will be considered when developing the staffing requirement model for diagnostic radiographers.
Boundary conditions (A detailed account can be viewed here)	• The boundary conditions which are the requirements that the framework must meet unconditionally and that may not be altered, are *met* by the radiotherapy staffing model of Tobergte and Curtis (2013) and which also has the *highest evaluation score*.

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Compatibility evaluation in conclusion

The staffing model approach by Tobergte and Curtis (2013), that forms part of the *radiotherapy staffing approaches*, achieved the *highest compatibility score*, indicating that these authors' approach to determining staffing requirements is the *most closely aligned* to the needs of the diagnostic radiology environment of all the models under investigation. However, their approach is developed for the *radiotherapy environment* and *not a diagnostic radiology environment*.

The shortcomings of Tobergte and Curtis' (2013) *radiotherapy staffing model in terms of the diagnostic radiology environment relate to: FR1 and FR2; UR1, UR2, UR8 and UR12; and all four design requirements.*

Given the scope of the shortcoming, a simple *modification* or *adjustment* to the Tobergte and Curtis (2013) model will *not suffice*. However, the *principles* and *approaches* of their model *align closely* to the *requirement specification* and therefore be *utilised* as a starting point in developing a diagnostic radiographer staffing framework.

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Diagnostic Radiographer Staffing Framework

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Diagnostic Radiographer Staffing Framework Overview

Steps	Description	Input	Process	Output
1. Establish staffing purpose and focus	*Define* the *purpose* and *focus* of the staffing assessment or review.	*Identification* of the *staffing objectives, focus* and *challenges.*	*Interviews* with key stakeholders to identify objectives and challenges. Review *of performance reports.*	Agreed upon *staffing objective*(s) and challenges definition.
2. Collect basic data	*Collect* basic *data* related to the objective(s) and challenges identified.	*Data* related to staffing numbers; leave, statutory and regulatory policies; demographic (age & gender); type and quantity of procedures, modalities and equipment; patient numbers per procedure and intervention; roles and organisation, working hours.	*Collect* all the relevant *information* using a structured approach; *analyse* the information to ensure a good understanding of the operating context of the facility or organisation where the staffing assessment will be performed including the *operating context* of the post(s) to be reviewed.	*Data sheet* containing all the *relevant* information pertaining to the organisation; staffing objectives; challenges and post(s) to be assessed.
3. Determine available working time	*Establish* the *available time* per FTE for the period under review.	The various *time allowances* are accounted for such as personal breaks, statutory and regulatory breaks.	The *total available working days* in a year is *subtracted* from the *total leave provision days* in a year and then *multiplied* by the *number* of *working hours* in a *day* to *reach the total hours available per year.*	The *total available hours* per year *represents* the time that one fulltime employee (or fulltime equivalent – *FTE*) has available in a year to perform the activities of the post being occupied.
4. Develop a task/ activity list	*Develop* a *task list* that identify all the activities that constitute the workers daily time.	An *understanding* of the *activities* of the post to be analysed together with the *operating context* within which the post functions. In addition, *job descriptions* or *job profiles* and *interviews* with the incumbents in the post that needs to be assessed.	Use all the *relevant documents* (e.g. interview responses) and information system(s) e.g. RIS to gather information that can be used by the appropriately experienced radiology staff to *create* an *all-inclusive activity list*. *Validate* the list with the appropriately experienced and qualified radiology staff.	An all-inclusive *activity list*; a good understanding of the *operating environment* and other activity related (raw) data such as procedure types, frequency and some activity times (from the RIS).
5. Assign activity time & frequency of occurrence	Each *activity* performed by the incumbent is *assigned* both an activity *duration* & *frequency* of occurrence (how often the activity is performed).	The primary input document is the *activity list* from the previous step and the *RIS data* or any other activity times collected through various other methods such as direct observations, log sheets, questionnaires and expert opinions.	Several approaches exist for *obtaining activity times* and *frequencies* which could involve direct observations, interviews, questionnaires, *self*-monitoring, expert opinions and the use of external sources for standards amongst others.	An all-inclusive *activity list* with activity *times* and *frequency* for each activity performed by the incumbent.
6. Determine required full-time equivalents (FTE)	*Calculating* how many *FTEs* are required to execute a particular workload for a set period considering the most critical variables.	All *outputs* from the *previous steps* are used.	*Calculate* the *total quantity* of *workload* divided by the *total available time* for one FTE for a set period considering critical variables that impact the staffing requirements.	The *number* of *FTE's* (or workers) to execute a particular workload for a specified period.
7. Analyse and interpret the results	*Analyse* the *results* and consider their likely consequences.	The *number* of *FTE's* that is calculated and that is required for a specified workload. The agreed *staffing objectives* and *challenges* defined.	*Interpret* the *difference* between the *existing* and *required staffing level; ratio* of *existing* staffing level to the *required* staffing level (*assessing the daily work pressure*) and *analyse* activity *proportion* to total *workload* for improvements.	*Staffing strategies* that addressed the staffing needs.

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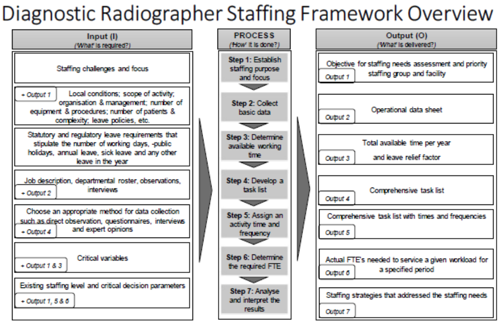
Diagnostic Radiographer Staffing Framework Overview



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Seven Step Diagnostic Radiographer Staffing Framework

Step 1: Establishing the staffing focus and purpose

- Any *staffing endeavour* should be *led* by a *purpose* or an objective for the pursuit. Many of the pursuits are *initiated* (or driven) by the *challenges* with *existing staffing models* (as mentioned previously). Increases in *demand, technological* advances and challenges in *delivering* a safe and premium service could trigger the evaluation of the workforce's workload and capacity to deliver a high quality and safe radiological service.
- Questions proposed by WHO (2010), WISN user manual was adapted to a diagnostic radiology setting and considering other questions based on the challenges within existing radiology staffing models, the *following questions* can be *used* as a *guideline* to *establish* the diagnostic radiographer *staffing purpose*:

No.	Description	Response
1	Are any alarming or concerning change, either increasing or decreasing, in radiographic imaging requests being experienced?	
2	Do these changes in radiographic imaging requests occur at any particular radiology site?	
3	Do these changes in radiographic imaging requests occur in any particular modality(ies)?	
4	Are acquisitions of any new facility or expansions of existing facilities being considered?	
5	Are any new radiographic imaging technology, techniques or procedures being introduced?	
6	Which staff category, such as general diagnostic radiographers including CT and MRI radiographers, sonographers and mammographers, are in shortest supply?	
7	Do staffing shortages affect multiple or specific radiology sites?	
8	Do staffing shortages affect multiple or specific radiological services?	
9	For which staffing category is staffing distribution likely to be most unbalanced or inequitable?	
10	Where (multiple or specific radiology sites) is the distribution of staff categories most unbalanced or inequitable?	
11	Is the quality of radiology service affected by staffing challenges? Examples include the following;	
	Does any of the radiology sites experiencing long waiting times and queues? Are radiological imaging requests completed within agreed standards? Are RTATs met?	

- The *output* of this step *builds* a *high-level understanding* of the key *staffing* requirement *purpose* and *focus* relating to the staffing category (diagnostic radiographer) and *location* (modality and site) that will be addressed by the staffing requirement assessment.

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Diagnostic Radiographer Staffing Framework

Step 2: Collect basic data

- This basic data should also be *related* to the *local conditions* where the staffing initiatives are planned.
- Authors Isambert *et al.* (2015), and others of the radiotherapy staffing approach group considered the collection of different basic data when determining staffing requirements for medical physics personnel.
- Considering the authors basic data requirements and adapting it to a diagnostic radiology environment, the *following list* can *serve* as a *guide* to *collect* the *appropriate data* to address the *purpose* and *focus* of the *staffing endeavour*.

No.	Description	Check/ Tick
1	Create a list with all the radiology sites	
2	Create a list of all services at each radiology site	
3	Create a list with all the examinations and procedures offered according to their modalities	
4	Create a list with all the examinations and procedures completed	
5	If any staff is involved in training, teaching, research and development, please provide the number of staff involved and the time spent (hours or minutes)	
6	Create a list of all qualified diagnostic radiographers including skill, employment status, gender and age group	
7	List all the equipment available and in use	
8	Is procedure and examination times available from the radiology information system (RIS)? If yes, please add times to the examination and procedure list	
9	Consider the leave and any statutory and regulatory policies that guide or prescribe how leave allocation are done and how many. Create a list of all leave types and the days available per leave type	
10	How many hours does a radiographer work in a day? How many days in a week does a radiographer work?	
11	Consider local conditions relevant to the workload of the radiology department or unit such as, physical layout of the department; organisational structure, and key clinical and non-clinical processes.	

- Once this data is *collected, analysed* and *logically arranged* it will *create* a *clear picture* of the *current situation* within the diagnostic radiology environment and *set* a solid *foundation* for the staffing requirement.

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Diagnostic Radiographer Staffing Framework

Step 3: Determine available working time

- Determining the available working time is a key component in the formula for determining the staffing requirements.
- This is the total working time available per FTE for the period under review (normally a year or a month). The available time considers the time allowed for breaks (such as tea and rest breaks). It also includes the allowances for statutory and regulatory breaks (such as sick days, public holidays, family responsibility leave and annual leave).
- To convert total activity hours to FTE's, the average available hours in a year (or month) for an FTE needs to be calculated. WHO (2010), WISN user manual proposed the following formula for estimating the available time per year:

AWT = [A - (B + C + D + E)] x F

- AWT is the total available working time
- A is the number of possible working days in a year
- B is the number of days off for public holidays in a year
- C is the number of days off for annual leave in a year
- D is the number of days off due to sick leave in a year
- E is the number of days off due to other leave, such as training, etc., in a year
- F is the number of working hours in one day

- S. L. S. MacDonald et al. (2013); Tobergte and Curtis (2013); Smoke and Ho (2015) and Smith et al. (2016), are amongst the several radiology researchers that used this approach when determining the available working time in their staffing models.

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Diagnostic Radiographer Staffing Framework

Step 4: Develop a task or activity list

- Compiling an *activity list* is a *key step* in determining *staffing* levels as all the tasks or activities associated with the position under review should be considered (listed). These are the activities that consume most of the position's daily working time.
- MacDonald *et al.* (2013) used *three methods* namely, *observation*, *measurement* and *consensus* to create an *activity* list and time requirements. *Alternative* methods for establishing an activity list is through the use of *manpower evaluation documents* such as the *Abt studies*, used by Klein (2010), and Smoke and Ho (2015), assigned a panel of *experts* to review and elaborate on an existing activity list.
- Klein (2010) in their study used CPT® codes from the Abt study and customised it to their clinical situation to create an activity list. Similarly Smith et al. (2016), used Medicare Benefits Schedule (*MBS*) *codes* as a *basis* for an *activity list* in their radiation therapy staffing model.
- The radiology environment and other medical professionals in *South Africa* similarly use *uniform codes* namely the National Health Reference Price List (*NHRPL*) and the Compensations for Occupational Injuries and Diseases Act (*COIDA*) as reference for reimbursement from medical aids. These codes are also referred to as medical aid tariff codes.
- The *NHRPL* reference uniform *codes* for *examinations* and *procedures* in radiology. Hence these codes *can* be *used* as basis to *develop* an *activity list* for *diagnostic radiographers* since it includes all the examinations and procedures performed by these professionals.
- The *output* of this step is a *comprehensive task list* that outlines the nature of each task and its unit of measure. This serves then as an *input* to the *measurement step.*

An example of an activity list using examination codes

Examination code	Modality	Examination description
110	X-ray	X-ray skeletal survey under five years
115	X-ray	X-ray skeletal survey over five years
120	X-ray	X-ray sinogram any region
140	X-ray	X-ray fluoroscopy any region
145	X-ray	X-ray fluoroscopy guidance for biopsy, any region
220	US	Ultrasound intra-operative study
230	US	Ultrasound guidance
240	US	Ultrasound guidance for tissue ablation
310	CT	CT planning study for radiotherapy
330	CT	CT guidance, with diagnostic procedure

Current Procedural Terminology (CPT®) codes are formulated by the American Medical Association (AMA) as a uniform language that assigns numbers to every task and medical service that doctors, and health care professional provide to patients such as surgical, medical and diagnostic services.

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Diagnostic Radiographer Staffing Framework

Step 5: Assign an activity time and frequency to each activity

- An activity time is assigned to each of the tasks/ activities identified and the associated frequency of occurrence (number of events) or activity volume.
- *Several methods* for determining staffing requirements were *identified* in the *literature.*

Ozcan and Hornby (1999)	Kolehmainen-Aitken (1993)	Maynard (2004)
1. direct observation of staff activities; 2. self-monitoring using a log or a diary; 3. questionnaires; 4. interviewing relevant staff; and, 5. expert opinion.	1. Standards obtained from external sources; 2. Standards based on expert opinion; 3. Standards based on experience; 4. Standards based on functional and task analysis; and 5. Indicators of staffing needs.	1. Estimation 2. Direct observation; and 3. Standard data systems

- Kolehmainen-Aitken (1993) argues that *no single best method* exists, though Ridoutt et al. (2006) point out that instead, *each approach* has its *strengths* and *weaknesses*, which pertains to its *accuracy*, *cost* and *time* to complete.
- *Estimation* is considered the *least accurate* method, but it *demands* the *least amount of time* to establish time standards (Maynard, 2004)
- The *limitation* of *accuracy* can be *mitigated* through the application of a process frequently applied in critical path scheduling namely programme evaluation and review technique (*PERT*) (Maynard, 2004). This model makes use of *judgement estimation* to determine the *time values* of *each task* (activity).
- *Three estimates* are done for each activity instead of one and they are an *optimistic time*, a *pessimistic time* and a *most likely time.*

$T_e=(t_o+4t_m+t_p)/6$

- where T_e = *mean of the beta distribution*, the mean time estimate for the task; t_o = *optimistic time estimate*; t_m = *most likely time estimate*; t_p = *pessimistic time estimate*

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Diagnostic Radiographer Staffing Framework

Step 5: Assign an activity time and frequency to each activity

- A *mean time estimate for each examination* is computed based on the following formula: $T_e=(t_o+4t_m+t_p)/6$
- *Below* is a table depicting the *template* used for *computing* the *mean time estimate for each examination*

An example of a template for logging activity data

Examination code	Modality	Examination description	Activity type	Examination frequency (per month)	Optimistic Time (To) (min)	Most likely time (Tm) (min)	Pessimistic Time (Tp) (min)	Mean Time Estimate for Examination (Te) (min)
110	X-ray	X-ray skeletal survey under five years	0					0
115	X-ray	X-ray skeletal survey over five years	0					0
120	X-ray	X-ray sinogram any region	0					0
140	X-ray	X-ray fluoroscopy any region	0					0
145	X-ray	X-ray fluoroscopy guidance for biopsy, any region	0					0
220	US	Ultrasound intra-operative study	0					0
230	US	Ultrasound guidance	0					0
240	US	Ultrasound guidance for tissue ablation	0					0

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Diagnostic Radiographer Staffing Framework

Step 6: Determine the workload and required FTE

- The mathematical product of the *activity time and frequency of occurrence* is the workload which is depicted by the following :

Workload = Business Volume x labour standard

- The frequency of occurrence or activity volume denotes the business volume in this formula and the activity time denotes the labour standard.
- Maynard (2004), proposes the following theoretical formula for full-time equivalent (FTE) which is the total time (workload) divided by total available time:

$$Theoretical\ full-time\ equivalent\ (FTE)\ needed = \frac{T}{Hours\ available\ per\ FTE\ per\ time\ period}$$

- Where T = *total workload in standard hours for a specific time period.*
- However, the above formula assumes staff are 100 percent utilised which is unrealistic. Demand variability, skill level requirements, coverage matters, scheduling constraints and factors alike will affect the actual required number of FTEs reference. When considering these types of factors, a utilisation standard can be added to the above-mentioned formula, more specifically to the *available hours*. Hence the following formula (Maynard, 2004):

$$FTE\ needed = \frac{T}{Hours\ available\ per\ FTE\ per\ time\ period\ \times \boldsymbol{utilisation\ standard}}$$

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Diagnostic Radiographer Staffing Framework

Step 6: Determine the workload and required FTE

- The *workload hours per month for each examination* is computed based on the following formula:

Workload = Examination frequency x Mean time estimate; and

$$FTE\ required = \frac{Workload}{Hours\ available\ per\ FTE\ per\ time\ period\ \times \%\ efficiency}$$

- Below is a table depicting the *template* used for *computing* the *workload hours per month for each examination* and the *FTE required (per month)* at different *efficiency levels*

An example of a template indicating the required FTE at various efficiency levels

Examination code	Modality	Examination description	Activity type	Examination frequency (per month)	Optimistic Time (To) (min)	Most likely time (Tm) (min)	Pessimistic Time (Tp) (min)	Mean Time Estimate for Examination (Te) (min)	Workload (hrs) per month for examination	FTE required (per month) @ …% efficiency: 100	Rounded @ 100	90	80	70
110	X-ray	X-ray skeletal survey under five years	0					0	0,00	0	0,0	0,0	0,0	0,0
115	X-ray	X-ray skeletal survey over five years	0					0	0,00	0	0,0	0,0	0,0	0,0
120	X-ray	X-ray sinogram any region	0					0	0,00	0	0,0	0,0	0,0	0,0
140	X-ray	X-ray fluoroscopy any region	0					0	0,00	0	0,0	0,0	0,0	0,0
145	X-ray	X-ray fluoroscopy guidance for biopsy, any region	0					0	0,00	0	0,0	0,0	0,0	0,0
220	US	Ultrasound intra-operative study	0					0	0,00	0	0,0	0,0	0,0	0,0
230	US	Ultrasound guidance	0					0	0,00	0	0,0	0,0	0,0	0,0
240	US	Ultrasound guidance for tissue ablation	0					0	0,00	0	0,0	0,0	0,0	0,0

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Diagnostic Radiographer Staffing Framework

Step 7: Analyse and interpret the results

This step is to *analyse the results* and consider their *likely consequences*. The results can be *scrutinised* in the *following ways* as described by WHO (2010):

- Drawing a *comparison* of the *existing staffing level* to the calculated or *required staffing level* will *indicate* where there is an *overstaffing* or *understaffing* issue that requires management's attention This can be computed by the following:

  Difference = existing staffing level - required staffing level

- If the *existing staffing level* is *greater* than the *required staffing level*, the result (difference) will be a *positive value* which indicates a *excess* of diagnostic radiographers.
- If the *required staffing level* is *greater* than the *existing staffing level* the difference will be *negative* resulting in an *shortage*, surplus or *overstaffing* of diagnostic radiographers.
- The results of the difference between the existing staffing level and the required staffing level should always be *considered* within the *context* of the *local condition* of the radiology environment where the staffing requirement assessment was performed.
- The results interpretation of the "Difference" calculation is depicted in the table below.

Results table depicting the current and required FTE as well as the interpretation

Radiology site	Current number of Diagnostic radiographer	Required FTE	Difference (current vs required)	Staffing analysis
MMC	16	18	-2	Shortage
RMC	15	12	3	Excess
KRM	17	16	1	Excess
VP	8	8	0	Sufficient

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Diagnostic Radiographer Staffing Framework

Step 7: Analyse and interpret the results

- The ratio of the *existing staffing level* to the *required staffing level* indicates the *degree of pressure or strain* under which the diagnostic radiographers are working to manage the annual or daily workload.
- The *workload strain ratio* is calculated as follows: Workload strain = (Existing staffing level) / (Required staffing level)
- A workload strain result, *greater than 1.0*, indicates that there are *enough* diagnostic radiographers to meet the required workload.
- When the workload strain is *less than 1.0*, it shows that the existing diagnostic radiographers is *not enough* to service the workload demand and a *shortage* of diagnostic radiographers exist. The *smaller the workload strain ratio*, the *greater the workload pressure or strain*.
- When the *existing staffing level* is *equal* to the *required staffing level*, the workload strain will equal *1.0*, which indicates that the existing diagnostic radiographers are *enough* to meet the workload demand and that the staffing level is in balance.

Results table depicting the current and required FTE including its interpretation and workload strain

Radiology site	Current number of Diagnostic radiographer	Required FTE	Difference (current vs required)	Staffing analysis	Workload strain	Workload strain analysis
MMC	16	18	-2	Shortage	0,89	High
RMC	15	12	3	Excess	1,25	Low
KRM	17	16	1	Excess	1,06	Low
VP	8	8	0	Sufficient	1,00	None

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Diagnostic Radiographer Staffing Framework

Step 7: Analyse and interpret the results

- The *numerical results* and *analysis* should be *considered* with the *knowledge* and *context* of the *local* radiology operating *environment* to provide a *common-sense analysis* and meaning to the calculated numbers.
- WHO (2010) *suggest* the following *questions* when *examining* the *staffing requirements output*:
  - Do the results portray an accurate representation of the staffing status at the radiology site or location?
  - If any discrepancy exists, consider what might the cause be between the calculated staffing requirements and what the current reality portrays;
  - Where the activity (and examination) times used in the workload calculation realistic?
  - Is there any need to validate the activity times? If yes, by whom?
  - Were all the activities both clinical and non-clinical considered when determining the workload?
  - Are all the activities suitable for the post under review or can it be done by someone else? If yes, by whom and what should the requirements of such a post be?
- When the outcomes and interpretation of the results after examination are questionable (or not accurately reflecting the local conditions of the radiology site or location), it can be improved.
- The *accuracy* of the *results* is most *affected* by the *activity times* which can be *refined depending* on the *method* used as discussed in *step 5*. However, this *higher accuracy* most certainly comes with *additional effort* and *cost* which should be considered in the light of the objectives, as identified in step 1, and whether it will substantially change the decision outcome of the staffing requirement.
- *Examining* and *interpreting* the staffing requirement *results* within the *context* of the *local conditions* is *vital* to *ensure* that it is *representative* of the staffing requirements and within an *acceptable level* of *accuracy*. Since, the results will inform future staffing decisions.

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Validation questions (open–ended)

Classification	Questions
Relevant bodies of literature	• Were the relevant bodies of literature considered in the development process of the *requirement specification* and *framework*? • Are you aware of any other literature that should be included?
Purpose of the framework	• Will the diagnostic radiographer staffing framework *achieve* its stated *purpose* - is it fit for purpose? • Do you know of *any other* radiology *staffing framework* that can determine the required number of diagnostic radiographers?
Framework development process	• Did the requirement specifications adequately *capture* the *staffing needs* of a diagnostic radiographers environment? • Are there any *other requirements* that should be considered or included? • Did the diagnostic radiographer staffing *framework* (the solution) adequately *address* the *requirement specification*?
Framework *Strengths*	• What would you describe as the key *strength* of the proposed framework? • Where do you think can the framework's strengths assist with its implementation that relates to practicability and usability?
Framework *weaknesses*	• What would you consider as the key *weakness* of the proposed framework?

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Appendices

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	Supply-based approaches				Demand-based approaches				Workload-based approaches				Radiotherapy staffing approaches					Radiologist staffing approaches		
Criteria (Legend: '1' if the criteria is supported by the methodology and "-1" if it is not supported or incompatible.	Training and supply (incl. stock of individuals)	Productivity (incl. [illegible] activities)	Skill mix	Worker to population ratio	Economic, utilisation, service utilisation ratio and level of service	Needs, health needs and epidemiology	Service targets and adjusted service targets	Ratio (staff to activity)	Procedure	Category of care or patient acuity	Diagnostic encounters	[illegible], Thomas & Heal, 2008)	(Griffiths, Craig & Abraham, 2008)	[illegible] & Ho, 2015)	[illegible], 2010)	[illegible] & Curtis, 2010)	(Smith et al., 2016)	RANZCR RVU [illegible]	Adjusted RANZCR RVU [illegible]	[illegible] MacDonald et al., 2013) [illegible]
Functional Requirements	-4	0	-2	-6	-4	-2	6	-2	6	2	2	-4	-4	-4	4	4	4	-6	-2	2
FR1: Calculate the number of healthcare professional required based on supply type data (defined in section ....)	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1	-1	-1	-1	-1	-1	-1
FR 2: Calculate the number of healthcare professional required based on demand type data (defined in section ....potential and effective) Ref to UR13 combine??	-1	-1	-1	-1	1	1	1	1	1	1	1	-1	-1	-1	1	1	1	-1	-1	-1
FR 3: Apply activity times to calculate workload (consider defining an activity in this context to include procedures and cases consisting of many activities)	-1	1	1	-1	-1	-1	1	1	1	1	-1	-1	-1	1	1	1	1	-1	1	-1
FR 4: Translate workload to full-time equivalents (FTE)	-1	-1	-1	-1	-1	-1	1	-1	1	1	1	-1	-1	-1	1	1	1	-1	1	1
FR 5: Accommodate productivity measures as part of the staffing requirements (what is defined as productivity measures? - productivity norms)	-1	1	-1	-1	-1	1	1	-1	1	1	1	1	-1	-1	-1	-1	-1	1	1	1
FR 6: Calculate the total available time per year (as used in calculation)	-1	-1	-1	-1	-1	-1	1	-1	1	-1	-1	-1	-1	-1	1	1	1	-1	-1	1
FR 7: Calculate the workload of the post/position under review	-1	-1	-1	-1	-1	-1	1	-1	1	-1	1	-1	-1	-1	1	1	1	-1	-1	1
FR 8: The calculation translating workload to FTEs required should be transparent (easily understood) and reproducible	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	-1	1

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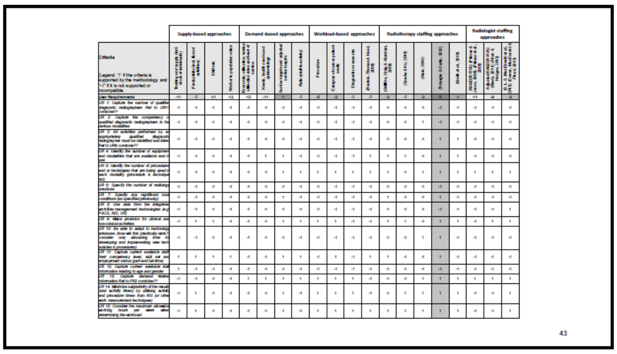

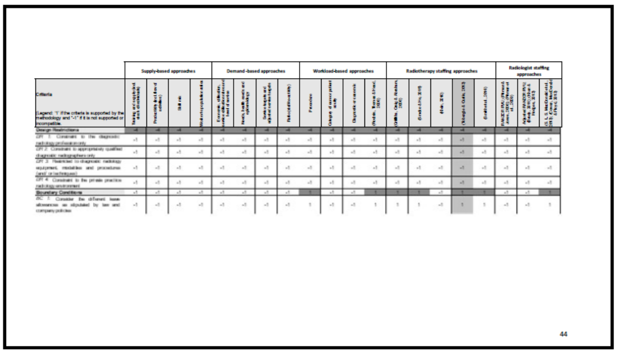

A.2 Appendix A: Conclusion

In this appendix, the pre-read document that contains the verification questions was presented.

Appendix B: **Activity list**

This appendix contains the activity list of both clinical and non-clinical activities that was used in the case application to determine the workload and staffing requirements (required FTE).

B.1 Clinical activity list from the case study

Table B.1 shows the clinical activity list extracted from the case study site's RIS and contains the examination description, exam code and modality name.

Table B.1: Activity list from case study application depicting clinical activities

Examination description	Exam code	Modality name
Doppler hep, spleen, IVC - portal hypertension / thrombosis (41210)	41210	Ultrasound
U/S Abdomen (41200)	41200	Ultrasound
U/S Abdomen + Pelvis (40210)	40210	Ultrasound
U/S Abdominal wall (40200)	40200	Ultrasound
U/S Bilateral lower limb, pulse & doppler, compress & reflux, all veins (70240)	70240	Ultrasound
U/S Biopsy (USB)	USB)	Ultrasound
U/S brain Neonatal (10200)	10200	Ultrasound
U/S breast (34200)	34200	Ultrasound
U/S Breast FNA (USBFNA)	USBFN	Ultrasound
U/S Breast Localisation (USBL)	USBL)	Ultrasound
U/S Carotids & Vertebral plus doppler (20220)	20220	Ultrasound
U/S Chest Wall any region (30200)	30200	Ultrasound
U/S Doppler resistive index transplant kidney vessels (42205)	42205	Ultrasound
U/S female pelvis transvaginal (43205)	43205	Ultrasound
U/S Groin Bilateral (USGB)	USGB)	Ultrasound
U/S guidance (00230)	00230	Ultrasound
U/S Guided Ascites Tap (USAT)	USAT)	Ultrasound
U/S Guided Aspiration FNA/localisation Breast (34205)	34205	Ultrasound
U/S Guided Breast Core Biopsy (USBCB)	USBCB	Ultrasound
U/S Guided Chest Drain Insertion (USCDI)	USCDI	Ultrasound
U/S Guided Drainage (USD)	USD)	Ultrasound
U/S Guided Joint Infiltration (USJI)	USJI)	Ultrasound
U/S Guided Liver Biopsy (USLB)	USLB)	Ultrasound
U/S Guided Pleural Aspiration (USPA)	USPA)	Ultrasound
U/S Guided Renal Biopsy (USRB)	USRB)	Ultrasound
U/S Guided Thyroid FNA (USTFNA)	USTFN	Ultrasound
U/S hip joints (56200)	56200	Ultrasound
U/S Lower Limb Soft Tissue any region (70200)	70200	Ultrasound
U/S LT Ankle (74210)	74210	Ultrasound
U/S LT Axilla Soft Tissue (60200LAX)	60200	Ultrasound
U/S LT Elbow joint (63200)	63200	Ultrasound
U/S LT Finger (USFL)	USFL)	Ultrasound

Examination description	Exam code	Modality name
U/S LT Foot (74220)	74220	Ultrasound
U/S LT Groin (USGL)	USGL)	Ultrasound
U/S LT Hand (USHL)	USHL)	Ultrasound
U/S LT Hip (USLH)	USLH)	Ultrasound
U/S LT Knee joint (72200)	72200	Ultrasound
U/S LT Shoulder joint (61200)	61200	Ultrasound
U/S LT Wrist (65200)	65200	Ultrasound
U/S Neck soft tissue (20210)	20210	Ultrasound
U/S pelvis transabdominal (43200)	43200	Ultrasound
U/S Peripheral Venous Lower Limbs & Doppler DVT (70230)	70230	Ultrasound
U/S Peripheral venous upper limbs & doppler DVT (60230)	60230	Ultrasound
U/S Pleural Space (30210)	30210	Ultrasound
U/S Pregnancy 1st trimester (43250)	43250	Ultrasound
U/S Procedure in Theatre (SOTHEATRE)	SOTHE	Ultrasound
U/S renal arteries + Doppler (42210)	42210	Ultrasound
U/S renal tract + bladder (42200)	42200	Ultrasound
U/S RT Ankle (74215)	74215	Ultrasound
U/S RT Axilla Soft Tissue (60200RAX)	60200	Ultrasound
U/S RT Elbow joint (63205)	63205	Ultrasound
U/S RT Finger (USFR)	USFR)	Ultrasound
U/S RT Foot (74225)	74225	Ultrasound
U/S RT Groin (USGR)	USGR)	Ultrasound
U/S RT Hand (USHR)	USHR)	Ultrasound
U/S RT Hip (USRH)	USRH)	Ultrasound
U/S RT Knee joint (72205)	72205	Ultrasound
U/S RT Shoulder joint (61210)	61210	Ultrasound
U/S RT Thumb (USTR)	USTR)	Ultrasound
U/S RT Wrist (65210)	65210	Ultrasound
U/S salivary glands/floor of the mouth (18200)	18200	Ultrasound
U/S testes (43220)	43220	Ultrasound
U/S thyroid (20200)	20200	Ultrasound
U/S Upper limb soft tissue any region (60200)	60200	Ultrasound
(blank)	(blank)	Ultrasound
U/S Soft Tissue Neck (20210)	20210	Ultrasound
U/S Venous Lower Limbs DVT & Doppler (70230)	70230	Ultrasound
U/S Soft Tissue Lower Limb any region (70200)	70200	Ultrasound
U/S Venous Upper Limbs DVT & doppler (60230)	60230	Ultrasound
U/S Soft Tissue Upper Limb any region (60200)	60200	Ultrasound
U/S Both Lower Limbs, pulse & doppler, compress & reflux, all veins (70240)	70240	Ultrasound
U/S RT Leg Arterial & Doppler (70220)	70220	Ultrasound
U/S Neonatal Brain (10200)	10200	Ultrasound
U/S RT Arm Arterial & Doppler (60220)	60220	Ultrasound
U/S Transplant Kidney Vessels Doppler resistive index (42205)	42205	Ultrasound
U/S Guided Cutting Needle or Trochar Biopsy (80610US)	80610	Ultrasound

Examination description	**Exam code**	**Modality name**
U/S Guided Fine Needle Aspiration Biopsy any region (80605US)	80605	Ultrasound
U/S LT Leg Arterial & Doppler (70210)	70210	Ultrasound
U/S Guided Abscess or Cyst drainage any region (80600US)	80600	Ultrasound
U/S Abdomen (41200)	41200	Ultrasound
U/S Abdomen + Pelvis (40210)	40210	Ultrasound
U/S breast (34200)	34200	Ultrasound
U/S female pelvis transvaginal (43205)	43205	Ultrasound
U/S pelvis transabdominal (43200)	43200	Ultrasound
U/S RT Knee joint (72205)	72205	Ultrasound
U/S Abdomen (41200)	41200	Ultrasound
U/S LT Knee joint (72200)	72200	Ultrasound
U/S Upper limb soft tissue any region (60200)	60200	Ultrasound
Percutaneous double J stent insertion + access (85605)	85605	Theatres
Theatre Fluoroscopy 1 x 30minutes (XT30)	XT30)	Theatres
Theatre Fluoroscopy 10 x 30minutes (XT5)	XT5)	Theatres
Theatre Fluoroscopy 2 x 30minutes (XT1)	XT1)	Theatres
Theatre Fluoroscopy 3 x 30minutes (XT1.5)	XT1.5	Theatres
Theatre Fluoroscopy 4 x 30minutes (XT2)	XT2)	Theatres
Theatre Fluoroscopy 5 x 30minutes (XT2.5)	XT2.5	Theatres
Theatre Fluoroscopy 6 x 30minutes (XT3)	XT3)	Theatres
Theatre Fluoroscopy 7 x 30minutes (XT3.5)	XT3.5	Theatres
Theatre Fluoroscopy 8 x 30minutes (XT4)	XT4)	Theatres
Theatre Fluoroscopy 9 x 30minutes (XT4.5)	XT4.5	Theatres
Abdomen multiple views (40105)	40105	Radiography
Abdomen multiple views plus Chest (40110)	40110	Radiography
Abdomen single view (40100)	40100	Radiography
AC Joints plus Stress Bilateral (61128)	61128	Radiography
Both Feet (BOTH FEET)	BOTH	Radiography
Both Feet standing single view (74140)	74140	Radiography
Both Femurs (BOTH FEMURS)	BOTH	Radiography
Both Hands (BOTH HANDS)	BOTH	Radiography
Both Knees (BOTH KNEES)	BOTH	Radiography
Both Knees standing single view (72150)	72150	Radiography
Both Lower Legs (BOTH LOWER LEGS)	BOTH	Radiography
Both Shoulders (BOTH SHOULDERS)	BOTH	Radiography
Cervical Spine multiple views (51120)	51120	Radiography
Cervical Spine multiple views plus stress (51130)	51130	Radiography
Cervical Spine one or two views (51110)	51110	Radiography
Cervical Spine stress only (51100)	51100	Radiography
Chest & Ribs (30155)	30155	Radiography
Chest complete with additional views (30120)	30120	Radiography
Chest PA and lateral (30110)	30110	Radiography
Chest single view (30100)	30100	Radiography
Facial Bones (11100)	11100	Radiography
Immigration Chest (9110)	9110)	Radiography

Examination description	Exam code	Modality name
LT A-C joint (61120)	61120	Radiography
LT Ankle (74100)	74100	Radiography
LT Calcaneus (74130)	74130	Radiography
LT Clavicle (61100)	61100	Radiography
LT Elbow (63100)	63100	Radiography
LT Femur (71100)	71100	Radiography
LT Finger (65120L)	65120	Radiography
LT Foot (74120)	74120	Radiography
LT Forearm (64100)	64100	Radiography
LT Hand (65100)	65100	Radiography
LT Hand bone age (65110)	65110	Radiography
LT Hip (56100)	56100	Radiography
LT Humerus (62100)	62100	Radiography
LT Knee multiple views (72110)	72110	Radiography
LT Knee one or two views (72100)	72100	Radiography
LT Knee plus Patella (72120)	72120	Radiography
LT Knee plus stress (72130)	72130	Radiography
LT Lower leg (73100)	73100	Radiography
LT Scaphoid (65140)	65140	Radiography
LT Scapula (61110)	61110	Radiography
LT Shoulder (61130)	61130	Radiography
LT Shoulder plus Subacromial Impingement (61140)	61140	Radiography
LT Toe (74145L)	74145	Radiography
LT Wrist (65130)	65130	Radiography
LT Wrist, Scaphoid plus stress (65150)	65150	Radiography
Lumbar Spine 2+ views plus stress (53130)	53130	Radiography
Lumbar Spine multiple views (53120)	53120	Radiography
Lumbar Spine one or two views (53110)	53110	Radiography
Lumbar Spine stress only (53100)	53100	Radiography
Namibia Visa Chest (9103)	9103)	Radiography
Nasal Bones (11120)	11120	Radiography
Naso-Pharyngeal Soft Tissue (13130)	13130	Radiography
NC008 Simplici TB - Chest PA (T1024912-30100)	T1024	Radiography
Orbits 3 or more views plus foramina (12110)	12110	Radiography
Orbits for foreign body (12120)	12120	Radiography
Orbits less than three views (12100)	12100	Radiography
Orthopantomogram (14110)	14110	Radiography
Orthopantomogram Jaw and Teeth (14110)	14110	Radiography
Paranasal Sinuses multiple views (13110)	13110	Radiography
Paranasal Sinuses single view (13100)	13100	Radiography
Pelvis (55100)	55100	Radiography
Pelvis & Hips (56120)	56120	Radiography
Pilot Chest (9204)	9204)	Radiography
Ribs (30150)	30150	Radiography
RT A-C joint (61125)	61125	Radiography
RT Ankle (74105)	74105	Radiography

Examination description	Exam code	Modality name
RT Ankle plus stress (74115)	74115	Radiography
RT Calcaneus (74135)	74135	Radiography
RT Clavicle (61105)	61105	Radiography
RT Elbow (63105)	63105	Radiography
RT Femur (71105)	71105	Radiography
RT Finger (65120R)	65120	Radiography
RT Foot (74125)	74125	Radiography
RT Forearm (64105)	64105	Radiography
RT Hand (65105)	65105	Radiography
RT Hip (56110)	56110	Radiography
RT Humerus (62105)	62105	Radiography
RT Knee multiple views (72115)	72115	Radiography
RT Knee one or two views (72105)	72105	Radiography
RT Knee plus Patella (72125)	72125	Radiography
RT Knee plus stress (72135)	72135	Radiography
RT Lower leg (73105)	73105	Radiography
RT Patella (72145)	72145	Radiography
RT Scaphoid (65145)	65145	Radiography
RT Scapula (61115)	61115	Radiography
RT Shoulder (61135)	61135	Radiography
RT Shoulder plus Subacromial Impingement (61145)	61145	Radiography
RT Subacromial Impingement only (61155)	61155	Radiography
RT Toe (74145R)	74145	Radiography
RT Wrist (65135)	65135	Radiography
RT Wrist, Scaphoid plus stress (65155)	65155	Radiography
Sacro-iliac joints (54110)	54110	Radiography
Sacrum and Coccyx (54100)	54100	Radiography
SBE Gastrografin follow through single contrast (40153)	40153	Radiography
Skeletal Survey over five years (00115)	00115	Radiography
Skeletal Survey under five years (00110)	00110	Radiography
Skull (10100)	10100	Radiography
Soft Tissue of the neck (20100)	20100	Radiography
Sternum (30180)	30180	Radiography
Thoracic Spine one or two views (52100)	52100	Radiography
Visa Chest (9109)	9109)	Radiography
Namibia Visa Chest - 2 views (9103A)	9103A	Radiography
Bone Mineral Densitometry (50120)	50120	Bmd
MVT601-3002 - BMD (T892110 - 50120)	T8921	Bmd
MVT601-3101 - BMD (T917330 - 50120)	T9173	Bmd
Skeletal Survey over five years (00115)	00115	Bmd
Myovant MVT601-3003 - BMD (T1032401-50120)	T1032	Bmd
Bayer-Bay Asteroid 6 - BMD (T914304 - 50120)	T9143	Bmd
LT TM Joint (15100)	15100	Dental/Cephalometry
Mandible (14100)	14100	Dental/Cephalometry
Maxillofacial Cephalometry (14120)	14120	Dental/Cephalometry
Orthopantomogram (14110)	14110	Dental/Cephalometry

Examination description	Exam code	Modality name
Orthopantomogram Jaw and Teeth (14110)	14110	Dental/Cephalometry
RT TM Joint (15110)	15110	Dental/Cephalometry
LT TM Joint Tomo (15120)	15120	Dental/Cephalometry
RT TM Joint Tomo (15130)	15130	Dental/Cephalometry
Mammogram (34100) 1	34100	Mammography
Mammogram unilateral (34101)	34101	Mammography
Mammogram (34100) 2	34100	Mammography
Mammogram unilateral (34101) 1	34101	Mammography
MVT601-3101 - Mammogram (T917330 - 34100)	T9173	Mammography
Mammogram (34100) 3	34100	Mammography
Mammogram unilateral (34101) 2	34101	Mammography
Biopsy specimen of the Mamma (34140)	34140	Mammography
Mammogram unilateral (34101)	34101	Mammography
Stereotactic Mammogram Biopsy (34130)	34130	Mammography
Stereotactic Mammography localisation (34120)	34120	Mammography
EISAI 2609-600-302 - MR Brain (T916843 - 10410)	T9168	Magnetic Resonance
MEDI-551-1115_1 - MR Thoracic Spine (T749616 - 52400)	T7496	Magnetic Resonance
MEDI-551-1155_1 - MR Brain pre & post (T749616 - 10430)	T7496	Magnetic Resonance
MEDI-551-1155_1 - MR Cervical Spine (T749616 - 51400)	T7496	Magnetic Resonance
MEDI-551-1155_1 - MR Orbits (T749616 - 12400)	T7496	Magnetic Resonance
MR Abdomen (40400)	40400	Magnetic Resonance
MR Abdomen pre & post contrast (40410)	40410	Magnetic Resonance
MR Abdomen Pre & Post Contrast with MRCP (41440)	41440	Magnetic Resonance
MR Abdomen with MRCP (41430)	41430	Magnetic Resonance
MR Angio Brain uncontrasted (10470)	10470	Magnetic Resonance
MR Bony Pelvis (55400)	55400	Magnetic Resonance
MR Bony Pelvis pre & post contrast (55410)	55410	Magnetic Resonance
MR Brachial Plexus Study (20400MR)	20400	Magnetic Resonance
MR Brain Limited study (10400)	10400	Magnetic Resonance
MR Brain plus Angio (10450)	10450	Magnetic Resonance
MR Brain Pre & Post Contrast (10430)	10430	Magnetic Resonance
MR Brain pre & post contrast plus Angio (10460)	10460	Magnetic Resonance
MR Brain uncontrasted (10410)	10410	Magnetic Resonance
MR Brain with contrast (10420)	10420	Magnetic Resonance
MR Cervical Spine & CCJ (51410)	51410	Magnetic Resonance
MR Cervical Spine & CCJ pre & post contrast (51420)	51420	Magnetic Resonance
MR Cervical Spine limited study (51400)	51400	Magnetic Resonance
MR Chest (30400)	30400	Magnetic Resonance
MR facial soft tissue (11400)	11400	Magnetic Resonance
MR Facial Soft Tissue Pre & Post Contrast (11410)	11410	Magnetic Resonance
MR Hip Joint/s (56410)	56410	Magnetic Resonance
MR Hip Joint/s Limited Study (56400)	56400	Magnetic Resonance
MR Hip Joint/s Pre & Post Contrast (56420)	56420	Magnetic Resonance
MR hypophysis (17400)	17400	Magnetic Resonance
MR Hypophysis Pre & Post Contrast (17410)	17410	Magnetic Resonance

Examination description	Exam code	Modality name
MR Internal Auditory Canals limited study (16400)	16400	Magnetic Resonance
MR Internal auditory canals pre & post contrast, complete (16420)	16420	Magnetic Resonance
MR Internal auditory canals pre & post contrast, limited (16410)	16410	Magnetic Resonance
MR kidneys pre & post contrast (42420)	42420	Magnetic Resonance
MR kidneys without contrast (42410)	42410	Magnetic Resonance
MR Liver/pancreas (41400)	41400	Magnetic Resonance
MR Liver/Pancreas pre & post contrast (41410)	41410	Magnetic Resonance
MR LT Ankle (74400)	74400	Magnetic Resonance
MR LT Ankle Limited Study (74400LTD)	74400	Magnetic Resonance
MR LT Elbow (63400)	63400	Magnetic Resonance
MR LT Elbow Limited Study (63400LTD)	63400	Magnetic Resonance
MR LT Foot (74420)	74420	Magnetic Resonance
MR LT Foot Limited Study (74420LTD)	74420	Magnetic Resonance
MR LT foot pre & post contrast (74430)	74430	Magnetic Resonance
MR LT Forearm (64400)	64400	Magnetic Resonance
MR LT Forearm pre & post contrast (64410)	64410	Magnetic Resonance
MR LT Hip Limited Study (56400LTDL)	56400	Magnetic Resonance
MR LT Knee (72400)	72400	Magnetic Resonance
MR LT Knee Limited Study (72400LTD)	72400	Magnetic Resonance
MR LT Knee Pre & Post Contrast (72410)	72410	Magnetic Resonance
MR LT Lower Leg (73400)	73400	Magnetic Resonance
MR LT shoulder (61400)	61400	Magnetic Resonance
MR LT Shoulder Limited Study (61400LTD)	61400	Magnetic Resonance
MR LT shoulder pre & post contrast (61410)	61410	Magnetic Resonance
MR LT Upper Leg (71400)	71400	Magnetic Resonance
MR LT Upper Leg pre & post contrast (71410)	71410	Magnetic Resonance
MR LT Wrist & Hand (65400)	65400	Magnetic Resonance
MR Lumbar Spine (53410)	53410	Magnetic Resonance
MR Lumbar Spine limited study (53400)	53400	Magnetic Resonance
MR Lumbar Spine pre & post contrast (53420)	53420	Magnetic Resonance
MR Mandible/Maxilla Pre & Post Contrast (14410)	14410	Magnetic Resonance
MR Neck Soft Tissue (20400)	20400	Magnetic Resonance
MR Neck soft tissue pre & post contrast (20410)	20410	Magnetic Resonance
MR Orbital pre & post contrast (12410)	12410	Magnetic Resonance
MR Pelvis soft tissue (40420)	40420	Magnetic Resonance
MR Pelvis soft tissue pre & post contrast (40430)	40430	Magnetic Resonance
MR Planning Radiotherapy/Surgery (00450)	00450	Magnetic Resonance
MR Planning Radiotherapy/Surgery with contrast (00455)	00455	Magnetic Resonance
MR Prostate (40420P)	40420	Magnetic Resonance
MR Prostate Pre & Post Contrast (40430P)	40430	Magnetic Resonance
MR RT Ankle (74405)	74405	Magnetic Resonance
MR RT Ankle Limited Study (74405LTD)	74405	Magnetic Resonance
MR RT Ankle Pre & Post Contrast (74415)	74415	Magnetic Resonance
MR RT Elbow (63405)	63405	Magnetic Resonance
MR RT Elbow Limited Study (63405LTD)	63405	Magnetic Resonance

Examination description	Exam code	Modality name
MR RT Foot (74425)	74425	Magnetic Resonance
MR RT foot pre & post contrast (74435)	74435	Magnetic Resonance
MR RT forearm (64405)	64405	Magnetic Resonance
MR RT Hip Limited Study (56400LTDR)	56400	Magnetic Resonance
MR RT Knee (72405)	72405	Magnetic Resonance
MR RT Knee Limited Study (72405LTD)	72405	Magnetic Resonance
MR RT Knee Pre & Post Contrast (72415)	72415	Magnetic Resonance
MR RT Lower Leg (73405)	73405	Magnetic Resonance
MR RT Lower Leg Limited Study (73405LTD)	73405	Magnetic Resonance
MR RT Shoulder (61405)	61405	Magnetic Resonance
MR RT Shoulder Limited Study (61405LTD)	61405	Magnetic Resonance
MR RT shoulder pre & post contrast (61415)	61415	Magnetic Resonance
MR RT Upper Arm (62405)	62405	Magnetic Resonance
MR RT Upper Arm Limited Study (62405LTD)	62405	Magnetic Resonance
MR RT Upper Arm Pre & Post Contrast (62415)	62415	Magnetic Resonance
MR RT upper leg (71405)	71405	Magnetic Resonance
MR RT Upper Leg Limited Study (71405LTD)	71405	Magnetic Resonance
MR RT upper leg pre & post contrast (71415)	71415	Magnetic Resonance
MR RT Wrist & Hand (65405)	65405	Magnetic Resonance
MR RT Wrist & Hand Limited Study (65405LTD)	65405	Magnetic Resonance
MR sacrum (54400)	54400	Magnetic Resonance
MR Sacrum pre & post contrast (54410)	54410	Magnetic Resonance
MR Spectroscopy any region (00420)	00420	Magnetic Resonance
MR Thoracic Spine (52410)	52410	Magnetic Resonance
MR Thoracic Spine limited study (52400)	52400	Magnetic Resonance
MR Thoracic Spine pre & post contrast (52420)	52420	Magnetic Resonance
MR T-M joints (15400)	15400	Magnetic Resonance
MR Upper Limbs limited any region (60400)	60400	Magnetic Resonance
MRA Abdominal Aorta & Branches (44400)	44400	Magnetic Resonance
MRA Aorta & Branches (32400)	32400	Magnetic Resonance
MRA Extra & intracranial vessels + brain uncontrasted (20460)	20460	Magnetic Resonance
MRA Extra & intracranial vessels + brain, with contrast (20470)	20470	Magnetic Resonance
MRA Extracranial vessels in the neck without contrast (20430)	20430	Magnetic Resonance
MRCP (41420)	41420	Magnetic Resonance
MSD MK3475-598 - MR Brain Pre & Post Contrast (T964141 - 10430)	T9641	Magnetic Resonance
MRA Brain plus Diffusion Uncontrasted (10492)	10492	Magnetic Resonance
MR RT Forearm pre & post contrast (64415)	64415	Magnetic Resonance
Abdomen single view (40100)	40100	Fluoroscopy
Barium meal double contrast (40143)	40143	Fluoroscopy
Barium meal double contrast + follow through (40147)	40147	Fluoroscopy
Barium meal single contrast (40140BM)	40140	Fluoroscopy
Barium swallow (31100BS)	31100	Fluoroscopy
CT Guided FNA Biopsy (80605CT)	80605	Fluoroscopy

Examination description	Exam code	Modality name
CT Guided Lumbar Puncture (50130G)	50130	Fluoroscopy
Cystography (42120)	42120	Fluoroscopy
Drainage tube replacement (84615)	84615	Fluoroscopy
Epidural block (86620)	86620	Fluoroscopy
Facet Block C4/C5 (86610L)	86610	Fluoroscopy
Fluoroscopy any region per half hour (00140)	00140	Fluoroscopy
Gastrografin meal single contrast (40140)	40140	Fluoroscopy
Gastrografin swallow (31100)	31100	Fluoroscopy
Hystero-salpingography (43120)	43120	Fluoroscopy
Hystero-salpingography with introduction of contrast (43130)	43130	Fluoroscopy
Large bowel enema double contrast (40165)	40165	Fluoroscopy
Large bowel enema single contrast (40160)	40160	Fluoroscopy
LT percutaneous nephrostomy external drainage (85600L)	85600	Fluoroscopy
Micturating cysto-urethrography (42140)	42140	Fluoroscopy
Percutaneous double J stent insertion + access (85605)	85605	Fluoroscopy
Percutaneous external/internal biliary drainage (84605)	84605	Fluoroscopy
Percutaneous nephrostomy tract establishment (85615)	85615	Fluoroscopy
Percutaneous nephrostomy, external drainage (85600)	85600	Fluoroscopy
Retrograde/prograde pyelography (42150)	42150	Fluoroscopy
RT percutaneous nephrostomy external drainage (85600R)	85600	Fluoroscopy
SBE Gastrografin follow through single contrast (40153)	40153	Fluoroscopy
Transhepatic percutaneous cholangiography (41130)	41130	Fluoroscopy
Urethrography (42130)	42130	Fluoroscopy
Venography patency of A-port or other central line (32570)	32570	Fluoroscopy
X-ray Guided Contrast intro LT Hip (56160)	56160	Fluoroscopy
Xray Guided Contrast intro LT Shoulder (61170)	61170	Fluoroscopy
X-ray Guided Contrast intro RT Hip (56160A)	56160	Fluoroscopy
Xray Guided Contrast intro RT Shoulder (61170A)	61170	Fluoroscopy
X-ray guided duodenal intubation (40175)	40175	Fluoroscopy
Xray guided gastro oesophageal intubation (40170)	40170	Fluoroscopy
X-ray guided lumbar puncture (50130)	50130	Fluoroscopy
X-ray guided reduction of intussusception (40190)	40190	Fluoroscopy
(blank)	(blank)	Fluoroscopy
Facet Block T10/T11 (86610ZC)	86610	Fluoroscopy
CT Abdomen & Pelvis with contrast (40333)	40333	Computerised Tomography
CT Brain uncontrasted (10300)	10300	Computerised Tomography
CT Chest for pulmonary embolism (30360)	30360	Computerised Tomography
Abdomen multiple views plus Chest (40110)	40110	Computerised Tomography
Cervical Spine one or two views (51110)	51110	Computerised Tomography
CT Abdomen & Pelvis pre & post contrast (40337)	40337	Computerised Tomography
CT Abdomen & Pelvis uncontrasted (40330)	40330	Computerised Tomography
CT Abdomen & Pelvis with contrast (40333)	40333	Computerised Tomography
CT Abdomen pre & post contrast (40313)	40313	Computerised Tomography
CT Abdomen triphasic study liver (41300)	41300	Computerised Tomography
CT Abdomen uncontrasted (40300)	40300	Computerised Tomography

Examination description	Exam code	Modality name
CT Abdomen with contrast (40310)	40310	Computerised Tomography
CT Bony Pelvis complete uncontrasted (55310)	55310	Computerised Tomography
CT Bony Pelvis limited (55300)	55300	Computerised Tomography
CT bony pelvis with contrast (55330)	55330	Computerised Tomography
CT BOS coronal HRES for CSF leak (10360)	10360	Computerised Tomography
CT BOS to symph pubis with contrast (40360)	40360	Computerised Tomography
CT Brain contrast only (10310)	10310	Computerised Tomography
CT Brain pre & post contrast (10320)	10320	Computerised Tomography
CT Brain pre & post contrast + angiography (10335)	10335	Computerised Tomography
CT Brain uncontrasted (10300)	10300	Computerised Tomography
CT Cervical Spine Complete (51320)	51320	Computerised Tomography
CT Cervical Spine complete study (51320)	51320	Computerised Tomography
CT Cervical Spine limited study (51300)	51300	Computerised Tomography
CT Cervical Spine Myelography (51340)	51340	Computerised Tomography
CT Chest & Upper Abdomen Contrasted (CTCUA)	CTCUA	Computerised Tomography
CT Chest complete high resolution (30350)	30350	Computerised Tomography
CT Chest complete HRES with prone & expiration (30355)	30355	Computerised Tomography
CT Chest contrasted (30320)	30320	Computerised Tomography
CT Chest for pulmonary embolism (30360)	30360	Computerised Tomography
CT Chest limited high resolution (30340)	30340	Computerised Tomography
CT Chest limited study (30300)	30300	Computerised Tomography
CT Chest pre & post contrast (30330)	30330	Computerised Tomography
CT Chest uncontrasted (30310)	30310	Computerised Tomography
CT Chest, abdomen & pelvis with contrast (40350)	40350	Computerised Tomography
CT Chest, abdomen & pelvis without contrast (40345)	40345	Computerised Tomography
CT colonoscopy (40365)	40365	Computerised Tomography
CT Facet Block C2/C3 (86610A)	86610	Computerised Tomography
CT Facet Block C3/C4 (86610B)	86610	Computerised Tomography
CT Facet Block C4/C5 (86610C)	86610	Computerised Tomography
CT Facet Block C5/C6 (86610D)	86610	Computerised Tomography
CT Facet Block C6/C7 (86610E)	86610	Computerised Tomography
CT Facet Block L4/L5 (86610G)	86610	Computerised Tomography
CT Facet Block L5/S1 (86610H)	86610	Computerised Tomography
CT facial bones (11300)	11300	Computerised Tomography
CT Facial Bones/soft tissue pre & post contrast (11320)	11320	Computerised Tomography
CT Guidance (separate procedure) (00320)	separ	Computerised Tomography
CT Guided Abscess / Cyst Drainage, any region (80600CT)	80600	Computerised Tomography
CT Guided Cutting Needle / Trochar Biopsy, any region (80610CT)	80610	Computerised Tomography
CT Guided Epidural Block (86620CT)	86620	Computerised Tomography
CT Guided FNA Biopsy (80605CT)	80605	Computerised Tomography
CT Guided Lumbar Puncture (50130G)	50130	Computerised Tomography
CT Guided Renal Abscess / Cyst Drainage (85645CT)	85645	Computerised Tomography
CT Internal auditory canal pre & post contrast (16320)	16320	Computerised Tomography
CT LT ankle/foot (74300)	74300	Computerised Tomography
CT LT elbow (63300)	63300	Computerised Tomography

Examination description	Exam code	Modality name
CT LT Hip complete (56310)	56310	Computerised Tomography
CT LT knee (72300)	72300	Computerised Tomography
CT LT Knee complete study with 3D recons (72310)	72310	Computerised Tomography
CT LT lower leg (73300)	73300	Computerised Tomography
CT LT shoulder joint uncontrasted (61300)	61300	Computerised Tomography
CT LT Shoulder uncontrasted (61300)	61300	Computerised Tomography
CT LT upper arm (62300)	62300	Computerised Tomography
CT LT Upper Leg (71300)	71300	Computerised Tomography
CT LT wrist & hand (65300)	65300	Computerised Tomography
CT Ltd Sinuses single plane (13300)	13300	Computerised Tomography
CT Ltd Sinuses two planes (13310)	13310	Computerised Tomography
CT Lumbar Spine complete study (53320)	53320	Computerised Tomography
CT Lumbar Spine limited study (53300)	53300	Computerised Tomography
CT Lumbar Spine Myelography (53340)	53340	Computerised Tomography
CT Lumbar Spine pre & post contrast (53330)	53330	Computerised Tomography
CT mandible (14300)	14300	Computerised Tomography
CT Middle & inner ear high definition plus all recons (16340)	16340	Computerised Tomography
CT Neck Soft tissue (20300)	20300	Computerised Tomography
CT Neck Soft tissue with contrast (20310)	20310	Computerised Tomography
CT Neck Soft tissue, pre & post contrast (20320)	20320	Computerised Tomography
CT Nerve Block [any region - please specify] (86615CT)	86615	Computerised Tomography
CT Nerve Block C4/C5 (81660N)	81660	Computerised Tomography
CT Nerve Block C5/C6 (81660O)	81660	Computerised Tomography
CT Nerve Block C6/C7 (81660P)	81660	Computerised Tomography
CT Orbits more than one plane (12310)	12310	Computerised Tomography
CT orbits pre & post contrast multiple planes (12330)	12330	Computerised Tomography
CT orbits pre & post contrast single plane (12320)	12320	Computerised Tomography
CT orbits single plane (12300)	12300	Computerised Tomography
CT Pelvis uncontrasted (40320)	40320	Computerised Tomography
CT Pelvis with contrast (40323)	40323	Computerised Tomography
CT Planning Radiotherapy (00310)	00310	Computerised Tomography
CT Pulmonary embolism plus venogram abdo/pel/lower limb (30370)	30370	Computerised Tomography
CT renal tract for a stone (42300)	42300	Computerised Tomography
CT RT ankle/foot (74305)	74305	Computerised Tomography
CT RT elbow (63305)	63305	Computerised Tomography
CT RT Hip complete (56310A)	56310	Computerised Tomography
CT RT knee (72305)	72305	Computerised Tomography
CT RT Knee complete study with 3D recons (72315)	72315	Computerised Tomography
CT RT lower leg (73305)	73305	Computerised Tomography
CT RT shoulder joint uncontrasted (61305)	61305	Computerised Tomography
CT RT Shoulder uncontrasted (61305)	61305	Computerised Tomography
CT RT Upper Leg (71305)	71305	Computerised Tomography
CT RT wrist & hand (65305)	65305	Computerised Tomography
CT Sacrum complete study uncontrasted (54310)	54310	Computerised Tomography
CT Salivary Glands uncontrasted (18300)	18300	Computerised Tomography

Examination description	**Exam code**	**Modality name**
CT SI joint block uni/bilateral (86610J)	86610	Computerised Tomography
CT Sinuses any plane complete (13320)	13320	Computerised Tomography
CT Spinal Nerve Block L2/L3 [uni / bilateral] (86615N)	86615	Computerised Tomography
CT Spinal Nerve Block L3/L4 [uni / bilateral] (86615O)	86615	Computerised Tomography
CT Spinal Nerve Block L4/L5 [uni / bilateral] (86615P)	86615	Computerised Tomography
CT Spinal Nerve Block L5/S1 [uni / bilateral] (86615Q)	86615	Computerised Tomography
CT Sterno-clavicular joints (30300A)	30300	Computerised Tomography
CT Thoracic Spine complete study (52310)	52310	Computerised Tomography
CT Thoracic Spine limited study (52300)	52300	Computerised Tomography
CT TM joints (15300)	15300	Computerised Tomography
CT Triphasic liver, abdomen & pelvis pre & post contrast (40340)	40340	Computerised Tomography
CTA Abdo aorta + branches + pre + post upper abdo (44305)	44305	Computerised Tomography
CTA Abdominal Aorta & outflow lower limbs (70320)	70320	Computerised Tomography
CTA Abdominal aorta + branches (44300)	44300	Computerised Tomography
CTA Aorta + branches (32300)	32300	Computerised Tomography
CTA Extracranial Neck & Intracranial Brain vessels (20340)	20340	Computerised Tomography
CTA Extracranial Neck vessels (20330)	20330	Computerised Tomography
CTA Heart Vessels (33310)	33310	Computerised Tomography
CTA Lower Limb (70310)	70310	Computerised Tomography
CTA Neck & Brain vessels plus pre + post brain (20350)	20350	Computerised Tomography
CTA Thoracic + abdominal aorta + branches (32305)	32305	Computerised Tomography
CTA Upper Limb (60310)	60310	Computerised Tomography
MRA Extra & intracranial vessels + brain uncontrasted (20460)	20460	Computerised Tomography
MSD MK3475-598 - CT Chest Abdomen Pelvis Contrasted (T964141 - 40350)	T9641	Computerised Tomography
Paranasal Sinuses multiple views (13110)	13110	Computerised Tomography
Thoracic Spine one or two views (52100)	52100	Computerised Tomography
U/S Abdomen + Pelvis (40210)	40210	Computerised Tomography
UCT CIDRI HRCT (T861997 HRCT)	T8619	Computerised Tomography
(blank)	(blank)	Computerised Tomography
CT Facet Block T4/T5 (86610ZM)	86610	Computerised Tomography
CT Guided Chemical Ablation Tumour/Cyst (80620CT)	80620	Computerised Tomography
GLPL1690-CL-304 HRCT - Chest Complete (T1065322-30350)	T1065	Computerised Tomography
CT Guided Chest drain insertion (82600CT)	82600	Computerised Tomography
CT Bony Pelvis complete uncontrasted (55310)	55310	Computerised Tomography
CT Brain uncontrasted (10300)	10300	Computerised Tomography
CTA Neck & Brain vessels plus pre + post brain (20350)	20350	Computerised Tomography
Angio abdominal aorta, pelvic & lower limb vessels unilateral (70510)	70510	Angiography
Arteriogram aorta + coeliac, mesenteric branches (44503)	44503	Angiography
Arteriogram intracranial vessels: 3 - 4 vessels (10510)	10510	Angiography
Arteriogram pulmonary vessels (32530)	32530	Angiography
Arteriogram the spinal column & cord, all vessels (50500)	50500	Angiography

Examination description	Exam code	Modality name
Embolisation, abdominal, other vessels (87664)	87664	Angiography
Embolisation, bronchial, intercostal (87662)	87662	Angiography
Embolisation, lower limb (87667)	87667	Angiography
Embolisation, mesenteric (87660)	87660	Angiography
Embolisation, pelvis, non-uterine (87668)	87668	Angiography
Embolisation, renal (87661)	87661	Angiography
Embolisation, uterus (87669)	87669	Angiography
Intravascular foreign body removal (87681)	87681	Angiography
Arteriogram intracranial vessels: 1 - 2 vessels (10500)	10500	Angiography
Stent placement Intracranial (including PTA) (81632)	inclu	Angiography
Venogram transhepatic portogram (44587)	44587	Angiography
Embolisation, pulmonary arteriovenous shunt (87663)	87663	Angiography
Adrenal venous sampling (87693)	87693	Angiography
Arteriogram intra & extra-cranial (non-cervical) vessels (10530)	non-c	Angiography
Arteriogram aortic arch, subclavian, upper limb, bilateral (60530)	60530	Angiography

B.2 Non-clinical activity list from the case study

Table B.2 shows the non-clinical activity list per modality compiled through interviews.

Table B.2: Activity list from the case study application depicting non-clinical activities

Activity description	Modality
Meetings (monthly)	Ultrasound
Meetings (weekly)	Ultrasound
Cleaning of examination room	Ultrasound
Meetings (monthly)	Radiography
Meetings (weekly)	Radiography
Quality assurance: Department of Health radiation control requirements	Radiography
Cleaning of examination room	Radiography
Meetings (monthly)	BMD
Meetings (weekly)	BMD
Quality assurance: Department of Health radiation control requirements	BMD
Cleaning of examination room	BMD
Meetings (monthly)	Fluoroscopy
Meetings (weekly)	Fluoroscopy
Quality assurance: Department of Health radiation control requirements	Fluoroscopy
Cleaning of examination room	Fluoroscopy
Meetings (monthly)	Magnetic Resonance
Meetings (weekly)	Magnetic Resonance
Cleaning of examination room	Magnetic Resonance

Activity description	Modality
Meetings (monthly)	Mammography
Meetings (weekly)	Mammography
Quality assurance: Department of Health radiation control requirements	Mammography
Cleaning of examination room	Mammography
Meetings (monthly)	Computerised Tomography
Meetings (weekly)	Computerised Tomography
Quality assurance: Department of Health radiation control requirements	Computerised Tomography
Cleaning of examination room	Computerised Tomography
Meetings (monthly)	Theatre
Meetings (weekly)	Theatre
Walk to theatre and back	Theatre
Change into theatre attire and change back	Theatre

B.3 Appendix B: Conclusion

The activity lists of both clinical and non-clinical activities were presented. The clinical activity list was extracted from the RIS, while the non-clinical activity list was generated via informal interviews. The importance of these lists was discussed in Section 4.3.4.

Appendix C: **SME Validation questionnaire**

This appendix contains the validation questionnaire which was presented to the SMEs after the results of the case study were presented.

C.1 SME Validation questionnaire

The validation questionnaire presented in Table C.1 represents both close ended and open-ended questions that were posed to the SMEs to solicit feedback pertaining to the outcome of the case study results. This aided in the validation of the diagnostic radiographer staffing framework's results for applicability and practicability.

Table C.1 Validation questionnaire

Validation Questionnaire					
Close ended questions					
Questions	**Criteria**				
	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
1. To what extent do you agree that the results (required FTE per modality) accurately reflect the staffing level per modality?					
If you disagree, please explain why:					
2. To what extent do you agree that the results are valid (i.e. reasonable and sensible) and can be used to inform staffing decisions?					
If you disagree, please explain why:					
3. To what extent do you agree that interpreting the results are enabled by the results interpretation table in Step 7 of the framework?					
If you disagree, please explain why:					
4. To what extent do you agree that the diagnostic radiographer staffing framework can be used for determining staffing requirements in a diagnostic radiology environment?					
If you disagree, please explain why:					

Validation Questionnaire	
Open ended questions	
5. Are you aware of any other scientific approach that has been proposed which is better suited to determine staffing requirements, specifically in a diagnostic radiology environment?	
6. What do you view as the *key strengths* of the framework?	
7. What do you view as the *key weaknesses* of the framework?	
8. Would you recommend the diagnostic radiographer staffing framework for determining staffing requirements in a diagnostic radiology environment?	
9. Are there any other additional comments and feedback?	

C.2 Appendix C: Conclusion

In this appendix, the validation questionnaire used during the validation process of the case study is presented.