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Modelling "Busyness" - Using discrete event simulation and soft systems methodology to create a multimethod decision support tool for Radiology

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Abstract

In line with an increase in the incidence of chronic disease and an aging demographic, demand for radiology services is growing year on year. Radiology staff combine patient care and clinical and technical skills to meet this demand. Radiology workload has historically been measured in terms of the number of examinations completed, without regard to the patient characteristics or staff experience of workload. The motivation behind the work was to create a model which measured staff workload inclusive of the patient population profile. The novelty of the work lies in the richness of outputs obtained using hard and soft modelling OR methods, while contributing to the literature on staff and radiology workload.

This work describes the design and application of a framework for modelling aspects of a Computed Tomography (CT) service. The dual propose of the work is to provide insights into the service and staff workload by capturing process metric and to provide decision support to address the problem of an increasing waiting list. The framework was designed to facilitate high stakeholder involvement using soft systems tools to identify the components of, and scenarios for use of a discrete event simulation (DES) model.

The action research framework was validated by application in a CT scanner radiology department. A conceptual group model building approach was taken using System Dynamics (SD) notation which identified the patient characteristics of age, infection status, mobility and examination type as desirable model components. Using soft systems methodology (SSM), a rich picture of the service was created, and three scenarios identified by local decision makers. The outputs for each scenario in terms of waiting list evolution and process metrics such as resource utilisation, process delays and reliance on flexible staff were obtained from the validated model.

Using DES, it was demonstrated that mixing inpatient and outpatient services results in significant variation in demand and utilisation of resources. Radiology workload in terms of staff time and process perturbations were shown to be greater for inpatients. In the case of non-contrast exams inpatients were found to consumed 127% more staff time than outpatients. A simulation of an outpatient only service demonstrated that radiographer utilisation was less despite a greater average number of patients being scanned. A recommendation was made to separate the services to increase outpatient capacity. It is also

recommended that any future radiology workload measurements include inpatient and outpatient characteristics such as mobility, infectiousness and exam type. Action research changes resulted from the work. The framework was endorsed by the case study department and future applications in other areas such as ultrasound were identified.

Declaration

I, the **Candidate**, certify that the Thesis is all my own work and that I have not obtained a degree in this University or elsewhere on the basis of any of this work.

Signed: ________________

Date: __________________

This work is dedicated to my darling husband Mark, beautiful children Tom, Norah and Saibh.

To my wonderful parents Liam and Clare Conlon. Mam, you were the first third level student I knew.

To Sarah Mul, Iron Woman and friend extraordinaire – Thank you for not giving me the option to stop!

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Abbreviations

ABM	Agent Based Modelling
AMAU	Acute medical assessment unit
CART	classification and regression tree
CPD	Continuous professional development
CSM	Consumed staff minutes
DES	Discrete event simulation
DSS	Decision support system
ED	Emergency Department
eGFR	estimated glomerula filtration rate
EHR	Electronic Health Record
GP	General Practitioner
HCAI	Healthcare Acquired Infection
HSE	Health Service Executive
IP	Inpatient
IT	Information Technology
IV	Intravenous
KPI	Key performance indicator
MRI	Magnetic resonance imaging
MTA	Multitask assistant
NIMIS	National Integrated medical imaging system
OP	Outpatient
OR	Operations Research
PACS	Picture archive and communication system
PAS	Patient administration system
PPE	Personal protective equipment
PUH	Portiuncula University Hospital
RIS	Radiology information system
RP	Rich Picture
RSM	Radiology Service Manager

SD	Systems Dynamics
SSM	Soft system methodology
TAP	Thorax, Abdomen and Pelvis
TPS	Toyota production system
TQM	Total quality management
WI	Winter initiative

List of Publications

Under Review

Conlon, M.; Molloy, O. and Zolzer-Bryce, N. (2020). Combining Soft Systems Methodology and discrete event simulation: A radiology case study focusing on future CT service provision and resource utilisation. Springer 2021

Conlon, M.; Molloy, O. (2021). A case study utilising mixed OR methods to understand a CT service and support decision making and resource planning in Radiology Departments, Special Issue for the Journal of Simulation, Submitted June 2021

Published

Conlon, M.; Molloy, O. and Zolzer-Bryce, N. (2020). Driving the Bus: A Radiology Case Study Utilizing Rich Picture Diagramming and CATWOE to Capture Staff Perceptions and Inform Service Improvement Scenarios. In Proceedings of the 12th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management - Volume 3: KMIS, ISBN 978-989-758-474-9, ISSN 2184-3228, pages 88-99. doi: 10.5220/0010145600880099 - *Best Industrial paper award*

Conlon, M. and Molloy, O. (2019) 'Knowledge management in healthcare: Information requirements when creating a decision support tool in radiology', IC3K 2019 - Proceedings of the 11th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management, 3(Ic3k), pp. 317–324. doi: 10.5220/0008352703170324. - *Best Poster award*

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Chapter 1: Introduction

O chestnut tree, great rooted blossomer,
Are you the leaf, the blossom or the bole?
O body swayed to music, O brightening glance,
How can we know the dancer from the dance?
W. B. Yeats from Soundings (Martin, 2010).

In the final stanza of the poem "Among School Children" Yeats asks if it is possible to separate the dancer from the dance. The poet recognises that although people are the sum of their separate deeds, life is an amalgamation of actions. Similarly, a health service is a complex system comprised of many functional as well as human components such as needs, purpose, communications and relationships. In this work we aim to separate out the patient and staff experience, the volume of work from the perception of workload, all with a view to informing improvement and the allocation of future resources. The process of modelling workflows in a CT department allows for a better understanding of this key part of a complex system. Radiology departments continually gather important data on throughput, patient populations, scheduling practices and process times. The conversion of this data into useful information, which is further augmented with qualitative staff insights and context to support decision making is examined in this work.

The thesis draws on and contributes to concepts from the field of Operations Research (OR). In the introduction chapter the problem is described in the context of increasing pressures due to demand and patient factors, media on government pressure to address waiting lists and current measures of radiology staff workload. The discipline of Operations Research (OR) is also introduced as a potential solution to address healthcare problems relating to resource utilisation, constraints and decision making. The specific research aims, and objectives and outline of the thesis are also described.

1.1 The problem context

A health service under pressure is not a uniquely an Irish problem, with growing demand for constrained healthcare resources a worldwide phenomenon. Ireland's close neighbour, the United Kingdom, is similarly experiencing population growth, an increase in chronic diseases and multiple comorbidities, and increased demands for diagnostics (King's Fund, 2021). The demand for radiology services is steadily rising with increases of between 8% and 10% per annum in OECD countries, including Ireland (Granja *et al.*, 2014; Health Services Executive, 2017). In particular, a UK report identified that the workload for complex imaging (such as CT and MRI) is increasing at 7% per year (Royal College of Radiologists, 2021).

The number of over 65 year olds is set to double between 2011 and 2031 and the increasing prevalence of diabetes and obesity among young people suggests that future elderly cohorts are likely to suffer from a range of co-morbidities (Lakdawalla, Bhattacharya and Goldman, 2004; Health Services Executive, 2015). As the population ages, the incidence of diseases associated with ageing will increase. In the United Kingdom, the rate of improvement of life expectancy has now slowed markedly, and at older ages may even be reversing (Hiam *et al.*, 2018). UK disability-free life expectancy is almost two decades shorter than life expectancy at 62.7 years for males and 61.2 years for females (Office for National Statistics, 2018). Healthcare systems worldwide will have to cope with additional demands due to the population profile and radiology will share these challenges as diagnostic imaging using as x-rays, MRI and CT is central in the clinical pathways resulting in informal competition for limited and shared CT resources (Gullhav *et al.*, 2017; Frangeskou, 2018).

An Irish report from 2017 showed that the number of adults aged 65 years and over will increase by up to 21.0% (131,000) in the five years up to 2022 (Health Service Executive, 2017). As the elderly population increases, the incidence of diseases associated with ageing will increase. Healthcare systems worldwide will have to cope with these extra demands, with radiology required to share in these challenges.

Chronic illness accounts for the largest cause of death and the largest source of healthcare costs in developed countries and has also become a significant problem in developing countries as well (Homer, Hirsch and Milstein, 2007). Whilst mortality rates from chronic illness are decreasing, the number of those living with, and experiencing the associated complications of chronic illness, is rising. Future economic development is expected to bring with it morbidity and mortality, and a resulting economic burden, linked to spending on people with chronic illness (Bernell and Howard, 2016; French *et al.*, 2017).

The obesity epidemic poses challenges for radiographers related to difficulties with positioning obese patients in plain radiography, with impacts on patient care, image quality, and insufficient table width and weight limits, as well as detector sizes (Whitley and Clark, 2005; Woods, Miller and Sloane, 2016). The arrival of the COVID-19 pandemic in 2020, meant an increase in the likelihood of patients presenting as infectious, or being suspected of such, resulting in an increase in scanner downtime due to cleaning and separation of infectious and non-infectious cohorts (Mossa-Basha *et al.*, 2020). 'Nosocomial' or 'healthcare associated infections' (HCAI) are those which appear in a patient under medical care in the hospital or other health care facility, which were absent at the time of admission (Khan, Baig and Mehboob, 2017). HCAIs are a major problem for health care worldwide, causing additional suffering for the patient and incurring major societal costs (Palmqvist *et al.*, 2019).

The advent of COVID-19 has resulted in an increase in the time spent on infection control measures in a bid to limit contamination (Zanardo et al., 2020). Thirty minutes to one hour of downtime is necessary where scanners have been used for suspected or confirmed cases of the virus and the allocation of dedicated "Fever" or COVID-19 CT scanners in departments has been recommended to facilitate room decontamination and passive air exchange (Mossa-Basha et al., 2020; Orsi, Oliva and Cellina, 2020).

1.1.1 Health services under pressure

Recent newspaper publications have alerted the public to growing waiting lists and low-quality service delivery issues (O'Regan, 2019). The number of out-patients experiencing delays of more than 18 months to see a specialist reached a new record in 2018, with more than 80,000 queuing in excess of that time. Separate waiting list figures reveal that 135,000 people are waiting for diagnostic imaging, with 17,648 waiting over one year (O'Regan, 2019). A growing and aging population has contributed to an 85% rise in cancer cases since the mid-1990s (ibid). More than 41,000 new patients are diagnosed with cancer annually, including non-invasive forms of the disease, according to the annual report of the National

Cancer Registry. More than 3,000 patients per year are finding out they have cancer only when they attend a hospital ED department. This can result from a lack of awareness of symptoms or being on a long waiting list for access to diagnostic scans. Such patients usually have advanced disease, limited treatment options and poorer prognoses (O'Regan, 2018).

Evidence exists that GPs may be advising some patients who face a long delay and need a diagnosis to go to already overcrowded hospital emergency departments (ED) (O'Regan, 2015). Recognising that there has been large growth in demand for diagnostics and that not all requests are justified the article concludes that improved access to radiology services would not just result in less delay for the patient, but also a reduction in referrals to out-patient clinics and EDs (O'Regan, 2015).

It appears that the extent of the problem relating to diagnostic imaging service provision is not clear. In 2017, the HSE (Health Service Executive) was criticised for not being in a position to disclose waiting list numbers for MRI scans, CT scans and bone scans during the previous three years (Gráinne Ní Aodha, 2017) as data was not available for same. Public patients are waiting for an average of almost two years for an MRI scan in County Galway, with more than 2,400 people on the list (Cunningham, 2017). Urgent cases – including those where there is a suspicion of cancer – must wait nearly three months for a scan. RTE, Ireland's public broadcaster, reported that public patients have delayed cancer detection compared to private patients (2018). In a report, consultant oncologist Professor John Crown claimed to be despondent about reform of the health system, asserting that it is unacceptable that it could take months for someone with suspected cancer to be seen or for in-patients occupying a hospital bed to be left waiting for up to a week for a diagnostic scan (RTE, 2018). Long waiting lists for diagnostic imaging services such as CT can be circumvented by private patients according to The Irish Cancer Society (Irish Cancer Society, 2019). The *Irish Independent* reported that 3,000 patients per year (14% of all new cancer diagnoses, excluding melanoma) received a cancer diagnosis in the ED department (O'Regan, 2018). This can result from a lack of awareness or from being on a long waiting list for scans (O'Regan, 2019). In 2006, Irish GPs identified that the lack of direct access to diagnostics was a barrier to early diagnosis of cancer and indicated that increased access to diagnostics would result in a 86% reduction in referrals to accident and EDs as a means of gaining access to diagnostic tests such as CTs (Irish Cancer Society, 2016).

The Irish Times (2020) reported that the COVID-19 pandemic forced the cancellation of all non-urgent hospital work in the spring and although activities did resume in many parts of the health service, capacity was reduced to approximately 80 per cent or less due to the requirement for infection control (Cullen, 2020). The number of patients waiting 12 to 15 months for an MRI or CT scan increased by one third (1,870) during the period April to July 2020 (O'Connor, 2020). According to the Irish Patients' Association (IPA), almost 400,000 fewer people were scanned for cancers and diabetic retinopathy in 2020 due to the impact of the COVID-19 pandemic and approximately 1,017 cancer diagnoses and treatment were delayed (Gleeson, 2021). This section evidences the media pressure on government to address waiting lists and the seriousness of the clinical implication of delays proffered by oncologists and general practitioners.

1.1.2 Staff workload

A desire to capture, through qualitative and quantitative OR means, radiology staff workload and indicators of high intensity work pressure were partial motivations for this research. Radiology workload has traditionally been measured in terms of the number of examinations completed, a reductionist and unnuanced metric (Sunshine and Burkhardt, 2000; Pitman *et al.*, 2009). Radiologist workload definitions have been broadened in recent times to include more than simply the number of examinations completed on a yearly basis, by including teaching and administration time, the time spent on the preparation and conduct of multi-disciplinary team meetings (RCSI, 2011). New technologies, an aging demographic, demand for patient centred care and governmental pressures have been identified as key drivers of increasing radiology workload (Woznitza *et al.*, 2014). In a study by Verrier and Harvey (2010), radiographers cited staff shortages, heavy workload and volume of patients as the greatest sources of pressure at work and their most common recommendations to reduce stress at work were increased staffing, improved communication and more effective feedback systems (Verrier and Harvey, 2010). Although episodes of care are brief while imaging is being provided, radiographers view care as a wider concept that encompasses administrative and technical elements as well as the traditionally considered close relational element (Brask & Birkelund, 2014). Further research into the pressures specific to the time-pressured, task-focussed and highly technical environment of radiography and the impact on compassionate patient care have been recommended (Bleiker et al, 2018).

1.1.3 Operations Research applied to healthcare

Operations Research (OR) can be described as both an art and a science. Gilbert LaPorte described OR as the art of applying analytical methods to the solution of complex management problems (Ackermann, 2012) while Kunc et al., described OR as the science of better (Kunc, Malpass and White, 2016). OR has the potential to improve radiology workflows and throughput times, and can capture human responses to work pressure (Oliva, 2002; Van Lent *et al.*, 2012; Booker *et al.*, 2016; Greasley and Owen, 2018). A model can be described as a simplified representation of a system intended to help answer questions about the system (Law and Kelton, 1991). In the virtual world of models, a simulation model can be run to test different decision alternatives and provide alternative solutions thus supporting decision makers with data. When modellers bring together various systems, ideas and techniques in an organised way and employ them to bring about a solution to a real-world problem, they are said to be using a "systems methodology".

The most considered simulation paradigms are Discrete Event Simulation (DES), System Dynamics (SD) and Agent-Based Simulation (ABS). Gunal (2012), , compares each paradigm in *"A guide for building hospital simulation models*" in terms of how patients are considered (as individuals or cohorts), the nature of events (stochastic or deterministic).

Comparison of Discrete Event Simulation (DES), System Dynamics (SD), and Agent-Based Simulation (ABS)

DES	*SD*	*ABS*
Individual focus (Entity)	Group focus (Cohort)	Individual focus (Agent)
Processors defined	Rates are defined	No processors defined
Rules are defined in processors	Rules are defined in differential equations	Rules are defined in Agents (autonomy)
Queues exist explicitly	Queues exist explicitly but as levels	Queues exist implicitly
Event derive the simulation	Rates derive the simulation	Local Environment and agents drive the simulation
Mostly stochastic	Mostly deterministic	Mostly deterministic
Discrete time intervals	Stepped time intervals	Stepped time intervals

Figure 1.1 Comparison of simulation methodologies (Gunal, 2012)

Modelling and simulation techniques are being increasingly applied within radiology and healthcare to support data-driven decision making and improve healthcare systems, however evidence of implementation remains low at 6-8% (Brailsford and Vissers, 2011). Recent years have seen an explosion in the quantity of healthcare operational research publications involving the use of modelling and simulation, with most of these papers reporting the use of Discrete-Event Simulation in modelling healthcare systems, with particular focus on a specific unit or department (Thorwarth, 2008; Günal and Pidd, 2010; Arisha and Rashwan, 2016). The growth in the popularity of OR applied to healthcare is discussed by Brailsford and Vissers (2011), who conclude that some of the key challenges facing healthcare providers in future years are perhaps more organisational and logistical in nature, rather than medical and scientific. Effective change in medical practice stems from an understanding of real-life situations for practitioners, including all of their socially specific complexities (Woods, Miller and Sloane, 2016). OR techniques can be considered as with “hard” quantitative or “soft” qualitative and may be combined with soft approaches used to facilitate hard approaches. More research into facilitated discrete event simulation has been called for if it is to become a common mode of practice, with calls for further case study examples of facilitated approaches (Fone *et al.*, 2003; Kotiadis and Tako, 2017). A more in-depth review of the literature on modelling paradigms is included in Chapter 2 with a view to defending the choice of OR techniques used in this research.

1.2 Research aims

Efforts must be made to optimise the utilisation of staff and equipment resources. State-of-the-art equipment and highly qualified staff in some departments are under-utilised, while other departments are over-utilised, leading to a risk of mistakes, burnout, and a reduction in quality (Liker, 2007). The aim of this work is to investigate resource utilisation, staff workload, patient complexity from a radiology viewpoint and to identify other factors affecting radiology service delivery using operational research tools and methods. This research endeavours to develop a framework with quantitative and qualitative features, to gain a deeper understanding of radiology workload and challenges to efficient service provision.

Using simulation modelling and a soft systems approach, the application of the framework aims to support radiology decision-making and address the problem of increasing waiting lists in a radiology department. Although it is applied at a single site, with a single CT scanner, it is expected that the work has wider applications and clinical implications for diagnostic imaging departments.

To date radiology workload has namely considered the volume of examinations completed. While radiologist workload is more nuanced including direct and indirect patient related activities little has been found pertaining to radiographer workload and this research seeks to expand the body of knowledge in this area.

A sustainable radiology service should balance compassionate patient care with efficiency, staff workload and patient workflow. Poor patient care, erosion of professional standards, errors and staff burnout are undesirable responses to work pressure, and efforts should be made to measure and acknowledge the human factors in healthcare services such as CT. The motivations for this research, described in Chapter 1.3, emerged over a 20-year career working as a radiographer in clinical and management roles in the USA, the United Kingdom and Ireland. The research questions were designed to gain new information on radiology staff workload and decision support in radiology and are described next.

1.2.1 Research questions and objectives

The research questions (RQ), sub-questions and research objectives are presented next.

RQ 1 - Can Operational Research methods be used to capture aspects and metrics of staff workload and the staff experience of providing a CT service?	
Research Sub-question	**Research Objectives**
1.(a) From the literature, what previous attempts have been made to model healthcare staff workload and patient complexity?	To identify from the literature suitable modelling methods, as well as previous attempts to model or measure staff workload and patient complexity.
1.(b) Which OR methods are most suitable to do so?	To identify a suitable modelling paradigm.
1.(c) What factors (patient and other) affect staff workload and resource utilisation?	To identify methods to capture the dynamics of the CT service and waiting list. To identify model components, output metrics and scope.

RQ 2 - What framework, facilitating stakeholder involvement, is most appropriate to capture staff experience, identify model components and metrics, and address the problem of increasing waiting lists?	
Research Sub-question	**Research Objectives**
2.(a) From the literature, what existing frameworks can be used or modified for use in Radiology?	To identify from the literature existing frameworks and suitable methods for inclusion in the framework.
2.(b) Can the developed framework be successfully applied and validated in Radiology to allow workload to be modelled and decision supported?	To implement the framework in a suitable CT department and create a model of the service. To capture service metrics which address RQ1. To identify simulations for testing in the model to inform decision-making.

1.3 Organisation of the thesis

The thesis is organised as follows to address the research questions.

1. Chapter 2: A review of the literature of how healthcare staff workload is measured was carried out. The operational research (OR) techniques used to model and provide decision support, with particular attention paid to radiology applications were examined. Particular attention is paid to the literature on discrete event simulation and soft systems methodology, as these methods are included in the conceptual framework. By including literature on the multiple types of patient care the reader is introduced to notion of complexity in healthcare service provision and the value of measuring and modelling radiology workload.

2. Chapter 3: In the research methodology literature on the various choices of conducting research are discussed, with a particular focus on healthcare research. Qualitative and quantitative methods used are discussed and the choice of a pragmatic, mixed methods approach is defended. The researcher used observation, process mapping and semi structured interviews to frame the problem situation. SSM tools were used to identify factors contributing to radiology workload and DES was used to create a simulation model of the service. While the researcher built on her previous experience as a clinical radiographer, she used OR tools to obtain the perspectives of other staff members, creating a quantitative DES model. In doing so an effort was made to minimise the potential for bias. The framework for application in radiology departments is described, identifying the components and methods employed to do so. Examples from OR literature where radiographers and radiology staff were involved in a facilitated use of DES to measure radiology staff workload or capture their experience were not identified in the literature and herein lies the novelty of the work.

3. Chapter 4: The framework described in Chapter 3, composed of mixed methods is empirically applied in a single scanner computed tomography radiology department. The service and its problem situation, i.e., its inability to address increasing waiting lists, is modelled using SSM and DES. In phase one an exploratory data analysis and conceptualisation of the problem situation is carried out. In phase 2 staff are

involved in the identification of factors affecting their workload and components for a DES model. Scenarios for testing in the DES model are derived from consultation with radiology decision makers.

4. The application and validation of the framework in the case study department is described in chapter 4. Results from workflow mapping and problem conceptualisation are presented.

5. Chapter 5 presents an analysis of results from the application of the framework and the mixed methods. A synthesis of the findings from the qualitative and quantitative methods are presented. The effects of mobility and infectiousness on workflow and workload were captured using hard and soft OR techniques. The dependence on flexible staff to assist with manual handling activities was highlighted. Examples of action research changes that resulted from the application of the framework are provided as well as evidence of increased staff problem solving capabilities.

6. In Chapter 6, the conclusions, key findings, contributions and limitations of the research are discussed, and recommendations for future work are offered. Recommendations for the separation of the inpatient and outpatient services are made. An endorsement of the use of OR tools in radiology provided by radiology decision makers is provided.

7. Chapter 7 concludes the work with a synopsis of the major findings and learnings.

1.4 Ethical considerations

Patient records were obtained from the hospital IT Department following an application for permission to the hospital's board of management (granted on 29 April 2015). The National University of Ireland, Galway's research ethics committee determined that ethical approval was not required, as personal data and sensitive data such as names, surnames, home addresses, email addresses and data pertaining to ethnicity, sexual orientation, religious beliefs, trade union membership and genetic details were not included in the analysis. The anonymity of patients was protected, and data was handled according to GDPR guidelines. Data was extracted from the hospital PAS to Microsoft Excel in comma-delimited format. The data was imported into Microsoft Excel and RStudio for data analysis. Patients were not directly involved in the observation process.

For those staff who participated in the rich picture diagramming, written consent was obtained for the use of their hand-drawn images and to confirm the text used to interpret these images. No personal information relating to the staff involved in the research project was recorded. The anonymity of staff participants was protected. Collaboration was voluntary, and staff were permitted to withdraw their involvement.

Chapter 2: Literature review

The research commenced with a review of the literature to establish the theoretical constructs that should underpin the development of a conceptual framework. The literature review provides a comprehensive review of OR methods applied in healthcare and in the radiology department setting. The state of the art in radiology modelling and simulation, and alternative modelling paradigms will be discussed. Healthcare staff workload and in particular radiology staff workload is considered.

The topics covered in the literature review include:

- Healthcare staff workload
- Measuring radiology performance
- Process improvement in healthcare
- Operational research (OR)
- Discrete event simulation
- System Dynamics
- Agent-Based Simulation
- Other modelling techniques
- Soft systems methodology

The act of reviewing literature enables the researcher to formulate ideas and concepts from previous works. The general topics to research may be determined in advance, although the focus can be broadened to include more areas of interest as the work progresses. The work focuses on the origins of modelling and simulation in healthcare as well as the current state of the art.

Reference books such as *Simulation Modelling and Analysis by* Law and Kelton (1991), *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Sterman, 2000) and *Soft systems methodology in action* by Checkland and Scholes (1992), provided an introduction to the researcher on OR. The objective of the review was to establish the amount and quality of information available on the research subject. The main focus of each paper reviewed was on how quality improvement initiatives and tools such as modelling and simulation have been used to inform decision making and improve outcomes (Checkland and Scholes, 1992).

The list of keywords and subject headings used in the search of the literature included the following: “modelling and simulation radiology”, “modelling care pathways”, “electronic patient records”, “lean workflow”, “process reengineering”, “change management”, “points of failure” and “batch and queue processes”. Key words used included the following: “lean”, “radiology”, “workflow”, “process”, “pathway”, “patient flow”, “efficiency”, “quality”, “patient care”, “outcomes”, “DES”, “simulation”, “modelling”, “quality” and “improvement”. Broad search concepts such as system dynamics, DES, radiology, continuous improvement, workflow modelling, simulation, radiographer fatigue, morale, compassion fatigue and radiology were combined using search statements and specific databases queried, such as Scopus and the Cochrane Library. The initial search was purposely broad, with some of the theory of modelling and simulation dating back to the 1960s, though it has only more recently been applied to healthcare.

Manuscripts were examined which included OR applications that addressed resource capacity issues and process improvement in Healthcare. Examples which employed facilitated or soft system methodologies and those involving staff workload measurement and/or patient complexity were of specific interest. Journals and online sources such as Radiography, Health Informatics journal, Radiologic Technology, Journal of Medical Imaging and Radiation Sciences, Journal of the Operational Research Society, BMJ Quality and Safety, Health Systems, The Irish Times, Journal of Simulation, BMJ Open, European Journal of Operational Research were identified as important. Mendeley Desktop was chosen as a means of managing references.

2.1 Operations research (OR)

OR is sometimes referred to as the "science of better" and is about people, their behaviours and creating models which can be used to inform decision making (Kunc, Malpass and White, 2016). At its roots, OR applied in healthcare is the operationalisation of the healthcare system and its elements, involving the introduction of some rationalisation in a world of politics and emotions. Delesie (1998) contended that an education in OR requires as much real-life experience as formal academia teaching and, in this way, is similar to specialist medical training. Even such emotional experiences as illness, caring or dying harbour elements of rationality, and astute hospital management is shifting its attention to information rather than data collection (Delesie, 1998).

OR has been described as a toolbox of methods, from which the most appropriate method for solving any particular problem can be selected (Brailsford *et al.*, 2019). The key challenges facing healthcare providers in future years may be more organisational and logistical in nature than medical and scientific (Brailsford and Vissers, 2011). "Good decision making" infers that decision makers are informed and have relevant and appropriate information on which to base their choices among alternatives and the process of organizing and examining the information is the process of modelling (Sauter, 2011). Models are created to help decision makers understand at least some of the consequences of selecting an option. For rational decision making to be carried out, the following is required:

- an explicit set of options, or possible courses of action;
- information that allows prediction of the outcomes of choosing each option;
- an explicit criterion for choosing the preferred set of outcomes, which is determined by the decision maker's goals and objectives (Sanderson and Gruen, 2006).

Using a model, or representation, of a system or situation, can provide improved understanding and consequently improved decision-making to be achieved. The use of simulation models can replace the need to experiment on real systems, an activity which may not be possible or ethical, and can lead to a greater understanding of a problem and a reduction in implementation times and costs (Rashwan, Abo-Hamad and Arisha, 2015). Simulations, categorised as discrete or continuous, are used to imitate a real-world scenario and how it evolves over time. Simulations can be used to investigate the feasibility of proposed options and accurately predict the future performance of a complex system of interrelated parts; the main weakness is that it requires specific skills, tools, and experience, and if these are in short supply, process modelling should be limited to problems that justify the extra effort required (Dodds, 2007).

The simulation model is used as an instrument to answer "what if" questions. Pidd (2010) identified four categories of model use: decision automation, routine decision support, investigation and improvement, and generating insights for debate. A differentiation can be made between decision-driven and evidence-driven modelling. Whereas decision-driven modelling decides what should be done, evidence-driven asks "what can be done?"(Sanderson and Gruen, 2006), see Table 2.1.

Table 2.1 Evidence-driven and decision-driven model building

	Evidence-driven	*Decision-driven*
Starting point	What can we find out about X?	What should be done about X?
Task	Learn from synthesis of data	Explore policy options and futures
Inputs	Scientific evidence	Science + expert opinion if need be
Outputs	Understanding of causal chains	Pros and cons of options
	Inconsistencies/implications of data	Robustness of outcome to scenarios
	Important gaps in knowledge	Important gaps in knowledge

The modelling of complex workflows is an important problem-solving technique within the healthcare setting. There are many examples of the applied use of modelling and simulation in healthcare (Brailsford and Vissers, 2011; Behzad, Moraga and Chen, 2013; Shukla, Keast and Ceglarek, 2014; Viana *et al.*, 2014) . Modelling and simulation facilitates problem solving through the identification of bottlenecks and subsequent system redesign, to the modelling of medication errors, to the modelling of access to diagnostics such as CT and Magnetic Resonance Imaging (MRI).

A challenge when modelling healthcare systems is that rapidly changing and dynamic hospital systems are intensely people-centred, being comprised of patients, staff and policymakers (Seila and Brailsford, 2009). A combination of strategies that include preventive programs as well as care and treatment is usually required to maintain or improve quality (Homer, Hirsch and Milstein, 2007). An introduction to some of the main simulation modelling paradigms and methodologies is presented in the next section of this chapter.

Brailsford et al. (2009) reported that only 5% to 8% of modelling and simulation papers in healthcare mention the implementation of results in practice (Brailsford *et al.*, 2009). Lame et al, (2020) create a generic model for considering the possible outcomes of OR interventions, Figure 2.1, which summarise recommendations, whether implemented and whether an improvement resulted (Lamé, Crowe and Barclay, 2020).

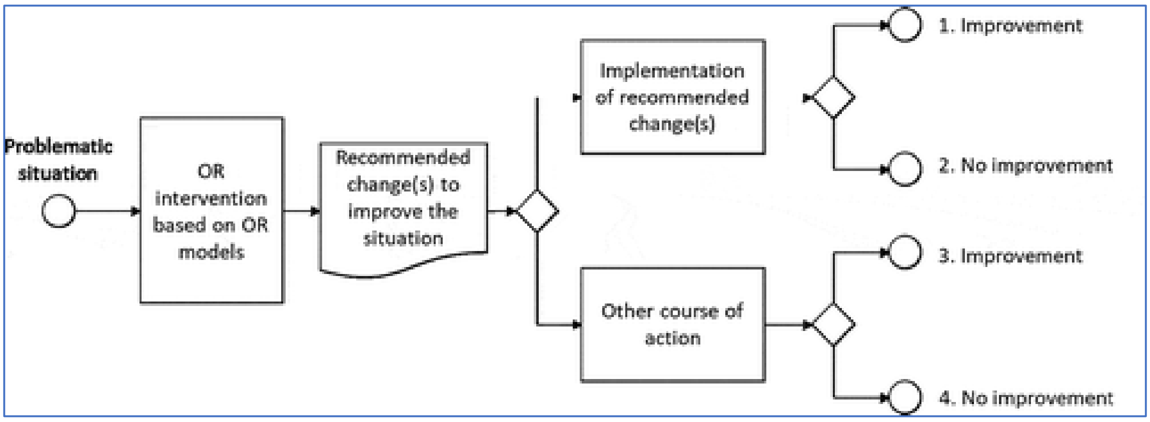


Figure 2.1 Possible outcomes from OR interventions (Lamé et al, 2020)

2.1.1 Discrete event simulation

Discrete event simulation has become a popular modelling tool for problem solving allowing the individual patients and their attributes as well as their unique trajectories as they flow through the care system to be captured. DES cannot be assigned to a hard OR paradigm because it is a tool and not a methodology and so can cross paradigm boundaries. Patients move through the model and they can experience events at any discrete point in time over a defined time horizon (Demir *et al.*, 2017). DES is a popular modelling tool for problem solving with quantitative or a qualitative features, that dynamically mimics a real-life system's structure and behaviour (Eldabi *et al.*, 2002). The steps in a simulation project were described by Law and Kelton and are shown in Figure 2.2 In step 1 the problem or issues under investigation is defined as well as the objective of the study.

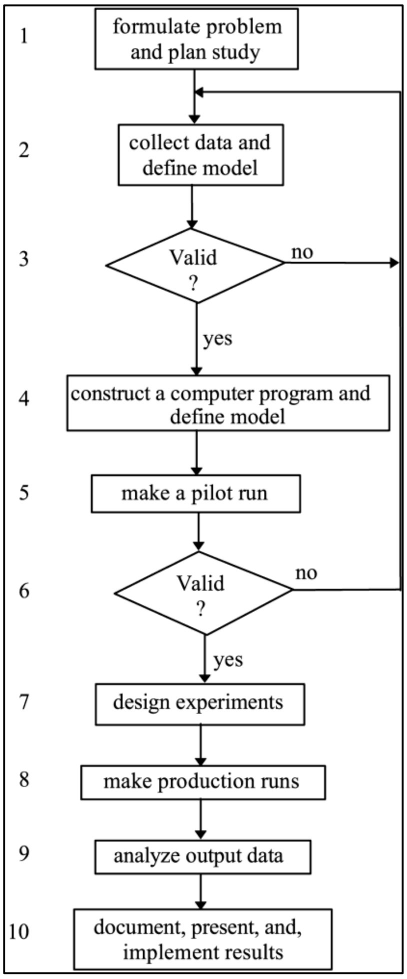


Figure 2.2 Steps in a simulation project (Law and Kelton, 2000)

DES may be used as a qualitative tool at the earlier stages for identifying the problem and the key components. It could also be used as a quantitative tool to provide specific outputs. At the later stages it could be used as a qualitative tool to give more meaning to the abstract outputs generated from the model. DES can be used as a qualitative tool when the situation is not well understood with no predefined theory (Eldabi *et al.*, 2002). DES models are stochastic and take into account variability in the time taken to carry out activities and the times between arrivals into the system, and are suitable for assisting in the management of resources both in normal times and in times of a pandemic (Currie *et al.*, 2020).

Figure 2.3 proposes a method of using DES as both a qualitative and quantitative tool, depending on the problem being (Eldabi *et al.*, 2002).

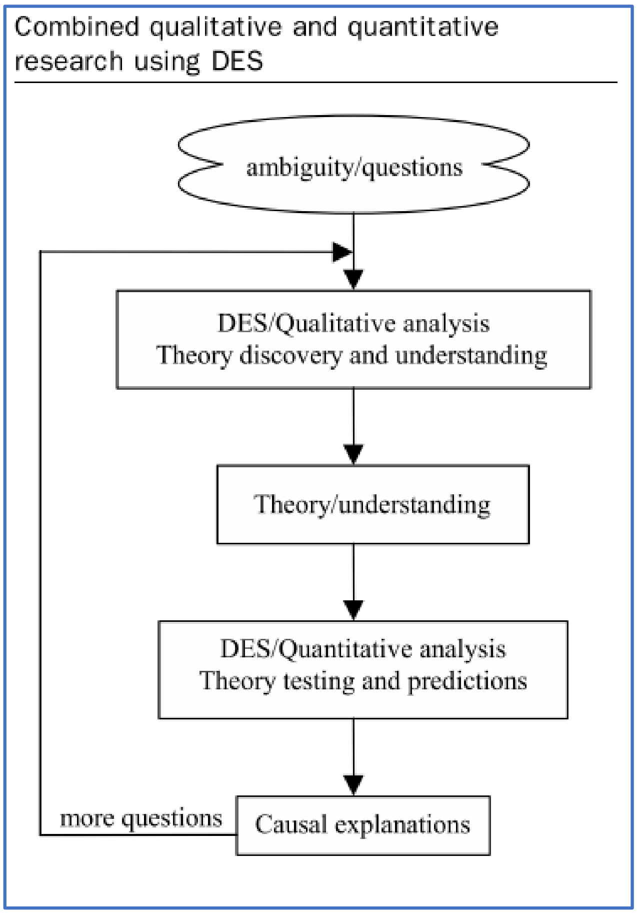


Figure 2.3: DES as a qualitative and quantitative tool (Eldabi et al, 2002)

Healthcare has many specific modelling needs which can be addressed using DES, such as: the need for individual patient focus, the power of animation to communicate results to users and the ability to inform of decision processes (Xu, 2013). DES allows modellers to explore the impact of change or interventions on wait times, length-of-stay/delays and resource utilization. DES is particularly suitable for capturing systems with a strong queuing structure, allowing key performance indicators such as care pathway times to be captured and pathways redesigned (Gunal, 2012; Tako *et al.*, 2014; Demir *et al.*, 2017; Rachuba, Salmon, *et al.*, 2018).

Shukla et al. (2017) described a limitation of DES, as its reliance on simplified qualitative models such as flowcharts to represent patient flow and historical process data. Arguing that qualitative models such as flowcharts (with high-level process visualisation) lack the ability to represent complex process relations and interactions between clinical staff, equipment and patients, they propose this leads to incomplete and unrealistic simulation results, favouring instead the use of role-activity diagram-based modelling as this better represents information obtained from staff interviews (Shukla *et al.*, 2017). . Brailsford (2015) however argues that many characteristics of agent-based models can just as easily be captured in DES and that throughout the 1990's modellers such as herself were already unknowingly using Agent-Based Simulation (ABS) (Brailsford, 2015).

Brailsford et al (2010), in their paper "*Towards the Holy Grail*", describe ways in which System Dynamics (SD) and DES can be combined. In some "combined" approaches, data is simply passed from one model to another, and models are created in different packages (Brailsford, Desai and Viana, 2010). With software such as AnyLogic, the simultaneous use of more than one simulation paradigm is no longer such a challenging task, allowing the limitations of DES to be compensated for using features associated with other paradigms such as ABS.

An early review of computer simulation modelling lamented the mixed quality of papers and the lack of demonstrable application of simulation results (Fone et al., 2003). Thorwarth (2008) carried out a review of the use of DES simulation in healthcare, including potential and challenges. Sixty articles were reviewed, providing examples of healthcare simulations, divided into examples from different sectors, such as hospitals, surgeries, intensive care units, EDs, demographic health provision, healthcare supply chains and special units. Projects covered included applications in the areas of bed management, theatre resource allocation, staff utilisation, portering services, patient care, admission, MRI and EDs and evidence the potential of simulation as a strategic tool for decision makers (Thorwarth, 2008).

Rashwan (2017) used DES and System Dynamics (SD) modelling to capture resource consumption over time and investigated the relationships and interactions between patients, staff as well as organisational and external factors. SD and DES were used as part of an integrated scheduling framework which utilised a hybrid multi-method modelling and simulation approach (Rashwan, 2017). Lame et al. used a combination of soft systems methodology (SSM), ethnographic observation and DES to model a service provided to oncology patients which included the pharmacy department and chemotherapy delivery suites (Lamé, Jouini and Stal-Le Cardinal, 2020). Ethnographic research is used to uncover user attitudes, emotions, cultures and contextual factors in a social setting and can involve the participant researcher either overtly or covertly collecting data (observation, interview, document analysis) for an extended period of time (Lamé, Jouini and Stal-Le Cardinal, 2020).

Frequent examples are found in the literature of DES projects which involve radiology as part of a care pathway. A radiation oncology centre used DES to model their process as part of a quality improvement initiative and reported utilisation rates of 56% for staff and 58% for equipment (Famiglietti *et al.*, 2017). In diagnostic radiology, DES has been used extensively in performance measurement, service improvement, staff burnout and fatigue, pathway redesign (Reinus *et al.*, 2000; Oh, Toh and Giap Cheong, 2011; Van Lent *et al.*, 2012; Booker *et al.*, 2016)**.**

DES modelling allowed a comparison of the current practice at the hospital with scenarios using radiographer-led discharge of patients directly after imaging, and also allowed an assessment of the reduction in patients' length of stay in ED in one NHS Hospital (Rachuba, Knapp, *et al.*, 2018). The model allowed trade-offs between the provision of radiographer-led discharge and its effects (i.e. reductions in waiting times and ED workload) to be quantified. This work combined evidence-based research addressing the benefits of radiographer-led discharge with operational research techniques and DES. Process mapping the current pathways through ED helped both operational researchers and clinicians to identify key bottlenecks and informed the subsequent development of the DES model. Various scenarios were compared to the status quo, and likely savings in terms of length of stay were determined. The study demonstrated that even a relatively small, predefined subset of patients made suitable for radiographer-led discharge can impact on time spent in ED, particularly for those patients discharged earlier than usual. This study has shown that the application of radiographer led discharge can potentially provide substantial reductions in patient journey times through ED as well as reducing the load on nurses and consultants (Rachuba et al, 2018). Few examples however evidence how varying inpatient and outpatient cohort characteristics affect the process or staff workload.

2.1.2 System Dynamics

System Dynamics (SD) is recognised as being fundamentally interdisciplinary in nature, helping individuals to understand complex systems and the sources of policy resistance in that system to be able to guide effective change (Sterman, 2001). Systems can change, adapt, respond to events, seek goals, heal, and attend to their own survival in lifelike ways, although they may consist of or contain non-living things (Sterman, 2007). Additionally, the behaviours of a system cannot be known just by knowing the elements of which the system is made (idib). When confronted by a complex social system one is anxious to fix, one cannot simply step in and set about fixing it; one is firstly obliged to understand the whole system (Sterman, 2000). Hospitals are complex organisations with many diverse internal and external stakeholders and functions which combine to deliver appropriate health services to a community (Loosemore, Chow and Mcgeorge, 2012).

Causal loop diagrams are a powerful way of capturing the essence of complex systems. Causal loop diagrams demonstrate cause and effect relationships and the interconnected nature of the problem of interest (Meadows, Meadows and Randers, 1992). Reinforcing feedback loops are sources of growth, explosion, erosion and collapse, and a system with an unchecked reinforcing loop will ultimately destroy itself (ibid). A fundamental tenet of systems thinking is that real complex systems are best described in terms of networks of interconnected feedback loops as described in the book “Seeing the forest for the trees” (Sherwood, 2002).

Systems dynamics is particularly useful where there are multiple stakeholders with various interests and backgrounds. Problems often have many interrelated factors where numerous stakeholders are involved and the problem should be captured simply so as to allow collaboration between stakeholders (McDaniel and Driebe, 2001). Systems strongly resist changes in their information flows, most especially in their rules and goals, by constraining individuals from operating by different rules or from achieving alternative goals within a system (Meadows, Meadows and Randers, 1992). Change in a part of the system without due concern to the overall system behaviour is frowned upon by systems thinkers, as it often results in what is considered partial improvement at the expense of the overall system (Ackoff, 2010).

Oliva and Sterman (2001) created a System Dynamics model capturing the erosion of quality in the service industry. They used estimation, observation, historical data and interviews to calibrate their model of a consumer lending service centre in the UK. Three responses to work pressure were examined: increasing service capacity, reducing time per order and increasing work intensity. They considered the effect of these policy changes on the permanent erosion of service standards and loss of revenue. They found that it took a combination of policies to maintain or improve quality. The feedback structure of erosion of service standards captures the vicious circles of corner cutting, overtime generation and goal erosion, which ultimately results in less time per order as shown in Figure 2.4. it has been noted that while quality norms decay readily, they rise with more difficulty (Oliva and Sterman, 2001).

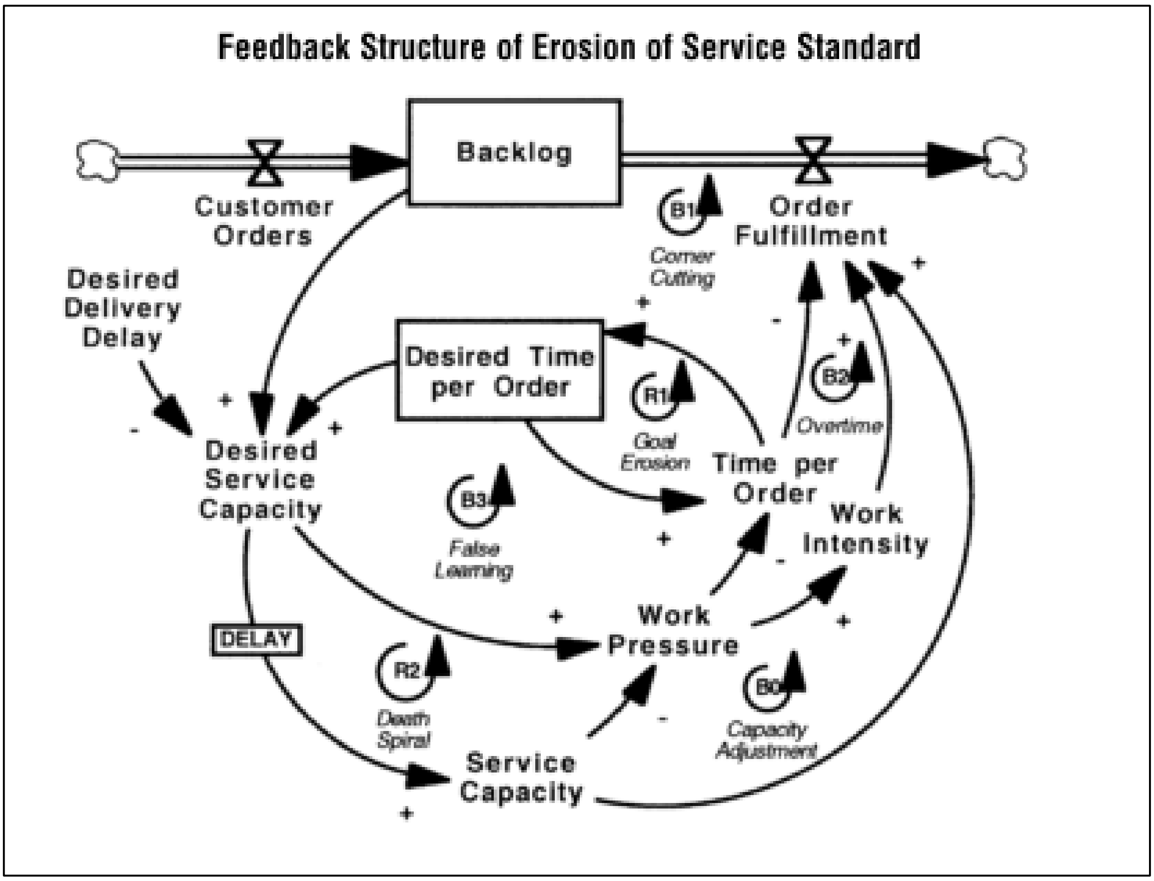


Figure 2.4: Rogelio and Sterman (2001) feedback structure for erosion of standards

Royston et al (1999) describe work spanning five years which used SD to help develop and manage policies and programmes in healthcare in the United Kingdom. SD was used in the areas of accessing risk, screening for disease, managing waiting lists, planning the healthcare workforce and developing emergency health and social care. The model determined that changes in capacity such as adding beds to the ED had less of an effect than behaviours such as referral patterns and length of stay. Their model was deemed highly successful as a communication and learning tool, and for helping to develop “what if” scenarios. While the original model was expanded to include external units and sub-systems such as rehabilitation and nursing homes, data was not available for this section, and the model was qualitative in nature. Royston et al concluded that System Dynamics is useful for rapid, intuitive understanding of a complex system (Royston *et al.*, 1999).

System Dynamics (SD) has been used to model chronic diseases such as diabetes, cardiovascular disease, and obesity. A common lesson in the modelling of such chronic diseases is the value of balanced strategies that include preventive programs as well as care and treatment (Homer, Hirsch and Milstein, 2007). Homer et al (2007) warn of the perils and promises of downstream and upstream reforms. Their model aggregates across all illnesses and demonstrates the potential impacts of attempting to improve downstream care or upstream prevention and described the economic mechanisms for such interventions. Lyons and Duggan (2014) used SD to investigate the sustainability of healthcare in terms of population growth and ageing, where sustainability is the ability of future generations to meet demands on the legacy system given pressures such as increased co-morbidity, population numbers and population age (Lyons and Duggan, 2014).

Taylor and Dangerfield (2005) used SD to model the feedback effects of reconfiguring health services. They modelled cardiac catheterisation services and how bringing these closer to home (i.e., providing a local service) can lead to an increase in demand. They hypothesised that demand for services was stimulated by increasing access and used System Dynamics (SD) to model this causal relationship. They discussed how little attention has been given to the actual mechanism of feedback effects associated with service shifts and the ability of SD to do so (Taylor and Dangerfield, 2005). Like earlier work carried out by Oliva (2002) “Trade-offs in responses to work pressure in the service industry” a combination of policy changes is advised to avoid unwanted changes in patient activity such as where demand is stimulated by ease of access.

On unintended consequences and the effect of feedback, Taylor and Dangerfield (2005) remarked on how their work contributes to the “Supplier-Induced Demand (SID)” debate. The SID debate considered whether doctors are “imperfect” referring agents and may, on occasion, recommend more or less services than a fully informed and knowledgeable patient would order. Patients also have a part to play whereby they demand services once they become aware of them. Demand can be stimulated by the improvements in access to services, where patients respond by demanding the service. Referrals for cardiac catheterisation were found to increase with the new service, which in turn led to increases in referrals for invasive treatment (Taylor and Dangerfield, 2005).

2.1.3 Agent-Based Simulation

Agent-Based Simulation (ABS) attempts to simulate intelligent, autonomous entities (agents), as they interact to attain some goal in their environment (Dubiel & Tsimhoni, 2005). Although simulation and modelling in healthcare facilities are not new, ABS is a relative newcomer. The foundational premise and the conceptual depth of ABS is that simple rules of individual behaviour will aggregate to illuminate complex and/or emergent group-level phenomena that are not specifically encoded by the modeller and which cannot be predicted or explained by the agent-level rules. In essence, ABS has the potential to reveal a whole that is greater than the sum of its parts (Friesen & McLeod, 2014).

The relevant factors for agent profiles are determined by the objective of the ABS, and they may include distributions of sex, age and other demographic factors, physical origin and destination within the topography and beyond the topography, and risk factors associated with, for example, the spread of infection. ABS offers tremendous potential for the better understanding and optimisation of these complex systems (Friesen & McLeod, 2014).

Sibbel and Urban (2001) report on how traditional modelling approaches, mainly stemming from technically oriented application domains, increasingly fail in terms of adequately supporting the economic and organisational planning process in the hospital domain. One of the major reasons for this problem arises from ignoring human decision making and behaviour as a relevant influence on the performance of such systems. To receive valid input data for the model, an adequate amount of data about the organisational processes and treated patients needs to be collected and carefully analysed in order to classify symptoms, as well as diagnostic and therapeutic measures(Sibbel and Urban, 2001). Dubiel and Tsimhoni (2005) argue that ABS can be integrated with DES to model humans travelling freely through a DES system.

Three distinct modelling paradigms have been described in this chapter; however, models may be comprised of elements from each paradigm and this is referred to as hybrid modelling. Hybrid modelling uses elements from the various paradigms interchangeably and its popularity has enjoyed exponential growth in the past two decades (Brailsford *et al.*, 2019). This is facilitated by modelling software such as Anylogic, where “all model elements of all methods, be they SD variables, state chart states, process blocks, and even animation shapes or business charts exist in the "same namespace": any element is accessible from any other element by name” (Anylogic Personal Learning Edition 8.4.0, 2019).

2.2 Facilitated modelling

Ackoff (1979) contended that “managers manage messes”, and that the behaviour of a mess depends more on how the solutions to its parts interact than on how they act independently of each other (Ackoff, 1979). In this section of the review of literature, the inclusion of stakeholders in operations research projects and benefits of doing so are discussed. The current trend in the extensive literature on DES in healthcare is to emphasise the importance of striving for a facilitated modelling approach (Proudlove *et al.*, 2017). A reason for this is that strategic decisions involve human beings who potentially construe the same situation quite differently from one another (Sanderson and Gruen, 2006). Recognised benefits of involving decision makers in modelling projects include:

1. providing them with an opportunity to internalize research knowledge,
2. promotion of trust and consensus building and a more meaningful focus,
3. improvement of relationships,
4. higher likelihood of implementation (Ross *et al.*, 2003; Harper and Pitt, 2004; Monks, Robinson and Kotiadis, 2016).
5. educating decision makers to know how and where modelling can be useful (Pitt et al., 2016).

Traditionally simulation modelling has taken place in the expert mode i.e. the problem situation faced by the client is given to the operational research consultant, who then builds a model of the situation, solves the model to arrive at an optimal (Franco and Montibeller, 2010). Disadvantages of an expert approach may include stakeholders not agreeing with the modeller’s interpretation of the problem situation or the eventual optimal solution. A simulation study where the whole intervention is conducted together with the client is called facilitated modelling (ibid).

It is important to acknowledge and work with multiple perspectives simultaneously when addressing complex problems in healthcare service provision, (Crowe, 2016). The importance of doing so ensures a greater likelihood of success and may address the reportedly low levels (6%) of implementation (Robinson and Robinson, 2001; Brailsford and Vissers, 2011).

Robinson (2012) in his paper “Soft with a hard centre:” describes how in the early days of SSM and DES integration, “poor” models (those which could not be validated or lacked data) could be used for problem conceptualisation and to assist managers in their understanding of systems. In the facilitated mode models are not judged by accuracy but on usefulness in promoting debate and generating understanding (Robinson *et al.*, 2014). Another benefit of mixing hard and soft OR can be a greater interest in OR methods, which opens the door for future studies with full institutional cooperation and less distrust (Pessôa *et al.*, 2015). It has long been accepted that combined DES and SSM approaches can complement stakeholder facilitation in the conceptualisation, experimentation and implementation and post coding stages of OR projects (Robinson and Robinson, 2001; Fone *et al.*, 2003; Kotiadis, Tako and Vasilakis, 2014; Robinson *et al.*, 2014; Kotiadis and Tako, 2017).

A SimLean approach was taken by Robinson et al (2014) where simulation was used in a Lean workshop. During the 2-day workshop process maps were converted into a DES model and used to discuss lean improvements (Robinson *et al.*, 2014). Tako and Kotiadis (2015) developed a framework for the structured use of different paradigms called the PartiSim Approach and provided two examples of its application in an obesity study and the modelling of a colorectal service. They report that members of the obesity care team were involved throughout the study and took a keen interest in its results and suggested different scenarios. The team suggested six different scenarios projecting one year forward focusing on waiting lists.

The approach is designed to aid modellers using facilitated DES modelling and consists of 6 stages and 5 sub-stages and describes the hard and soft OR activities and expected outputs for each stage. PartiSim suggests three workshops (with 1-3 month gaps between workshops) and identified 6 roles for individual though it is recognised that the modelling team can consist of as few as two individuals. The six roles identified included:

1. The simulation modeller (coder) – someone experienced in DES modelling.
2. The recorder – assists the facilitator, takes notes and observes.
3. The facilitator – leads activities within a workshop to enable the group to meet objectives – may be more than one.
4. The project champion – the link between stakeholder and modelling teams.
5. Key stakeholders – those with tacit knowledge and decision-making power.
6. Other stakeholders - those with tacit knowledge of the organisation.

In both the SimLean and PartiSim approach model coding was performed in the "back room", meaning that clinical stakeholders/those with tacit knowledge of the system did not participate in model coding. Proudlove et al (2017) proposed an approach using BPMN that would support model coding during facilitated stakeholder workshops (which included coding during workshop events) and provided three case study examples. Problems were encountered during facilitated coding in tow of the examples, where the limitations of the coder/software were reached when trying to capture system complexity. A matrix was created which considered model complexity (high or low) and data analysis complexity (high or low) and the barriers to fully facilitated approaches determined that facilitated coding was possible where model complexity and data analysis complexity where both low Figure 2.5, (ibid).

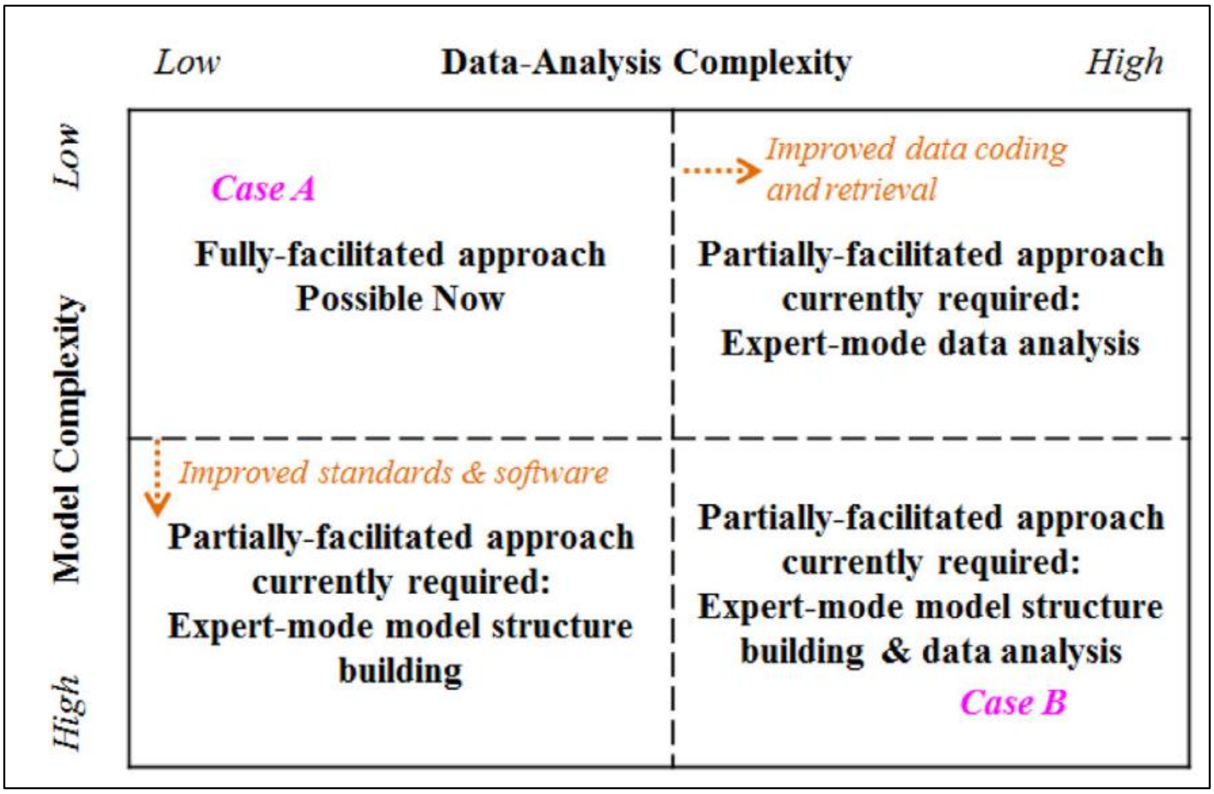


Figure 2.5 Proudlove et al, matrix of model and data complexity and barriers to full facilitation

2.2.1 Soft systems methodology (SSM)

SSM is one of the most developed systems methodologies in terms of its theoretical premises and philosophical underpinnings and usage (Lewis, 1992; Rose, 1997; Mingers and

Rosenhead, 2004; Rodriguez-Ulloa and Paucar-Caceres, 2005; Lamé, Jouini and Stal-Le Cardinal, 2020). SSM articulates a learning process which leads to action in a never-ending learning cycle: once the action is taken, a new situation with new characteristics arises and the learning process starts again (Rodriguez-Ulloa and Paucar-Caceres, 2005).

Crowe et al (2017) described combining qualitative and quantitative operational research methods to inform quality improvement in pathways spanning multiple settings. A rich picture (RP) was developed, capturing the main features of services for infants with congenital heart disease which are pertinent to service improvement Figure 2.6.

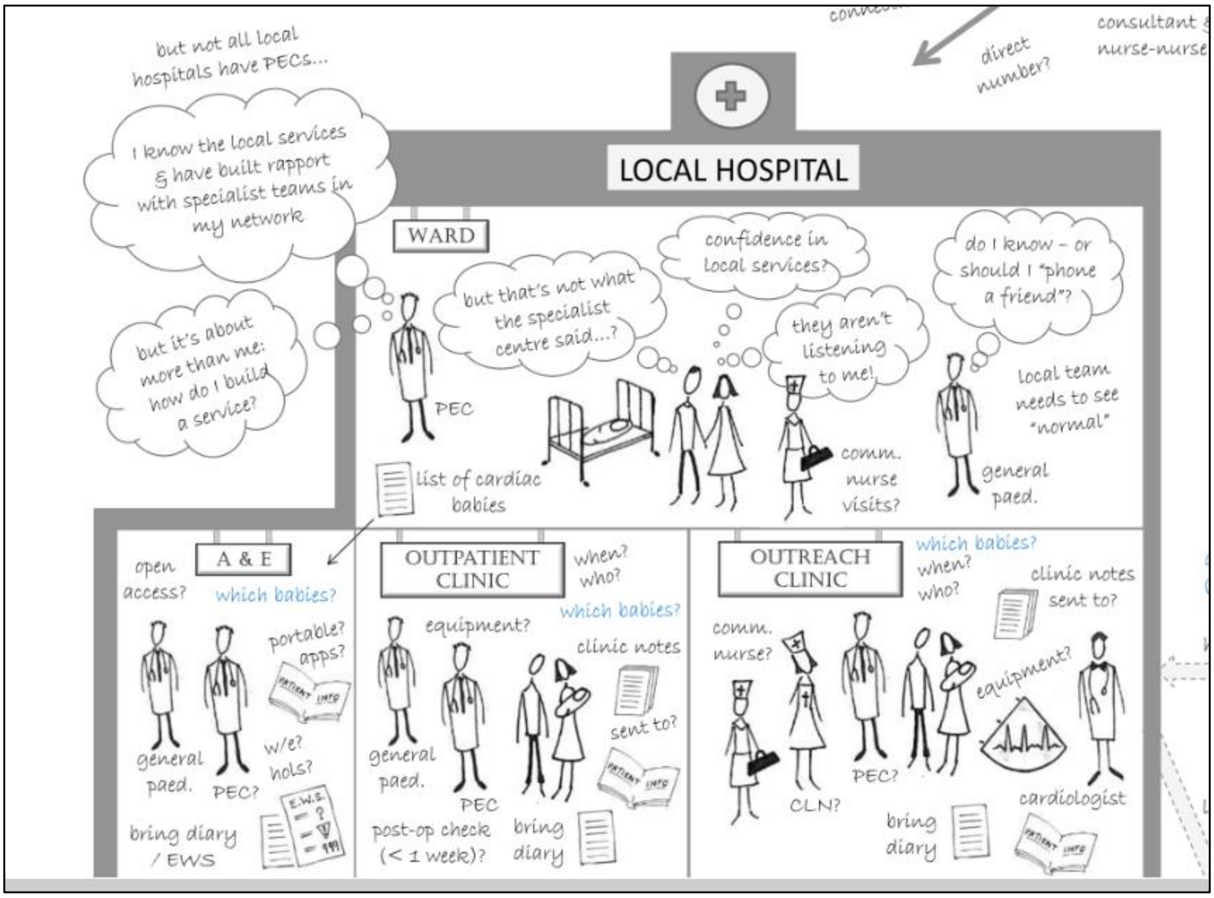


Figure 2.6 Rich Picture diagram created by Crowe et al, (2017)

A soft systems methodology (SSM) was chosen so as to consider systematically, changes to services from the perspectives of the community, primary, secondary and tertiary care professionals and a patient group, incorporating relevant evidence. Classification and regression tree (CART) analysis of national audit datasets was conducted along with data visualisation designed to inform service improvement within the context of limited resources. This was used, along with a graphical summary of the CART analysis, to guide discussions about targeting interventions at specific patient risk groups. Formal models need not be quantitative, and a class of qualitative problem-structuring methods within the "soft" (interpretivist) OR paradigm exists to help groups explore and address complex problems. These approaches permit pragmatic partial or local improvements to be agreed without requiring consensus across different interests on an overall solution (Crowe *et al.*, 2017).

In the teaching of radiography students, drawing has been encouraged as a means of improving learning and comprehension (Clark, 2020). Drawing definitions of key terms and concepts such as the various photon interactions with matter (e.g., Compton scattering effect, photoelectric absorption, pair production, and classical) as a means of improving understanding in an attempt to process information and improve recall (Clark, 2020). Creating a visual representation through drawing of an item or preparing to do so affords that item a substantive memory benefit, relative to writing out words (Wammes, Roberts and Fernandes, 2018). The advantage for drawn information has been attributed to the integrated contributions of at least three components of visual production through drawing, which can independently facilitate memory: elaborative, motoric, and pictorial (Wammes, Roberts and Fernandes, 2018).

While some argue that SSM is a post-hoc effort of understanding what happened, others view it as a process of tackling real-world problems in all their richness, and formally expressing them. Operational Research is by nature a collaborative discipline (De Gooyert *et al.*, 2017). How OR studies consider stakeholders has been shown to vary widely, from 'enemies' to minorities that should be given a voice with multiple means of including them:

1. Optimizing - where much of the problem is already known and the problem can be translated into mathematical relationships.
2. Balancing - eliciting stakeholder preferences, by involving them in the identification of alternatives, the identification of criteria, the scoring of alternatives, and weighting of the criteria.
3. Structuring - aimed at increasing the knowledge about a problem.
4. Involving - focuses on conflicts between viewpoints, (De Gooyert *et al.*, 2017)

Gaining buy-in for a modelling project can be achieved by ensuring that important and relevant issues are addressed, and that the work can show obvious and quick benefits to the organization (Harper and Pitt, 2004).

RP diagrams use cartoon-like freeform drawings to enact or provoke knowledge and reflection and therefore allow a problem situation to be viewed in a more structured way, without commitment to any particular solution (Checkland, 1985, 1999). The purpose of a RP is to firstly determine what is learnt in the process of its construction and secondly to use the picture as a means of conveying a message or sharing an understanding. RP diagramming allows groups to explore their information flows, communications, subconscious, occult sentiments and conflicted understandings (Rodriguez-Ulloa and Paucar-Caceres, 2005; Berg, 2015; Bell, Berg and Morse, 2019). The end point of this stage in the analysis should be a picture of the problem situation, one as rich as can be assembled in the time available (Checkland, 1985). RPs are considered by some as merely a by-product, and by others as a means of communicating a shared understanding and perspective (Lewis, 1992; Checkland, 1999; Fougner and Habib, 2008). Fougner and Habib (2008) tested SSM tools (RP diagramming and CATWOE) to support action research and gain insights into inter-professional education development Figure 2.7. The aim of the project was to create an interdisciplinary module for radiography, physiotherapy, pharmacy and other health professions to support the faculty's teaching philosophy which seeks to challenge boundaries between disciplines. In this example the tools were met with suspicion and a lack of enthusiasm. This was attributed to the approach taken by the researcher who presented a draft RP to stakeholders and asked for contributions rather than creating a RP from scratch (Fougner and Habib, 2008).

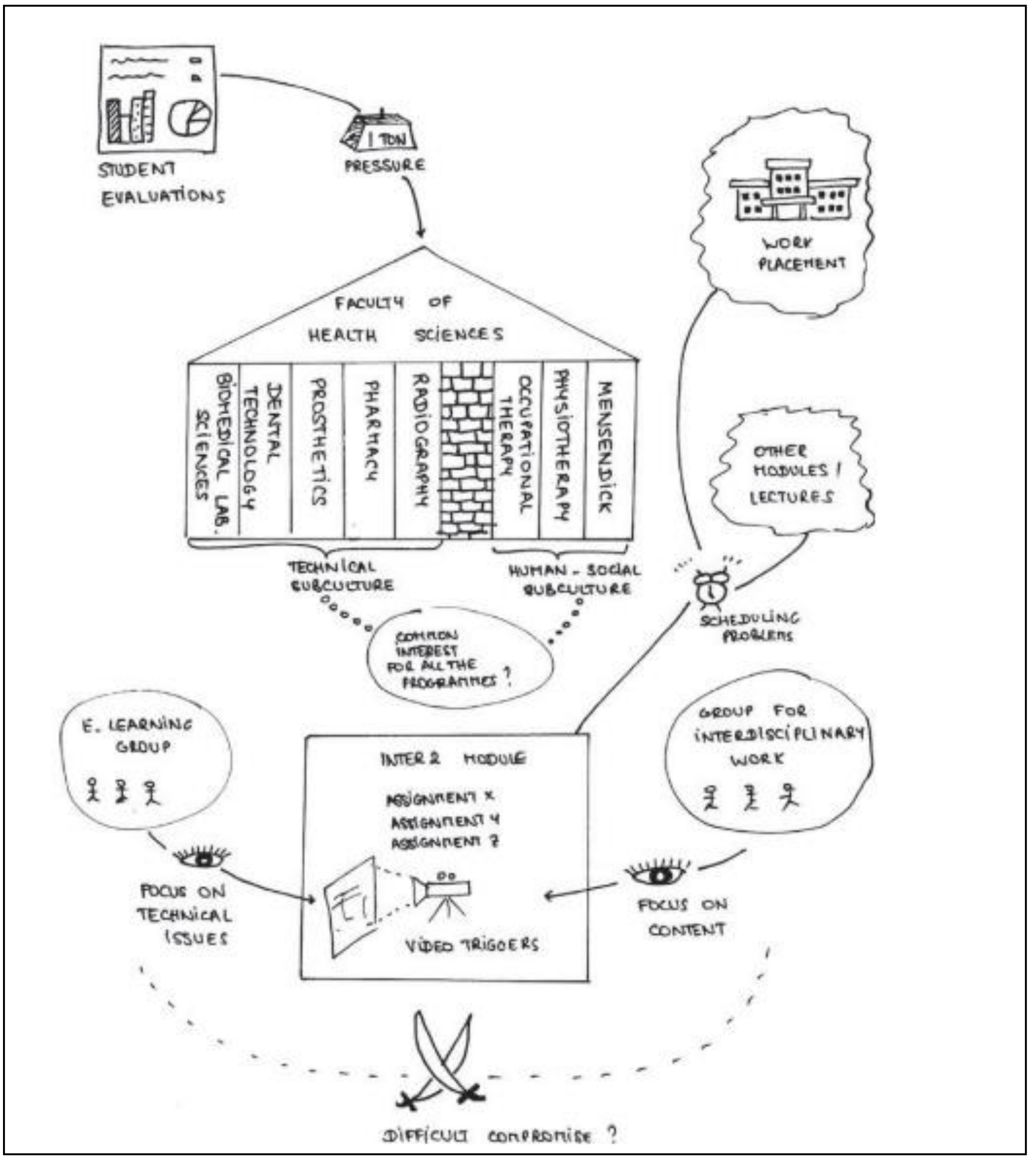


Figure 2.7 Example of RPD (Fougner et al., (2008))

The process of generating a RP can highlight the different motivations, priorities and constraints of health professionals across the organisations involved, these different “worldviews”, which are important to articulate as part of the process of learning about and improving the situation (Crowe *et al.*, 2017). Crowe et al., (2017) created a RP that captured key features of a service provided to infants with heart conditions and their parents, one interested in the people, processes, places, relationships and viewpoints involved), perceived issues (e.g., barriers to accessing care) and the characteristics of possible service improvements.

RP is generally agreed to work best within the context of a small group of between 2 to 6 people, positioned around small tables, which encourages creative problem identification through visual understanding of complex socio-technical systems (Bell, Berg and Morse, 2019). Though less common, RP diagramming can be conducted with individuals where it is not possible to meet as a group and RPs combined to produce a group contribution (Bell, Berg and Morse, 2016). While groups may agree on key issues, this is not a requirement as multiple perspectives can be captured. While reproducibility of rich pictures is questionable, some efforts have been made to analyse the content of these drawings using Eductive Interpretation, abbreviated to EI, though caution is advised to avoid importance being attribute to the frequency with which issues appear (Bell, Berg and Morse, 2019).

In SSM, the acronym CATWOE is used to identify the Customers, Actors, Transformation, Weltanschauung/Worldview, Owner and Environmental constraints of a system in order to create a root definition of a service from varying perspectives (Crowe *et al.*, 2017; Lamé, Jouini and Stal-Le Cardinal, 2020). A root definition is a short statement capturing the intention of someone's worldview, aiming to elicit perspectives on an issue. A root definition can be created by considering the CATWOE elements described in Table 2.2. The CATWOE elements provide a systematic way of defining problems within systems, by including the necessary elements that together constitute a human activity system from a certain perspective, that permit a task "T" to be completed (Bergvall-Kåreborn, Mirijamdotter and Basden, 2004).

Table 2.2: CATWOE elements

C	Customers	The victims or beneficiaries of T
A	Actors	Those who would do T
T	Transformation process	The conversion of input to output
W	Weltanschauung	The worldview that makes this T meaningful in context
O	Owners	Those who could stop T
E	Environmental constraints	Elements outside the system which it takes as given

Stakeholders and investogators can use the RP diagram as an object to stimulate debate. The aim of the debate is to seek both changes, which could improve the situation and are regarded as both desirable and (culturally) feasible, and accommodations between conflicting interests, which will enable action-to-improve to be taken (Kotiadis *et al.*, 2013). Taking action may involve structural, process or attitude change or can even be about making sense (learning) of a complex situation (Checkland, 1999). A root definition should be expressed in the following form: a system to do P (what the system does) by Q (how it does it) in order to achieve R (why is it being done) (Železnik, Kokol and Blažun Vošner, 2017). The letters P, Q and R do not stand for anything, except that they are subsequent letters in the alphabet, but they do have a special meaning: P = what, Q = how, and R = why.

Applications of SSM can be considered as either externalised Mode 1 or internalised Mode 2. Mode 1 is methodology-driven, and follows the steps and tools as described in the original seven-step model of SSM. A Mode 2 interpretation uses SSM as an internalised model to guide actions in a manner appropriate to the situation at hand (Lamé, Jouini and Stal-Le Cardinal, 2020).

2.3 Healthcare staff workload

2.3.1 Radiology workload

Radiology workload has historically considered the number and type of examinations completed (RCSI, 2011). Radiology workload is inherently reductionist in that it is based on medical requests for imaging of different body parts and assessment of same in terms of numbers of examinations completed (Naylor, 1992; Sunshine and Burkhardt, 2000; Ondategui-Parra *et al.*, 2004; Pitman and Jones, 2004; RCSI, 2011; Snaith, Milner and Harris, 2016). The Royal College of Surgeons, maintain that the throughput metric as a measure of radiologist workload is an old-fashioned, discredited and inappropriate use of data, due to its lack of context, and results in an unfiltered and un-weighted analysis of their workload.

Pitman et al described the need to measure (radiologist) reporting workload in teaching departments (Pitman and Jones, 2004) to include the additional workload associated with staff training. The study separated measurement of radiologist workload into reporting, with its associated tasks (e.g. examination protocoling, phone calls), and time spent performing interventional procedures, taking meetings and similar long-duration tasks. Study-ascribable time includes the time expended by a radiologist interacting with one specific diagnostic imaging study through all the steps of its diagnostic journey. Another method of capturing radiologist workload is the Body System Framework which provides a clear classification of radiologist work into three categories: patient-related study-ascribable tasks; patient-related non-study ascribable tasks; and non-patient-related tasks (Pitman, 2018). Radiologist workload has been defined by clinical productivity or examinations completed, however newer definitions of workload include case mix, participation in multi-disciplinary meetings and other non-patient related activities (Pitman and Jones, 2004; Pitman *et al.*, 2018).

Focusing on radiographers, the major sources of stress for those employed in the profession include nature of the work, physical demands, system defects, administrative functions including patient scheduling (Sechrist and Frazer, 1992).The work from 1992 identified that radiographers have responsibility but lack authority and that this was one of the most important sources of stress (Sechrist and Frazer, 1992). More recent work by Nightingale et al (2021), identified workload pressures as one of three themes affecting radiographer retention see Figure 2.8. Increasing workload was noted for all participants and a vicious circle identified whereby the denial of a request for flexible working was often seen to lead to loss of an experienced radiographer from the service (Nightingale *et al.*, 2021).

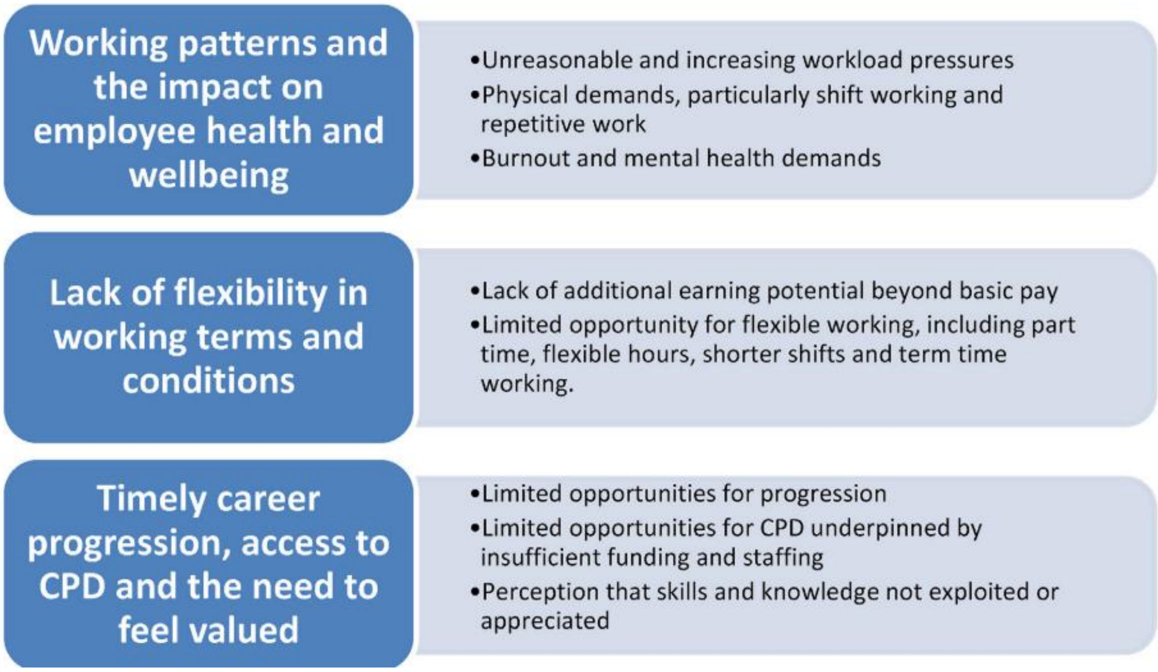


Figure 2.8 Factors influencing radiographer decisions to leave or stay in the NHS

Hyde and Hardy (2021) recognise the dichotomy between increasing efficiency versus patient centred care to deal with increased demand for services. A prioritisation of care over efficiency for the sake of the patient as well as staff was recommended, and a call for management to support same (Hyde and Hardy, 2021). With regards to the physical demands of the service, the daily work of radiology staff requires lifting, pulling, turning, and general moving of patients, and 83% of female radiographers report themselves as suffering from back pain (Kumar, Moro and Narayan, 2004).

Radiology workload includes the prioritisation of tasks and scheduling of patients to ensure a smooth workflow. Zhang et al,. (2018) recognise that little is known about how these prioritizing and coordination skills are learned, how people performing them build their mental system models, what information and strategies they use, and which work practices are most successful. Most of the individuals performing coordination tasks are trained on the job in an unsystematic manner, and the knowledge remains, for the most part, tacit (Zhang *et al.*, 2018). The importance of coordination is evidenced by the fact that approximately 10% of errors in radiology are related to communication, which includes radiology examinations performed on the wrong patient, incorrect examinations performed on the correct patient, delays in diagnosis, and a failure to properly communicate the findings to the clinician (Swensen and Johnson, 2005).

As per the Radiological Protection Act (2019) an important aspect of a radiologists and radiographers work is determining whether exams are justified (EPA, 2019). As per the Irish Institute of Radiographers and Radiation Therapists, patient care related aspects of a radiographer's role include but is not limited to:

1. Provision of a detailed explanation of the procedure prior to examination,
2. Verification that written informed consent has been obtained,
3. Assessment of physical and psychological suitability for CT,
4. Appropriate preparation of patients such as fasting and oral contrast administration,
5. Assessment of patient risk factors,
6. Monitoring and reassurance at periodic intervals during the procedure,
7. Clear communication with the patient and their carer prior to, during and after the examination (Irish Institute of Radiography and Radiation Therapy, 2014).

Research by Woznitza et al., examined the increase in the number of examinations performed/interpreted by radiographers but did not include the individual activities or physical workload associated with the variation between IP and OP characteristics and profiles (Woznitza *et al.,* 2014). The work of radiographers is time-pressured, task-focussed and highly technical (Bleiker et al, 2018). Electronic health records (EHRs) have been shown to increase healthcare worker workload and suggests the need for both individual and organizational-level interventions to improve alert workload and subsequent burnout

(Gregory, Russo and Singh, 2017). Cognitive information overload arises from either having too much information when a person is performing a task or from the difficulty in inferring what information is required for the task (Gartner, Zhang and Padman, 2018).

2.3.2 Medical staff workload in ED

Medical staff workload in the ED includes the total number of patients managed, the maximum number of patients simultaneously managed, occupancy, length of stay and patient acuteness as well as teaching, charting, answering emergency calls, reviewing diagnostic results and direct patient care (France *et al.*, 2005). In terms of nursing workload, Saville et al. (2019) identified that further research into skill mix, nursing work aside from direct care, quantifying risks and the benefits of under- and over-staffing was required and that OR techniques could be used to address these issues alongside traditional methods. They determined that OR can help to structure such problems, deal with complexity, and allow numerical experiments before implementation. In the article entitled "How many nurses do we need?", active collaboration was encouraged between operational research specialists in the field and clinical staff (Saville *et al.*, 2019). Gregory et al., (2017) proposed that workload may be considered either as objective or subjective. Objective workload may be considered as the number of hours spent on work and work activities, with subjective workload being an individual's perceptions of whether they have sufficient time to complete work tasks (Gregory, Russo and Singh, 2017). In his PhD thesis, Rashwan (2017) separated the care activities provided by healthcare staff into either direct, indirect, unrelated to a specific patient or personal, as shown in Figure 2.9. The study which developed a framework for staffing and shift scheduling in hospitals, applied a staff utilisation threshold of 60% in a system dynamics model before staff were expected to experience undesirable consequences such as fatigue and burnout.

Figure 2.9 Categories of medical staff activities (Rashwan, 2017)

2.3.3 Patient care related workload

The primary goal of healthcare is to offer services to people that help to improve the quality and health of their daily lives, with patients as the primary focus (Faezipour and Ferreira, 2013). The patient care steps that must be taken at every stage in the radiology workflow are difficult to map. Radiographers must continually assess the psychological and physical wellbeing and suitability of the patient; they must ensure that consent is obtained and that patients are informed. They must ensure that the procedure is justified, that the patient is prepared and reassured and that optimum standards of hygiene, comfort and privacy are provided (IIRRT, 2010). Patient care also requires administrative tasks necessary to ensure the safety of patients. Patient care is undoubtedly an important part of the radiographer's role, and it must be defined. Radiology has been perceived as an "anti-care" area due to the short time periods spent with patients. (Brask & Birkelund, 2014). Again, the dichotomy of speed and patient care noted by Hyde and Hardy (2021) is addressed when Brask and Birkelund (ibid) refer to the skills required to carry out technical tasks in a timely manner while concurrently inviting the informed patient to discourse, participate, and cooperate.

A patient and family-centred care approach is one which embraces health-care professionals working together as partners with patients and their families recognising that both patients and their families are vital allies for quality and safety improvement, building education for healthcare professionals, research, and future policy development (McHugh, Bevans and Paradis, 2020). The four core concepts for the "Ladibug" approach are respect and dignity, information sharing, participation, and collaboration. A communication tool designed specifically for radiographers is shown in Figure 2.10 and was based on responses from over 20,000 patients. Patients indicated their areas of greatest dissatisfaction were in waiting times while in department, explanations from staff prior to the test and information provided during the test.

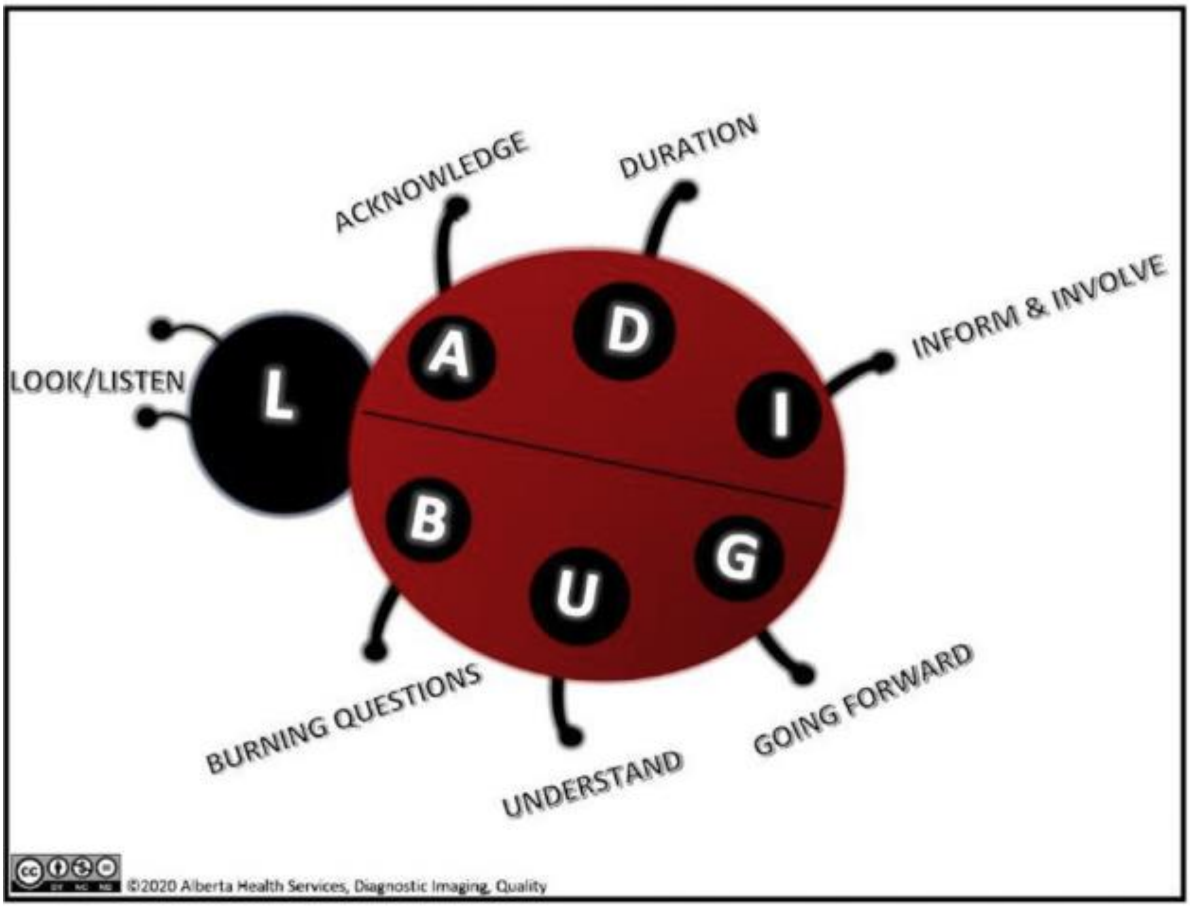


Figure 2.10 Communication tool designed for radiographers (McHugh, 2020)

In a study involving 34 semi-structured interviews with individual patients, Bleiker et al., (2018) explored the experiences of patients undergoing diagnostic radiography examinations, and the interviewees were asked about what compassionate care meant to them. Radiographers view care as a wider concept that encompasses administrative and technical elements as well as a relational element. Four key themes were identified from the analysis: feelings and vulnerability; hidden emotions; professionalism; and valued qualities and communication. Further research into the pressures specific to the time-pressured, task-focussed and highly technical environment of radiography and the impact on compassionate patient care was recommended (Bleiker et al, 2018).

2.3.4 IT related workload

Clinical information technology (IT) systems such as radiology information systems (RIS) and Picture Archive and Communication Systems (PACS) are designed to support radiology staff in their workflow. IT systems are growing increasingly complex and should provide the appropriate information, in the appropriate place to the appropriate people at the appropriate time if they are to be firstly, useable and secondly, useful (Bundschuh *et al.*, 2011). While patient care and the support of workflow should be the main aim of an information system, some are instead designed for legal or management purposes (Oroviogoicoechea and Watson, 2009). The relationship between information technology and business process redesign are recursive, as shown in Figure 2.11, IT systems reshape as well as support processes (Davenport and Short, 1990).

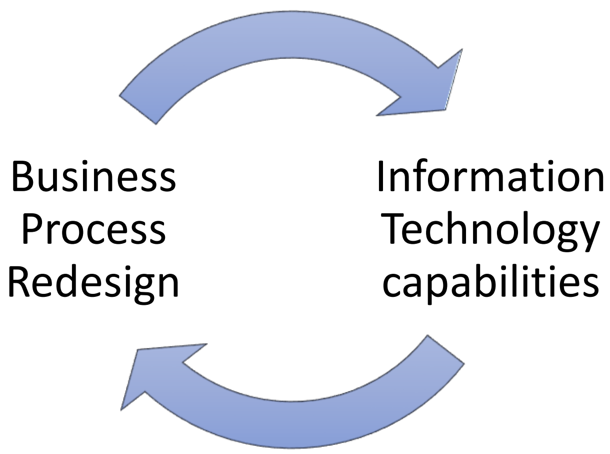


Figure 2.11 Recursive relationship described by Davenport and Short (1990)

Usability is “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (HIMSS, 2011). Usability consists of three goals: effectiveness, efficiency and satisfaction. Effectiveness is the accuracy and completeness with which specified users achieve specified goals in particular environments, including safety as defined by the ISO standard 9126-1 (ibid). Efficiency includes the resources expended in relation to the accuracy and completeness of goals achieved. Satisfaction is the comfort and acceptability of users and other people to the work system (HIMSS, 2011). Mazur et al,. (2019) investigated usability of EHRs and suggested that improved data grouping and decision support functionality in an EHR resulted in improvements in cognitive workload and performance levels among clinicians. While studies recognise that an individual’s experience of workload may be in part due to subjective differences at an individual level, and not solely a function of the objective work environment, efforts should be made to minimise the cognitive workload associated with information system usage (Gregory, Russo and Singh, 2017).

2.3.5 Summary of literature relating to healthcare staff workload

In a bid to answer research question 1 (a) “From the literature, what previous attempts have been made to model healthcare staff workload and patient complexity?”, a breakdown of the literature found on the topic of healthcare staff workload is presented in Table 2.3.

Table 2.3 Literature relating to the healthcare staff workload

Author and paper title	Healthcare staff workload components discussed or measured.
France, D. J. *et al.* (2005) ‘Emergency physicians’ behaviours and workload in the presence of an electronic whiteboard’, *International Journal of Medical Informatics*, 74, pp. 827–837. doi: 10.1016/j.ijmedinf.2005.03.015.	ED staff workload is considered in this paper as a combination of the total number of patients managed, the maximum number of patients simultaneously managed, occupancy, length of stay and patient acuity as well as teaching, charting, answering emergency calls, reviewing diagnostic results and direct patient care.
Saville, C. E. *et al.* (2019) ‘How many nurses do we need? A review and discussion of operational research techniques applied to nurse staffing’, *International Journal of Nursing Studies*, 97, pp. 7–13. doi: 10.1016/j.ijnurstu.2019.04.015.	This paper provides a call to use OR to model more than just direct care and to include the skill mix, as well as the care provided aside from direct care. Here the risks and the benefits of under- and over-staffing are considered.
Gregory, M. E., Russo, E. and Singh, H. (2017) ‘Electronic health record alert-related workload as a predictor of burnout in primary care providers’, *Applied Clinical Informatics*, 8(3), pp. 686–697. doi: 10.4338/ACI-2017-01-RA-0003.	In this paper workload is considered as either objective or subjective. Objective workload may be considered as the number of hours spent on work and work activities, with subjective workload being an individual’s

	perceptions of whether they have sufficient time to complete work tasks.
Rashwan, W. (2017) ‘An Integrated Framework for Staffing and Shift Scheduling in Hospitals’, (November)	In this research developing a framework for staff shift scheduling, care was considered as either direct, indirect, unrelated (to a specific patient) or personal (breaks etc.).
Naylor, A. F. (1992) *Quantitative assessment of radiology workload and facilities requirements*, *European Journal of Radiology*.	Radiology workload is inherently reductionist in that it is based on medical requests for imaging of different body parts and assessment of same in terms of numbers of examinations completed.
Sunshine, J. H. and Burkhardt, J. H. (2000) ‘Radiology groups’ workload in relative value units and factors affecting it.’, *Radiology*, 214(3), pp. 815–822.	A study of radiology groups and their workload in terms of relative value units and reported large variance between groups.
Ondategui-Parra, S. *et al.* (2004) ‘Essential practice performance measurement’, *Journal of the American College of Radiology*, 1(8), pp. 559–566	Radiology report turnaround times were found to be used by 82% of departments and transcription time by 71% as performance indicators in one study other categories defined were volume and productivity, radiology reporting, access to examinations, customer satisfaction, and finance.
Snaith, B., Milner, R. C. and Harris, M. A. (2016) ‘Beyond image interpretation: Capturing the impact of radiographer advanced practice through activity diaries’, *Radiography*, 22(4), pp. e233–e238. doi: 10.1016/j.radi.2016.07.005.	This study demonstrated the breadth and complexity of the activities performed by advanced practice radiographers using activity diaries to identify activities completed which included reporting, direct care activities and

	decision support. The study acknowledged frequency of interruptions.
Pitman, A. *et al.* (2018) 'Measuring radiologist workload: Progressing from RVUs to study ascribable times', *Journal of Medical Imaging and Radiation Oncology*, 62(5), pp. 605–618. doi: 10.1111/1754-9485.12778.	Radiologist workload has been defined by clinical productivity or examinations completed, however newer definitions of workload include case mix, participation in multi-disciplinary meetings and other non-patient related activities.
Pitman, A. G. and Jones, D. N. (2004) 'Radiologist workloads in teaching hospital departments: Measuring the workload'. doi: 10.1111/j.1440-1673.2005.01524.x.	A call to include the additional workload associated with staff training.
RCSI (2011) *Measuring Consultant Radiologist workload in Ireland*	Radiology workload has historically considered the number and type of examinations completed. A call for more nuanced measurement of activities to include currently uncounted activities such Interventional, procedural, Nuclear Medicine work, formal teaching, preparation for and conduct of MDMs and administration.
Sechrist, S. R. and Frazer, G. H. (1992) 'Identification of stressors in radiologic technology.', *Radiologic Technology*, 64(2), pp. 97–103.	A call for further research into professional characteristics, physical demands, system defects, administrative functions including patient scheduling.
Kumar, S., Moro, L. and Narayan, Y. (2004) 'Perceived physical stress at work and musculoskeletal discomfort in X-ray	This work identified the physical demands of the profession and the risk of manual handling injuries resulting from lifting, pulling, turning,

technologists', *Ergonomics*, 47(2), pp. 189–201	and general moving of patients, which is an important part of radiographer workload.
Famiglietti, R. M. *et al.* (2017) 'Using Discrete-Event Simulation to Promote Quality Improvement and Efficiency in a Radiation Oncology Treatment Center', *Quality Management in Health Care*, 26(4),	In this study a DES model was created using data, including direct observation, equipment logs, timekeeping, and electronic health records. Workload and utilisation of staff and scanners was ascertained and average utilisation of staff determined to be 56%.
Zhang, C. *et al.* (2018) 'A systematic literature review of simulation models for non-technical skill training in healthcare logistics', *Advances in Simulation*, 3(1).	A study with a healthcare focus of the non-technical skills such as prioritisation and coordination and how these are learned, how people performing them build their mental system models, what information and strategies they use.
Swensen, S. J. and Johnson, C. D. (2005) 'Radiologic quality and safety: Mapping value into radiology', *Journal of the American College of Radiology*, 2(12),	The importance of coordination and communication tasks in radiology where 10% of errors in radiology are related to communication, which includes radiologic examinations performed on the wrong patient, incorrect examinations.
EPA (2019) *RADIOLOGICAL PROTECTION ACT 1991 (IONISING RADIATION) REGULATIONS 2019*.	An important aspect of a radiologists and radiographers role is determining whether exams are justified (EPA, 2019).
Irish Institute of Radiographers and Radiation Therapists 2014	Acknowledgement of the patient care related aspects of a radiographer's role identified and listed though no means of measuring provided.
Woznitza, N. *et al.* (2014) 'Optimizing patient care in radiology through team-working: A case	The study identified radiographer workload and the increase in the number of examinations

study from the United Kingdom', *Radiography*, 20, pp. 258–263.	performed/interpreted by radiographers.
Bleiker, J. *et al.* (2018) '"It's what's behind the mask": Psychological diversity in compassionate patient care', *Radiography*, 24, pp. S28–S32	The work of radiographers is time-pressured, task-focussed, and highly technical and called for further research.
Gregory, M. E., Russo, E. and Singh, H. (2017) 'Electronic health record alert-related workload as a predictor of burnout in primary care providers', *Applied Clinical Informatics*, 8(3), pp. 686–697.	The study analysed how the use of electronic health record (EHR) and their alerts have been shown to increase healthcare worker cognitive workload and suggests the need for both individual and organizational-level interventions to improve alert workload and subsequent burnout.
Brask, K. B. and Birkelund, R. (2014) '"patient care in radiology" - The staff's perspective', *Journal of Radiology Nursing*, 33(1), pp. 23–29.	Patient care contributes to workload as it requires administrative tasks necessary to ensure the safety of patients.
McHugh, C., Bevans, K. and Paradis, S. (2020) 'LADiBUG – A Communication Tool for Diagnostic Imaging', *Journal of Medical Imaging and Radiation Sciences*, 51(4), pp. S31-S38.	Designed a communication tool for radiographers with seven basic tasks required for adequate patient care which is recommended to be used for each examination.
Olthof, M. *et al.* (2018) 'Actual and perceived nursing workload and the complexity of patients with total hip arthroplasty', *Applied Nursing Research*, 39,	Actual workload is defined as the "number of nursing activities" or time spent performing tasks, while perceived workload has been defined as the feeling of responsibilities in care provision.
Nightingale, J. *et al.* (2021) 'Retention of radiographers: A qualitative exploration of factors influencing decisions to leave or remain within the NHS', *Radiography*, (In Press). doi:	A paper focusing on radiographer retention and reasons for staff to leave or remain in the NHS. Reasons for leaving included workload pressures, physical and mental demands,

10.1016/j.radi.2020.12.008.	earnings limitations, wasted skillset, inability to use skills or expand knowledge into new areas.
Hyde, E. and Hardy, M. (2021) ‘Patient centred care in diagnostic radiography (Part 2): A qualitative study of the perceptions of service users and service deliverers’, *Radiography*, 27(2), pp. 322–331	This paper looks at patient centred care (PCC) and the effect of increasing workloads, asking whether staff should put forward the case for prioritising PCC over efficiency. Checklists are created to measure indicators of PCC for use as an audit tool.

Table 2.4 Tasks and factors identified contributing to healthcare staff workload

Healthcare staff tasks	**Factors affecting Workload**
Teaching activities	Number of patients/cases
Charting	Patient length of stay
Reviewing results	Patient acuity
Direct patient care	Interruptions from emergency calls
Indirect patient care	Skill mix
Personal activities	Use of technology and alerts
Unrelated patient care	System defects
Justification of examinations	Subjective perception of workload
Coordination and prioritisation	Feeling of responsibility
Responding to IT system alerts	
Administrative functions	
Participation in multidisciplinary meetings	
Teaching and staff training	
Administration	
Interventional work	
Procedural work	
Nuclear medicine	
Weighting by modality and exam type	
Weighting by modality and exam type	
Manual handling activities	
Administrative patient care	
Direct patient care tasks	
Decision support	
Physical demands	

In Table 2.4 the factors affecting healthcare staff workload and the radiology specific workload tasks are presented. While efforts have been made to differentiate between objective and subjective workload for nursing and medical staff there is little in the literature to be found relating to radiology staff. Efforts have also been made to model nursing staff experience of high level of workload but this is again absent for radiology staff (Rashwan *et al.*, 2015; Olthof *et al.*, 2018). While examples in the literature have been identified where radiology staff utilisation has been measured using DES, the purpose of doing so has not been to further the understanding of radiology staff workload (Famiglietti *et al.*, 2017). A gap in the literature is identified as regards attempts to measure or model radiographer workload in any detail greater than the number of examinations completed or staff utilisation. We are however cognisant that workload results from the aggregation of many different demands and so is difficult to define uniquely (Cain, 2007). The work herein aims to contribute to the body of knowledge on the time-pressured, task-focussed and highly workload of radiology staff providing the CT service by modelling the service with a view to capturing staff workload metrics.

2.4 Measuring radiology performance

Performance indicators are considered to be task-specific metrics intended to enable monitoring and allow measurement of the quality of a work process, product, or service, using relevant parameters (Harvey *et al.*, 2016; Mildenberger *et al.*, 2020). As such, performance indicators allow one to interrogate a health care process and identify potential gaps in quality. Key performance indicators (KPIs) should represent a distillation of all potential performance indicators down to those that are most valuable for quality management of a particular radiology operation. (Harvey *et al.*, 2016). KPIs should be evidence based, built by consensus, reproducible, attributable to radiology performance, and involve events that occur in sufficient numbers to make statistical evaluation measurable (Donnelly *et al.*, 2010).

Some KPIs can be unique to a patient care pathway and may include many departments such as in the case of acute ischemic stroke, where metrics for speedy access to diagnostics and CT brain scans is essential for good outcomes where human nervous tissue is rapidly lost as time progresses (Saver, 2006). In patients with a suspected acute ischemic stroke one study used a KPI of how long it took from patient arrival in hospital to the administration of a thrombolytic drug. The KPI goal was a time under 60 minutes. Significant delays have been reported throughout pathways and processes of treatment, at stages such as referral, assessment, radiology imaging and administration. Changes that can be made within radiology to ensure compliance with the stated KPI goal include having a CT trained radiographer onsite at night time and emergency room staff transporting patients to radiology when porters are not available to do so (McGrath *et al.*, 2018).

KPIs create the basis for accountability, quality improvement, prioritisation, and transparency in the department. A Delphi study involving 30 radiology experts identified 92 indicators as having good potential to use as departmental performance indicators (Karami, 2017). Radiology report turnaround times were found to be used by 82% of departments and transcription time by 71% as performance indicators (Ondategui-Parra *et al.*, 2004). The study defined volume and productivity, radiology reporting, access to examinations, customer satisfaction, and finance as important radiology KPIs (ibid).

Scorecards are used in some organisations to record and present KPIs on a regular basis to institutional leaders and radiology employees (Donnelly *et al.*, 2010). In one case, 33 measures in six areas, clinical services (safety, quality, timeliness); education; research; professionalism, communication, and user satisfaction; finances and administration; and staffing were summarised using a scorecard and audited at intervals (Donnelly *et al.*, 2010). The measures, which related to staff, included the number of unfilled positions, whether staff were treated with dignity and respect and evidence of participation in research activities. No measures were identified in the scorecard which alluded to staff utilisation or their workload.

Harvey et al. (2016) separated radiology KPIs into structural, outcome and process indicators. Structural indicators include average age of the equipment, radiographer-to-scanner ratio, nurse-to-patient ratio, compliance with equipment maintenance for example. Outcome performance indicators include referring physician satisfaction rates, employee satisfaction scores, patient satisfaction and 30-day readmission rates. Process performance indicators include appropriateness of examinations performed, order-to-completion time, patient waiting time, error rates on imaging, and diagnostic radiation levels for examinations (Harvey *et al.*, 2016).

Hyde and hardy (2021) aimed, in their study, to develop tangible, observable and measurable indicators of patient centred care, resulting in checklists for departments. Included in the study were managers, radiographers as well as patients receiving care. The "pause and check" and organisational checklist audit tools were developed for clinical practice to determine the levels of individual and organisations engagement in patient centred care (Hyde and Hardy, 2021).

2.5 Process improvement

Quality of healthcare is defined in many ways by different healthcare systems. One of the most widely accepted definitions is that of the Institute of Medicine, USA where quality is divided into six domains: patient centred, safety, effectiveness, equity, timeliness and efficiency (HSE, 2016). In Ireland, quality is defined by the four quality domains: 1. Person centred - care that is respectful and responsive to individuals needs and values and partners with them in designing and delivering that care 2. Effective - care that is delivered according to the best evidence as to what is clinically effective in improving an individual's health outcomes 3. Safe - care that avoids, prevents and minimises harm to patients and learns from when things go wrong 4. Better health and wellbeing - care that seeks to identify and take opportunities to support patients in improving their own health and wellbeing (HSE, 2016).

A systematic literature review on the impact of service delivery initiatives on patient waiting times within the radiology department identified the following types of initiatives: six sigma, lean methodology, continuous quality improvement, extended scope practice, quality management, productivity-enhancing technologies, multiple interventions, outsourcing and pay-for-performance (Olisemeke *et al.*, 2014). "Lean" is a set of principles and techniques that drive organisations to continually add value to the product they produce by examining and refining process steps that are necessary, relevant and valuable, while eliminating those that do not add value. Lean has been used in manufacturing for decades to enhanced product quality and overall corporate success and as such has applications in healthcare and the emergency department(Dickson *et al.,* 2009).

Companies (most notably Toyota) have adopted the concept of continuous lean flow in their workflows in a bid to improve efficiency (Liker, 2004). A key ideal in lean workflow is the elimination of batch and queue processes (ibid). Such batch and queue processes are typical in most radiology departments. Appointments are batch-scheduled; patients arrive in batches (e.g. at the out-patient clinic), and images are batch-read. Liker (2004) describes this as a clumsy type of process that can allow errors to remain unaddressed. At the centre of lean is product flow therefore in a lean assembly line, the product continuously flows, with no backlogs, even at the expense of having some downtime for the individual worker (Dickson et al, 2009). The standard of lean dictates that, firstly, the product or patient flow is improved, then processes are synchronised, and then efficiency is improved. (Dickson et al, 2009). Load balancing in radiology is desirable to prevent large differences in waiting times and to allow greater numbers of patients to be scanned. Load balancing is a concept taken from the Toyota Production System or TPS (Womack, Jones and Roos, 2007). Using the TPS, Toyota was able to produce reliable and competitive-costing cars with great consistency of process and product while paying high wages. One of the 14 lean principles is the levelling out of workload, or *heijunka*. Toyota recognised that the over-burdening of people can lead to safety and quality problems, while the over-burdening of equipment can lead to breakdowns and defects (Liker, 2004). With the correct application of load balancing, unevenness in production is reduced. Unevenness can mean that it is necessary to have the correct number of people to hand, as well as equipment and materials for the highest level of production – even if average, requirements are lower (ibid). However, lean is not a panacea and its adaption to healthcare is not fully complete or understood (Holden, 2011; Holden *et al.*, 2015).

Total quality management (TQM) refers to management methods used to enhance productivity and quality in organisations, attributed to Dr W. Edwards Deming, Joseph Duran and Kaoru Ishikawa (Hackman and Wageman, 1995). TQM principles concentrate on the quality of the product or service delivered. Various systems, tools and processes are used, and one of the core principles of TQM is the involvement of stakeholders. A fundamental premise of TQM is that the costs of poor quality (such as inspection, rework, lost customers, and so on) are far greater than the costs of developing processes that produce high-quality products and services ibid). Seltzer (1997) addressed re-engineering of the radiology department using TQM techniques, resulting in a 55% decrease in the mean time required to sign reports. TQM methods have be used to accelerate radiologists' signing of reports but can be expanded and generalised for department-wide projects and KPIs (Seltzer et al, 1997).

In a "Handbook of Healthcare delivery Systems" observation of work in action and the identification of roadblocks that prevent work from happening with continuous flow is considered the first activity of discovering how to redesign current work (Yih, 2010). The author state that interruptions in work create wasted time, risk, declining confidence of the patient in the organization's ability to care for them and frustration for the worker, see Figure 2.12 (Yih, 2010).

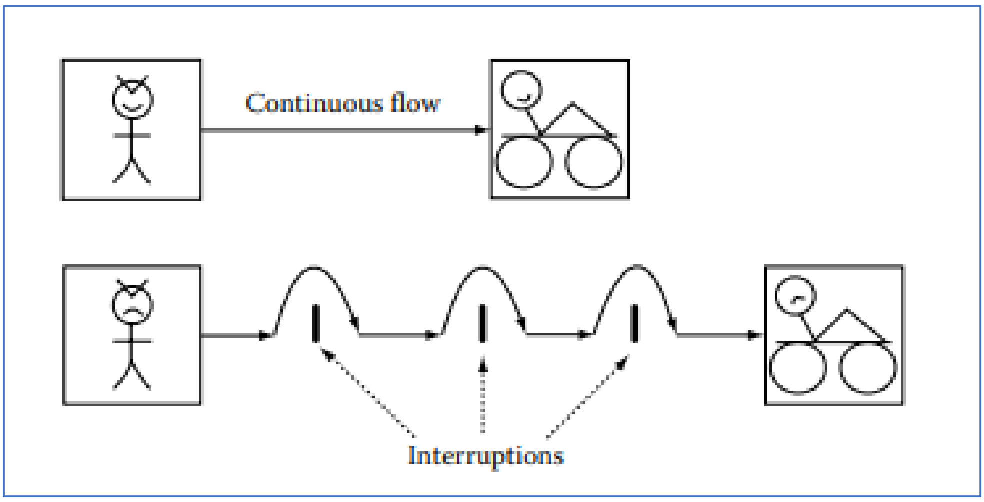


Figure 2.12 Continuous flow versus interrupted flow

Business analytics were used in one Irish radiology department and hospital to improve decision support and resource management in radiology using the hospital's own data sets (Jones et al., 2013). The final decision business analytics software support tool was evaluated by stakeholders and it was determined that the tool could assist with improving operational efficiencies and management of resources. A dashboard was created for radiology using commercially available software called Qlikview. KPIs such as report turnaround, times taken to access scanning from three different information systems (Jones et al., 2013). While useful for a performance overview and future demand prediction, few insights were obtainable on the process, staff or patient experience of the service.

2.6 Conclusions

Little has been found in the literature which estimates or quantifies the daily effort or workload of radiographers and healthcare assistants who provide a CT service. A review of common radiology KPIs found few measures of staff workload besides the number of examinations completed. Meanwhile, substantial references have been found pertaining to radiologist workload and the necessity to weight radiologist workload in a nuanced fashion including details of caseload, study complexity and indirect tasks such as teaching and administration. The literature review identified several applications of OR techniques in radiology and in particular the use of discrete event simulation but failed to identify a granular measurement of the specific tasks undertaken in the CT process or the inclusion of patient characteristics and how these affect resource utilisation and workload.

While System Dynamics has been used specifically to model erosion of standards and increases in fatigue and burnout because of workload (increased tasks), SD was deemed unsuitable for capturing the granularity required and the activities and utilisation of individuals. Despite the many strengths of SD, it is not as well-suited as DES when it comes to detailed modelling, and copes badly with stochastic variation (Brailsford and Hilton, 2001). SD has been identified as a powerful communication and conceptualisation tool and has potential for use as a qualitative method.

A universal increase in demand for diagnostic imaging including CT has been reported. In the western world, the patient profile has been shown to be both increasingly ageing and ailing in terms of chronic disease and incidence of comorbidities. While modelling examples have been identified which refer to patient characteristics such as mobility and the types of examinations being requested these have mainly been referenced in relation to scheduling of examinations and not in relation to the resultant staff workload or utilisation.

A review of the literature identified discrete event simulation (DES) as a suitable means of capturing staff workload and it also allows for decision support for radiology (research question 1 (b)). Discrete Event Simulation (DES) permits analysis of the impact of change or interventions on waiting lists and can capture resource utilisation and the tasks completed by staff. Some hybrid modelling, using agent based simulation can be used in Anylogic

(Anylogic Personal Learning Edition 8.4.0, 2019) where the process trigger the activities and use of resources, both human and material to model behaviours between staff and patients.

The peer reviewed framework developed by Rashwan (2017) has been identified as a useful starting point on which to base the design of a framework suitable for use in radiology. Additionally, facilitated approaches that interweave complementary hard and soft OR methods aimed at successful stakeholder involvement were identified (Robinson and Robinson, 2001; Kotiadis, Tako and Vasilakis, 2014; Robinson *et al.*, 2014; Tako and Kotiadis, 2015; Crowe *et al.*, 2017) and are seminal papers in this regard.

Further research into the pressures specific to the time-pressured, task-focussed and highly technical environment of radiography and the impact on compassionate patient care has been recommended by Bleiker et al, (2018). A study of the relevant literature shows an opportunity to contribute to the existing knowledge on modelling patient complexity and staff workload, while supporting decision making. Examples from OR literature where radiographers and radiology staff were involved in a facilitated use of DES to measure radiology staff workload or capture their experience were not identified in the literature. Herein a gap in the literature has been identified whereby the use of OR methods to capture the relationship between the complexity of the patient cohorts and radiology staff workload remains under-explored. The research methods used by the researcher to investigate this gap further are described in the next chapter.

Chapter 3: Research Methods

So, oft in theologic wars
The disputants, I ween,
Rail on in utter ignorance
Of what each other mean;
And prate about an Elephant
Not one of them has seen!
(Saxe (1816–1887) as cited in Burt, 2017)

The poem quoted above by John Godfrey Saxe, describes how six blind men examine parts of an elephant coming to their own conclusions about what the overall animal may be. Each examine a part and reach differing findings. The elephant is to some a wall, a spear, a snake, a fan, a rope or a tree. In an article entitled "Getting to grips with the beast", Burt discusses the potential of integrating quantitative and qualitative operational research techniques, to help generate an accurate picture of the whole "beast" or in this case elephant (Burt, 2017). The approach and mixed methods used to describe the phenomenon and generate a picture of a CT service and staff workload are described next.

This chapter describes the framework of inquiry, the chosen methods, the case study setting, data collection and analysis methods. The choice of a pragmatic approach using both qualitative and quantitative methods is explained. This work is an example of interdisciplinary research. Information, data, techniques, tools, perspectives, concepts and theories from different disciplines are integrated to create a shared understanding, and help address existing problems. It was undertaken because the solutions to the problem identified were beyond the scope of a single discipline or area of research practice. This multidisciplinary research harnesses the expertise of a group of people from different specialisms to investigate the factors affecting CT /diagnostic imaging service provision.

3.1 Research paradigms

Epistemology is a field of philosophy concerned with the nature, source and legitimacy of knowledge. In the domain of health research, knowledge is relevant to the selection and implementation of practices, the production and interpretation of evidence, and finally the construction and application of theories to practice (Polgar and Thomas, 2013).

A quantitative or positivist approach views knowledge as "hard", objective and tangible, and it requires the researcher to adopt the role of observer. Numerical data is generally collected and analysed through a range of quantifying methods and techniques. The objective of this type of research is to find causal relationships and to connect empirical observations with mathematical expressions of these observations. Findings from quantitative techniques are generally considered unbiased and are analysed using statistics. Findings are generalisable across a larger population and reproducible.

The qualitative or interpretivist approach considers knowledge as personal, subjective and unique in nature, and requires that researchers interact with their subjects (Eldabi *et al.*, 2002). Using qualitative methods, groups or individuals in their social setting are investigated and the researcher seeks to interpret experiences and feelings in a given environment or under certain conditions (Polgar, 2008). Interpretivist or qualitative research is holistic with the individual considered in the context of their social setting which aims to understand a phenomenon from the subjects point of view (Eldabi *et al.*, 2002). Qualitative research is essential in the clinical context if research is to include personal values and experiences. In the health field, with its strong tradition of research using conventional, quantitative and scientific methods, qualitative research is often criticised for lacking experimental rigour (Mays et al., 1996). Positivism and interpretivism are useful in the exploration of change or conflict and are contrasted in Table *3.1*.

Table 3.1 Differences between qualitative and quantitative research (Holloway, 2009)

	Qualitative	Quantitative
Aim	Exploration, understanding and description of participants' experiences and life world Generation of theory from data	Search for causal explanations Testing hypothesis, prediction, control
Approach	Initially broadly focused Process oriented Context-bound, mostly natural setting Getting close to the data	Narrow focus Product oriented Context free, often in laboratory settings
Sampling	Participants, informants Sampling units such as place, time, concepts Purposive and theoretical sampling Flexible sampling that can develop during the research	Respondents, participants (the term 'subjects' is now discouraged in the social sciences) Randomised sampling Sample frame fixed before the research starts
Data Collection	In-depth non-standardised interviews Participant observation/fieldwork Documents, diaries, photographs, videos	Questionnaire, standardised interviews Tightly structured observation Documents Randomised controlled trials
Analysis	Thematic or constant comparative analysis, latent content analysis ethnographic, narrative analysis, etc.	Statistical analysis
Outcome	A story, ethnography, a theory	Measurable and testable results
Relationships	Direct involvement of researcher Researcher relationship: close	Limited involvement of researcher with participant Researcher relationship: distant
Rigour	Trustworthiness, authenticity Typicality and transferability Validity	Internal/external validity, reliability Generalisability

Qualitative research methods require close personal contact with participants and interpretation of findings thus allowing potential for bias to colour results. A common complaint is that qualitative research may lack reproducibility, may produce contradictory results or lack reproducibility, is susceptible to researcher bias, and may not allow generalisations (Mays et al., 1996).

Lofland (1971) outlined four principles for conducting field research. The first principle advised that the investigator establish proximity with the subjects in both a physical and social sense on a long-term basis to reduce the subjects' reactivity to the presence of the investigator. The report should be truthful, not including ideological bias. The data should contain "pure description of action, people, activities and the like", and should also include some direct quotation from participants (Lofland, 1971).

This is a particularly important point as, given the close personal interaction with the participants, one may be predisposed to report favourably (Polgar and Thomas, 2013). Scientific enquiry is conducted by individuals with personal aims and values with these human values being an integral part of the scientific enquiry (Polgar and Thomas, 2013). In qualitative inquiry the participants have more power because they can guide the researcher to issues that are of concern for them. The researcher should answer questions about the nature of the project as honestly and openly as possible without creating bias in the study (Holloway and Wheeler, 2009).

In studies where observation is one of the chosen methods, the Hawthorne Effect must be considered. The Hawthorn Effect refers to a phenomenon where there is a change in behaviour such as an increase in worker productivity produced by the psychological stimulus of attention being paid such as being singled out and made to feel important (McCarney *et al.*, 2007).

3.2 Pragmatism

Pragmatism is a hybrid epistemological approach with both positivist and interpretivist elements. Quantitative methods are reliable but not valid, qualitative methods are valid but not reliable (Mays et al., 1996). The hybrid approach recognises that qualitative and quantitative methods have limitations and that the strengths of one can counteract the limitations of the other and vice versa. As such, contemporary health research follows a pragmatic paradigm which includes both qualitative and quantitative methods (Polgar and Thomas, 2013). Checkland and Scholes (1992) write that when considering the application of theory and practice, neither should dominate the other. Theory which is not practised is sterile, and practice which is not reflective of the ideas upon which it is based will lessen the opportunity to learn better ways of action taking (Checkland and Scholes, 1992). For interdisciplinary projects to flourish, scientists must transcend the scope of a single discipline or program and think across silos and boundaries. Mixing qualitative and quantitative approaches also facilitates data triangulation where findings can be considered from multiple angles.

3.3 Reflection and "The Mangle"

Pickering, a physicist turned sociologist, was interested in both the micro and macro analysis of practice and advised against rendered down or sanitised versions of OR projects asking that the organisational hurdles, the changes in direction, the influences of people involved and the effect of technologies available on the path also be included. By applying the perspective of "The Mangle" a richer, real time understanding of the OR project and human experience results (Pickering, 1997).

The concept of the mangle aims to help writers produce a more realistic description and help them make sense of their project. Omerod (1985) proposes reflection on the fundamental purpose of a model by asking the following questions:

1. Was the right problem tackled?
2. Were the boundaries correct?
3. Were the right people involved?
4. Were outcomes validated?
5. Was the voice of the affected but uninvolved heard?

Chapter 8 includes an analysis of the key factors and events that influenced development of the project over time, lessons learnt and opportunities for further research.

3.4 Research Strategy

The chosen research strategy shown in Figure 3.1 adopts a pragmatic approach, using mixed qualitative and quantitative methods to define the problem and inform potential solutions. To achieve the research objectives a case study was undertaken.

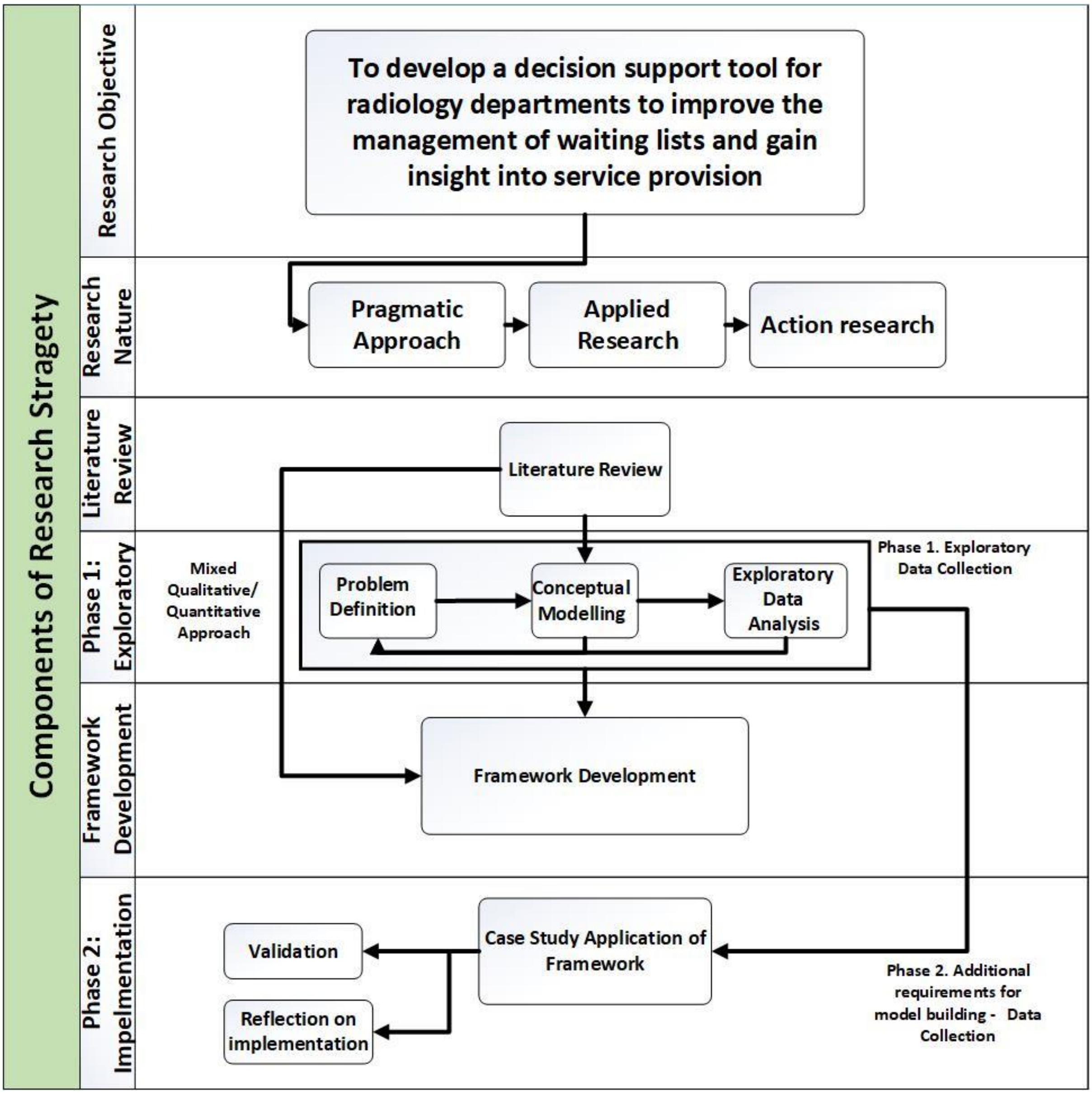


Figure 3.1 Proposed research strategy

3.4.1 Case study

A case study is a qualitative research method, using multiple approaches that results in profound insights, a holistic appreciation of a phenomenon and is similarly difficult to reproduce and make generalisations. A case study is a type of qualitative research in which in-depth data are gathered relative to a single occurrence of an event or phenomenon, for the purpose of learning more about the unknown situation (Leedy and Ormrod, 2020). By undertaking a case study, the context, values, perceptions and experiences of clinical and clerical staff were captured, thus allowing subjective data to explain or enhance the interpretations of the quantitative findings. As a result, findings from a case study may not allow generalisations and could reflect bias.

Reasons for the choice of the case study department included:

1. Awareness of the issue of increasing waiting list
2. Awareness of the staff perception of increasing workload levels and patient complexity.
3. Availability of data both primary and secondary as the researcher was a staff member.
4. Enthusiasm from management for the research to be carried out.
5. Single CT scanner department representative of other sites across Ireland, where most activity occurs in core hours of operation i.e. 8.30am to 5pm.
6. Existing familiarity with staff members which reduced the likelihood that behaviours would alter due to the presence of the researcher radiographer.

3.4.2 Action research

Action research refers to a type of enquiry which aims to use research to take action and invoke a real-world change. Action research is highly collaborative and the researcher is often a member of the group being researched (Leedy, 2021). Action research is discussed as the inclusion of decision makers and clinical staff throughout the framework, naturally provided opportunities for these staff to observe and reflect on their workflow and the problem under consideration, which in turn introduced the potential for change. Action research is a cyclical and reflexive research, a systematic process of enquiry to enhance the outcome for clients, providing methods to improve intervention effectiveness (Morgan, Belton and Howick, 2017). The action research cycle consists of four steps – those of planning, acting, observing and reflecting Figure 3.2.

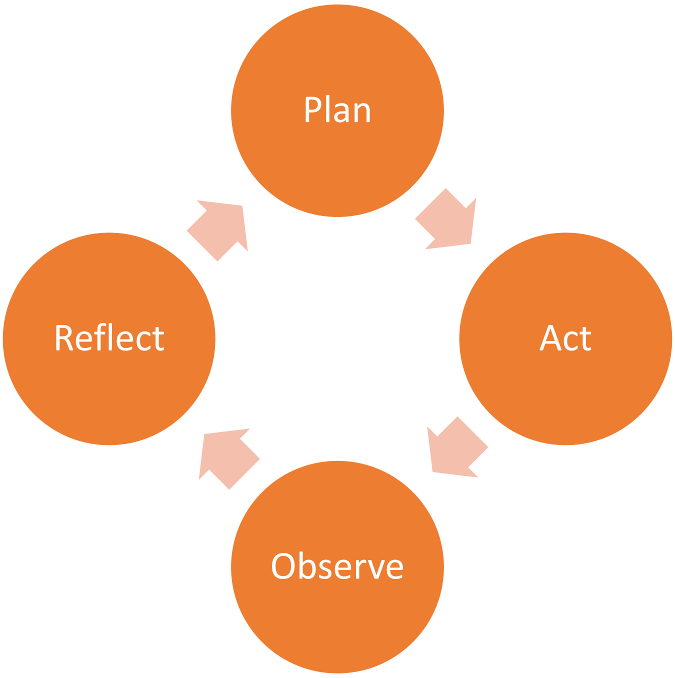


Figure 3.2 Cycle of action research

Morrison and Lifford (2001) extolled the qualities of action research mainly its ability to capture varied perspectives on organizational problems, and flexible and imaginative ways of working and problem solving.

As context was deemed important a case study approach was undertaken. It was expected that changes would result from insights gained and as such the work is also considered an example of action research. These changes were documented and are included in the thesis.

3.5 Research Framework

The framework provides an underlying structure to support the collective research methods used to answer the research questions. The work was completed over a four-year period. The framework included the following stakeholder roles identified in previous work by Tako and Kotiadis (2015), Table *3.2*. As can be seen from the table below, the primary researcher undertook four of the six identified roles.

Table 3.2 Roles and individuals identified in application of framework

Role	**Person responsible in case study application**
The simulation modeller (coder)	Primary researcher with help from an experienced coder.
The recorder	Primary researcher took notes, interviewed staff and observed workflow and processes.
The facilitator	Primary researcher led activities to meet objectives.
The project champion	Primary researcher.
Key stakeholders (those with tacit knowledge and decision-making power)	Radiology Manager and CT Clinical Specialist.
Other stakeholders	Radiographers, Radiologist, Porter, Nurse, ED consultant.

The framework was implemented in three stages, as shown in Figure 3.3, and allowed an iterative, cyclical approach to be taken to the conceptualisation of the problem situation and requests for data required to support model building and understanding. Note the two-way call for data where additional data is requested that helps reframe the problem and which may lead to further requests for data. A reinforcing loop is shown to demonstrate the increasing understanding of the problem situation which results from repeated insights gained. Stakeholders are involved in each stage of the project. The data requirements, specific to a radiology department and CT service, are also included in the Figure 3.3. The activities and expected outputs for each stage are presented in the figure.

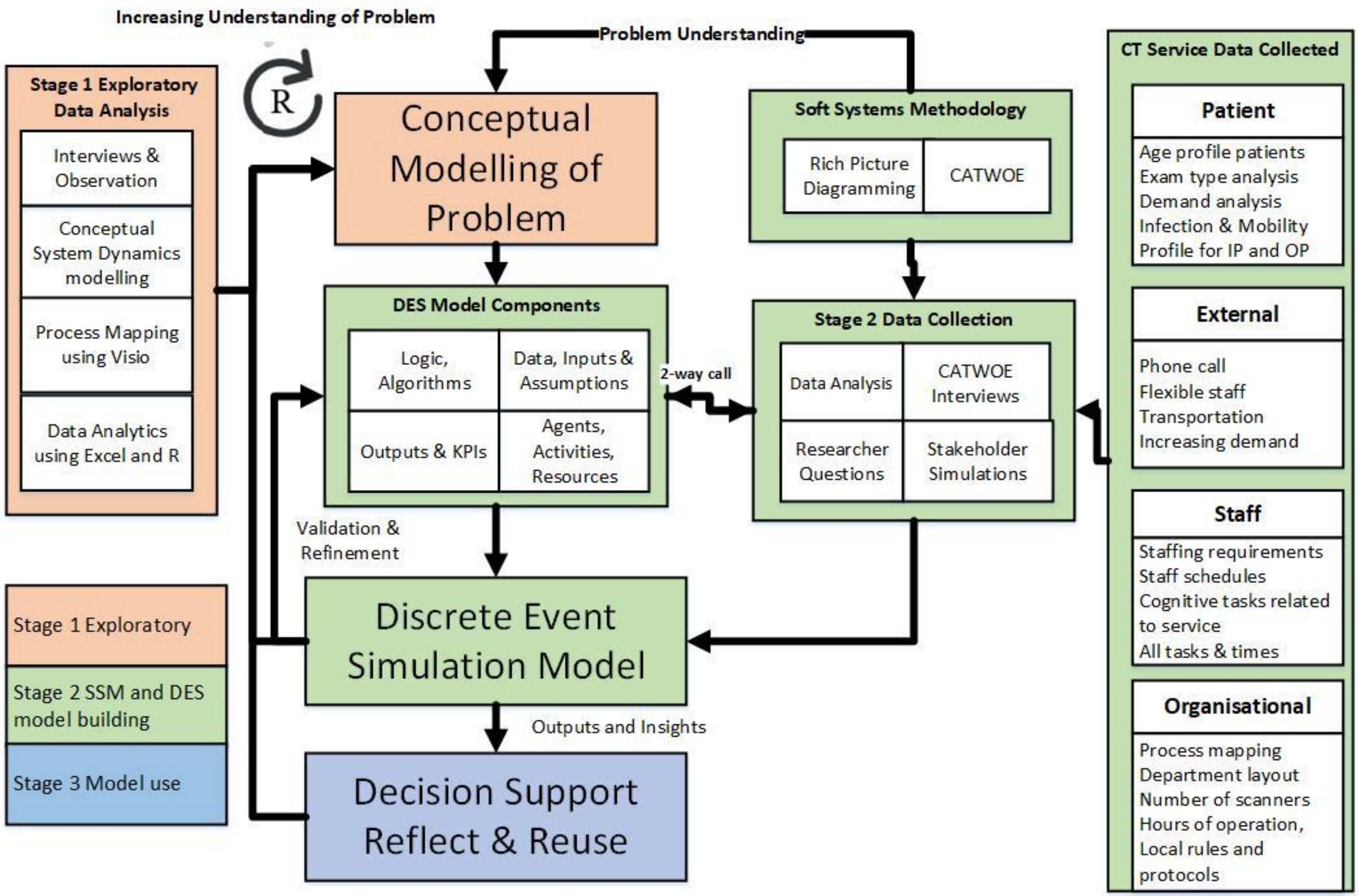


Figure 3.3 Framework components

3.6 Qualitative research methods

3.6.1 Observation

The researcher was an observer participant who worked as a radiographer in the case study department for several years prior to the commencement of the research. A recognised effect of being observed is that subjects/individuals can alter their behaviour as a result (Parsons, 1974; McCarney *et al.*, 2007). The identity of the radiographer as a researcher and the purpose of the research were disclosed to the staff. Observation was used to perceive and record phenomenon relating to:

- how tasks were prioritized,
- staff requirements to carry out tasks,
- duration of tasks
- complications arising and disruptions to workflow.

The individual tasks and times were recorded and maximum, minimum and mode times were estimated, and findings verified with the clinical specialist radiographer in CT. These observations became parameters for use in the DES model. Pen and paper were used to record the observations regarding tasks and workflow at the end of each session (9am to 1pm and 2pm to 5pm).

3.6.2 Interviews

Structured Interviews between the investigator or researcher and the research participants were conducted with a view to eliciting information. Structured interviews using a predefined set of questions with pre-planned answer sheets intended to elicit closed answers were conducted using the mnemonic CATWOE. Interviewees were selected based on their likeliness to provide the required insights, though willingness to participate and availability were also of great importance. Handwritten notes were taken to document the answers provided by staff. Audio recording of interviews were not used due to the impromptu nature of the timing of interviews which took place when time permitted.

Both structured and unstructured interviews were conducted, at various intervals;

- For process mapping (unstructured interview, notes taken, drawings of workflow sketched),
- For conceptual model creation (unstructured interview, notes taken, Venism used to create system dynamics diagrams),
- During stage 2, where SSM tools were used to create a root definition for the CT service and services related to the CT service, such as transportation and cleaning services using the CATWOE acronym (structured interviews, answers written for predefined questions),
- To verify model scenarios for testing, (unstructured interview, notes taken),
- To validate the model and verify observations, (unstructured interview, notes taken).

3.6.3 Process Mapping

Process mapping was used to visually describe the flow of work and included inputs, actions, and outputs. A process as a set of activities that transforms one or more inputs into outputs of value to a customer (Hammer and Champy, 1993). Since its origins in the manufacturing industry, process mapping has become a familiar tool used to visually represent the inputs, outputs, and steps of healthcare processes (Lu *et al.*, 2021). Some of the benefits of process mapping include providing a starting point for quality improvement, involving users not frequently asked to contribute, and creating an end product which can be used as a visual tool for discussion (Trebble *et al.*, 2010).

Based on their knowledge of the CT service draft workflow diagrams were created for each part of the CT process including subprocesses such as patient transportation. Elements of workflow including the flow of information and communications were included in the process maps. Process mapping was carried out to include every step from generation of the examination request or order, to report sign off. Interviews were limited to 20 minutes with the clinical specialist, and interruptions were frequent.

Due to the complexity and difficulty of displaying process activities and interactions on a single diagram, diagrams were separated by functional area or staff member roles. Workflow diagrams were created for the following:

- IP workflow and scheduling and scanning considerations
- Outpatient workflow and scanning considerations
- Patient preparation
- Patient scanning including observation
- Patient transportation,
- Scheduling workflow diagram,
- Exam vetting
- Patient transportation

To reduce the likelihood of bias, workflow maps was verified with the CT Clinical Specialist in charge of the area and where necessary diagrams were altered to reflect this input. Email was used to clarify assumptions or to address outstanding questions for example on the different protocols that are used, or the schedules used to book outpatient exams. Interviews were carried out with clinical and clerical staff members, and Microsoft Visio was used to create process maps for the various processes carried out within and across departments. The maps were divided into different swim lanes for the different staff roles involved in the examination. For the purposes of process mapping, individual meetings were organised with the CT Clinical Specialist, Clerical Manager and Information System Administrator. Unstructured interviews were held with staff relating to the specific part of the CT process they had responsibility for. As part of the continuous validation, the resultant diagrams were discussed with the staff member once completed and amended where necessary, with amended staff feedback incorporated into the final process flow diagrams.

3.6.4 Soft systems methodology - Rich Picture Diagramming and CATWOE

Using a Soft Systems Methodology (SSM) approach, the way hospital staff in a problem situation perceive, judge, and interpret the world was captured. The use of SSM was deemed appropriate as the objective was to engage multiple staff perspectives, allowing feasible and desirable simulations/solutions to be identified for a complex situation or "mess" (Checkland, 1999; Bell, Berg and Morse, 2019). A Rich Picture (RP) was constructed as an epistemological device with which to interpret and construct meaning as well as unravel and integrate understanding (Bell, Berg and Morse, 2019). The aim of RP diagramming was to create a visual tool, metaphorically and literally, "rich" enough to reflect the important and meaningful aspects of the organization (Patching, 1990). Furthermore, RP diagramming was used to create a list of issues perceived by staff in the process.

The acronym CATWOE was used to identify the Customers, Actors, Transformation, Weltanschauung/Worldview, Owner and Environmental constraints of the service. A root definition was created by considering these elements. CATWOE interviews were carried out with the following staff members, acute medical assessment unit nurse, ED consultant, hospital porter (n=3), in their various places of work. For RP diagramming the researcher met with the radiology manager, CT clinical specialist, three senior radiographers, and one radiologist individually (n=6) and not in a group setting, this was mainly due to time limitations and difficulties meeting as a group due to night shift commitments. Meeting with staff individually also mitigated any issues of power and authority where staff may be less inclined to proffer their experience in front of others.

The following steps were taken in the rich picture diagramming process, see Figure 3.4.

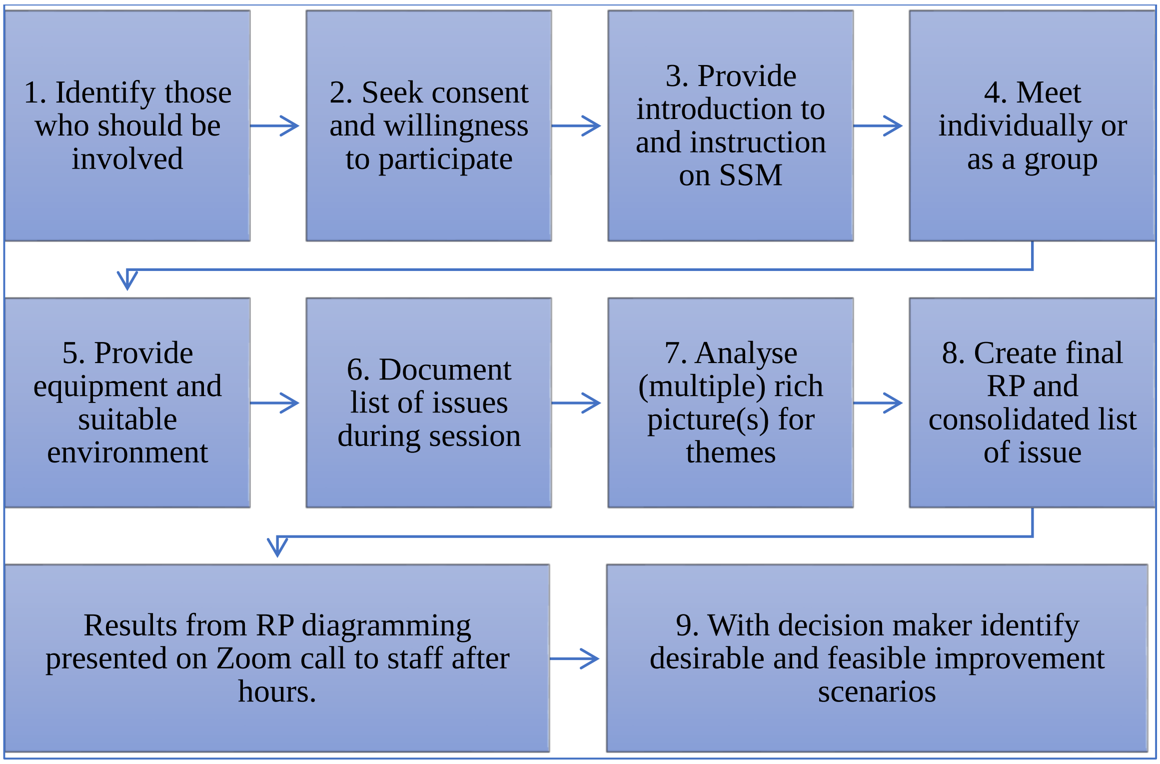


Figure 3.4 Steps taken to RP building

Willingness to participate and consent was sought from all participants before commencement of the RP diagramming and CATWOE interviewing sessions. In Step 3 a twenty minute PowerPoint introduction was provided to participating staff members, n= 6 on the use of the SSM tools such as RP diagramming and CATWOE. Staff were provided with examples of RP diagrams such as that shown in Figure 3.5, (Crowe *et al.*, 2016). The situation did not allow to meet as a group for RP diagramming so instead the researcher met with the radiology manager, CT clinical specialist, three senior radiographers, and one radiologist individually. Session duration was 10-20 minutes, depending on how much time staff had available and provided no interruptions occurred.

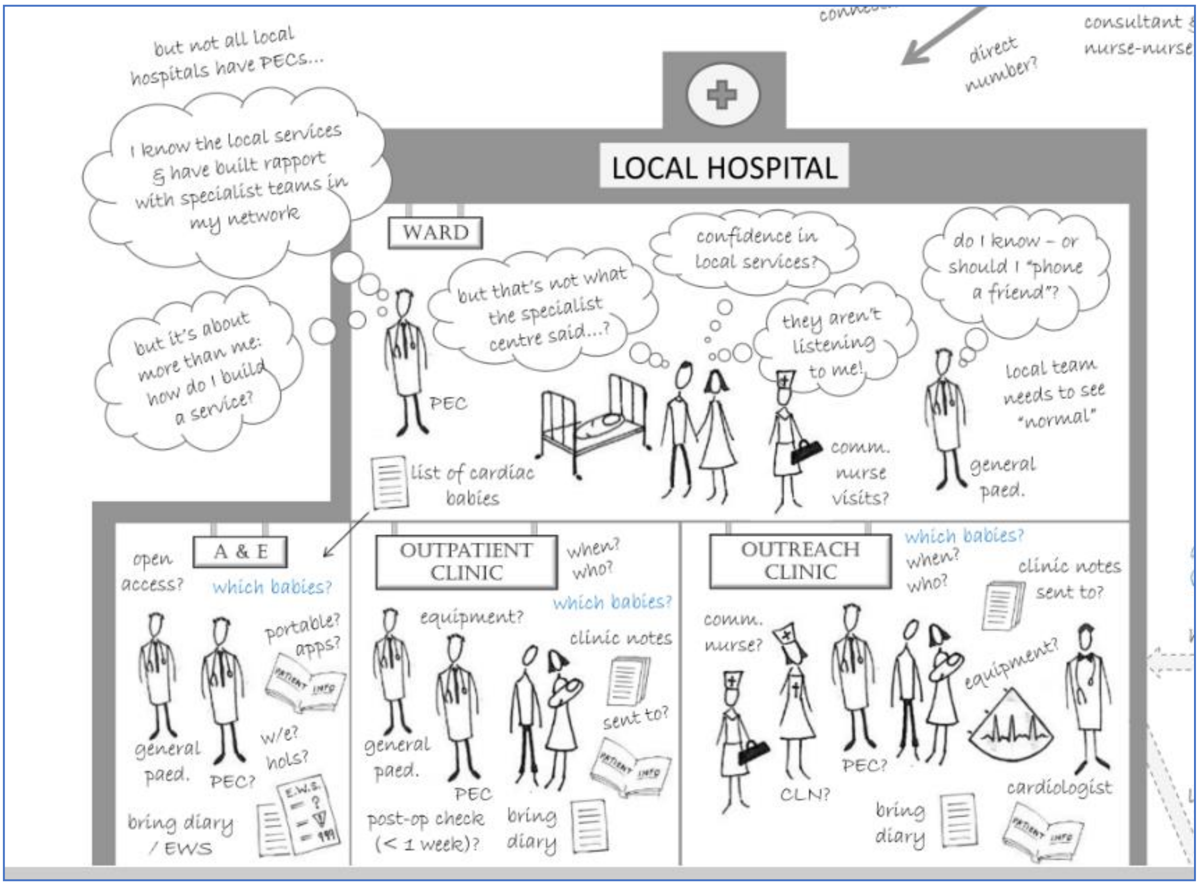


Figure 3.5: Subsection of RP diagram Crowe et al, 2016

As per Step 5, the staff member was provided with a suitably quiet environment and presented with a blank page and a set of coloured pens, and were asked to draw freehand graphics representing their interpretation of the service (Berg, 2015). Participants were instructed to avoid the use of text where possible (Bell, Berg and Morse, 2019). Questions were encouraged throughout, and the researcher/facilitator prompted to uncover difficult to observe workflows and communications. Where text could not be avoided comments and speech bubbles were written directly onto the RP poster, as well as a list of perceived issues generated (step 6). As a group meeting was not possible the lists of issues and RPs were merged to create the final RP and consolidated list of issues. Finally in step 9, a separate discussion with decision makers took place. The purpose was twofold. Firstly to offer them an opportunity to contribute to the RP diagram, and secondly to identify desirable and culturally feasible solutions to the waiting list problem. These would be tested later in the

DES model. The RP was augmented with feedback from this group discussion to create the final RP.

A list of icons was created of staff members, equipment, examples of interruptions, demands, and tasks. Additional graphics were used to portray the setting (Conlon, Molloy and Zolzer-Bryce, 2020). The original hand-written comments and speech bubbles and list of issues were typed, and a soft copy version of the RP created. The final RP was constructed using the software Microsoft Paint and Microsoft Publisher which contravenes the predominantly freeform and unstructured nature favoured for RP generation (Berg, 2015). As the purpose of the model was to convey a shared understanding and to disseminate to a wider community a more professional finish and clarity was required. A targeted set of culturally feasible and desirable recommendations for quality improvement was created. In order to reduce the potential for bias the researcher's interpretations of the RP diagrams and the final list of issues were verified with the staff.

3.6.5 Conceptual model building

Conceptual modelling is probably the most important aspect of a simulation study, and it is often described as the most difficult and least understood stage (Robinson, 2008). The purpose of the conceptual model is to inform the system's boundaries, inputs and outputs, necessary elements/components, and interactions between agents. During a continuous professional development (CPD) meeting, an introduction was given jointly to staff on SD, the concepts of stocks and flows, causal loop diagrams, and mental models (Sterman, 1994, 2000). Many conceptual models of the problem situation were created using a System Dynamics approach, to ensure an accurate shared understanding of the problem and inform DES model components and model scope. This corresponds with stage 1 in Figure 3.3. These models were created in a face to face meeting with staff using Vensim (Ventana Systems, 2018). Modeller and staff sat together and used a laptop to create the diagrams in Vensim. The introduction of staff to systems thinking, yielded benefit throughout the work. Staff returned to discussions on the problem situation outside of formal workshop opportunities once learning had been internalised. Decision makers were also asked in stage three to consider desirable and feasible scenarios for testing in the final simulation. The benefits of creating SD conceptual models with staff using Vensim are discussed further in Chapter 6.4

3.7 Quantitative research methods

While interpretivists try to understand the relationships between events and the triggers for certain behavioural patterns of an object under investigation, positivists focus more on the components of a phenomenon, and they aim to describe the relationship between these components during their investigation (Eldabi *et al.*, 2002). Positivism is therefore a quantitative approach, as these components are quantifiable and measurable.

3.7.1 Discrete event simulation

A DES model of the CT service was created and reported on using a standardised checklist approach (Monks *et al.*, 2019) in Simulation Modelling, Chapter 4.5 see Table 3.3.

Table 3.3 STRESS guidelines 20 point checklist for model reporting

Section	Item no.	Checklist item
1. Objectives	1.1	Purpose of the model
	1.2	Model outputs
	1.3	Experimentation aims
2. Logic	2.1	Base model overview diagram
	2.2	Base model logic
	2.3	Scenario logic
	2.4	Algorithms
	2.5	Components
3. Data	3.1	Data sources
	3.2	Input parameters
	3.3.	Pre-processing
	3.4	Assumptions
4. Experimentation	4.1	Initialisation
	4.2	Run length
	4.3	Estimation approach
5. Implementation	5.1	Software or programming language
	5.2	Random sampling
	5.3	Model execution
	5.4	System specification
6. Code access	6.1	Computer model sharing statement

A DES model building approach based on that proposed by Law and Kelton (2000) was used Figure 3.6.

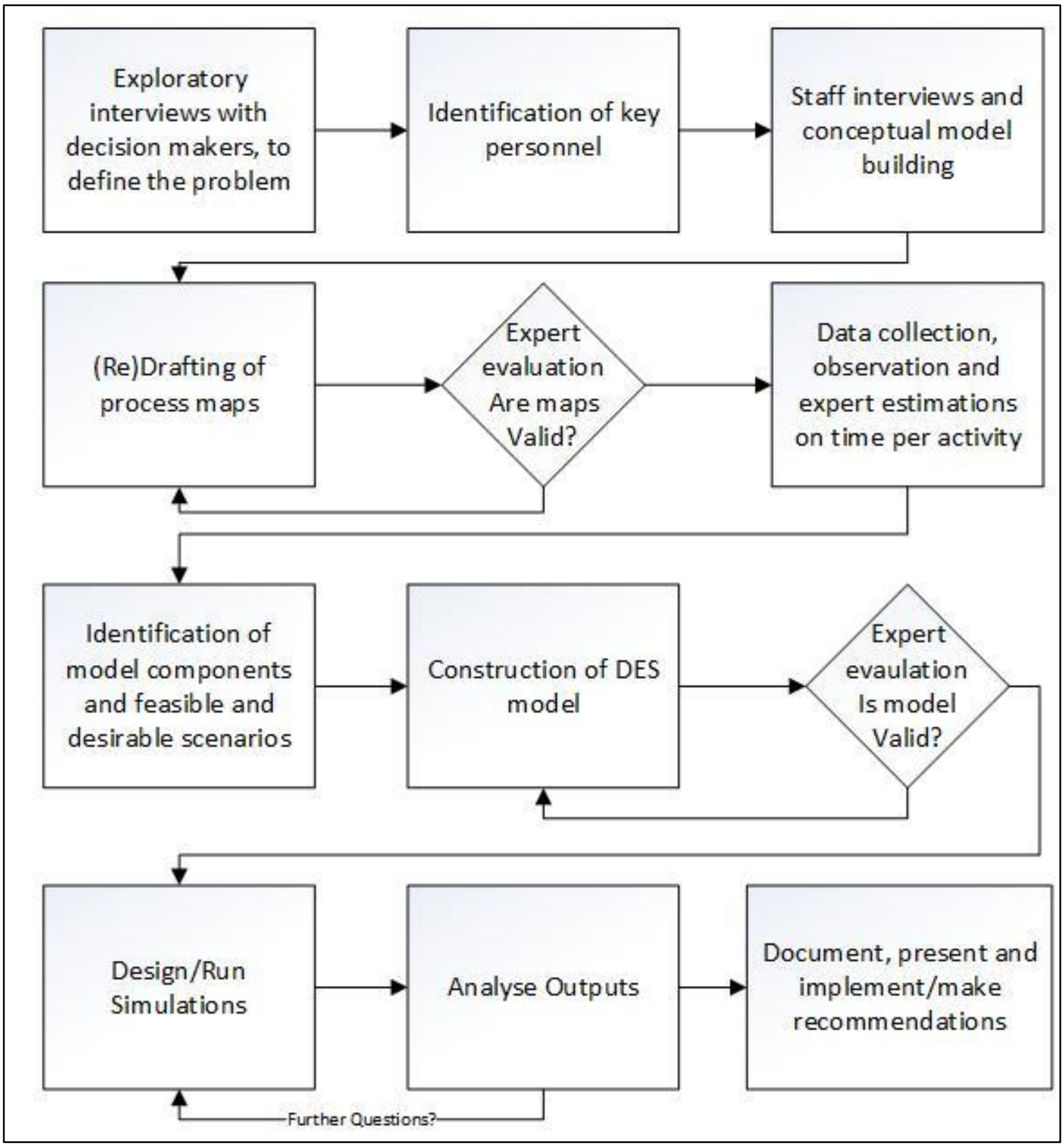


Figure 3.6 Creating a DES model for radiology

Model validation was completed using statistical as well as face to face validation with process owners, namely the process owner or person in charge of the clinical area. Once the simulation model was created, the results from simulation runs were outputted and analysed. These interpretations, as well as the influence of the statistical analysis, often resulted in the need for further scenario analysis or the addition of further model detail. Further changes to the model were made, model was validated and simulations repeated.

The following are examples of how the model was validated:

- Validation of workflow diagrams with CT Clinical Specialist stakeholder and comparison with DES model logic,
- Validation with CT Clinical Specialist stakeholder of the assumptions and observations that led to parameter inputs and model logic,
- Face to face stakeholder validation whereby the model can be workshopped by clinical and clerical stakeholders,
- Case by case validation where the actual patient time in the system was compared with model data using notes made using observation notes made for a specific day.
- Statistical validation using one year of historical data.

3.7.2 Data requirements

Data was exported from the PAS in comma delimited format. Data was checked prior to use to ensure column names were correctly described, by comparing exported rows of data with information from the radiology information system and the CT scanner. Data collection was carried for the following purposes:

1. Data required to frame the problem, such as the number of examinations performed per year, and data on the growth of the waiting list.

2. Data required to build the model by providing model parameters, such as patient arrival rates, length of patient time in radiology, examination types.

Descriptive analytics was used to analyse historical data and capture insights from the data on patient demand and the varying IP and OP characteristics as part of Phase 1, see Figure 3.7.

CT demand	Inpatient & Emergency Department demand
	Outpatient and GP demand
	Weekend demand
	Demand during COVID-19
CT waiting list	Outpatient and GP waiting list growth
	Breakdown of waiting list by examination
	Nationwide breakdown of radiology services
Patient Aspects	Inpatient versus Outpatient Mobility
	Inpatient versus Outpatient Age and Infection rates
	Exam type breakdown for IP and OP cohorts
	Phone call interruptions
External	Phone call interruptions
	Transportation delays
	Waiting for flexible staff

Figure 3.7 Data analysis Phase 1

In phase one exploratory data collection and analysis commenced. Interviews and observation were carried out, and access to data obtained ensuring local and GDPR guidelines were satisfied. The flow of patients through the CT process was observed over a period of one month and the measurement of task durations ascertained and validated with the clinical specialist. Microsoft Visio was used to map the workflow. Data was obtained from the patient administration system. Examples are provided below of the data preparation steps required before data could be used in the model.

1. Data rows relating to images for exams being imported into the PACS which originated from outside institutions were deleted from the CT data.

2. Rows were deleted where the time between arrival and scan start was greater than two hours and 40 minutes. These exams length were determined to be outliers which resulted from staff members opening a case in CT before the patient was in the department or where an exam had to be suspended and later completed due to complications.

3. Rows of data were deleted in cases where a patient's exam was started then paused. Such cases in the model would mimic the appearance of two patients being scanned simultaneously which does not occur in real life and stopped the model from working. These cases were found to effectively stop the model and caused major bottlenecks. These cases were identified and deleted.

4. Double, triple and quadruple studies occurred whereby a patient can attend for two or more exams, such as CT brain and CT sinuses or CT cervical, thoracic and lumbar spine. In these instances, the model identified them as separate patients. Using the Microsoft Excel feature 'conditioning formatting' identical exam arrival times were identified, and the additional exams were deleted.

5. Using Microsoft Excel all exams were categorised by exam type and referral source. Using the 'find and replace' feature all exam referral sources were categorised as scheduled or unscheduled. Using the 'find and replace' feature all exam types were categorised as IV, Oral, "Procedure", "IVandOral" or "No contrast" categories determined by the researcher and CT Clinical Specialist.

3.8 Ethical considerations

Ethical considerations play an important role in healthcare research planning and implementation, where the health and lives of people participating in a study may be at stake (Polgar and Thomas, 2013). Ethical rules and principles that are considered in conventional forms of inquiry must also be considered in e-mail and other electronic research, for instance informed consent, confidentiality, the right not to be harmed or identified and the possibility of withdrawal at any time (Holloway and Wheeler, 2009).

Local policies regarding the accessing of data as well as general data protection regulations must be adhered to when accessing date from any hospital system. The purpose of the General Data Protection Regulation (GDPR) (Regulation (EU) 2016/679 of the European Parliament and of the Council) is to protect all EU citizens from privacy and data breaches in today's data-driven world (http://eugdpr.org/the-regulation/). GDPR came into effect on May 25, 2018 following a 2-year transitional period granted by the European Parliament and repeals the Data Protection Directive 95/46/EC. Personal data is defined as any information relating to an identified or identifiable natural person, including names, surnames, home address, email address, or an identifier number or data held by a hospital/doctor that could be used to identify a living individual (Clarke *et al.*, 2019).

In the case of medical research, the Helsinki guidelines must be adopted. In 1964, the World Medical Association established the Declaration of Helsinki as a guide for performing research on humans. Under this agreement research must conform to accepted scientific principles, be conducted by qualified personnel, risk must be assessed in terms of the perceived benefit and subjects privacy safeguarded (The World Medical Association, 2000).

Chapter 4: Application of Framework - Case Study

The case study is focused on radiographer workload and the problem of increasing waiting lists. The research was conducted in Portiuncula University Hospital (PUH), a Model 3 hospital providing 24/7 acute surgery, acute medicine and critical care along with Emergency Department and maternity services to adults and children. Portiuncula has academic links with the National University of Ireland, Galway and the University of Limerick (HSE, 2020). There are approximately 180 beds, in addition to the ED treatment places, delivery suites, and the Acute Medical Assessment Unit (AMAU).

PUH is part of the Saolta University Health Care Group which provides acute and specialist hospital services to the West and Northwest of Ireland. The Saolta University Health Care Group comprises of 6 hospitals across 7 sites (Figure 4.1):

- Letterkenny University Hospital (LUH)
- Mayo University Hospital (MUH)
- Merlin Park University Hospital (MPUH)
- Portiuncula University Hospital (PUH)
- Roscommon University Hospital (RUH)
- Sligo University Hospital (SUH)
- University Hospital Galway (UHG)

The Radiology Directorate delivers an extensive range of radiology services for inpatients, outpatients and GP referred patients across the six hospital sites within the Saolta Group (HSE, 2020).

Figure 4.1 Saolta group (courtesy of saolta.ie)

The hospital has natural referral pathways to the Midlands of Ireland, particularly in respect of patients that are referred in via the Emergency Department and discharged back for appropriate care i.e. orthopaedics, elderly care services etc. In addition, the hospital's paediatric service has linkages with Crumlin Children's Hospital for shared care arrangements in relation to oncology. From herein general practitioner patients and outpatients shall be referred to as outpatients (OP). Emergency, AMAU patient's and Inpatients shall be referred to as inpatients (IP).

4.1 Phase 1 – Framing the situation

A qualitative approach using interviews and observation is carried out. Here the problem is defined, and conceptual models are created with stakeholders using a System Dynamics approach initially. Software such as Vensim (Ventana Systems, 2018) can be used to create softcopy versions of the resultant hand written diagrams which identify stocks and flows, causal relationships and effects.

Individual unstructured interviews were arranged (n=6). One radiologist, one x-ray nurse and four radiographers were involved. Staff were asked to consider how workload differed from day to day and what factors contribute to workload variations, see Figure 4.2. Interviews were held individually to mitigate for the reluctance of less senior members of staff to voice their opinions, particularly if negative, about the system. In most situations Vensim was used to capture feedback from staff. In some situations where time did not allow a pen and paper were used to draw using System Dynamics notation, stocks, flows, links and causal loops. This feedback was amalgamated at a later stage using Vensim to create a final softcopy version (Ventana Systems, 2018), see Figure 4.2.

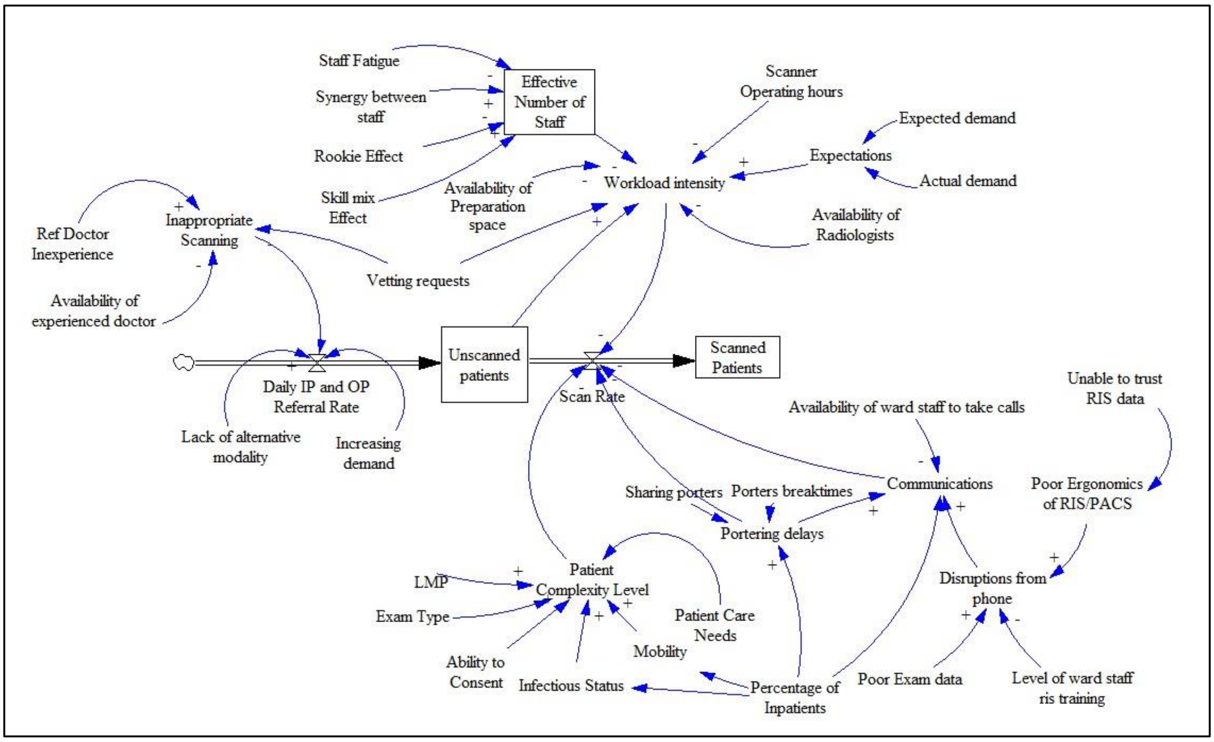


Figure 4.2 Using SD to capture staff perception of workload

Staff identified that demand for CT was growing and that some CT scans were being carried out because the MRI scanner was not available. Also identified were inappropriate CT scan requests which failed to meet the iRefer Guidelines (see (The Royal College of Radiologists, 2017)). Exams are often requested from inexperienced doctors, the risk of inappropriate imaging can be mitigated by the supervision of inexperienced doctors and also by radiologist and radiographer vetting of requests. Staff workload was contributed to by the lack of preparation space for procedures and IV cannulation, as well as by the availability of radiologists.

The effective number of staff in CT was affected by the skill mix or competency of staff each day, where fully trained staff were considered to be more effective than inexperienced. This has been referred to as "the rookie effect" in a call centre example where training staff were considered to be 35% effective compared to trained counterparts (Oliva and Sterman, 2001). Skill mix included whether staff were able to cannulate and also what level of proficiency they had in CT (post graduate course completed or no or years of experience). Staff identified the expectation to have all scans completed on the day of request as contributing to their subjective perception of workload.

Communication was identified by all interviewees as a major contributor to the perceived workload in CT. Communication arises from enquiries regarding patient scheduling, failure of ward staff to check times online and poor data entry into the RIS. Patient complexity was discussed in relation to the examinations being requested, the patient's mobility and infectiousness as well as the unique patient care needs of each patient.

SD was used in a further conceptual group model building exercise with the clinical specialist, department manager and researcher to model the multiple sources for CT examination referrals. Examinations were categorised as either scheduled or unscheduled, scheduled exams included general practitioner and outpatient department examinations and unscheduled included emergency department, Inpatient, acute medical assessment unit examinations. To conceptualise the waiting list problem and the mixed IP and OP service a stock and flow diagram of the dual service was co-created. The initial stock for the OP waiting list as well as the daily inflow and outflow of radiology orders for IPs and OPs were determined per day for both patient cohorts.

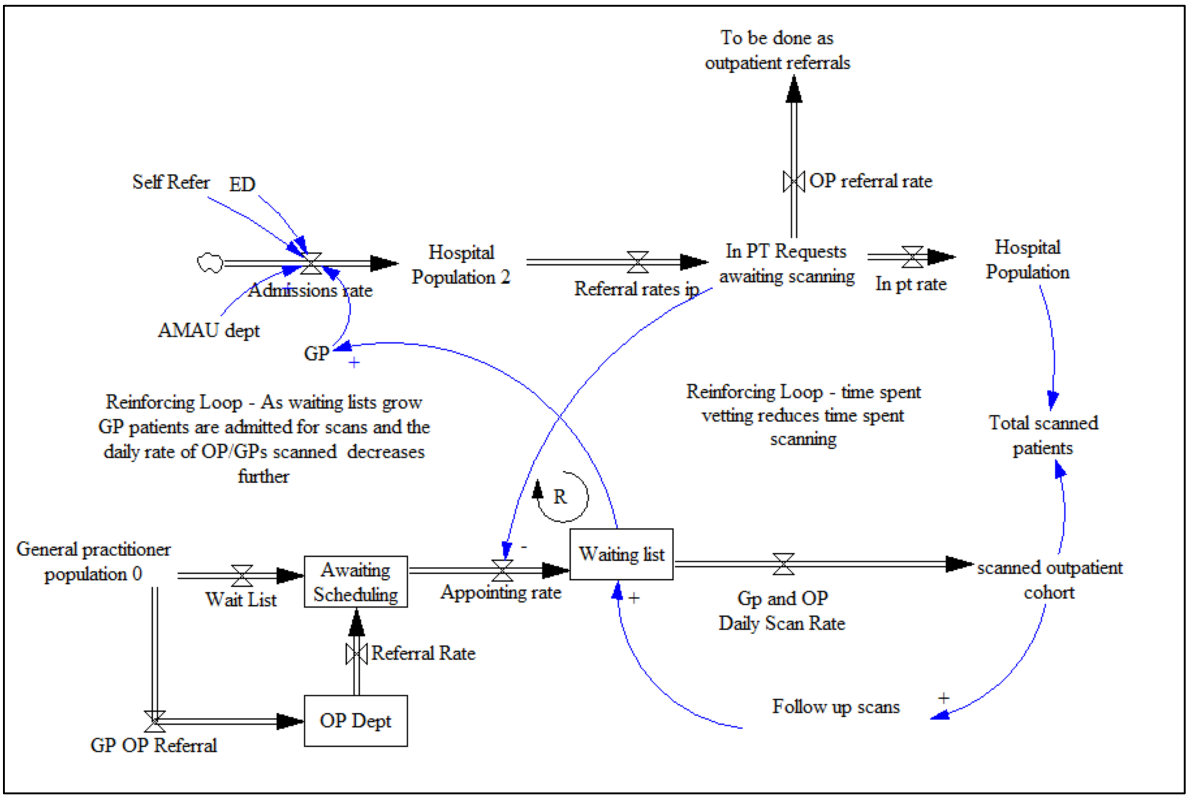


Figure 4.3 Mixed IP and Outpatient service conceptual model

Causal loop diagrams with stocks and flows were also used to capture the hypothesis that the IP service had a negative affect the OP service. A conceptual reinforcing loops was identified as shown in Figure 4.3, while capturing the feedbacks responsible for the perceived problem in conjunction with stakeholders. The researcher and staff identified a vicious cycle, where “status flipping” occurs where outpatients become inpatients in order to circumvent the long waiting lists. This flipping from an OP to an IP status further increases the inpatient workload and results in pressure to decrease further the number of outpatient examinations scheduled per day to counteract this, and some support for this was found in the literature (O’Regan, 2015; Irish Cancer Society, 2016). Additionally, the dual role of the Clinical Specialist who has scanning as well as vetting responsibilities is demonstrated. Vetting is a process whereby the clinical specialist reviews the requests for general practitioner and outpatient exams prior to an appointment time being allocated to them. A causal link was identified between patient scanning and vetting. If the radiographer is busy scanning, then they have less time to vet the outpatients on the waiting list. Therefore, the rate of scanning negatively affects the OP appointment rate.

The representation of the services using conceptual model was validated by the clinical specialist and radiology manager to check for accuracy.

Following on from the conceptual model building exercise it was determined that there was a need to carry out a preliminary analysis of the available data as part of phase 1 pertaining to:

1. Change in yearly CT demand,
2. CT demand for various sources identified,
3. Patient complexity in terms of mobility, infection status and exam types requested,
4. Service disruptions resulting from phone calls.

4.2 Process mapping

A process is a series of events or sequence of tasks and process mapping is the technique by which activities are documented in a detailed graphic form, enabling understanding of processes and their sequence (McLaughlin et al., 2014). A high-level macro process map was created for the CT service to illustrate the activities included when providing a CT service and is shown in Figure 4.4. The flow of patients, staff activities and decisions made from the point of scheduling of exams to the reporting of exams was documented using Visio.

Figure 4.4 Areas of the CT process mapped in exploratory phase 1

Initial data analysis: During this phase, the sources of data pertaining to the problem such as the number of examinations completed over previous periods as well as the current waiting lists should be ascertained. A breakdown of examinations by patient type, referral source and exam type should be completed. Records can be extracted from relevant information systems such as the patient administration system (PAS), radiology information system (RIS) or patient administration system (PACS) provided permission is obtained and local and GDPR guidelines are complied with.

Semi-structured qualitative interviews were carried out to provide the building blocks for model development and help identify data requirements. The following was determined:

1. The process steps, where decisions, queues and delays occur.
2. Staff involved in the service, relevant skill mix and scheduling of staff.
3. Activity types and durations such as the scan duration time including preparation times required for each exam type.

4. Identifying distinct patient populations or sources of CT demand, including the needs of the patients, and how the handling of patient populations vary.
5. Any scanner limitations and the operational hours of the scanner.
6. The policy for exam preparation for differing examination types and the grouping of exams into different categories by the preparation required.
7. Common process delays and patient-related complications such as extravasation and contrast reactions for IPs and OPs.
8. Communications required for scanning and scheduling and other staff activities including staff interactions, disruptions, and distractions as well as necessary.

4.2.1 Inpatient scheduling

A workflow map for Inpatient scheduling detailing the complexity of decision making and scheduling and the numerous outcomes associated with the task is shown in Figure 4.6 and Figure 4.6. Interestingly, despite two thirds of the CT work being inpatient related, clerical staff are not involved in the scheduling of inpatients. Clerical staff call the porter to ensure inpatients are brought to and from the department. They update the information system once the patient has arrived in the department, a step which notifies the radiographer of the arrival by triggering the printing of a paper document called the “arrival” sheet.

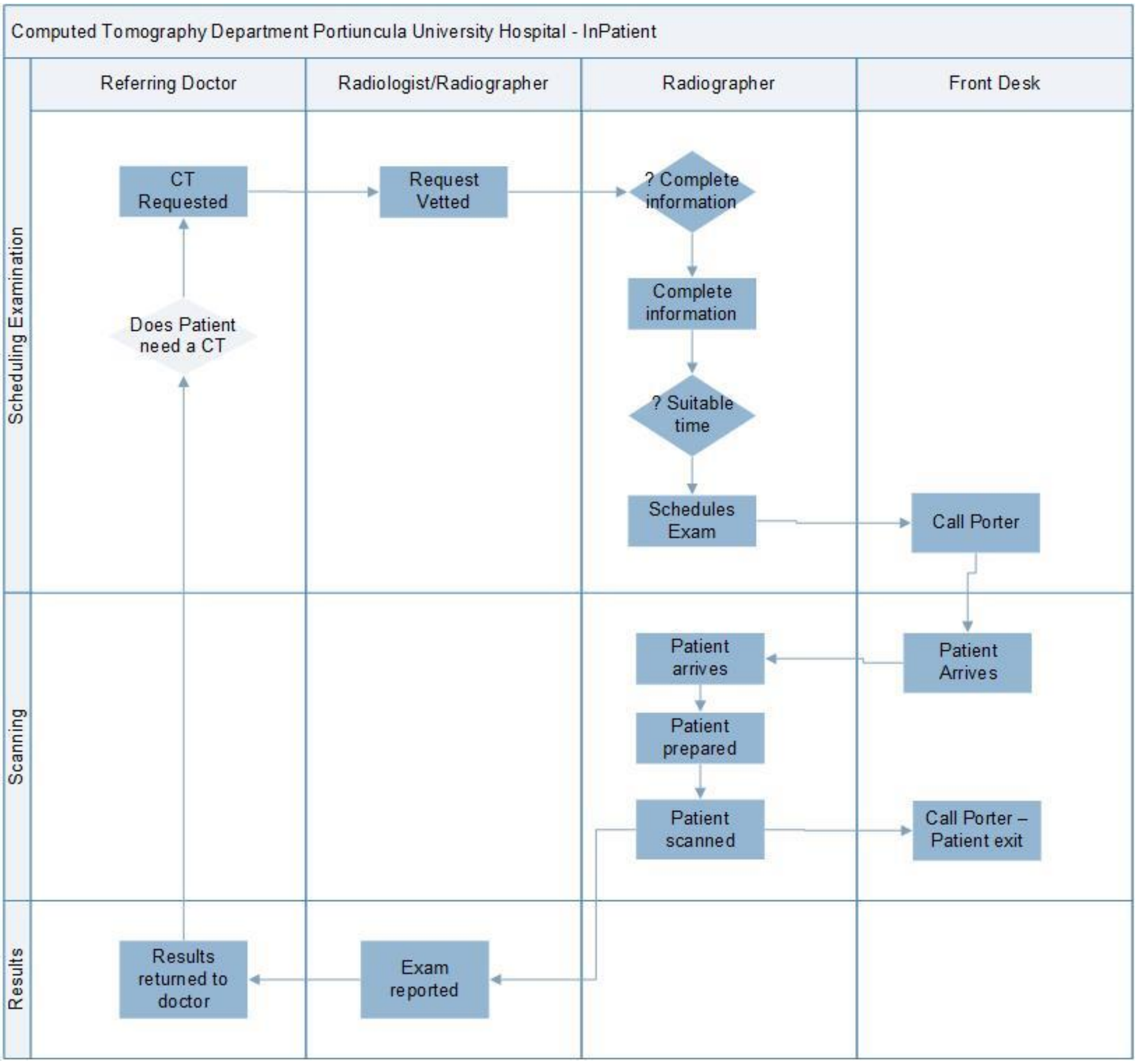


Figure 4.5 Inpatient activities for clinical and clerical staff

A more detailed workflow diagram was created for the safety considerations and scheduling considerations for IP cases, Figure 4.6. As can be seen in the diagram there are numerous communications between staff across multiple locations such as on the wards, the emergency room, porters. All the required information must be determined before the patient is sent for. Where a case is delayed or must wait until the following day the lead radiographer, responsible for scheduling must ascertain that the information documented the previous day has not changed, so they are in effect starting over with the case. This thinking, reasoning, and necessity to remember information particular to specific patients provides evidence of cognitive workload, and explanation for patient and service delays.

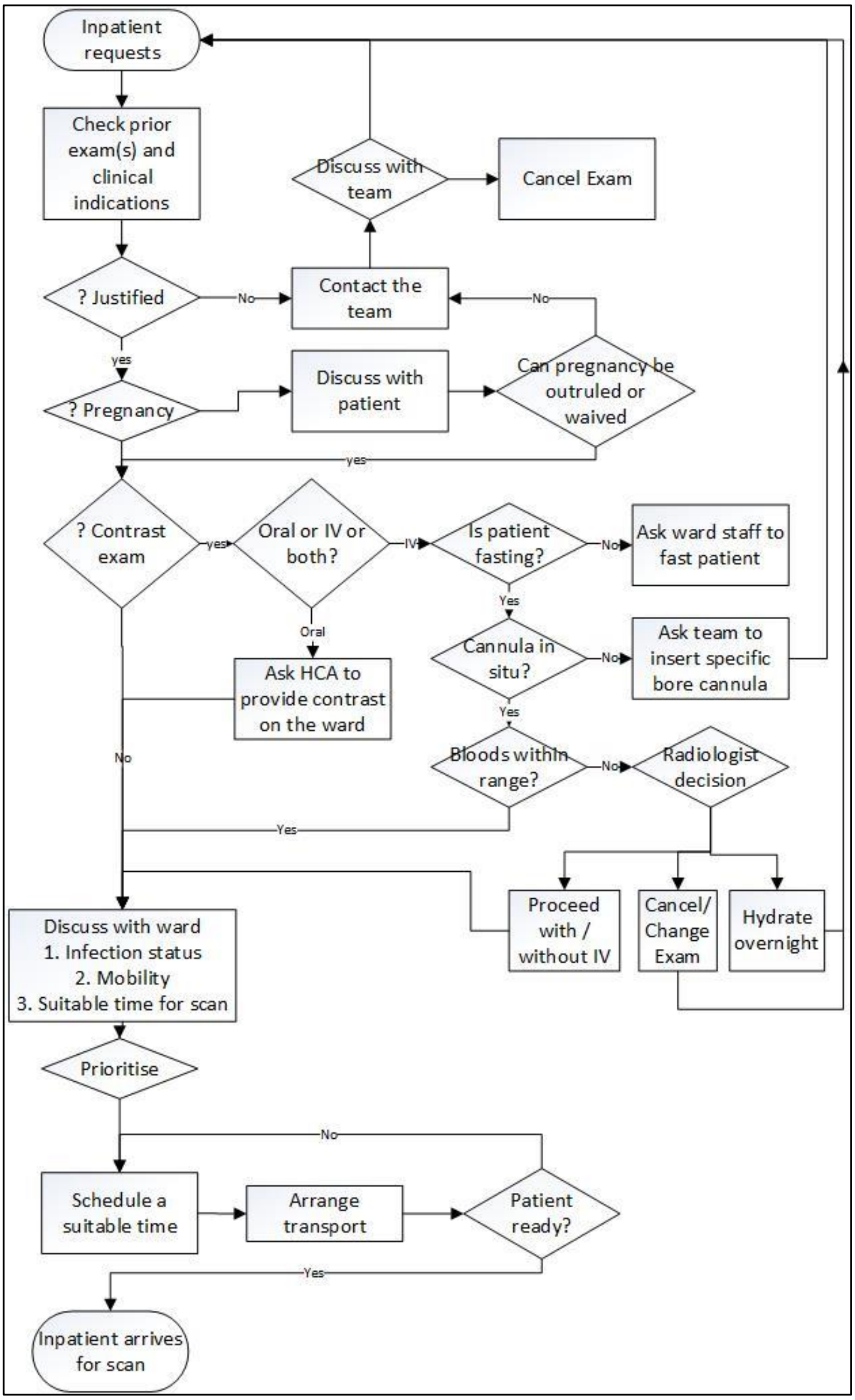


Figure 4.6 Considerations when scheduling IPs

4.2.2 Outpatient scheduling

The considerations and steps required when scheduling an OP exam are captured in

Figure 4.7. This diagram indicates where exam vetting is completed by the Clinical Specialist or a radiologist and that the time is assigned to the exam by the clerical staff. The scheduler receives new request for examinations in both electronic and paper format, on a daily basis. The paper document is scanned onto the RIS at this point and an accession number is generated for the new examination request. Clerical staff allocate a time for the outpatient examinations and obtain a copy of the patient's blood results. The patient receives a letter in the post with details on how to prepare for the exam.

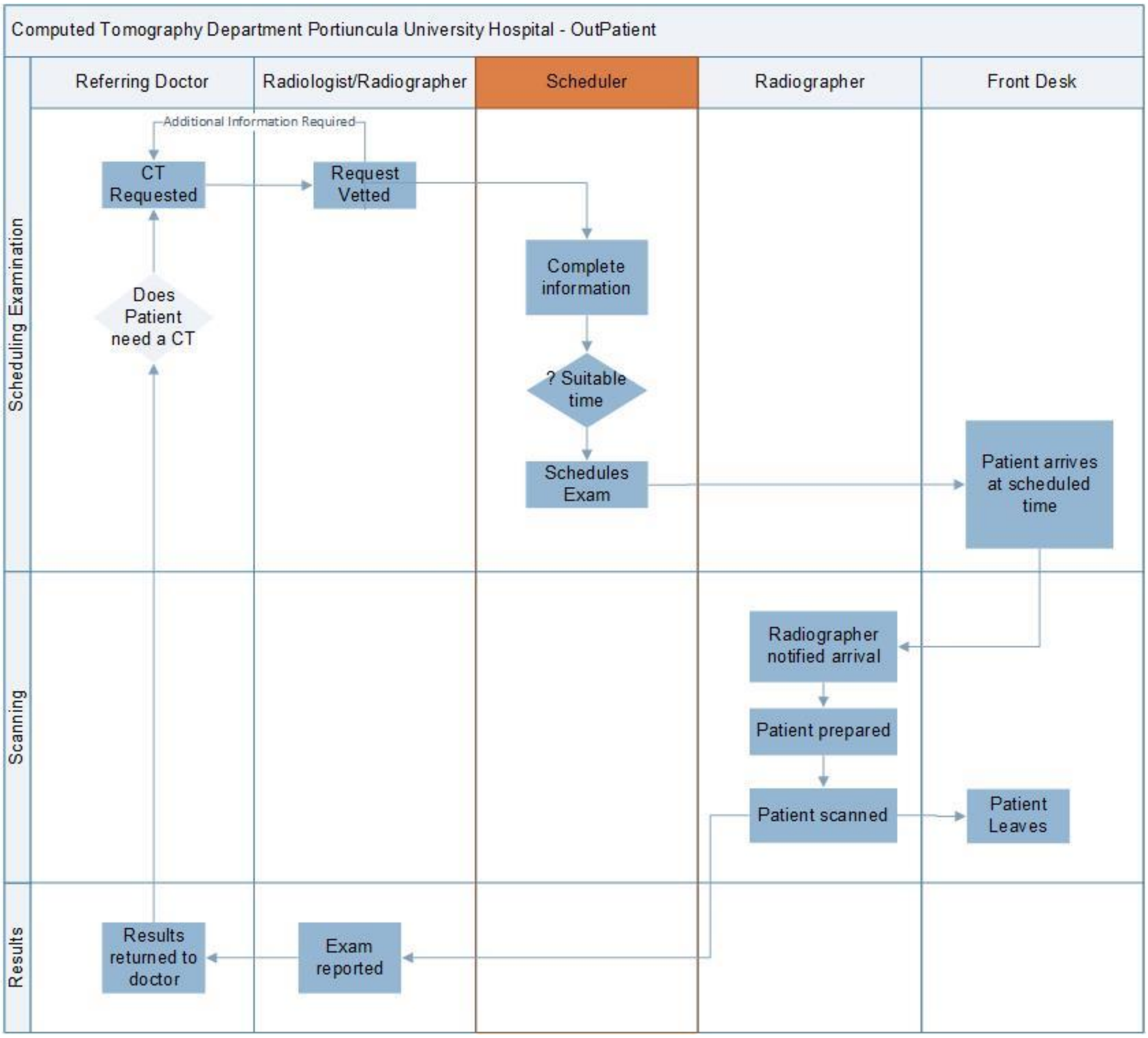


Figure 4.7 Outpatient activities for clinical and clerical staff

OP and GP patient exams are vetted to ensure appropriateness and then protocolled (a specific exam protocol assigned) see Figure 4.8. Vetting is carried out by the modality clinical specialist or radiologist who decide whether the examination is justified. For an exam to be justified the clinical specialist must determine the appropriateness of the request and whether there is sufficient clinical information to justify the examination as per the iRefer guidelines (The Royal College of Radiologists, 2017). The radiographer and radiologist consider the clinical urgency, and exams are assigned a priority status which determines the time interval at which they are to be scanned. Vetting is carried out once a day or less frequently if clinical duties demand the staff member’s time. Appointment slots are typically 30 minutes long. In the case study hospital, the clinical specialist radiographer indicated suitable dates and added comments regarding patient's blood results etc.

The appropriate protocol to use during scanning is decided at this prescheduling stage by the Clinical Specialist or radiologist. The appointment scheduling process in CT is the process by which available capacity is allocated to incoming demand for scans from referring doctors. It relies upon the expertise of the scheduling staff and involvement of the clinical specialist radiographer as described above. Appendix C includes a sample protocol for a CT examination of the thorax, abdomen and pelvis (TAP).

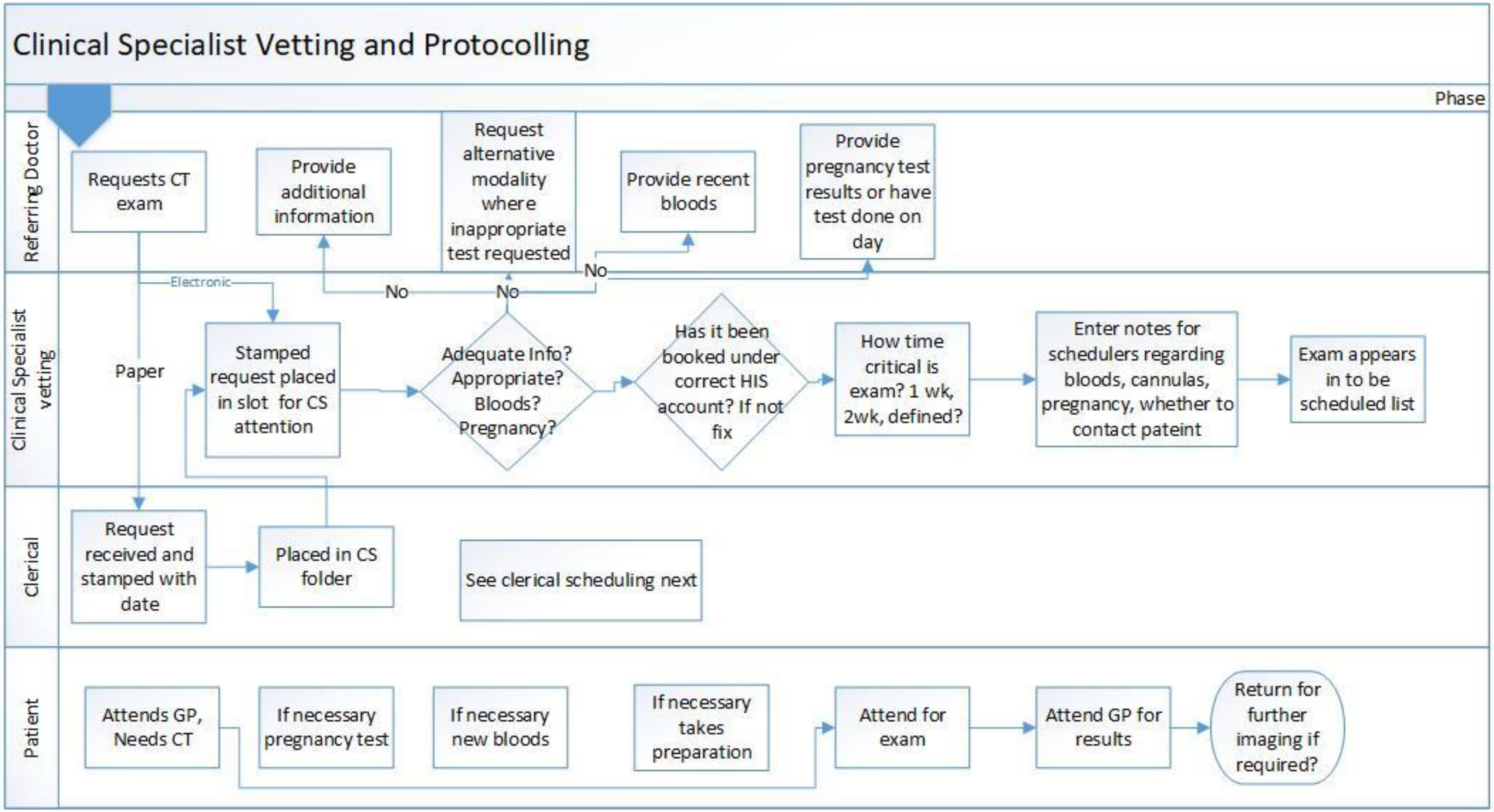


Figure 4.8 Outpatient and GP patient exam vetting and protocolling

The CT clinical specialist or lead radiographer administrative duties can be separated into:

- Daily scheduling of IP work (CT Clinical Specialist or lead radiographer)
- Vetting of examination for future work (CT Clinical Specialist only)

IP/ED/AMAU examinations - Referring doctors place requests for CT on the National Integrated Medical Imaging System (NIMIS). The work list is continually checked throughout the day to determine whether any new orders have arisen. New orders must be discussed doctor-to-doctor although the radiographers have some autonomy to decide to proceed with certain studies, such as CT brain and CT KUB (kidneys, ureter, bladder) studies, without consulting the radiologist. IPs are not scheduled far in advance and are instead "sent for" based on patient acuteness, the length of time spent waiting, the nature of the scan requested and scanner availability. The clinical considerations which are taken on the day of scanning for OP examinations are provided in Figure 4.9 and are based on discussions with the clinical and clerical staff identified above. While there are numerous considerations and points of decision evident on the diagram, the cognitive workload is less for outpatients than for inpatients (Figure 4.6).

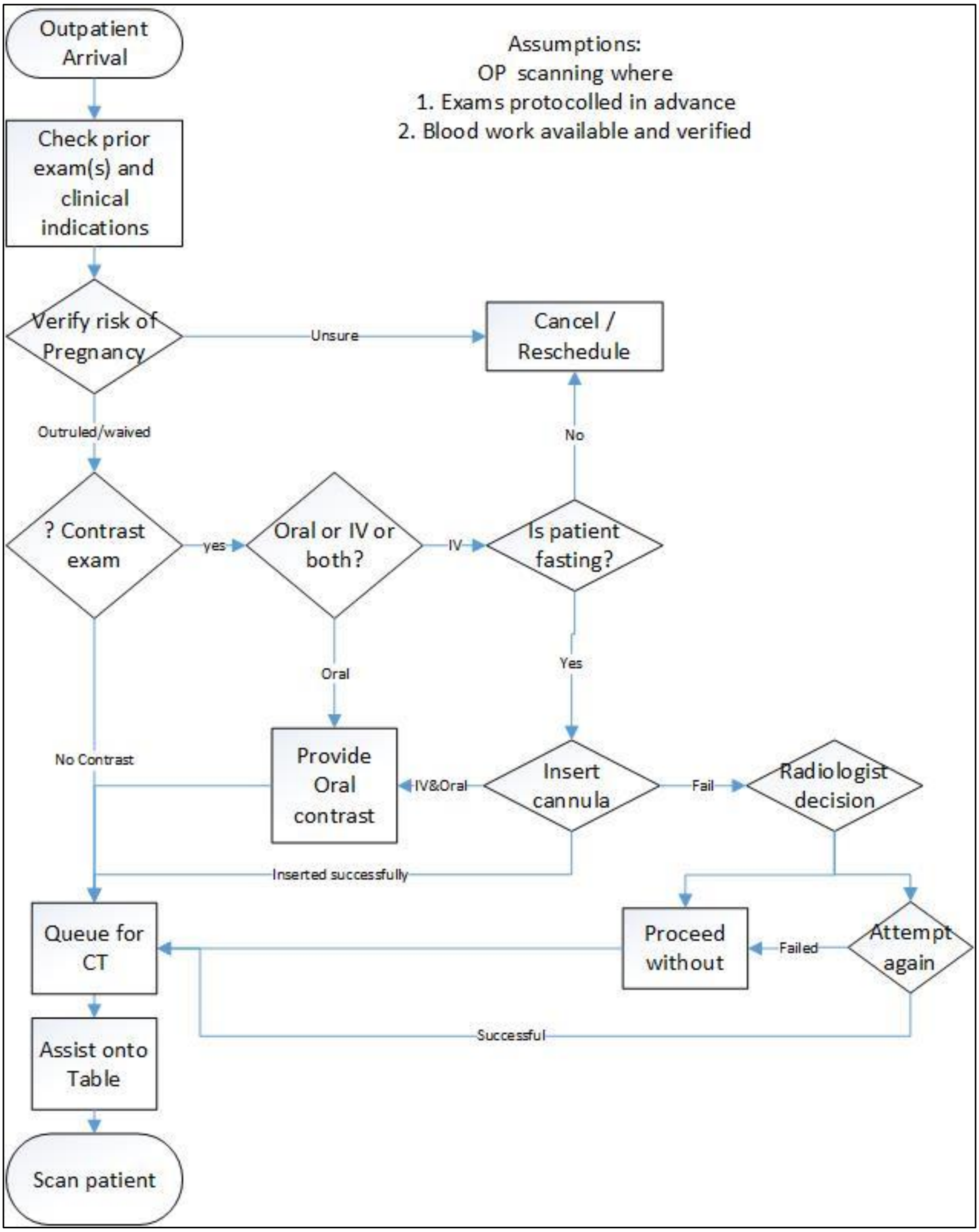


Figure 4.9 Detailed considerations taken on patient arrival for GP and Outpatients

4.2.1 Patient Preparation

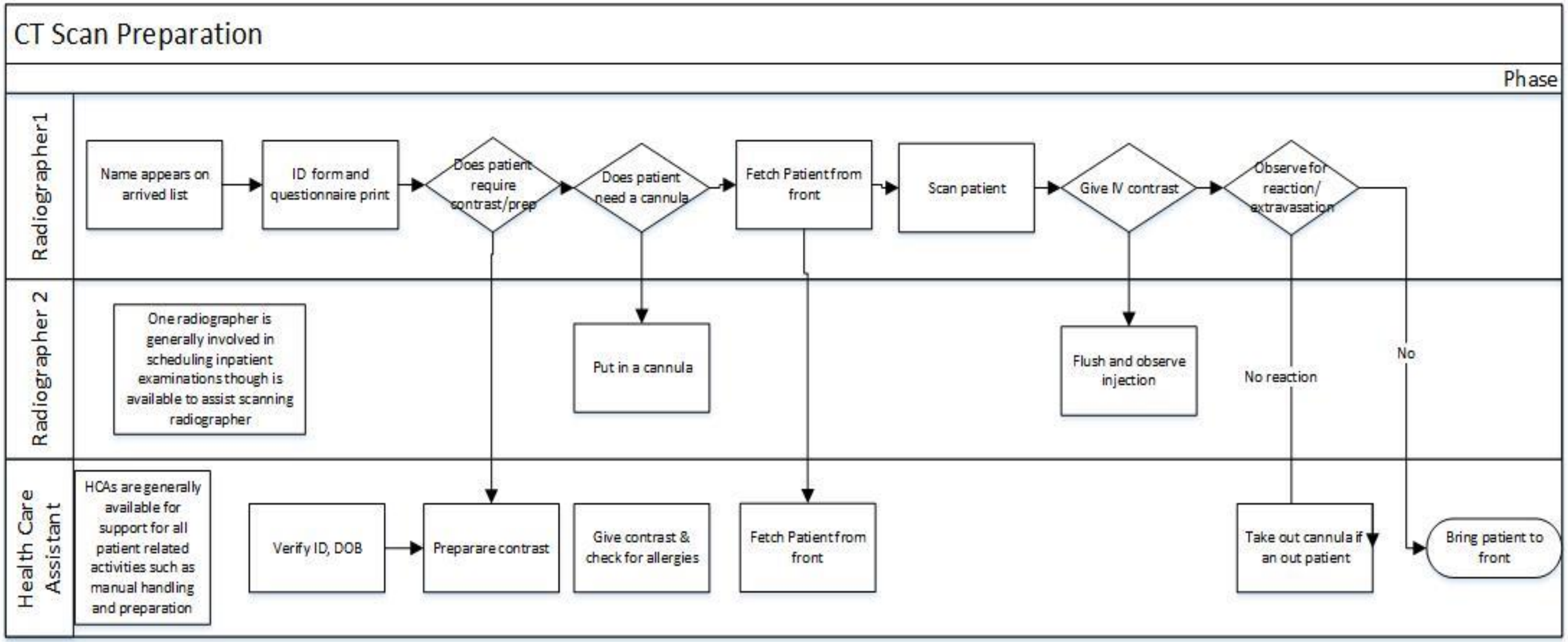


Figure 4.10 CT scan preparation 2 radiographer 1 HCA workflow

In Figure 4.10, the workflow for two radiographers and one HCA is shown for patient preparation. Here the radiographer determines the preparation required and communicates to the HCA where it is possible for them to complete tasks such as the preparation of patients requiring oral contrast, the removal of cannulas and the movement or transportation of patients to and front the scan room.

4.2.2 Patient preparation

Healthcare assistant staff and radiographers were interviewed using unstructured interviews to document patient preparation. Patient examinations were categorised by exam type based on the use of IV and /or oral contrast and exam preparation required. The exam categories were as follows:

- Non-contrast – an examination requiring neither oral nor IV contrast and as a result requiring minimal preparation.
- IV – an examination requiring IV contrast therefore a cannula must be sited and flushed, and contrast administered.
- IV and oral – an examination requiring an IV injection as well as the patient to drink 1000 millilitres of fluid containing radiopaque contrast.
- Procedure – examinations that require patient preparation such as the siting of a cannula plus some observation before and after the scan.
- Oral - an examination requiring the patient to drink 1000 millilitres of fluid containing radiopaque contrast.

For exams involving the use of oral contrast, patients are required to drink one litre of water plus 20ml of a positive contrast called Omnipaque 320. Positive contrast is radiopaque and appears white on X-rays. Opacification of the bowel using oral contrast material is carried out for the correct interpretation of abdominal CT scans and for identification of pathology. In the case study hospital, the protocol dictates that this process takes 90 minutes as standard. Oral contrast can be administered by the radiographers or healthcare assistants.

For exams involving IV administration of radiopaque contrast a cannula must be in situ. IV contrast may not be given where there is a history of a reaction to previous contrasts or to substances such as shellfish or medications. The patient will also be consulted on his/her history of asthma, hay fever, diabetes, and kidney problems or surgery. The patient’s blood results will be considered prior to administration of IV contrast to establish a recent (six-week) eGFR (estimated Glomerular Filtration Rate) and creatinine level.

Where a patient needs to be cannulated, the radiographer or nurse will insert a cannula into a vein at the elbow or hand. IPs and oncology and AMAU patients should already be cannulated, but it is necessary to recheck these lines and sometimes replace them if they have stopped working or are inadequate to handle the follow of contrast from the pump. Documenting this oral history takes approximately 5 minutes. Insertion of the cannula takes 10-20 minutes depending on the complexity of the patient. A failed attempt by Radiographers at cannulation requires a second attempt by a doctor or anaesthetist.

Exams which require the presence of the radiologist were categorised as procedures during this study. Such exams include CT colonoscopy, calcium scoring, cardiac angiography, nerve blocks, CT guided drainage etc. These exams also require that a nurse is present, and patients require preparation before, and observation afterwards. Radiographers must ensure a radiologist or medical doctor is in the department during the scan if IV contrast is being administered. Radiographers must have completed training in CT and training in IV administration before being qualified to complete a CT scan using IV contrast. A detailed workflow map was carried out of the CT scanning process, The steps leading up to and following the completion of a CT scan are captured including the role of the radiologist in supporting the service and reporting on the resultant images in Figure 4.11. The time taken for patient preparation and scanning was captured using a watch and later verified with the clinical specialist to determine maximum, minimum and mode values for each parameters in the DES model.

Following the administration of IV contrast the patient must be observed for 20 minutes to determine if they are experiencing any side effects of the IV contrast or scan. Radiographers observe the patients for any signs of nausea, rash, hives, urticaria (redness), difficulty breathing. This takes 30 minutes though if complications are observed this can take longer. IPs are not observed and are returned to their ward or the emergency room for observation.

Staff must also reconstruct images post capture and forward these to the PACS. Radiographer must also scan paperwork accumulated and used for documenting evidence of an identity verification with patient, the patient's allergies, the technique used, the amount of contrast administered and the rate of administration. This documentation is scanned into the RIS.

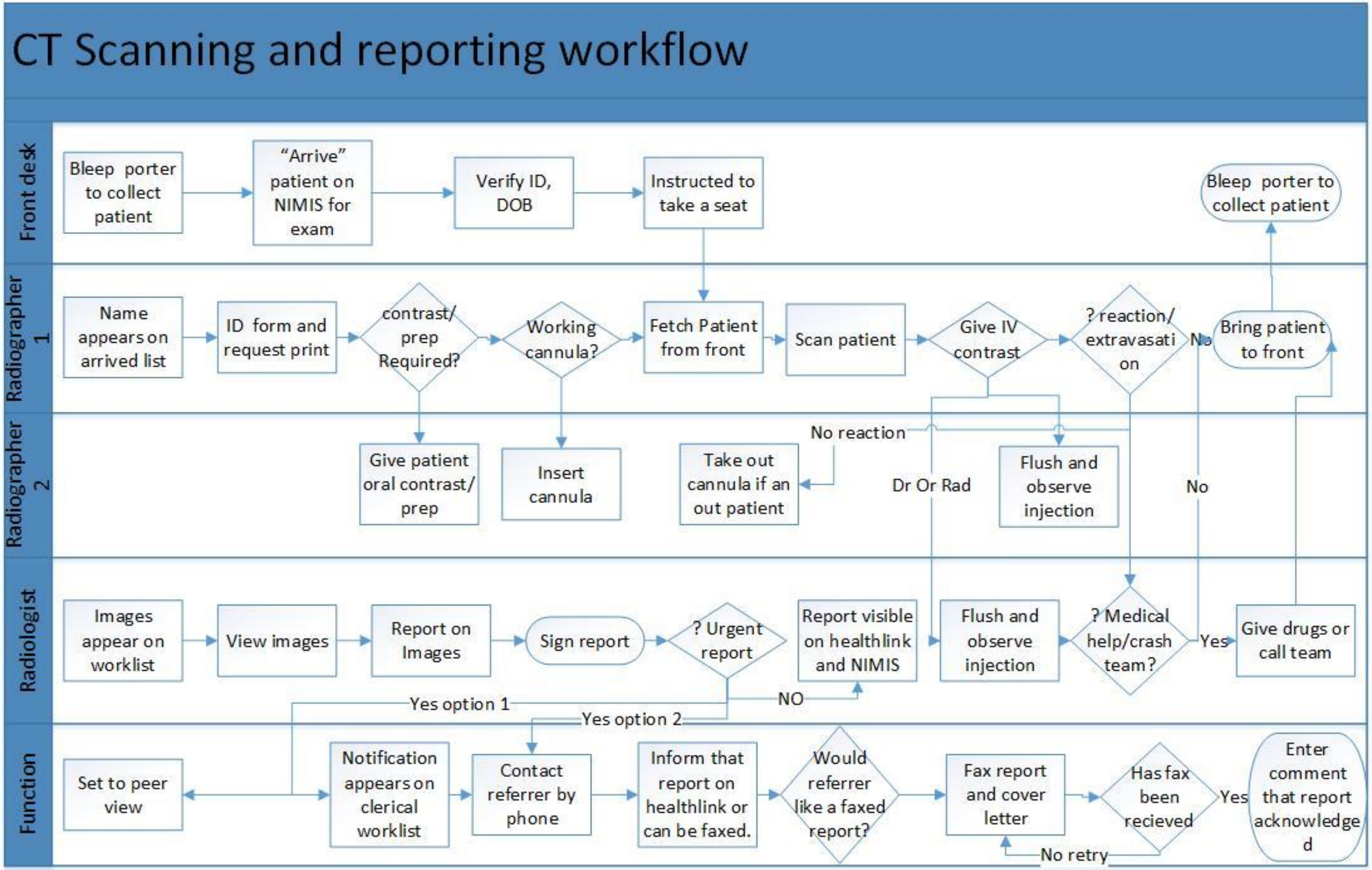


Figure 4.11 Scanning and reporting workflow

4.2.3 Patient Transportation

A patient's mobility was categorised as walking (ambulatory), wheelchair, trolley or hospital bed. Walking patients required the least assistance getting onto the CT scanner or X-ray table. Wheelchair patients frequently required assistance getting onto the bed. Trolley-bound and bed-bound patients always required assistance, with four staff members required to carry out the transfer, as per the correct manual handling protocol in the hospital. The radiographer must properly assess the mobility level of the patient to avoid physical injury to him/herself and the patient. The radiographer determines the method of transfer of the patient onto the CT scanner and additional staff must be located to assist with this transfer. Times are affected by the availability of staff and the mobility status of the patient. The availability of a porter to assist with a transfer or to bring a patient to or from the CT room also influences the overall efficiency of the department and was included in the model. Figure 4.12 depicts the means through which transportation is arranged for a ward patient. For model building the stochastic delays experienced and the task of arranging transportation were included and times determined for same.

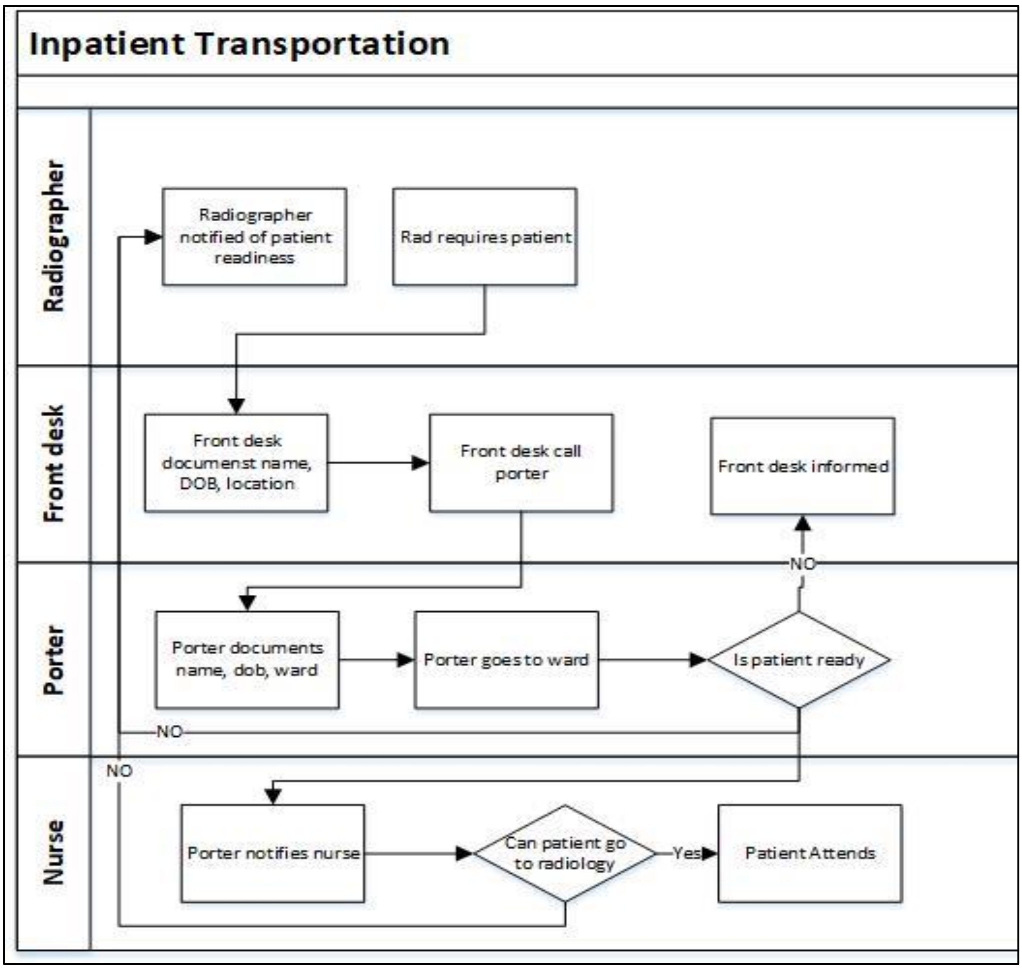


Figure 4.12 Arranging IP transportation

4.2.4 Infection control measures for COVID-19 cases

The communications required and downtime resulting following the scanning of a patient who is undergoing aerosol generating procedures (AGP) in CT is depicted in Figure 4.13. The COVID-19, questionnaire to be completed for each exam during exam planning has 11 to 6 questions depending on scan type (11 where intravenous contrast is administered). There are three additional phone calls pre-CT scan plus completion of COVID-19 questionnaire with staff nurse/referring doctor. While infection control considerations exist for all CT patients, in the case of COVID-19 the department must be closed to all other patients while the patient is entering and existing the department. In cases where a patient has undergone an aerosol generating procedure (for example ventilation and suction) the room cannot be accessed for a period of one hour (Mossa-Basha et al., 2020; Orsi, Oliva and Cellina, 2020).

The additional considerations for COVID-19 cases are circled in green as shown in Figure 4.13.

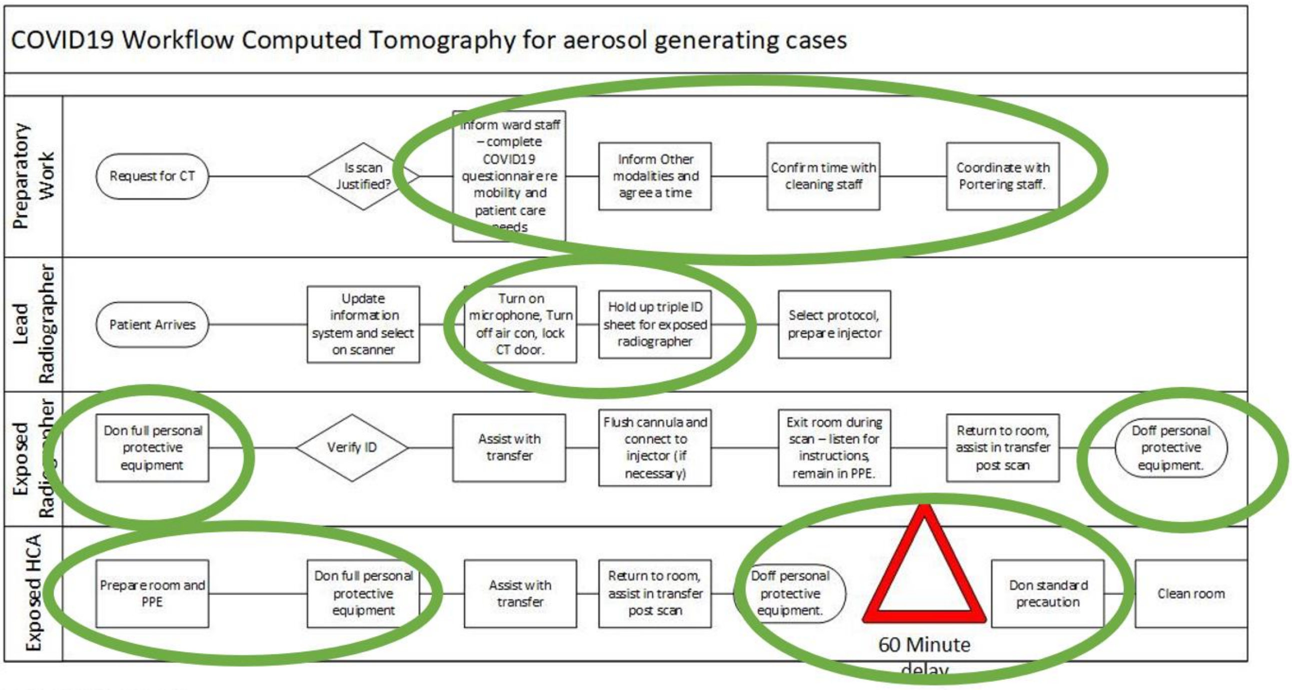


Figure 4.13 Workflow for patients undergoing aerosol generating procedures in CT

4.3 Exploratory data analysis

An exploratory analysis of data pertaining to IP and OP demand for CT, the growth of the CT waiting list and the IP and OP patient profiles was undertaken to better understand the extent to which the service failed to meet the demand and variation between IP and OP profiles.

4.3.1 CT Demand and CT Service provided

4.3.1.1 Breakdown of CT service provision in Ireland

CT examinations may be considered as either scheduled or unscheduled. Unscheduled exams may be broken down into emergency or inpatient. The following results from a HSE activity report (2017), compare the case study site (PUH) with 28 other Irish departments in terms of the ratio of inpatient to outpatient CT activity Figure 4.14.

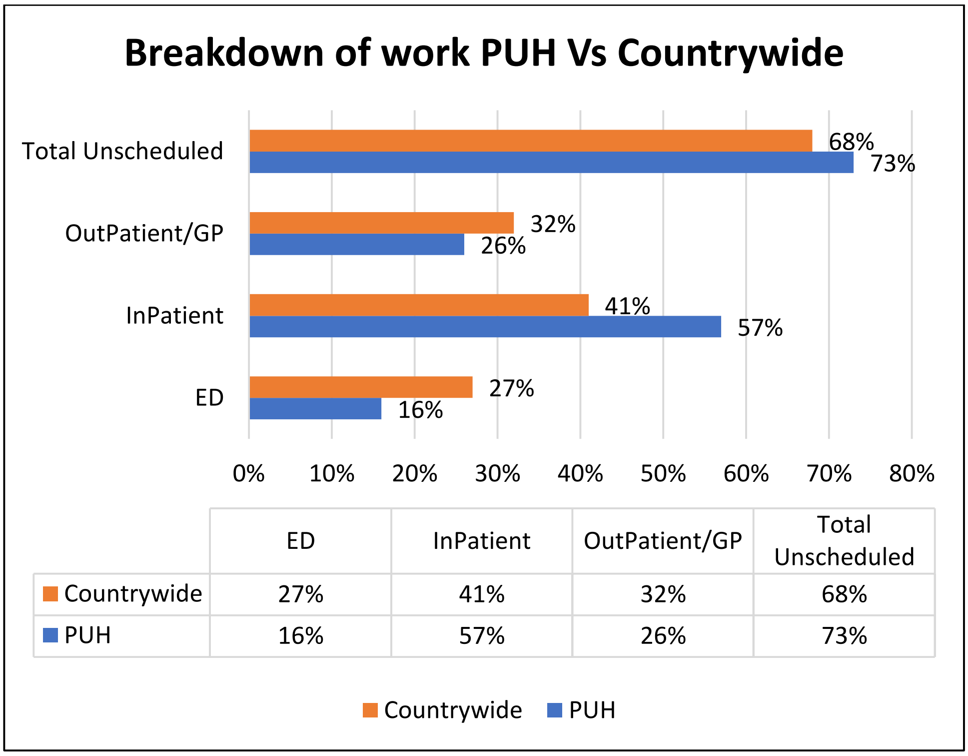


Figure 4.14 Countrywide activity breakdown scheduled versus unscheduled

PUH carries out less emergency patients and more inpatient work than the national average. PUH also has a lower OP to IP patient ratio (26:73) than the nationwide average (32:68).

4.3.1.2 Overall CT demand

An analysis of yearly demand for CT using linear regression demonstrated a significant increase (p= 0.0095) over the study period at an estimated increase rate of 430.2 scans per annum. In this case the p value is evidence of whether the increase in the number of exams per year is random or not. With a p value of 0.009, the chance of the increase not being related to time is 9/1000 i.e., the smaller the p-value, the stronger the evidence that the null hypothesis should rejected. Confidence interval lines of 95% are shown in grey in Figure 4.15. Here we see the number of CT exams yearly rising from less than 5000 in 2013 to in in excess of 6,500 in 2017. The R squared value is 92%, therefore the CT variability in CT demand is mostly explained by the year variable.

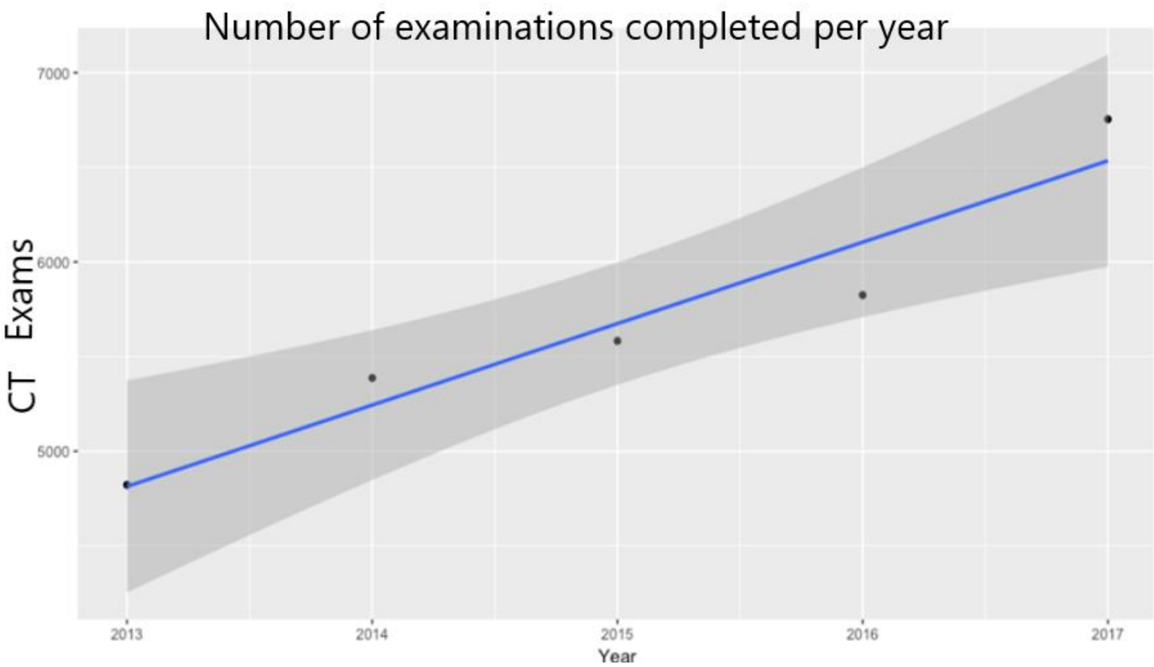


Figure 4.15 Increase in yearly demand for CT

4.3.1.3 Unscheduled (IP and ED) CT demand

The number of unscheduled patient examinations completed monthly was examined. An analysis using linear regression demonstrated a significant increase (p=0.01305) over the study period at an estimated rate of 184.2 examinations per annum, see below Figure 4.16. In 2017, the average number of scans per day was 21.8, with a max of 32 and a mode of 23, standard deviation was 6.1.

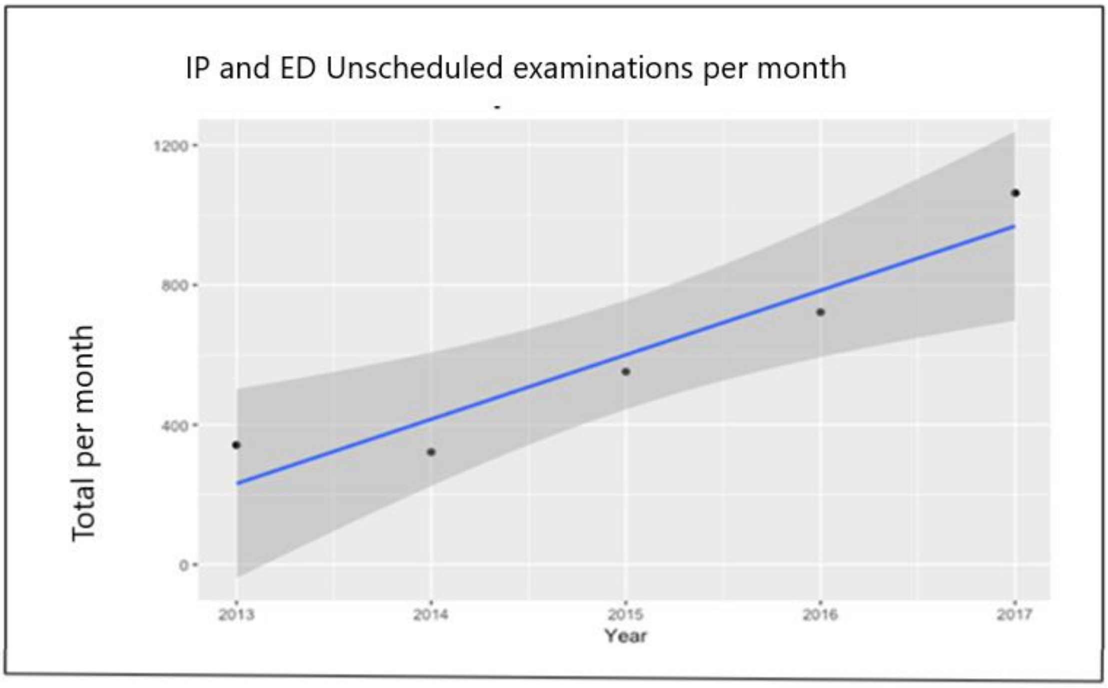


Figure 4.16 Increase in monthly Inpatient and emergency department patient demand

4.3.1.4 Scheduled (OP and GP) CT examinations

Using linear regression, the number of scheduled exams being completed was analysed. Despite an overall increase in CT the number of CT exams completed as shown in Figure 4.15, the number of GP and OP examinations performed was not shown to have increased significantly (p=0.9077) over the period Figure 4.17. The slope is zero, indicating neither an increase or decrease in the number of exams being completed.

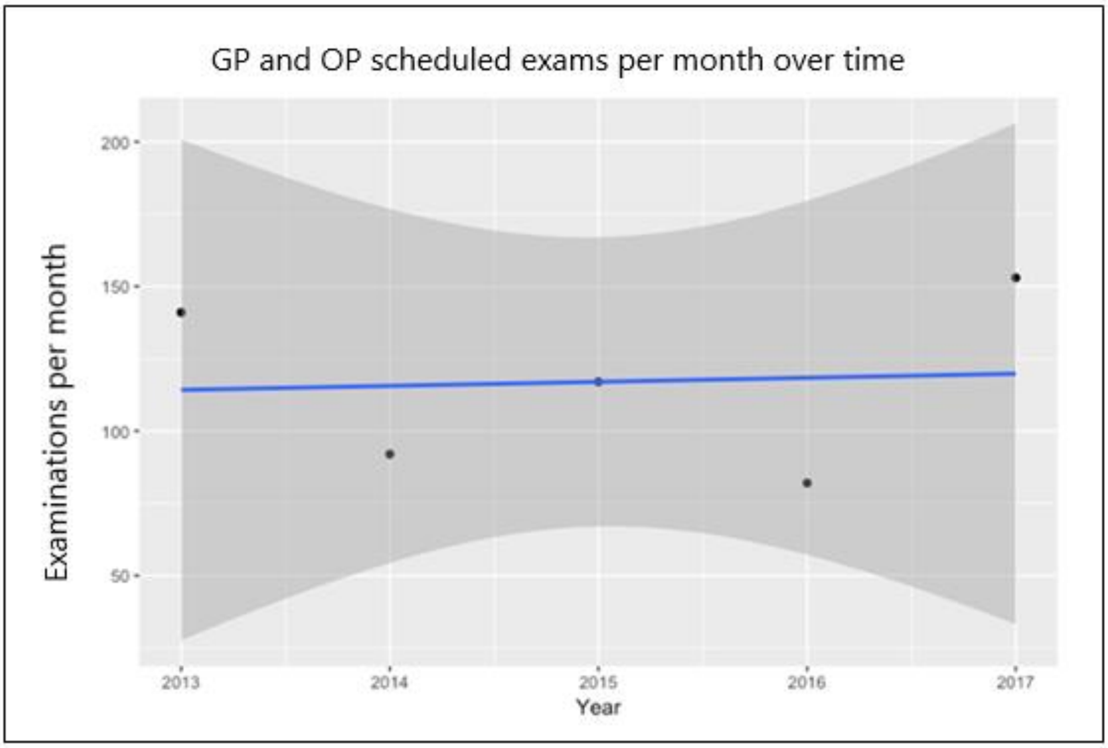


Figure 4.17 OP and GP scheduling rate over time

A Poisson distribution was used to model the number of arrivals occurring with a given time interval (e.g., between 9am and 5pm on a weekday) over a 1-year time period. In Table 4.1 and Table 4.2, a Poisson arrival rate for each patient type (IP and OP) and for each exam type is provided. These rates were used as arrival parameters for the IP and OP sources in the DES model when running stochastically. From this analysis of 250 weekdays as shown in Table 4.1 and highlighted in bold, each day .99 outpatients arrive for an IV exam, compared to 2.19 inpatients. Similarly, in Table 4.2, in bold we can see that 4.24 inpatients are scanned on average for exam category "None", we can also note from the table that no OP/GP patients are scanned at weekends.

Table 4.1 Weekday IP and OP arrival rates (250 days)

Patient Type	Exam Categories	Number	Rate
GP/OP	**IV**	**247**	**0.99**
ED/IP	**IV**	**547**	**2.19**
GP/OP	IVandOral	689	2.76
ED/IP	IVandOral	834	3.34
GP/OP	None	432	1.73
ED/IP	None	1982	7.93
GP/OP	Oral	66	0.26
ED/IP	Oral	81	0.32
GP/OP	Procedure	513	2.05
ED/IP	Procedure	20	0.08

Table 4.2 Weekend arrival rates for inpatient exams (112 days)

Inpatient	Exam Categories	Number	Rate
TRUE	IV	81	0.72
TRUE	IVandOral	170	1.52
TRUE	**None**	**475**	**4.24**
TRUE	Oral	25	0.22

4.3.1.5 Inpatient demand variation

A frequency distribution analysis was completed for the total number of IP CT exams completed per day in 2017, see Figure 4.18. An average of 13.5 IP exams were completed daily, with a high standard deviation of 10.5. This evidences the high variation in CT demand on a daily basis i.e. 13.5 inpatient exams completed per day plus or minus 10.5 exams.

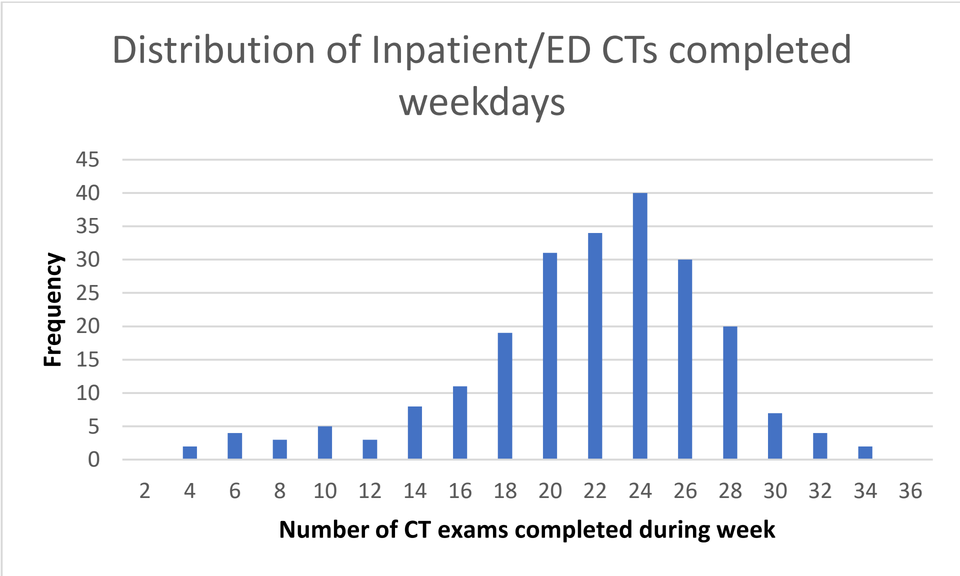


Figure 4.18 Frequency distribution of variation of IP work completed on weekdays

4.3.1.6 Daily workload distribution

The daily distribution of IP and OP/GP scanning is shown in Figure 4.19 and the timing of staff breaks indicated. The y-axis indicates the number of scans being completed per hour at each time interval for example at 11am 5 examinations were being completed per hour. The green line indicates the total number while the red and blue indicate the scheduled (GP and OP) work and the unscheduled emergent ED and IP work. Break times between 10am and 11am for 20 mins and at 1pm for one hour are indicated on the graph and correspond with interview data.

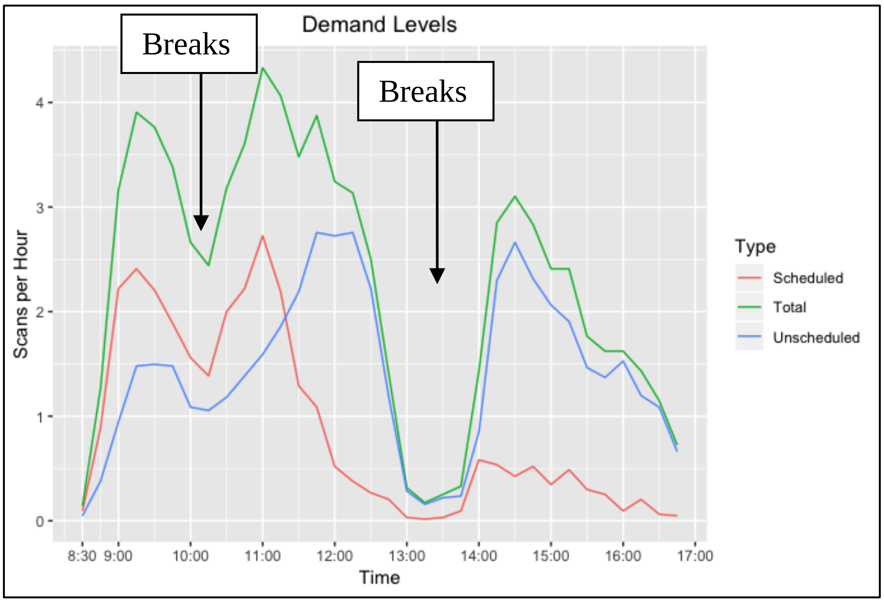


Figure 4.19 Number of patient scans performed per hour

4.3.1.7 CT weekend demand

The CT "Winter Initiative" (WI) was launched in December 2016, in response to an increase in CT weekend demand. The WI was a radiology initiative to provide a second radiographer at weekends to assist the radiographer on call. In 2019 an analysis of CT weekend demand was undertaken as part of this research project and also at the request of management. Prior to the WI, the oncall CT and X-ray service was provided by 1 radiographer covering a 24 hour shift. An oncall service is one where staff are available out of hours to carry out xrays or CTs at short notice. Following one weekend (December 2016) where one staff member completed in excess of 50 xrays and 15 CTs in a 24 hour period it was decided to introduce a dedicated weekend session from 9 to 2 on Saturday and Sunday with CT staffed by 1 radiographer, and to carry out IP scanning during this time. The objectives were:

1. To alleviate the unsustainable workload for the on-call radiographer who covers general radiology oncall service as well as the oncall CT service,
2. To prevent a backlog of IP CT scans at weekends and load balance the workload.
3. To decrease the patient length of stay by enabling weekend discharges,
4. To prevent weekend patient admission where a CT result would allow discharge from the emergency department,
5. To improve the quality of service provided to patients.

Data analysis of CT demand at weekends was undertaken to determine the uptake and use of the initiative and to plan for its permanent implementation. Data was taken from NIMIS RIS pertaining to the number of CT scans completed at weekends from January 2016 to May 2018 and this was revisted to include 2019 figures. Data was inputted to Excel for analysis.

Linear regression and descriptive statistics were carried out using the data analysis toolkit package in Microsoft Excel, see Table 4.3. A significant increase was observed ($p<0.001$).

Table 4.3 Analysis of demand growth

	2013	2016	2018
Average weekend scans	3	4	7.5
Maximum weekend scans	8	11	16

Figure 4.20 graphs the overall demand for CT, with the first green line indicating the time when weekend scanning was introduced. Prior to this only emergencies were completed at weekends, with non-urgent scans postponed until weekdays. The second green line indicates when an analysis of the service took place (2019).

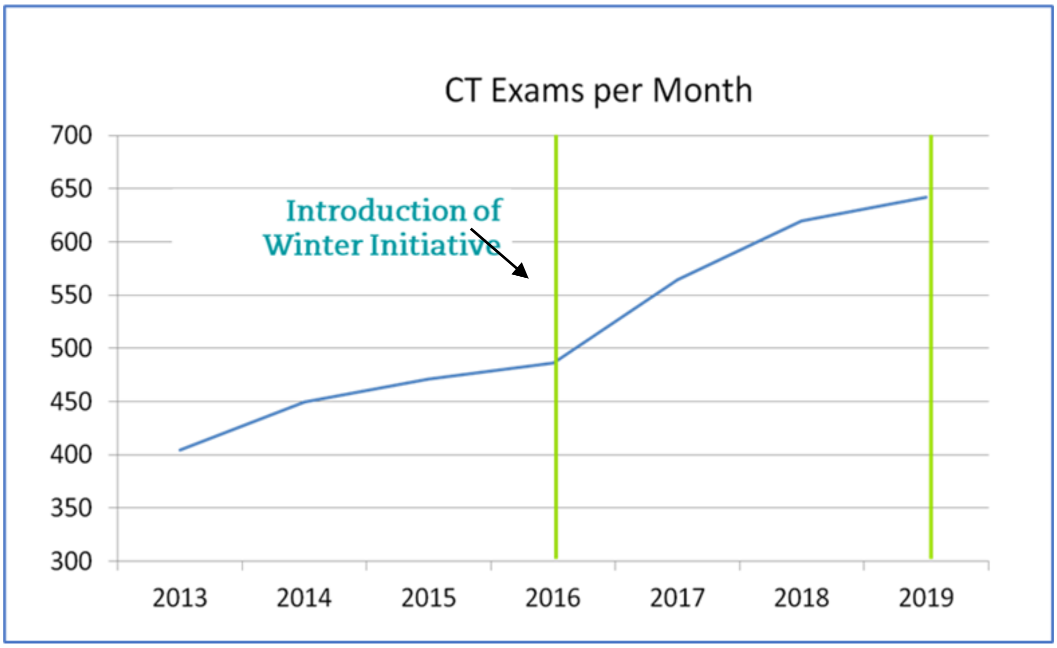


Figure 4.20 Audit of CT Winter Initiative 2019

4.3.1.8 CT Demand Post COVID-19

As is typical of action research the cyclical nature of data collection meant that the researcher responded to events throughout the research, including the arrival of the COVID-19 pandemic. During this period, the number of CT examinations being carried out was found to decrease significantly (p= 0.34), over the period 01/01/2019 to 31/01/2021 as shown in Figure 4.21. This was partly due to a decrease in the number of scheduled GP and OP exams being booked and partly to do with lower admission rates for non COVID-19 related illness.

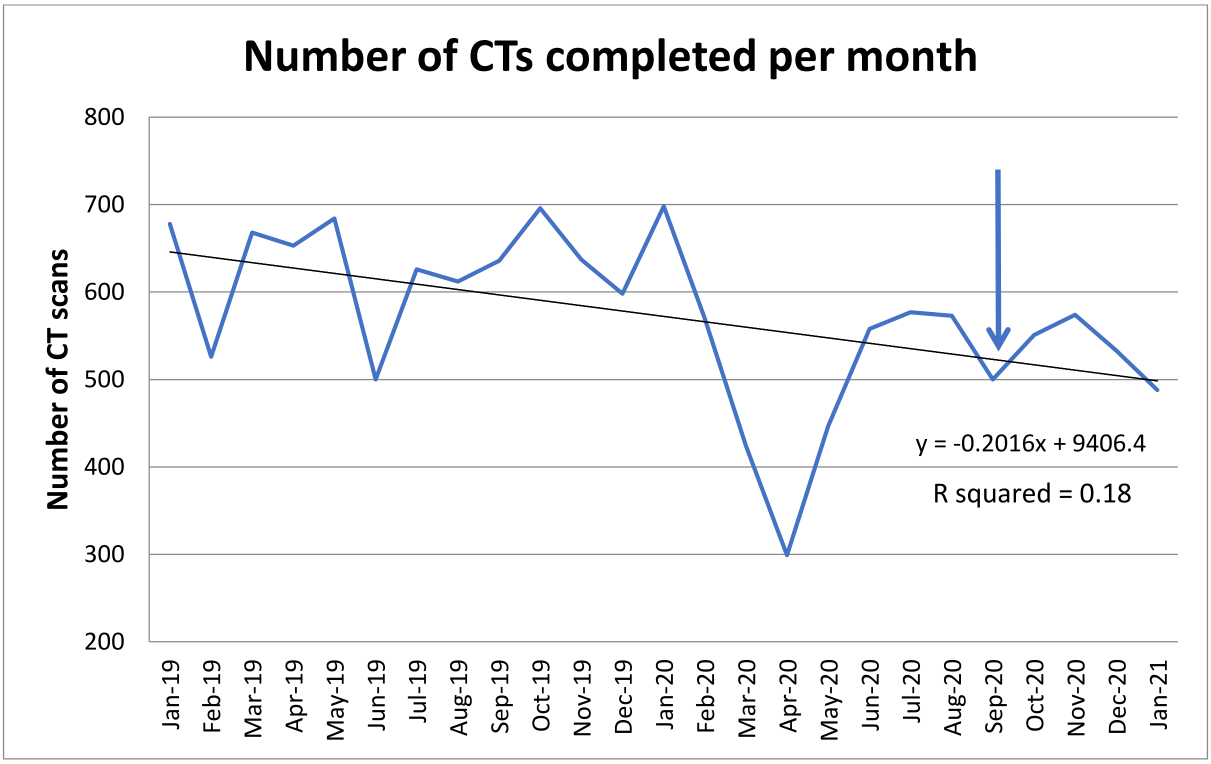


Figure 4.21 Effect of COVID-19 on number of CT exams completed

4.3.2 CT waiting list

The OP waiting list increased significantly (p=0.014) over the period 01/06/2017 to 01/10/2020, Figure 4.22. A decrease can be noted in the waiting list when in June 2020 CT exams were performed in another site to support the public health service during the COVID-19 pandemic.

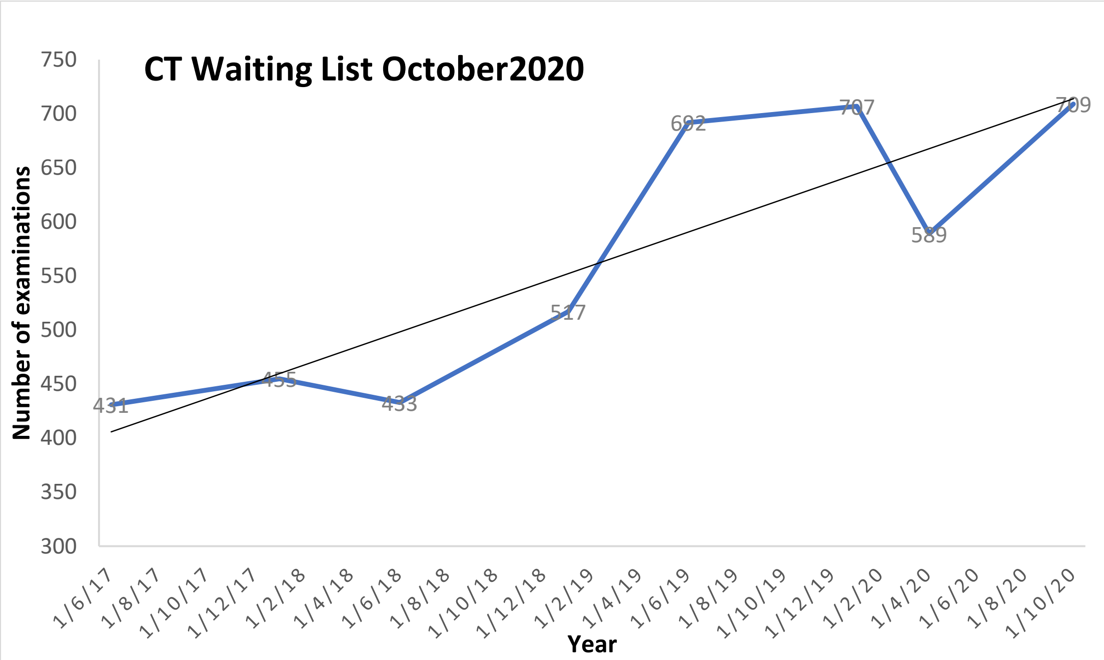


Figure 4.22 CT waiting list

Of significance to the creation of the DES model is the number of exams in the waiting list on model start-up and the breakdown of the examination types Figure *4.23*.

Exam Type	Number of Exams
None	293
IV	107
Oral	32
IVandOral	195
Procedure	82
Total	**709**

Figure 4.23 Breakdown of waiting list by exam type

When the waiting list is examined by exam type the exams requiring no contrast constitute the greatest percentage of exam types at 41% Figure 4.24. Exam type is relevant to the DES model as each exam type has a different exam preparation and requires different resources and is routed within the model based on the examination type.

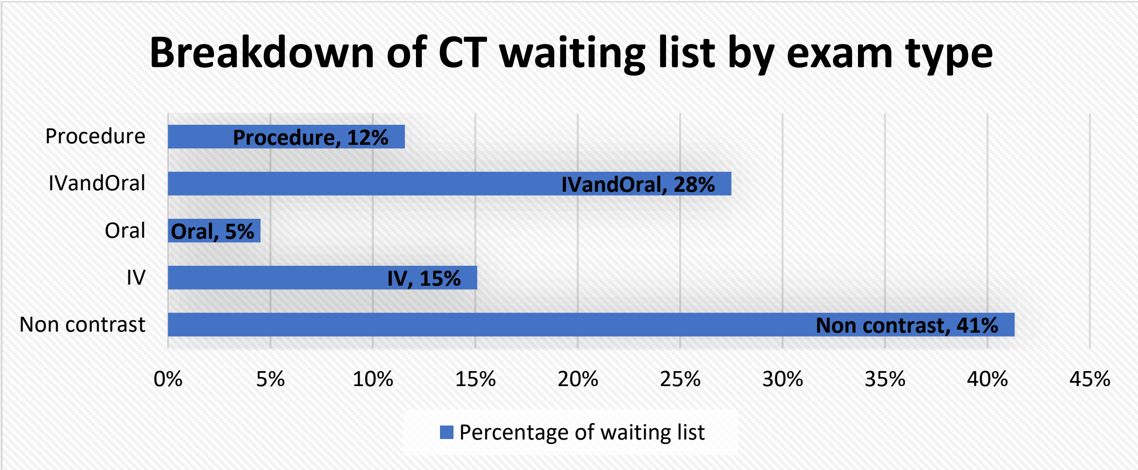


Figure 4.24 CT waiting list categorised by exam type

4.3.3 Patient data analysis

Following on from the conceptual model building exercise it was determined that an exploratory analysis of available data be completed in terms of:

1. Inpatient and outpatient mobility,
2. Inpatient infection status,
3. Examinations requested for Inpatients and outpatients.

The significance of these findings is discussed in detail in Chapter 6.

4.3.3.1 Mobility

Analysis of 2 months of data from the patient administration system showed that 10% of patients required a trolley, while 17% required a wheelchair, with the remaining 73% documented as walking. However, during the observation period (March 2018), 26% of IPs were observed to require a trolley/bed, while 36% needed assistance getting from a wheelchair to the CT scanner bed, with the remaining 38% walking. Notes were taken throughout the day on each patient’s mobility status and percentages determined for each category of mobility. For GP/OPs, 5% were observed to require a wheelchair or walking aid, and the remaining were ambulant.

4.3.3.2 Age

The age profile of 3204 inpatients, and 1535 outpatients was examined. A comparison showed IPs had a median age (middle value) of 68 years compared to 62 years for OPs, see Figure 4.25 and Figure 4.26. In the DES model age is assigned to IP and OP based on custom distributions found for the two populations Figure 4.26. Maximum IP age was found to be 101 while the maximum OP range was 96.

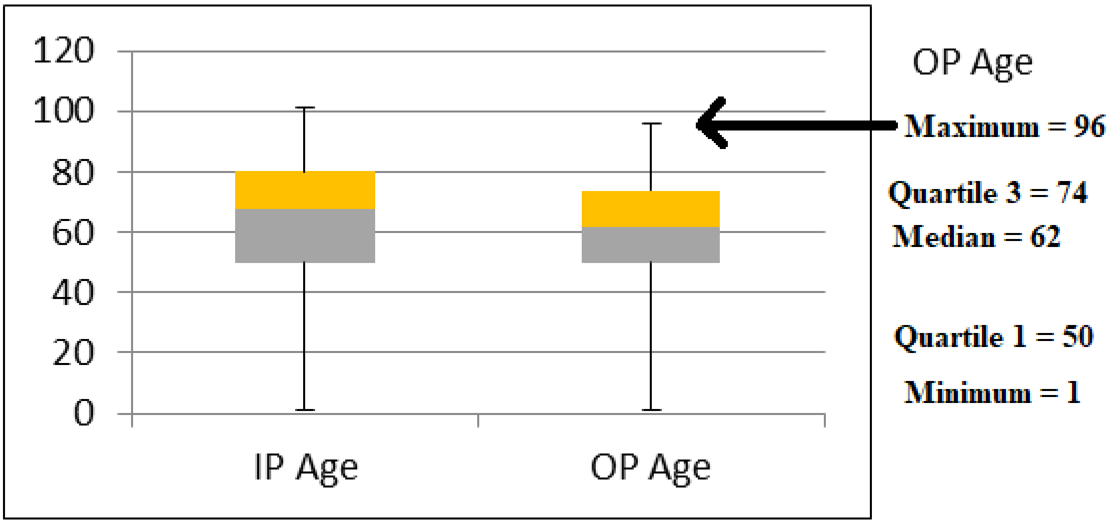


Figure 4.25 Box Plots demonstrating distribution of patient ages for IP and OP

The box plot above shows the distribution based on a five-number summary of two sets of data for IP and OP age. The interquartile range is shown between the first quartile (grey) and third quartile (yellow). In this case whiskers are used to indicate the variability between the upper and lower quartiles and the actual maximum and minimum values for age. As can be seen in the corresponding Figure 4.26, for age distribution, the IP age is skewed to the right indicating a greater number of IP are older.

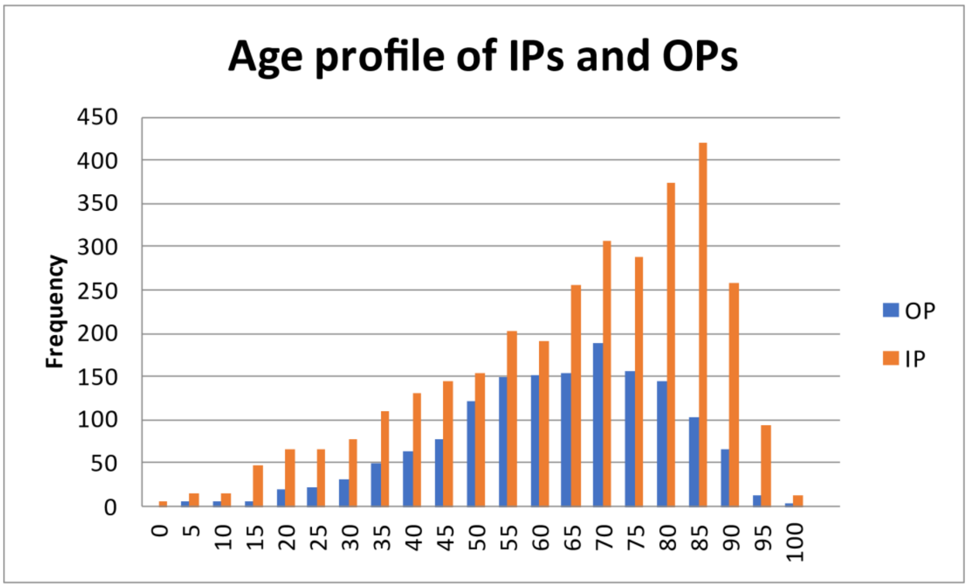


Figure 4.26 Patient age distribution

4.3.3.3 Infection

Using linear regression, the rate of infection in IPs was examined over a 4 year period and was not found to increase significantly over that period (P-value: 0.965), no significant change between 2015 to 2018, Figure 4.27. The overall percentage of CT patients who were identified as being infectious or having an infectious status which was positive was 24.9%.

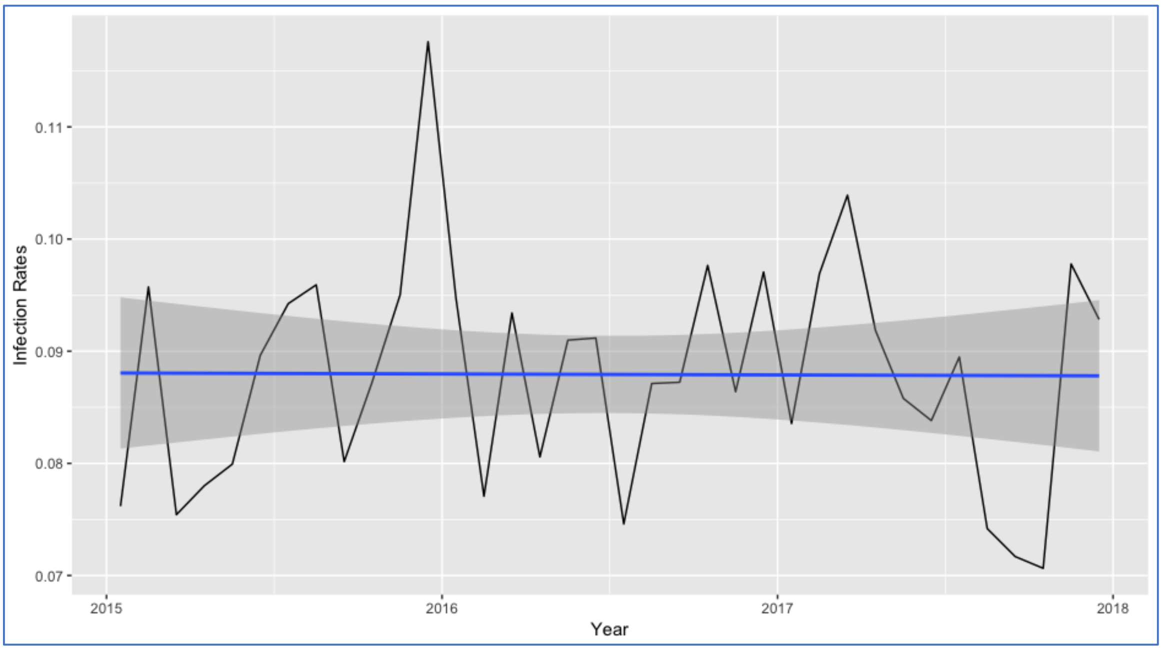


Figure 4.27 Rate of infection over time

No data was available regarding OP infection rates. OPs may alert staff to a previous or existing infection status and infection control measures are taken at that time. Using logistic regression (probability), the relationship between the infection rate and IP age was examined. 37 observations were deleted due to missingness. In conclusion, infection rate increases with age with a base infection rate of 1.5% and a ceiling of 36.6%, ($p<0.00001$) Figure 4.28. For DES modelling, likelihood of infection was assigned to inpatients (no data pertaining to GP and outpatients was available) based on the age assigned to them and the likelihood of infection at that age, as determined from Figure 4.28.

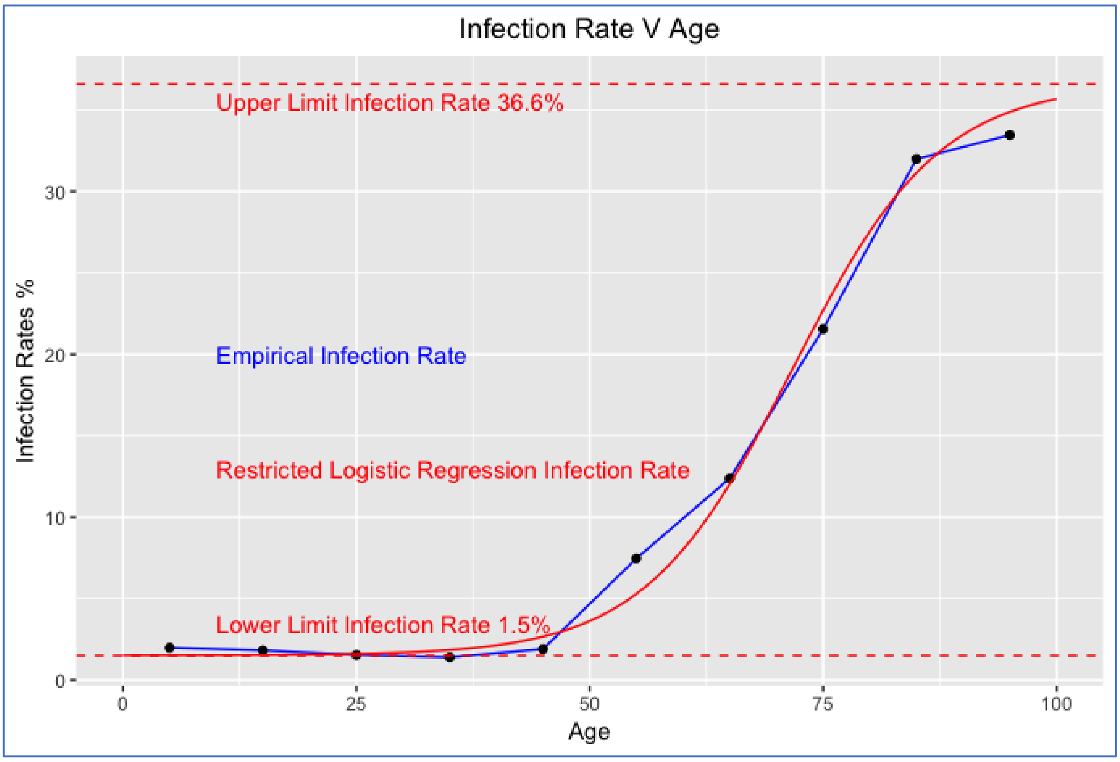


Figure 4.28 Infection rate versus age using regression analysis

Using polynomial regression the relationship between length of stay and infection rates were examined. In conclusion, the likelihood of having a positive infection status increases with length of stay, p-value < 0.0001, Multiple R-squared: 0.9762, as shown in Figure 4.29. This information was not relevant for use in the DES model but is clinically significant as it explains the necessity to prevent patient discharge delays and justifies the prioritisation of inpatient scans where a mixed IP/OP service is provided.

Figure 4.29 Likelihood of infection versus length of stay

4.3.3.4 Exam Type

Completed examinations were categorised by exam type as shown in Figure 4.30 for the IP and OP populations. 64% of IP exams did not require either IV or Oral preparation. Non-contrast exams are considered the technically least complex of exams and have the shortest scan time. Procedures include exams such as CT Colonoscopy, biopsy or nerve root injection for pain relief. These are lengthier exams which involve a radiologist being present. 20% of OP exams fall under this category compared to 2% of IP exams.

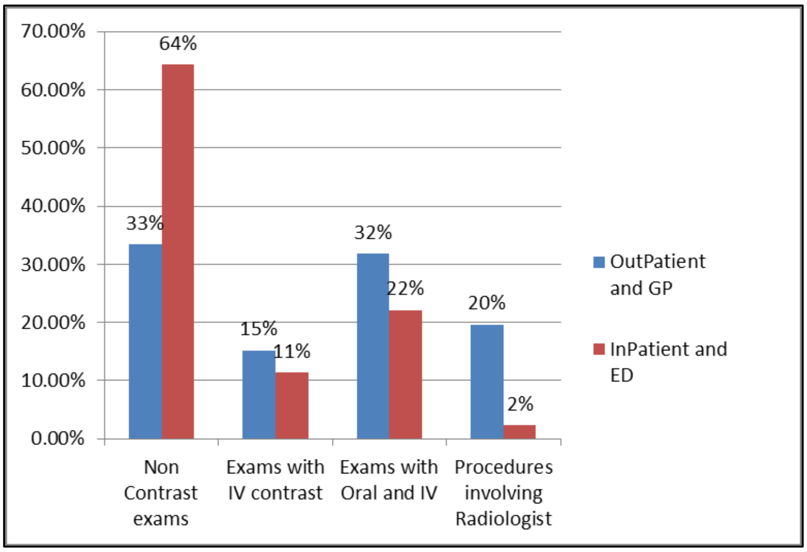


Figure 4.30 IP/OP breakdown of examinations completed

4.3.3.5 Summary of exploratory patient data analysis

A summary of results obtained, which differentiate the inpatient and outpatient cohorts and input parameters for the DES model is provided in Table 4.4 Inpatients are older, less mobile and present infection control related scheduling considerations. It should be noted that an outpatients infection status is not known in advance and that standard precautions are adopted for all outpatients (Health Service Executive, 2009).

Table 4.4 CT patient characteristics summary

Characteristic	**Inpatients**	**Outpatients**
Age	Mean 63 Median 68	Mean 61 Median 62
Infectiousness	Infectiousness increases with age to a maximum of 30% of 80 year olds. 24.9% of IPs attending for a CT examination are infectious.	N/A Infection status unknown unless disclosed. Standard precautions used with all OP.
Mobility	26% Trolley or bed 36% Wheelchair 38% Walking	5% Wheelchair 95% Walking
Exam Type	64% of IP exams did not require either IV or Oral preparation.	67% of OP exams require IV or Oral preparation or are procedures.

4.3.3.6 Phone call interruptions

As identified in the conceptual model, Figure 4.2, phone calls were identified as a source of interruption and a factor affecting staff workload. For this reason, it was determined to include call occurrence and durations for all incoming and outgoing calls in the DES model, based on the distribution pattern identified in Figure 4.31.

Data was obtained from the PUH IT department on the volume of calls received and made in the CT department daily. Over a 6 month period a total of 8489 calls occurred, 5703 outgoing and 2786 incoming. The results for PUH showed an average of 65 and maximum of 111 calls per day, with an average duration of 30 seconds per call. There is on average 6.5 calls per hour with a maximum of 12 per hour experienced at peak times between 10am and 1pm, Figure 4.31

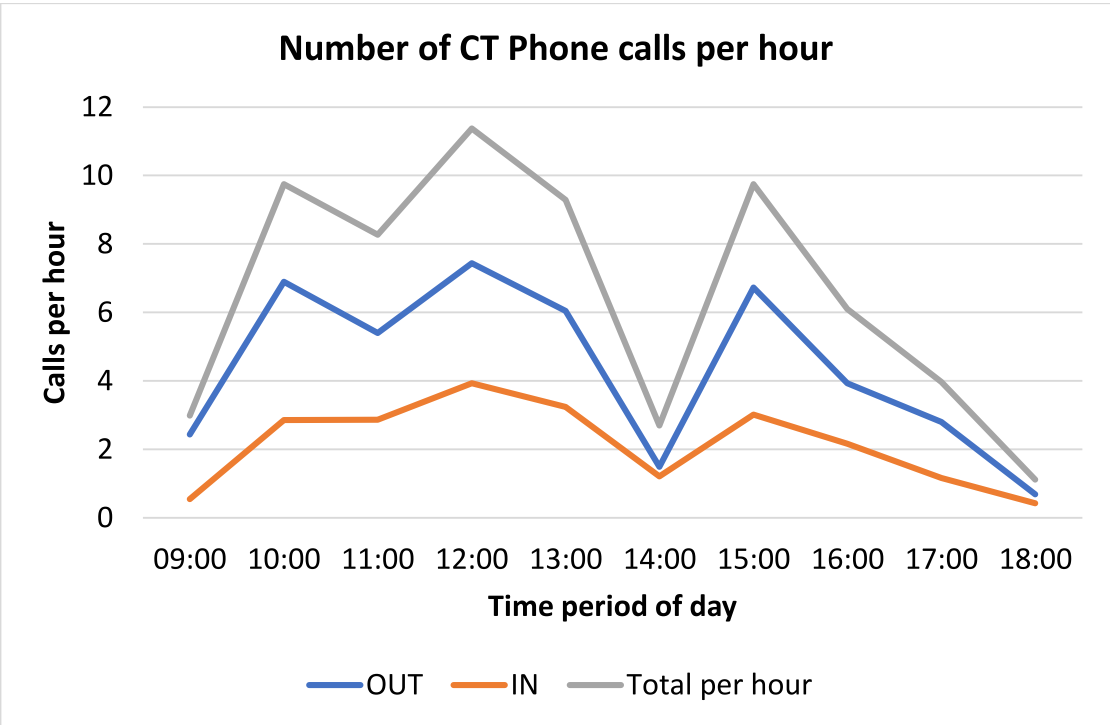


Figure 4.31 Incomming and outgoing phone call distribution

4.3.4 Survey of Irish Radiographers

The survey was created using SurveyMonkey and contained 10 multiple choice-style questions with options for comments, see Table 4.5. A clinical specialist radiographer reviewed the cover document and survey to assess ease of comprehension and question validity, with minor changes resulting from this review. No identifiable data was attached to responses, to encourage participation and honesty in the description of practices. The online survey link was published on a social media page belonging to Radiographers Ireland, and all members were invited to participate. Questions relating to the number of examinations carried out, the number of infectious patients, patient mobility as well as the individual radiographer participant's experience of manual handling practices and incidences of back and neck pain. Responses were imported to Microsoft Excel for analysis and free responses were analysed manually.

Table 4.5 Survey questions for exploratory phase

When managing your list of patients do you or your team use: (N.B. You may select more than one option). Bloods, infection status, mobility, pregnancy, allergies, clinical indications. *White Board Paper List NIMIS*
When planning your list where do you document information on the following? Bloods, infection status, mobility, pregnancy, allergies, clinical indications. *White Board Paper List NIMIS*
Re bloods: Do you trust information on prompts/RIS or do you verify it against laboratory information system (LIS)?
At the Point of scanning/injecting where can you see the following information? Bloods, infection status, mobility, pregnancy, allergies, clinical indications. *White Board Paper List NIMIS*
Manual Handling (within normal hours): When staff are required for manual handling do you:
How many patient slides are carried out per day on average in your modality?
Do you or have you suffered from a repetitive strain injury or back pain?
How many infectious patients do you scan per day (9am to 5pm)?
Per Hour: How many phone calls do you take in your area (within normal hours)

Approximately how many patients do you scan per day?

There were 62 respondents from an online community of 1,420 members, indicating a 5% response rate.

Results from the survey indicated that the most popular means (27%) of managing the CT worklist was using the picture archive and communication system, see Figure 4.32. The next most popular means for managing the list was using paper at 23%. Some 16% of respondents reported using a combination of three means.

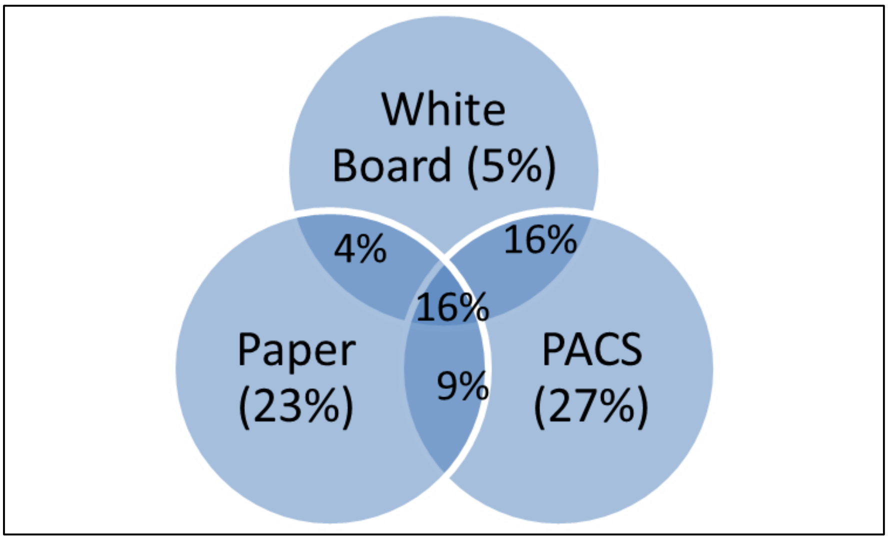


Figure 4.32 Nationwide use of systems for scheduling exams

Only 16% of respondents reported that they trusted the blood result information on the PACS system, with 74% reporting that they checked all blood results against the laboratory information system before scanning. The average percentage of infectious patients was 17.92%. Regarding patient mobility, the survey showed that 26% of patients were reported as immobile (requiring a wheelchair or trolley/bed) with 10 patients requiring a patient slide (four staff required for same). The number of examinations carried out per day across sites varied from 4 to 70, with on average 34.6 patients scanned per day. Regarding manual handling, as shown in Figure 4.33, only 35% of departments reported that they were adequately staff for patient transfers, with 36% reporting that they required staff from other areas. Interestingly almost 50% of staff admitted to carrying out manual handling with inadequate staff numbers.

When staff are required for manual handling	%
Generally have staff available in your area	35%
Call Radiology staff from another area?	36.67%
Sometimes make do with inadequate number of staff?	48.33%
Call ward/porter for assistance?	26.67%
**Possible to select more than 1 option	

Figure 4.33 Manual handling and staffing levels

Radiographers were asked whether they had experienced back pain or a repetitive strain injury, 60% responded that they had.

4.4 Modelling Dynamics: Phase 2

Utilising tools from SSM, an account of the problem situation being modelled in this research project was captured which included the key features of the service, namely the people, processes, places, relationships and viewpoints (Crowe *et al.*, 2017). Stakeholders identified included radiographers, radiology manager, radiologists, referral doctors (AMAU and ED), nursing staff AMAU and porters. The patient was not involved in the process at any stage.

4.4.1.1 Resultant Rich Picture diagrams

The RP diagram shown in Figure 4.34-56 represent various individual contributions by participants which contributed to the final RP Figure 4.38. Radiographer 1 created their own drawing using the metaphor of a bus (Figure 4.34). The halo represents the radiographer arriving to work like an "angel". Conscious of staying ahead of demand, the radiographer arrives early to prepare the necessary blood results and information required for each patient request, she deemed it important to be organized before the hospital wakes up. This all changes by 11am however at which point their "heart is broken" and "brow furrowed" due to the number of phone calls and interruptions.

They describe being the lead radiographer in CT as like being the driver of a bus with other staff on board. If the bus goes into third gear, there will be casualties – speed kills. If they stay in first or second gear everyone is smiling at the end of the day. The mantra of the radiographer is "one man, one job", while it may be possible to scan (acquire images), plan (schedule work) and run (transfer patients, test IV lines, inject, position patients etc.), errors are a potential consequence.

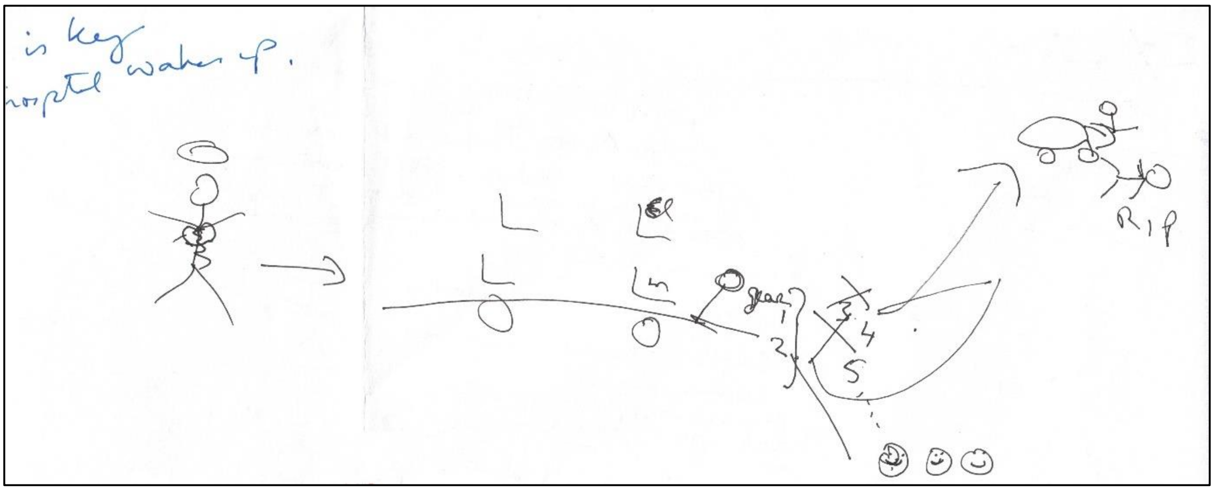


Figure 4.34 Radiographer 1 Driving the Bus

In Figure 4.35, the radiographer is constantly being asked “Did you do this….”, “Did you do that….”, “is it left or right?”, “have you checked…”, “Did you call the porters….”. A conveyor belt is drawn as there is always another patient to come down the line. False information is coming from the wards, despite phone calls to check what colour cannulas have been inserted (IV) and what the patient’s mobility is etc. The radiographer has drawn her notebook and commented that she must refer to notes rather than try and remember all the protocols, due to time spent in other modalities constant training is required to keep up skills.

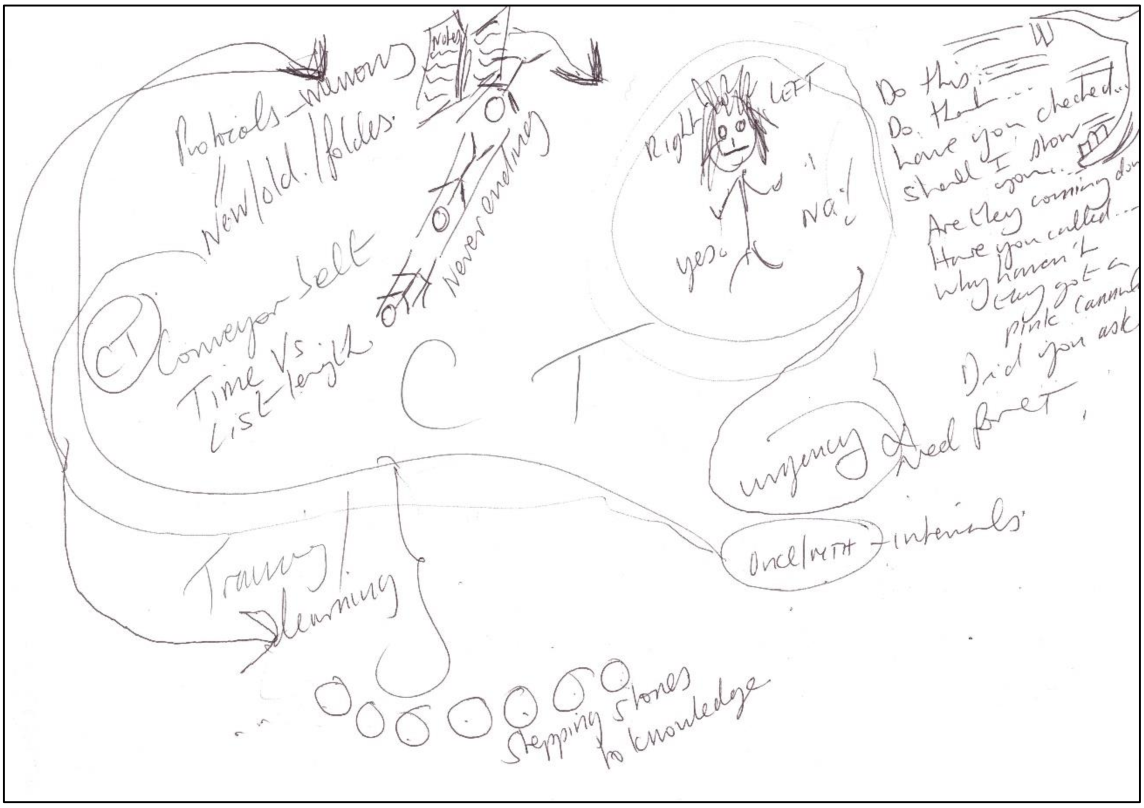


Figure 4.35 Radiographer 2 The Conveyor Belt

In the next hand drawn image (Figure 4.36), the radiographer weights up the rough and the smooth hoping that the simpler work will balance out the complex and that by 5pm the list will be zero, Figure 4.36. Many questions must be asked and the phone causes lots of distractions as a result.

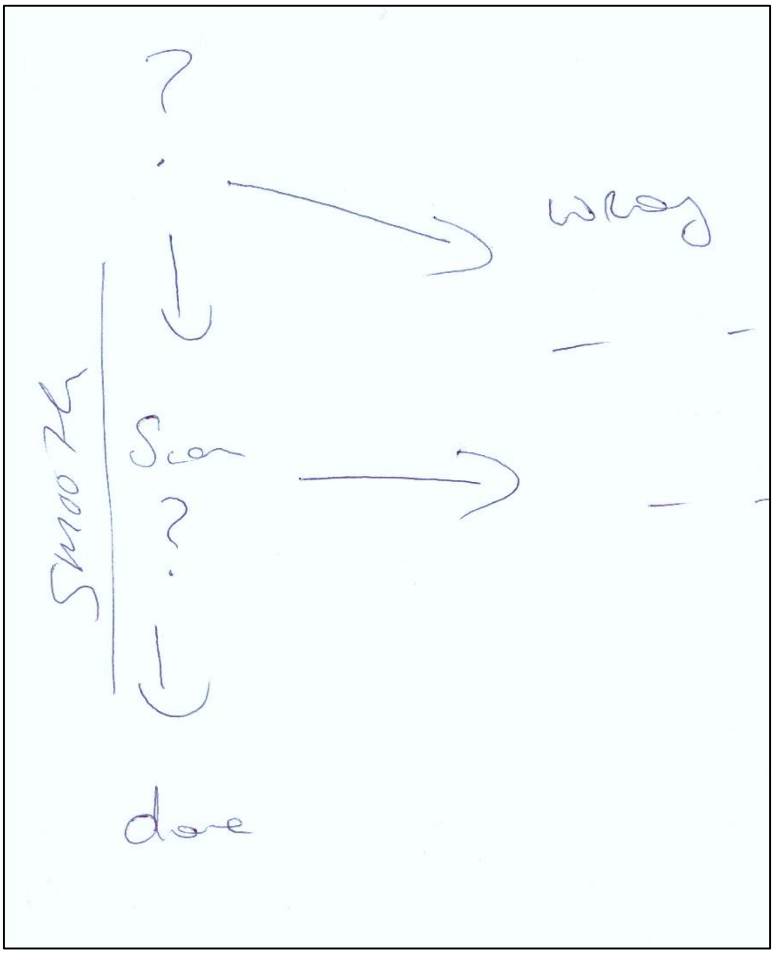


Figure 4.36 Radiographer 3 The rough and smooth nature of the work

The RP diagram shown in Figure 4.37 is a hand drawn composite including staff contribution.

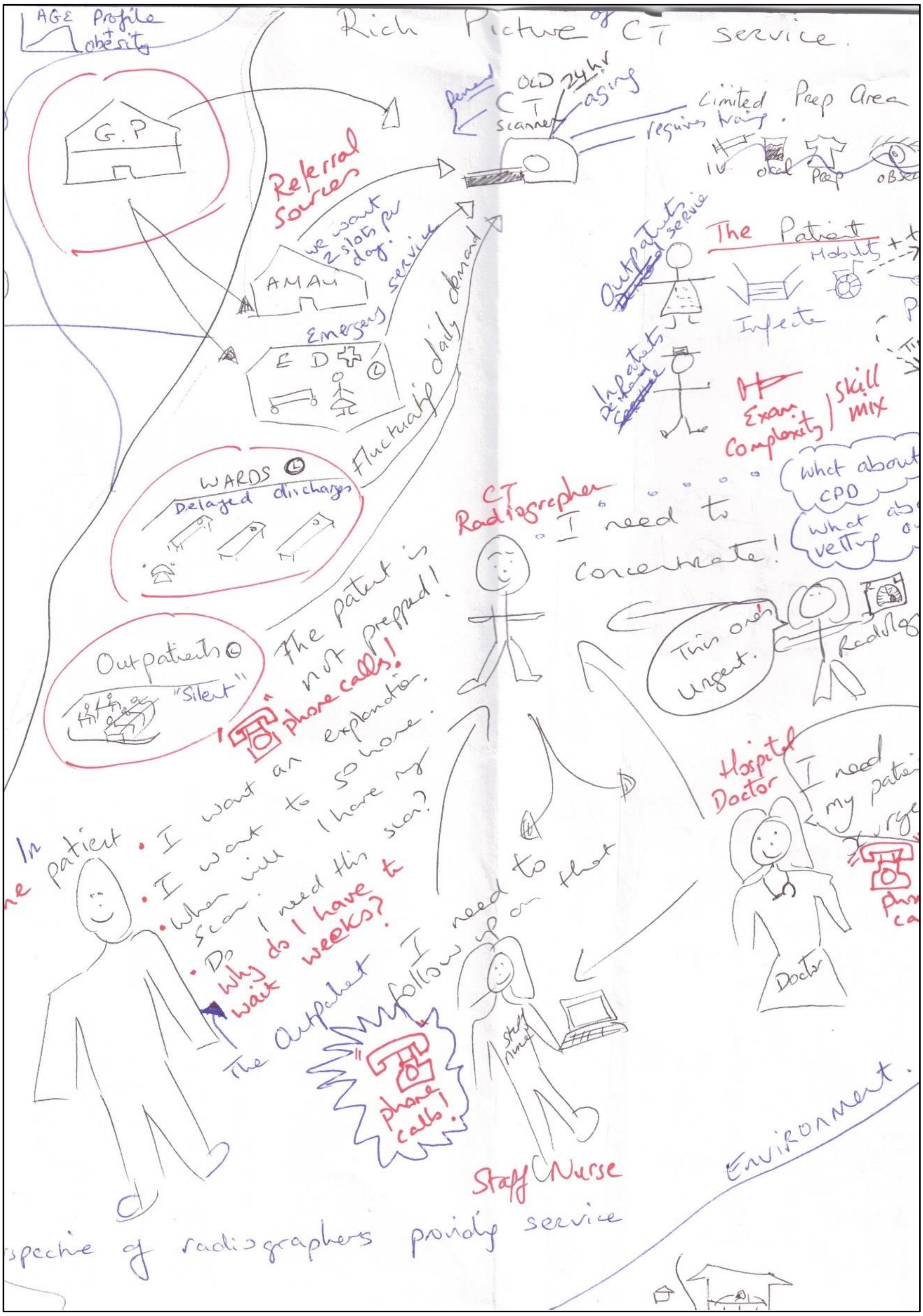


Figure 4.37 Original RP diagram

A soft copy version of the RP (Figure 4.38) augmented with feedback from the CATWOE interviews, captured the key features of the CT service, such as staff activities, the process, the environment, the delays, distractions and external factors contributing to workload and affecting service deliver. A clock in the shape of an eye and phone are visible in each room to represent the time sensitive nature of the work and constant "often repetitive" communications occurring between staff. The computer is seen with an "X" through it as some staff prefers to call CT for the scan time instead of checking the RIS.

A clear distinction is made between the IP and OP services by placing these groups on separate floors of the hospital. The IP service includes the AMAU and ED, whose patients generally require an immediate service. The experience of the GP in the community is depicted and their awareness of growing waiting lists. GP and OP waiting lists appear as an external factor as these do not impact the daily operations of the service and were a concern at management/decision maker level. A graphic representing an IP depicts how patient complexity varies in terms of a patient's care needs, infectiousness, mobility, and exam complexity. The OPs are seen to be experiencing delays and the staff are conscious of the inconvenience a delay causes and feel responsible.

The increasing demand and increasing OP and GP patient waiting lists were purposefully described as external factors as they are not a concern for those directly involved in providing the service on a daily basis. They are an unintended consequence or emergent behaviour related to the increase in demand and become a managerial or governance problem over time (Sterman, 1994; Marshall *et al.*, 2015).

The frustration of the staff nurse as they seek to confirm a patient's future scan time is also depicted. They just want a verbal answer and do not want to refer to the information system; they may not remember their password or may imagine a phone call is quicker than logging on to the RIS/PACS. Bad habits have appeared over the years, and they are conditioned to expect verbal confirmation of a time. They are under pressure to ensure a scan happens in a timely manner because they know discharge is dependent on it or are aware the patient is waiting a long time or is deteriorating. External factors affecting service provision are grouped to the left of the diagram and appear outside of the drawing of the hospital. It was agreed to locate waiting lists and GP referral source as external factors affecting CT service provision. Staff working in radiology are not conscious of the waiting list daily and focus on the IP demand. The age and infectiousness and chronic diseases of the population appear external to the hospital building. Additional external factors affecting radiology are the pressure from media represented by the newspaper icon as well as the limited financial resources.

A radiographer is also represented in the RP diagram in Figure 4.38, and is seen to have many items on their mind. Phone calls can result where a referring doctor is looking for a phone number or where they are seeking verbal confirmation of a scan time which may already be available on the RIS or in some cases the patient may already have been scanned.

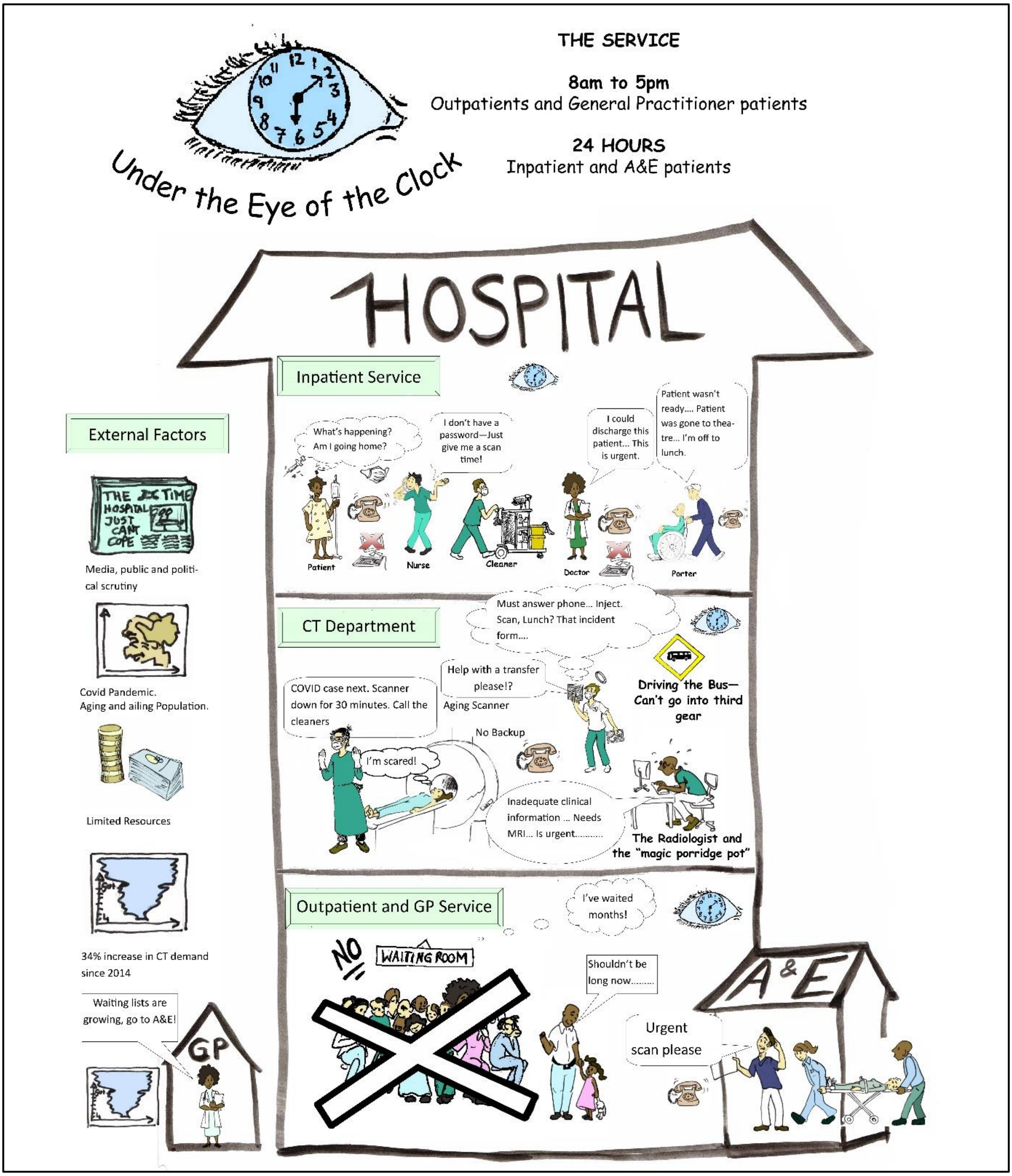


Figure 4.38 RP diagram of CT service from multiple perspectives

4.4.1.2 CATWOE statements

While not directly involved in the RP session, the worldview and environmental constraints of the porter and the AMAU nurse were obtained using a structured interview approach based on the acronym CATWOE. These structured interviews were conducted to elicit information from staff regarding the important aspects of the service, by identifying the customers, actions, transformation process, worldview, owners and environmental constraints of the CT service (Crowe *et al.*, 2017). Convenience sampling was used to recruit interview participants (n=5), which included an ED Consultant, a hospital porter and the Acute medical Assessment Unit nurse. Staff were interviewed individually in their place of work and the interview questions were based on the CATWOE acronym (Checkland, 1985, 1999). Notes were taken on a pre-printed document with sections for each part of the CATWOE and a root definition of the service was created (see Appendix B).

A root definition of the service was created for radiographers, radiology managers, the ED and the acute medical assessment unit (AMAU). Interviews were not recorded given the time-sensitive nature of holding interviews in a working environment. Interviews took place as and when the interviewee was available, often by the CT scanner or in the CT viewing area. Handwritten notes were made of the interviewee responses.

Table 4.6 CATWOE statement for Radiographers

Customers - Patients who require a CT scan and referring doctors who require a diagnostic report and images for their patients. Patients may be from the OP department, IP wards, AMAU, ED or referred from their dentist, physiotherapist or GPs.
Actors - Radiographers scan patients under the direction of the radiologists on behalf of referring doctors, assisted by HCA, nursing staff, clerical staff, porters.
Transformation process - Patients are scanned and cared for. Referring doctors are provided with diagnostic images and/or a report. The referring doctor’s questions are answered.
World view- We want to meet the needs of the patients by providing them with a

diagnostic report and a safe service. We want to meet the needs of referring doctors in a timely manner to contribute to the patient's management.
Owners - Head of department, RSM, Hospital management
Environmental constraints - Examinations must be justified and radiation dose kept as low as reasonably achievable, patient safety and care must be ensured. There is only 1 scanner providing a full service from 8.30am to 5pm with a 1 hour lunch break Monday to Friday. An emergency service is provided 24 hours a day, 7 days a week. Not all radiographers are CT trained or able to cannulate patients on commencement of work. Patient priority can change and the needs of the most urgent cases must be met first. The HSE has national time frame within which to scan patients.
Root definition - A safe radiology service delivered to patients of varying urgency and from various sources for justified examinations, to facilitate referring doctor who make decisions based on the findings from high quality diagnostic images and reports.

Based on findings from the exploratory phase and the framework used by Rashwan (2017), the following DES model components were identified for inclusion in the DES model: staff, patient, environment or external. The subcomponents identified from the exploratory phase of the research as well as from the use of SSM are shown in Figure 4.39.

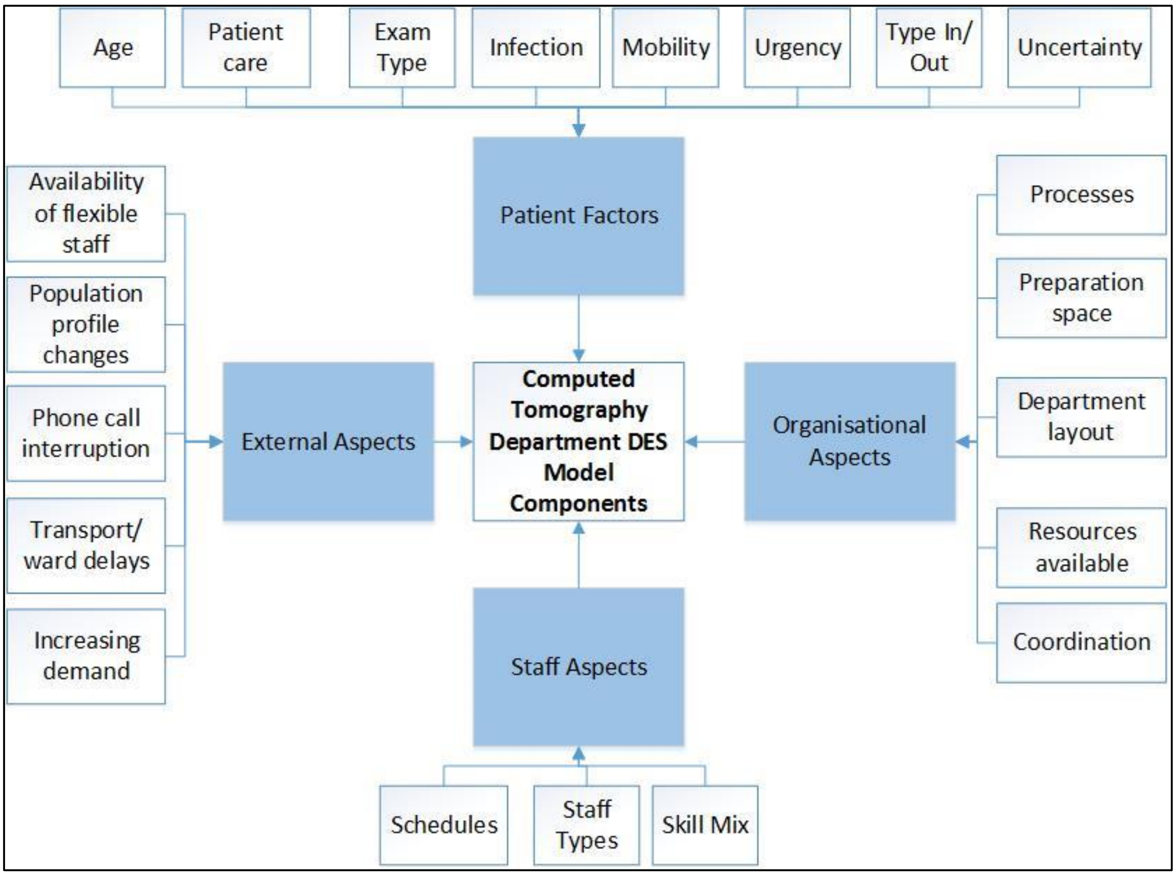


Figure 4.39 DES model components adapted from Rashwan (2017)

4.4.1.3 List of issues identified

A list of issues (n=51) was created following interviews with the following stakeholders during the CATWOE interviews and also during the RP diagramming exercise, radiographers and radiology manager (n=35 issues identified), radiologists (n=4), ED and AMAU doctors (n=3), nursing staff (n=4) and porters (n=5).

The following issues were identified during the RP building:	If included in the model and how included.
1. The CT service has multiple referral sources with patients of varying priority, priority may change over time. Constant reprioritisation is required.	Inpatient and ED cases prioritised. This varying priority captured in workflow diagrams
2. The staff workload associated with patients is increasing due to their mobility, age profile and infectiousness.	IP and OP profiles created for the different populations.
3. The varying demand for IP exams limits the department's ability to schedule OPs.	OP scheduling limited
4. Interruptions from the various referral sources cause time delays and distract radiographers who are scanning.	Number of activities captured per day, including phone calls.
5. "We are constrained by limited preparation and observation space. This means that multiple patients cannot be prepped for lengthy examinations such as CT coronary angiography. Waiting lists for such exams are longer than the waiting lists for exams requiring less prep."	Not included in model
6. "Staffing is a constraint that prevents us from extending the working day".	Affected the identified feasible and desirable simulation scenarios.
7. Delays are found to result when staff are not available for the manual transfer of patients from their bed/trolley to the CT scanner and back again.	Population of flexible staff created with time delays built in

8. Delays occur when patients are not correctly prepared for their examination, do not have a name band, do not have up to date blood results or do not have a working suitable cannula in place etc.	Not included in model
9. The skill mix amongst the radiographers and percentage of staff able to cannulate and inject patients has been depleted due to recent staffing changes, thus limiting the efficiency of the department.	Not included in model - all radiographers in model assumed to be able to cannulate.
10. The CT scanner is 10 years old and replacement parts are no longer covered under the service contract. The purchase of a new scanner and replacement of the old must occur within the coming years.	Affected the identified feasible and desirable simulation scenarios.
11. Some radiographers have clerical responsibilities pertaining to the vetting of OP requests. Failure to vet ensures a delay in scheduling OPs but time spent vetting interferes with daily staffing of the CT scanner.	Identified in conceptual model
12. Phone call interruptions result where other hospital staff do not check the information system to see if a time has been allocated to their patient's request.	Included in model
13. "OP waiting lists are growing - Patients may suffer if they don't get their scans at the time they need them. We try to ensure patients are scanned in the recommended time window to meet national guidelines but are under pressure to do so."	waiting lists modelled
14. Transportation of patients causes delays (lack of wheelchairs, breaks, patients not ready to be transported).	Included in model
15. Delays result where transportation is not immediately available for IPs, this may be due to porter or wheelchair shortages or where patients on the wards are not ready to leave the ward when the patient arrives.	Included in model

16. “Doctors do not always fill in the prompts correctly and we have learnt not to trust them. All lab results are verified against the laboratory system which requires moving to a different PC. You frequently get interrupted moving between PCs or have to ask someone to work with you to call over the dates of birth of patients.”	This activity and associated cognitive workload not included in model
17. “We are demand lead and are at the whim of the doctors (and nurses), this leaves it difficult to risk scheduling more OPs.”	Included in model by limiting the number of OP booking per day
18. “Even though our numbers may not appear particularly high, we have severe peaks and troughs in the day.”	Graph of arrivals and their scanning captured
19. “We feel the pressure of having multiple patients waiting outside.”	Not included in model
20. “Its not the actual scanning work (that is difficult), it’s the planning.”	Only included in terms of phone calls required to schedule.
21. “Managing the IP worklist is more of an art than a science and requires skill and experience. Its nearly a requirement to remember patient names and their bloods results, infection status etc so as to respond quickly enough to all of the phone calls.”	Not included in model
22. “You may be focused on arranging an IP case but get interrupted and then have to start from scratch making phone calls once free again. There is information loss at those points and the feeling of starting over.”	Not included in model
23. “Some are better than others at managing. Some don’t want to manage and are happy not to be the lead radiographer ever.”	Not included in model
24. “What we need is something to smooth the flow of work, so that we have some element of control and are not subject to snowballing delays.”	Effort made to compensate for variation using simulation of OP only scanner.

25. “Doctors are asking for scans because they are afraid not to. We need to be gatekeepers and to justify every examination.”	Not included in model
26. “We are so worried about urgent IPs and non urgent IPs that we cannot deal with the about to be urgent OPs.”	Not included in model
27. “We must always be thinking of more than one patient at a time. It’s doesn’t feel safe.”	Not included in model
28. “At the point of scanning we should only think of the patient in front of us.”	Not included in model
29. “We don’t always have enough staff for transferring patients.”	Population of flexible staff created with time delays built in
30. “Just when we decide to send for a patient someone will announce that the patient is infectious or gone to theatre or has been transferred to ICU. Then all the communications were in vain till that point. Then communications must start up again with a new team of doctors and nurses. “	Not included in model
31. “The effect of being short staffed affects our ability to train up in other areas or acquire new skills, it’s a vicious circle.”	Not included in model
32. “Transportation delays vary depending on who is on.”	Not included in model
33. “Lab systems and RIS system are on different PCs.”	Not included in model
34. “Duplication of tasks because tasks so important such as checking bloods.”	Not included in model
35. “Background chatter is an issue, there are two doors into CT.”	Not included in model
Nursing Staff	
1. “Frequently in radiology the only preparation space we have is required by other staff.”	Not included in model
2. “While I am aware of the backlog outside, I can only care for the patient in front of me.”	Not included in model

3. “On the wards it is my responsibility to chase up when my patient will have their CT scan – it is part of my job – discharge may depend on it.”	Included by virtue of including phone call activity.
4. “Not all staff use NIMIS or remember their passwords.”	Not included in model
Radiologist	
1. “We are conscious of the waiting lists”	Not included in model
2. “We keep on being interrupted.”	Not included in model
3. “We must educate junior doctors on what scans are warranted and what are not.”	Not included in model
4. “Sometimes a CT scan is requested because we do not have easy access to MRI.”	Not included in model
Consultants and junior doctors	
1. “My patient needs a scan regardless of how busy CT is.”	Priority given to ED and IP cases and scan provided on demand.
2. “Poor access to the CT service for IPs sometimes delays discharges.”	Not included in model
3. “While I may know a cannula is working at 9am I may not know when it stops working later I the day.”	Not included in model
Porters	
1. “Patients are not always ready when we go for them.”	Not included in model
2. “Sometimes we think the patient is coming in a wheelchair and they actually need to go by bed. This delays us.”	Not included in model
3. “At points during the night we are covering more than one area and may also be covering the switchboard.”	Not included in model
4. “If we get a bleep to for an emergency caesarean we must respond immediately, and delays will be caused elsewhere.”	Not included in model
5. “There can be a shortage of wheelchairs on occasion, but its not often.”	Not included in model

4.4.1.4 Scenario identification

Radiology decision makers were identified as the Radiology Services Manager (RSM), clinical director and hospital manager. The RSM and clinical director were involved in the RPD session and their insights included in the RP of service provision. In a facilitated session, they were asked to consider desirable and feasible recommendations for future service reengineering, which would become the basis for the model simulations. Simulations were designed to answer stakeholder questions as well as the researchers own research questions. When discussing potential opportunities for service improvement/simulations the problem was framed based on the following:

- The RP diagram, issues identified and insights of staff
- The results from the exploratory data analysis
- The conceptual models and workflow diagrams for IP and OP scheduling
- Prompts were provided regarding scenario redundancy and the resources required for each scenario.

Four scenarios for testing in the Radiology decision support system were identified. The scenarios examined and are listed below:

1. Waiting list evolution in the event of no change being made
2. Extension of the CT schedule to an 8am to 8pm schedule
3. Installation of a second CT scanner.

Shown in Figure 4.40 is an algorithm produced for decision makers based on the identified scenarios.

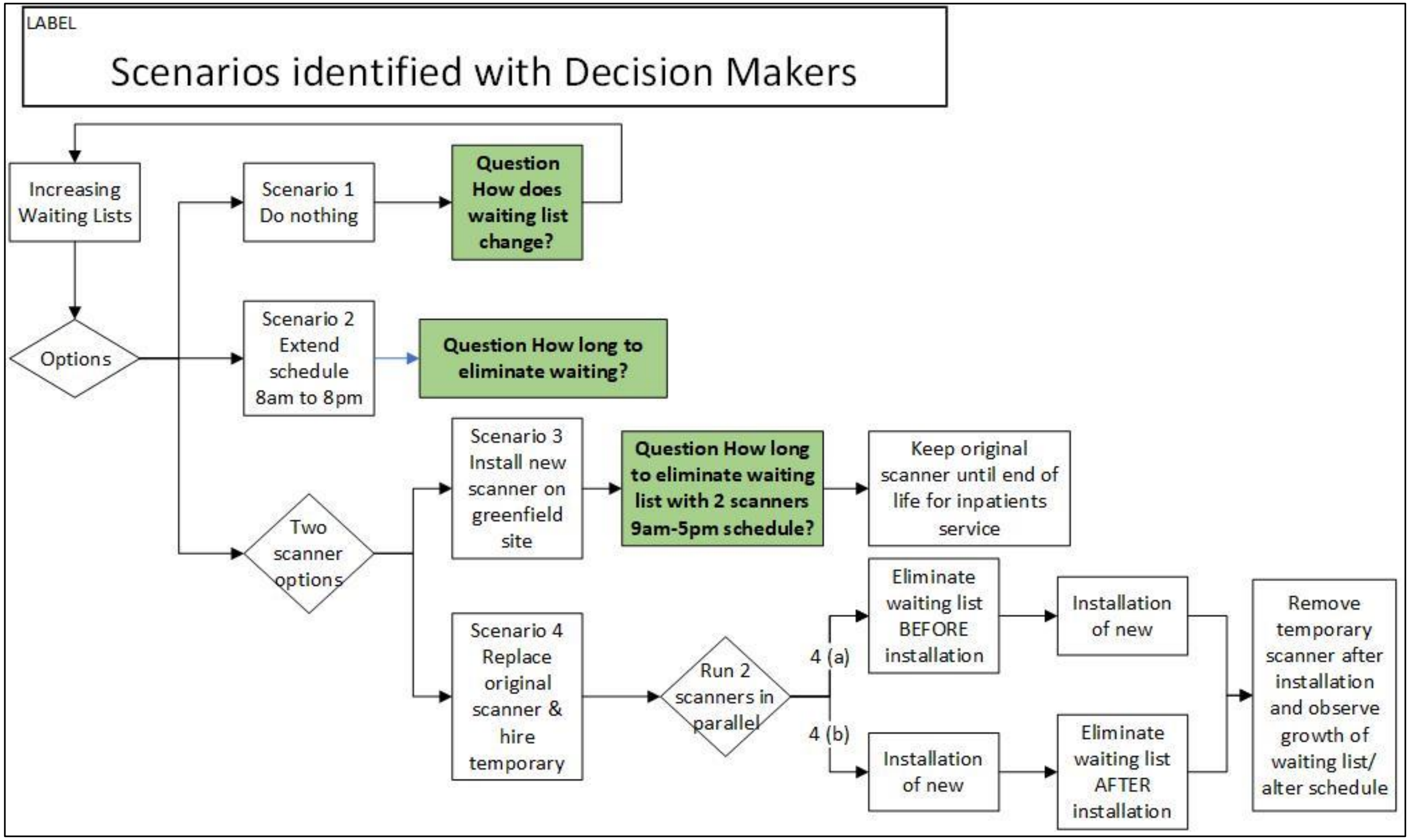


Figure 4.40 Simulation scenarios identified in case study

4.5 Simulation Modelling – STRESS-DES Checklist

The data obtained from the data analysis phase was used to provide input parameters for the simulation model. Further data requirements were identified during model building. To improve reproducibility and strengthen reporting of model building, a standardised checklist approach was used to report on the final operational research DES model created for the framework (Monks *et al.*, 2019).

4.5.1 Objectives

4.5.1.1 Aims

The purpose of the discrete event simulation study, as an important component of the overall framework and decision support tool was twofold:

1. To capture metrics for the current service and gain insights into the service,
2. To run simulations designed to inform decision making in the CT department.

In doing so the DES model can be used to answer the research questions and provide decision support for the case study department, as defined in Chapter 1.2.1, Research questions and objectives).

4.5.1.2 Model Outputs

The DES model was designed to capture staff and scanner resource utilisation, and the metrics listed in Table 4.7

Table 4.7 Process Metrics captured using DES

Process Metrics
Scanner Utilisation Daylight
Radiographers Utilisation Daylight
HCA Utilisation Daylight
Average daily flexible staff requests
Average Inpatient Perturbations
Average Outpatient Perturbations
Consumed staff time (IV and Oral) Inpatient
Consumed staff time (IV and Oral) outpatient
Consumed staff time Non Contrast Inpatient
Consumed staff time Non Contrast Outpatient
Number of Daily Tasks completed
Average number of scans total
Number of scans completed per day

An explanation is provided for these metrics;

- Daily utilisation - the percentage of time when a resource (radiographer, healthcare assistant or scanner) was being utilised.
- The “average daily flexible staff requests” metric captures the number of occasions during the day when staff are required to assist with manual handling. Where a manual handling task requires four staff such as in the transfer of a patient from a trolley to the CT scanner the required number of staff may not be available so flexible staff are called upon. Time is also captured for staff waiting time who are waiting for the full quota of staff to carry out a manual handling transfer.

- Perturbations, herein described as process disruptions caused by inpatients and outpatients due to preparation delays, transportation delays, manual handling delays, and infectiousness.

- “Consumed staff minutes” is a metric which aggregates all of the times associated with tasks and activities for each individual patient. Where a patient requires four staff to assist in manual handling the consumed time is calculated for each staff member and includes any delays waiting for the required number of staff to be sourced. Time is consumed for patient preparation, patient transportation, scanning, scheduling, administrative work as well as cleaning. An arrival schedule was designed for the OP only scenario with exact arrival times. Examination types are also predefined, although the model assigns age and mobility characteristics based on previously identified frequency distributions.

Metrics were displayed on the DES model and visible while the model was running. Examples of the DES dashboard created using AnyLogic are provided in Figure 4.41 and Figure 4.42. Shown here are the various process queues throughout the day as well as resource utilisation for the CT scanner and for individual staff categories, i.e. radiographers and healthcare assistants.

Figure 4.41 Model metrics page 1

Figure 4.42 Model metrics page 2

In Figure 4.43 a floor plan of the CT department used in the DES model is shown and was used for face-to-face validation carried out with department staff/clinical stakeholders.

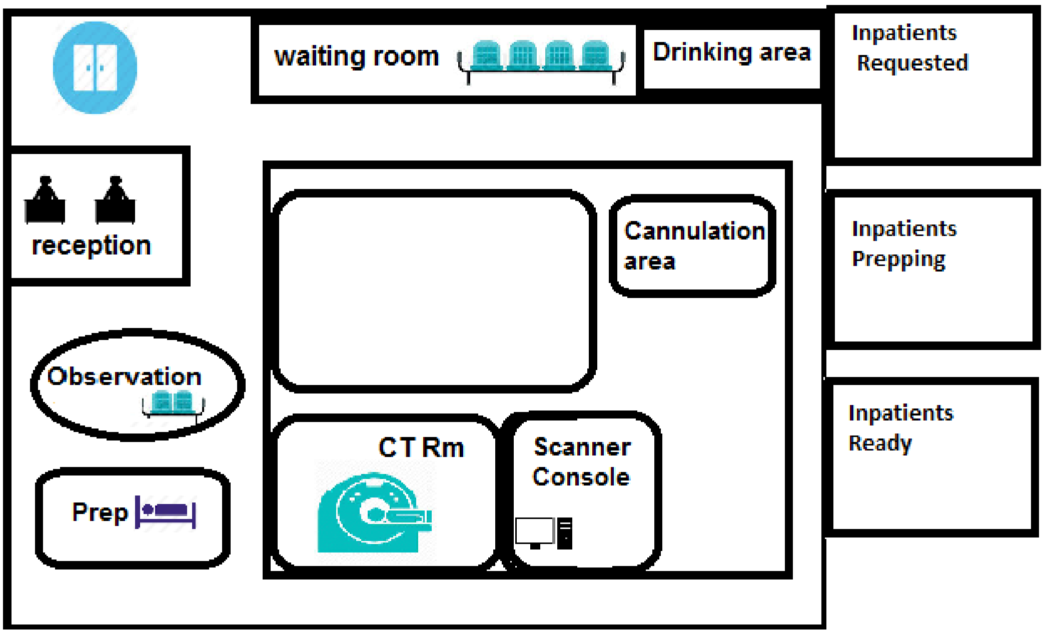


Figure 4.43 Floor plan of department used in DES model

4.5.1.3 Aim of experimentation

In describing the aims of experimentation specific information is provided about how the model was used to achieve the stated purpose (Monks *et al.*, 2019). The aim of experimentation was to determine

1. How waiting lists will evolve over time under the current service and other identified scenarios.
2. How staff workload in terms of utilisation, percentage of time spend on various tasks, reliance on flexible staff and other metrics varies between simulations.

4.5.2 Logic

Using the software AnyLogic (University Edition 8.4) a DES model for the CT department and service was created. Model parameters were informed by the data from the exploratory data analysis. Adhering to the logical process identified in the workflow diagrams, the flow of patients from arrival in radiology to departure from radiology was recreated using scheduled and unscheduled stochastic patient arrival sources and historical arrival time where the model was executed to run stochastically. For ease of viewing the process logic diagrams from the patient arrival to exit are divided between Figure 4.44, Figure 4.45 and Figure 4.46. A subsection of the model where patients are prepared for one of five categories of CT examination is shown in Figure 4.44.

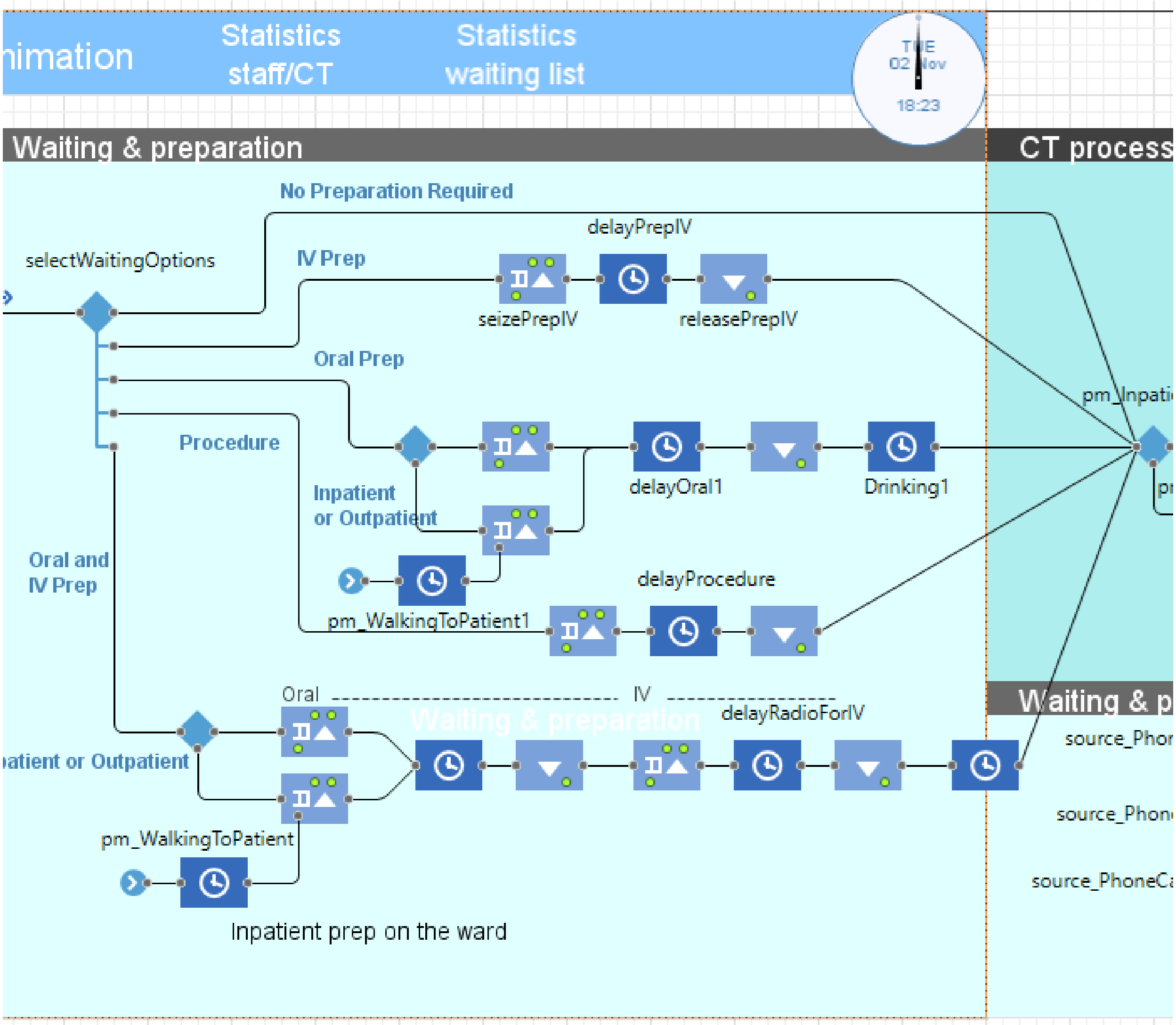


Figure 4.44 Subsection of model depicting patient preparation, constructed in Anylogic

Patients are here seen to move through each process block based on their examination type and are then seen to incur a preparation delay, based on their examination and time spent waiting for staff to administer the preparation. Patients then queue for the CT scanner and have a changing priority based on their patient type and how long they have already been waiting.

In the following figure can be seen the section of the DES model where patients are scanned Figure 4.45. Here the scanner and staff resources are seized and released before and after the manual handling tasks as well as scanning task. There are wrap up tasks associated with scanning for paperwork and post processing of images. This allows radiographer time to be differentiated between scanning and these other value-adding administrative tasks.

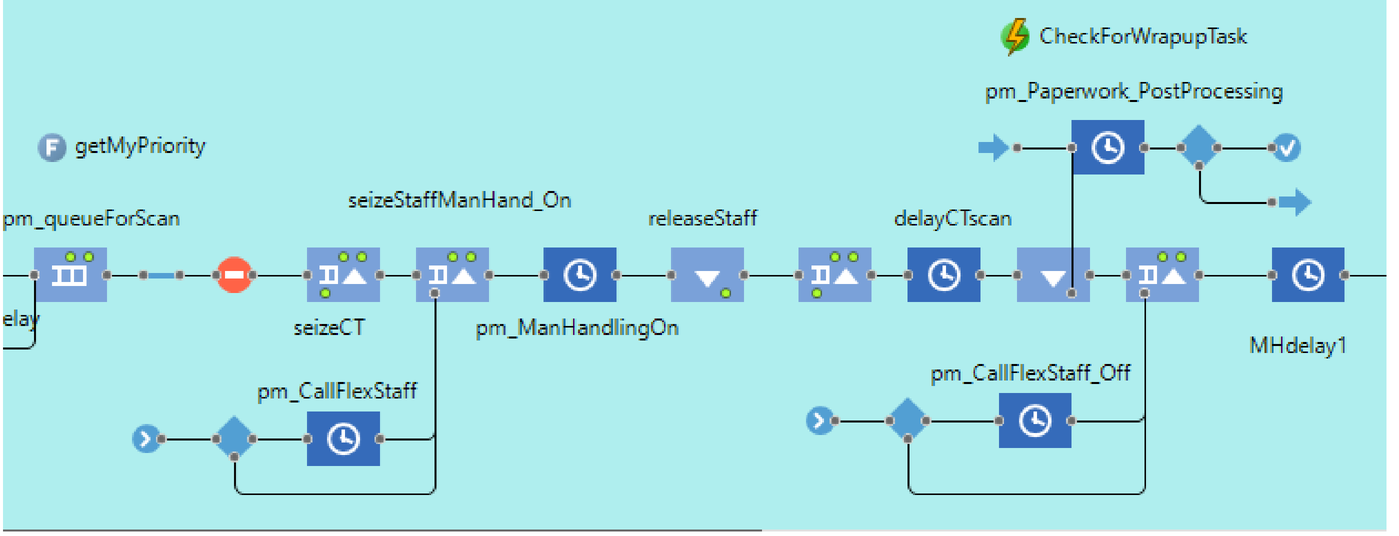


Figure 4.45 Model logic scanning section

In the next stage of the CT scanning process, shown in Figure 4.46, the patient has left the CT scanner, but the scanner cannot be released until infection control measures have been taken. Here a HCA or radiographer is seized for this task. The patient is observed if they are an outpatient and have had an IV injection, otherwise they proceed to the exit/sink.

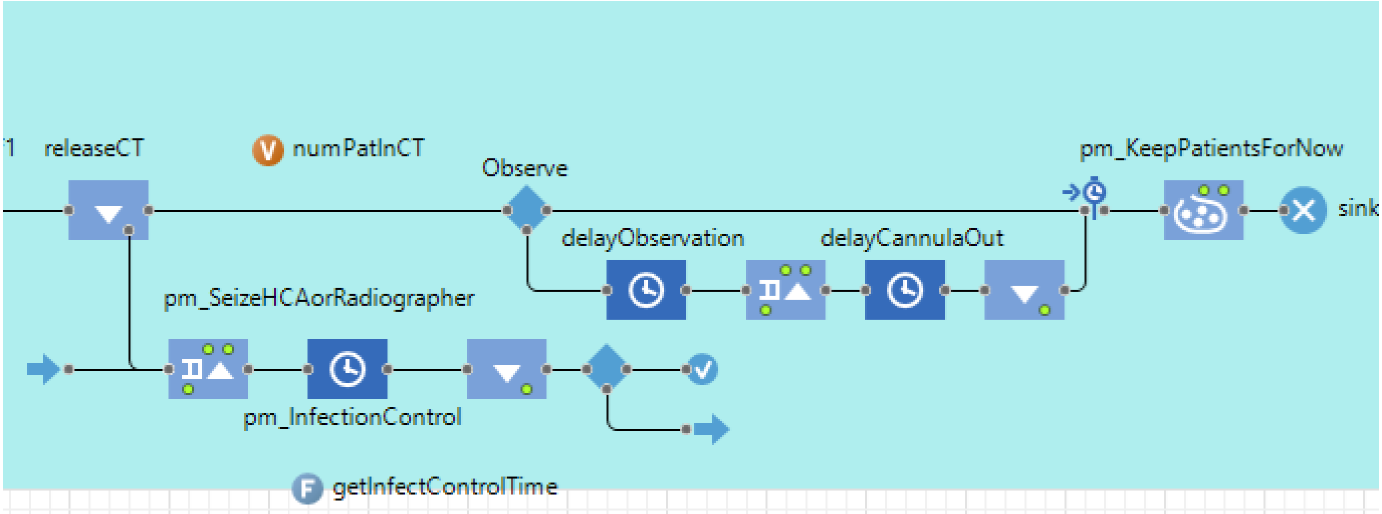


Figure 4.46 Model logic post scan wrap up cleaning tasks

All exam types were categorised based on what type of contrast was used and therefore what preparation was required see Figure 4.47.

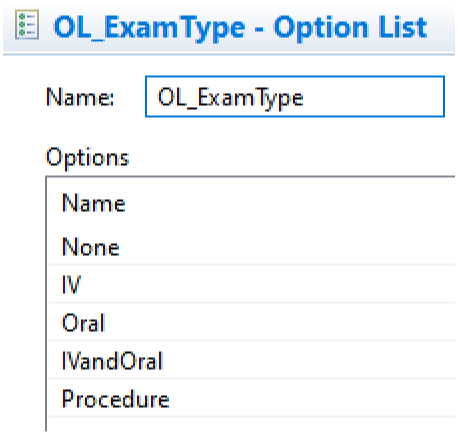


Figure 4.47 Exam type categories

An explanation of each examination types is provided:

1. None - No preparation required,

2. IV - Intravenous cannula to be inserted, this applies to outpatients only as inpatients have a cannula inserted automatically.

3. IV and Oral - IV cannula to be inserted plus oral contrast to be given,

4. Oral - Oral contrast only,

5. Procedure requiring nursing support and radiologists.

For experimentation, patients arrived stochastically based on historical arrival rates for the current scenario. For the remaining scenarios, arrival schedules for outpatient arrivals were identified in collaboration with the CT Clinical Specialist. In the baseline scenario there was two radiographers, one HCA and one CT scanner with a 9am to 5pm schedule but these variables could be changed.

Custom distribution functions were created using data sets from the case study department and values filled according to the probability distribution that was specified. For example, for age, bin intervals were decided and the number of observations for each bin range inputted, Figure *4.48* and Figure *4.49*.

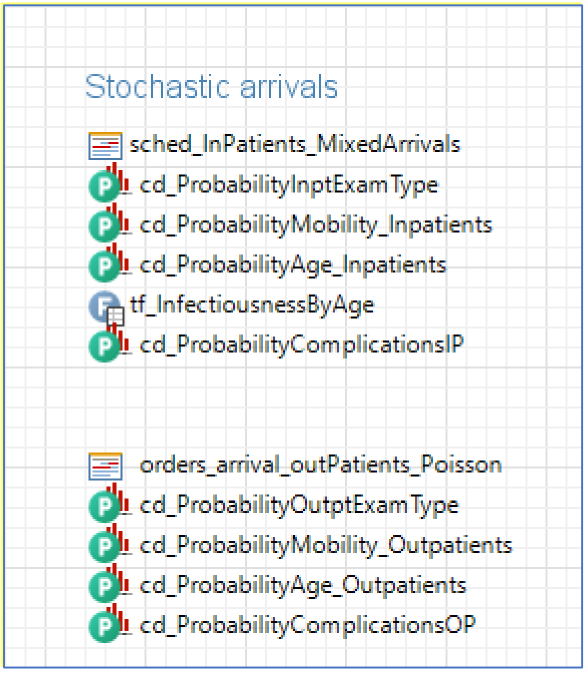


Figure 4.48 Using custom distributions to assign patient characteristics

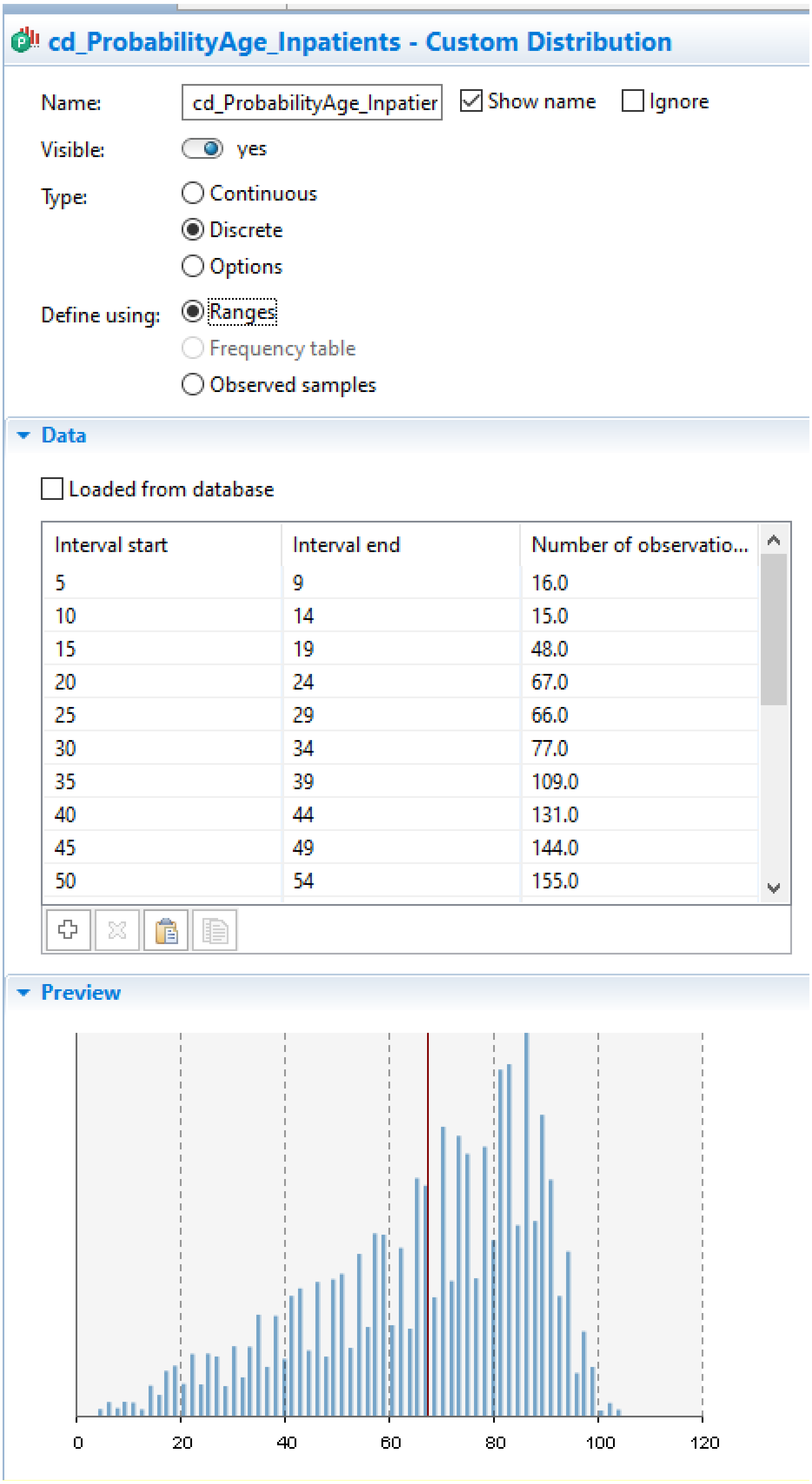


Figure 4.49 Custom distribution for patient age

Values were then assigned randomly following the probability determined by historical source data for the different patient parameters Figure *4.50*.

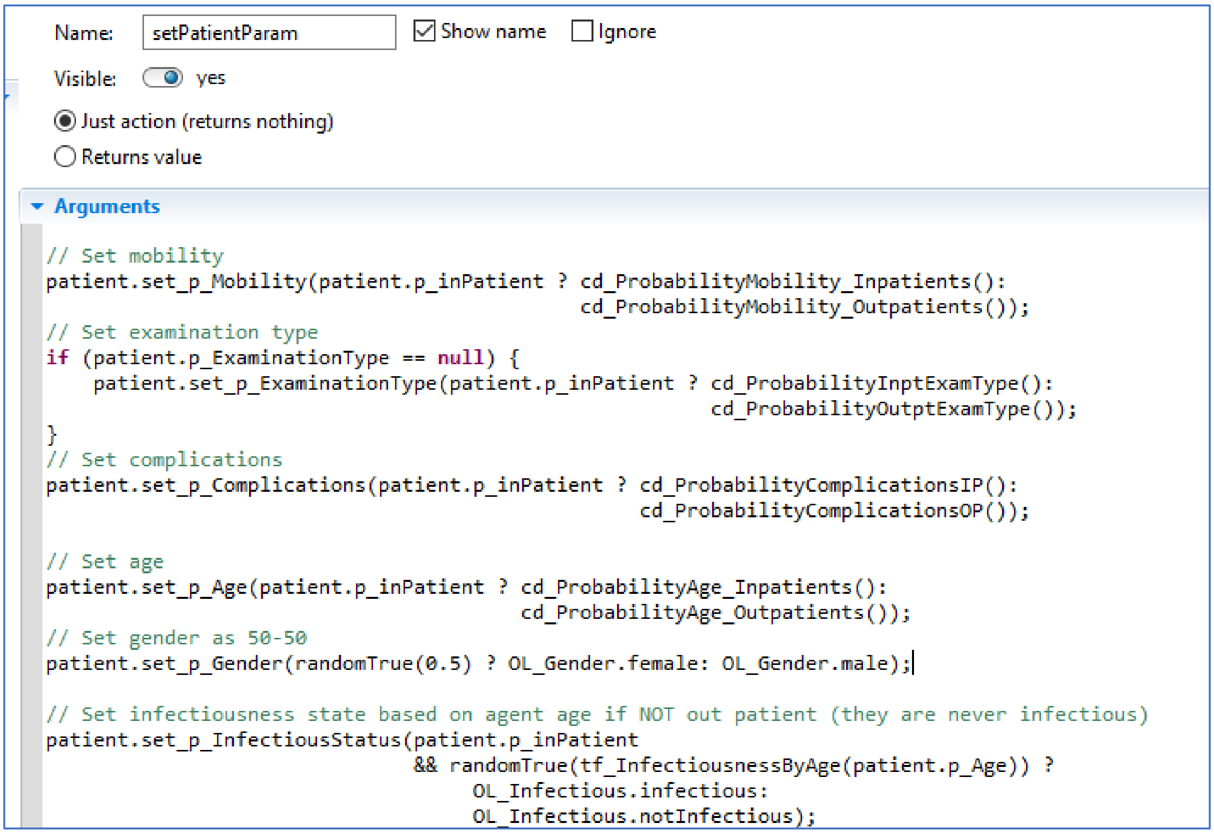


Figure 4.50 Assigning patient characteristics

4.5.2.1 Scenario logic

In scenario 1 (No change) the model ran stochastically using Poisson arrival rates rate for OPs and IPs determined from the data, see Table 4.1 Weekday IP and OP arrival rates (250 days). Inflow of patients was greater than the outflow therefore changes in the waiting list over time could be determined by the model. In scenario 2, the scheduled was extended and the arrival rate increased to allow extra OP scheduling between 5pm and 8pm, which permitted the scanning of 10 additional OP cases. In scenario three, a second scanner is introduced for outpatients only. The schedule for this scanner is shown in Table 4.8. Note that examinations such as procedures were not permitted on the additional scanner. This schedule was designed with the clinical specialist to allow a one hour lunch break and for the final patient to be completed by 5pm. While optimisation was not used, it has been determined to allow the maximum number of patients to be scanned and prepared simultaneously. The schedule allows 90 minutes for oral contrast, though this may vary across sites, as some sites choose to omit the use of Oral contrast for abdominal CT scanning (Razavi *et al.*, 2014).

Table 4.8 OP-only arrival schedule for second scanner (24 patients)

OP Only Arrival schedule	
Time	Exam Type
08:30	IVandOral
08:31	None
08:45	IVandOral
08:46	None
09:00	IVandOral
09:01	None
09:15	None
09:30	IVandOral
09:31	None
09:45	IVandOral
09:46	None
10:00	IVandOral
10:30	IVandOral
10:45	IVandOral
13:00	IVandOral
13:15	IVandOral
13:30	IVandOral
15:00	IV
15:15	IV
15:30	IV
16:00	None
16:15	None
16:30	None
16:45	None

4.5.2.2 Algorithms

Queues were captured for patient preparation, scanning. Patients were prepared based on a first in first out queue and the routed for preparation based on their examination types (see Figure 4.51).

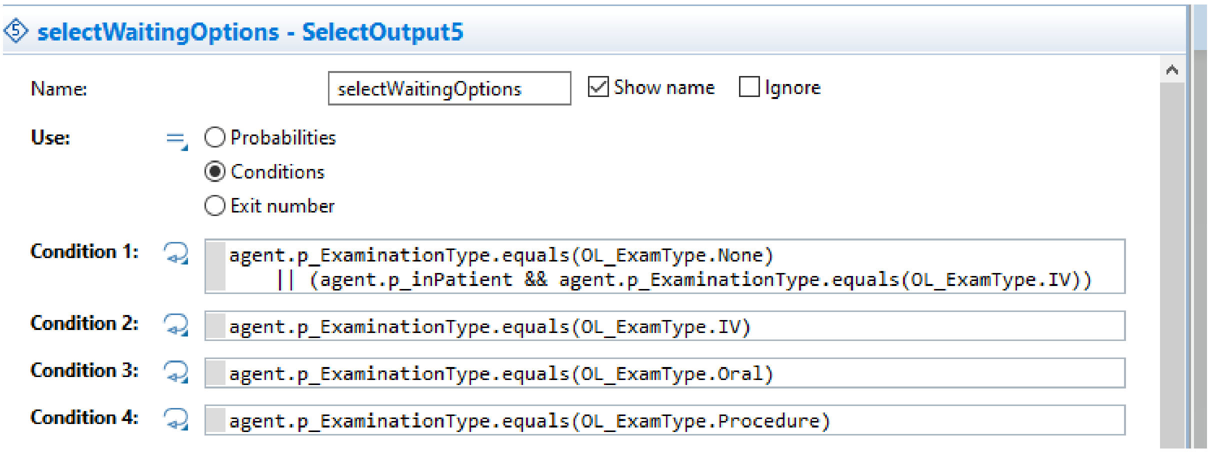


Figure 4.51 Patient preparation options

Inpatients are prepared for their scan whilst on the wards, therefore the HCA or radiographer must walk to the wards to provide the preparation. This infers a task of ten minutes duration in addition to the regular preparation time Figure *4.52*.

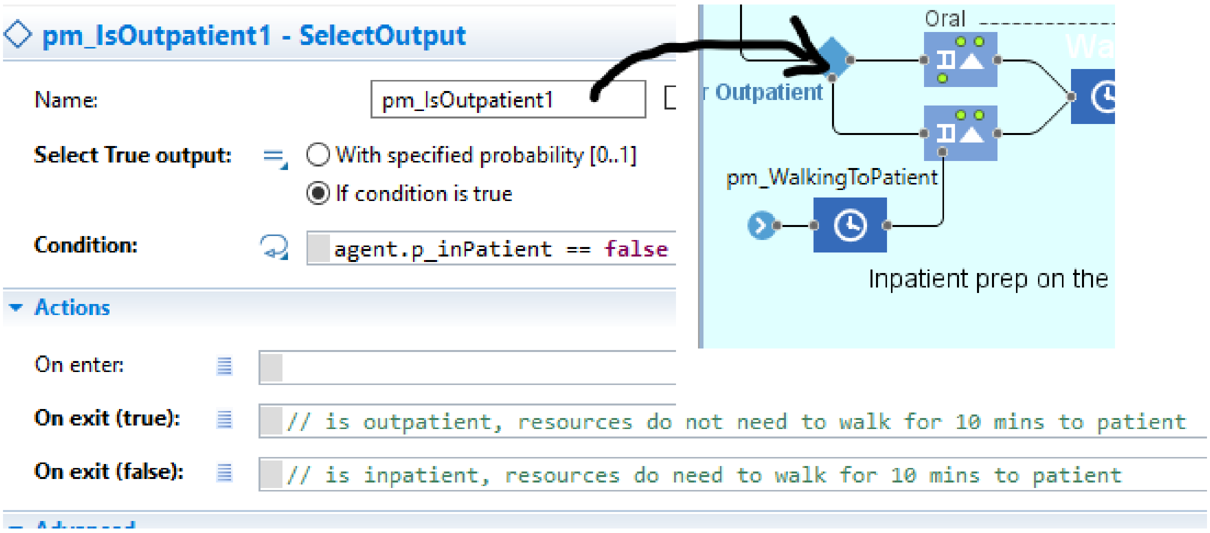


Figure 4.52 Routing for patient preparation

An infection control delay is set based on the patient's infection status using the following code, shown in Figure 4.53:

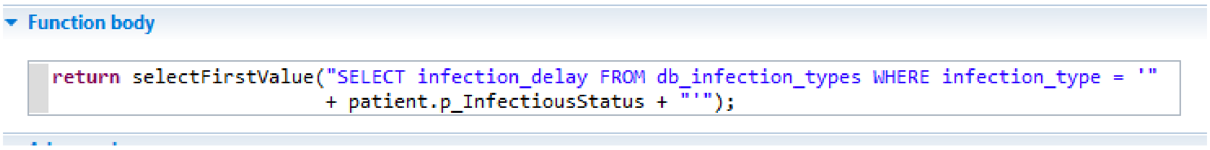


Figure 4.53 Infection control delay defined by patient infection status

On completion of the scan, the patient either immediately exits or waits for their cannula to be removed (if an outpatient and if they had a cannula inserted), see Figure 4.54.

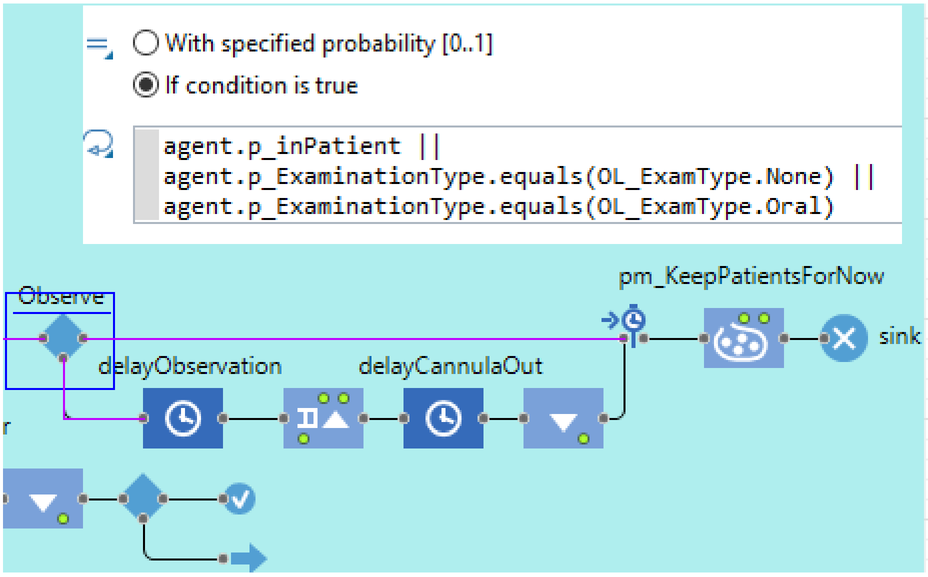


Figure 4.54 Routing of outpatients for observation prior to exit

4.5.2.3 Components

The model components can be considered as either staff, organisational, external or staff related Figure 4.55.

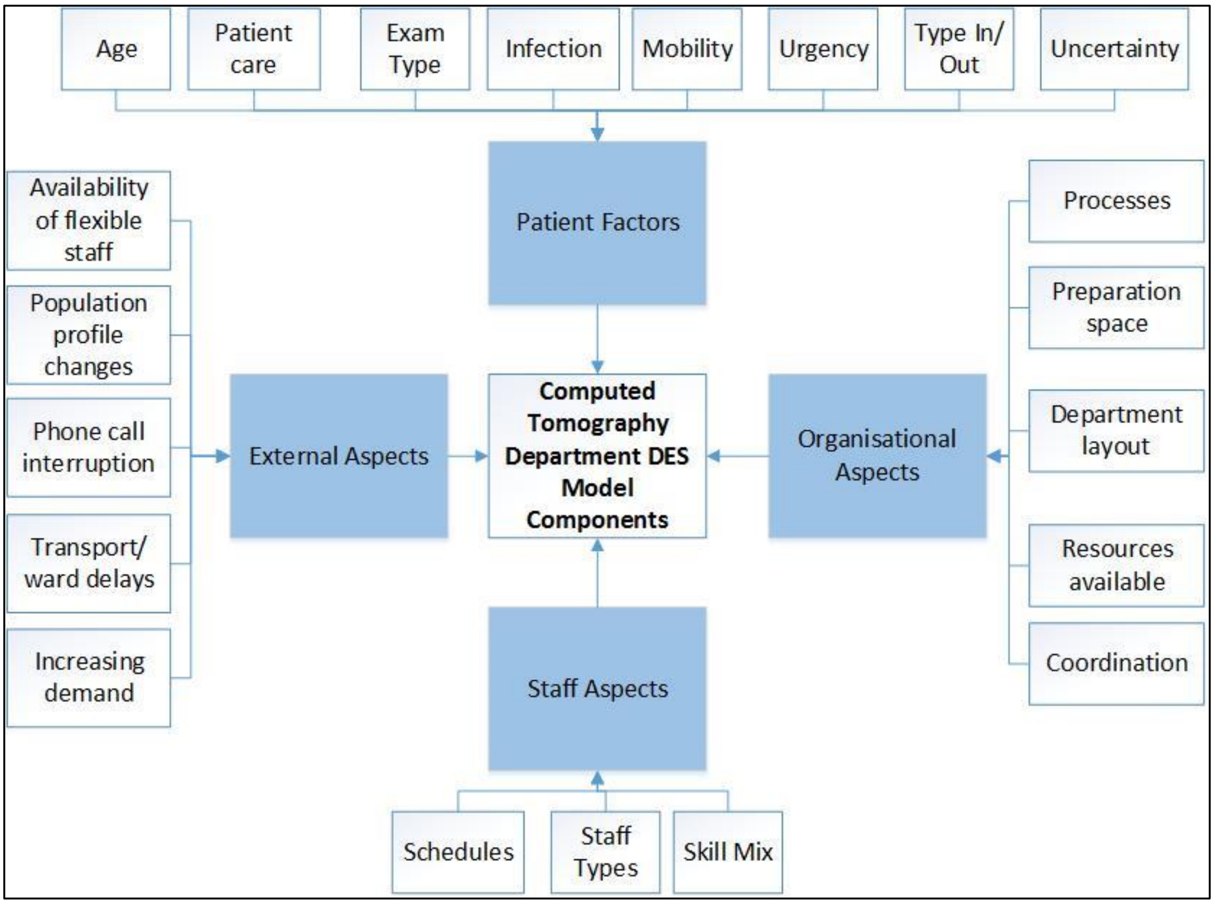


Figure 4.55 DES model components adapted from Rashwan (2017)

4.5.2.3.1 Entities and Resources

In AnyLogic agents are the main building blocks, may have variables, behaviours, memory and may represent diverse things: vehicles, units of equipment, projects, products, ideas (Anylogic Personal Learning Edition 8.4.0, 2019). Staff and scanner resources were consumed by the patient. Staff and scanner are also considered as agents and metrics captured for them also. Resources and agents are shown in Figure 4.56.

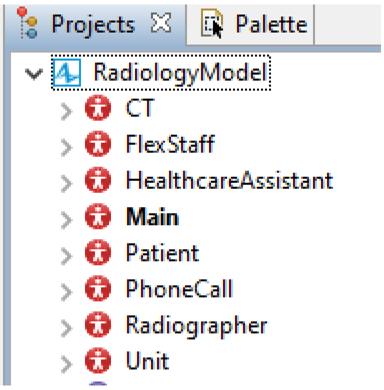


Figure 4.56 Agents and resources created in model

4.5.2.3.2 Activities

Activities captured in the DES model included:

1) patient preparation, (cannulation, providing oral contrast, procedure preparation)
2) walking to provide preparation to ward patients,
3) scheduling
4) scanning,
5) phone calls,
6) transportation,
7) manual handling,
8) cleaning, observation,
9) cannula removal,
10) post processing and paperwork
11) Idle/non scanning activities

Delays were recorded where resources were not immediately available for manual handling, cannula removal. A population of flexible staff were called upon where inadequate numbers of staff were available for manual handling activities and the number of occasions recorded. Phone call arrival patterns were based on historical arrival patters and linked to transportation activities Figure 4.57.

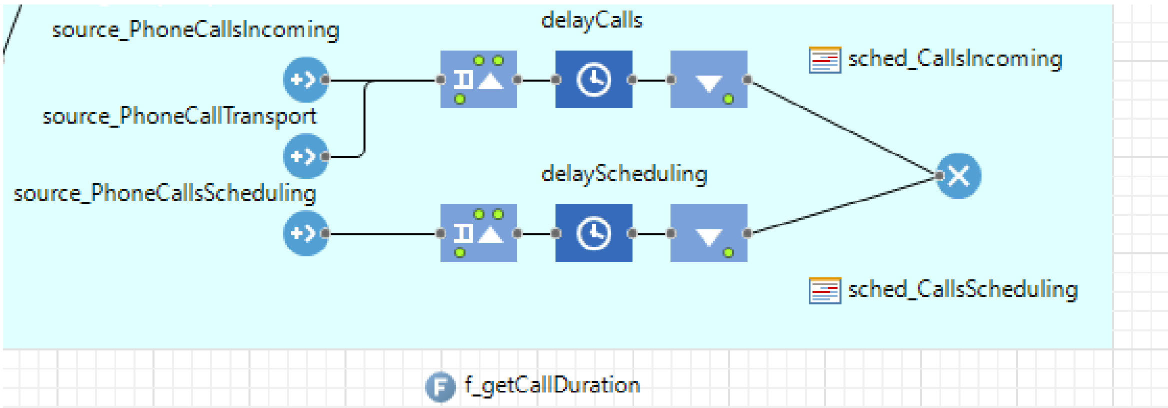


Figure 4.57 Inclusion of phone call activity

4.5.2.3.3 Queues

Patients queued for the CT scanner and were assigned priority based on first in first out. Patients were scanned based on a first in first out (FIFO) rule. Patients were prepared for their exams by the HCA however if a HCA was unavailable and a threshold of 10 minutes breached a radiographer could prepared the patient Figure 4.58

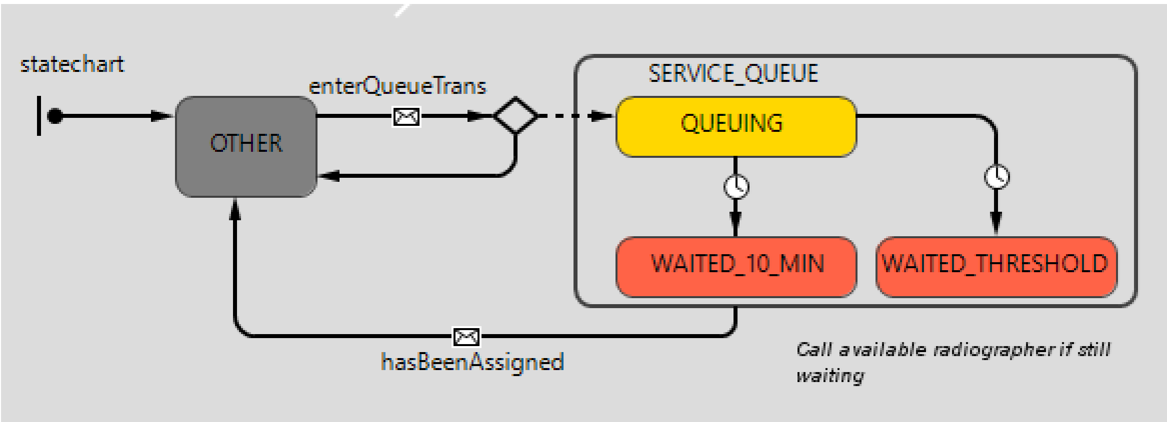


Figure 4.58 10 minute timeout for patient preparation

4.5.2.3.4 Entry and Exit points

Entry occurs from inpatient and outpatient waiting lists objects created for the deterministic outpatient work and the stochastic inpatient work Figure 4.59. There was a separate source for patients generated from historical excel database which was used for validation. On completion of the scan, the patient either immediately exits or waits for their cannula to be removed (if an outpatient and if they had a cannula inserted), see Figure 4.54.

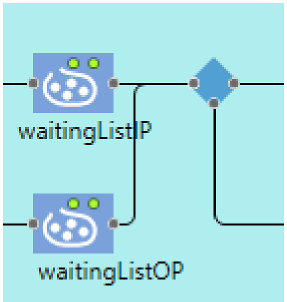


Figure 4.59 Patient entry from waiting list

4.5.3 Data

Quantitative methods were employed to analyse the anonymised patient data obtained from the PAS using Microsoft Excel and RStudio (RStudioTeam, 2015). Linear regression was used to determine whether the change in demand for examinations was significant, and, in the ANOVA analysis, the adjusted R-squared and p values were ascertained. Restricted logistic regression using upper and lower limit infection rates was used to determine how the infection rate varies with age. Box plots were created to compare the ED/IP and GP/OP age profiles. Descriptive statistics were used on the groups of examination types. Poisson distribution for OP/IP referral rate (how many new orders are added to the system per day), and Poisson distribution for OP/IP arrival rate (how many scheduled patients being scanned, on average, per day) were determined from historic data. Data required to create a model of the service and to answer the research questions are included in Table 4.9. Greater detail is provided in Appendix A of the tasks and times included in the model.

Table 4.9 Data and data sources required for DES modelling

Data analysed	Data type	Data source
1. CT demand	Aggregated data on total number of examinations	5 years of data obtained from a CT activity report for the period 2013 to 2017.
2. Exam type	Categorical data, defined by whether the examination used intravenous contrast (IV), oral, IV and oral or no contrast, or a procedure involving a radiologist.	Two years of CT examination data obtained from the patient administration system (2014, 2015) exported to Microsoft Excel for analysis
3. Infection status	Boolean data, alert on PAS used to identify whether patient is positive for infection, precaution type not specified.	Patient administration system (2014, 2015)
4. Patient mobility	Categorical data; ambulatory status of the patient, walking or wheelchair or trolley/bed; Observation data	PAS data (December 2018 to January 2019)

5. Task durations	Observation data	Observation (March 2018 and July 2021). Tasks and times verified with CT Clinical Specialist.
6. Phone calls	Obtained from IT department – records of all incoming and outgoing calls for a 6 month period.	IT Department records

4.5.3.1 Model parameters

The following are the model parameters used in the model see Table 4.10.

Table 4.10 Parameters for DES model Experimentation

Exam Duration		
Examination Type	**Examination Scan Duration**	**Staff Resources Required**
No Contrast	3	Radiographer x 1
IV	7	Radiographer x 2
Oral	3	Radiographer x 1
Oral and IV	7	Radiographer x 2
Procedure	15	Radiographer x 2
Exam Preparation		
Examination Type	**Examination Preparation Time**	**Staff Resources Required**
No Contrast	0 Mins	Radiographer/HCA
IV	Triangular (5,7.5,15) Mins	Radiographer/HCA
Oral	10 Mins	Radiographer/HCA
Oral and IV	Combination IV and oral	Radiographer
Procedure	15 Mins	Radiographer
Patient Type		
Patient Type	**Value (Boolean)**	**Percentage of each type**
Inpatient	TRUE	67%
Outpatient	FALSE	33%
Manual Handling		
Patient Mobility	**Number of handlers required**	**Resource Pool Required**
walking	1	Radiographer/HCA
wheelchair	2	Radiographer/HCA/Flexible staff
trolley	4	Radiographer/HCA/Flexible staff
Patient mobility for each patient type		
Mobility Type	**Outpatients %**	**Inpatients %**
walking	95	40
wheelchair	5	30
trolley	0	30
Manual Handling Activity Duration		

Mobility Type	**Manual Handling Task duration**	**NB - Task completed pre and post scan**
walking	1	
wheelchair	2	
trolley	2	
	New Request/Order Arrival Rate	
Examination Type	**Outpatient**	**Inpatient**
None	1.73	7.93
IV	0.99	2.19
Oral	0.26	0.32
IVandOral	2.76	3.34
Procedure	2.05	0.08

	Task Prioritisation	
ActionPrepIV	5	NB - Order in which staff commence a task
ActionPrepOral	5	NB - Tasks are non preemptive, staff must
ActionPrepProcedure	5	complete a task before starting the next
ActionManHandling	6	task.
ActionScanning	10	
ActionCalls	11	
ActionScheduling	6	
ActionCannulaOut	4	
ActionCleaning	10	
ActionPostProcessing	4	
	Infection Control Parameters	
Infection status	**Infection control task time (mins)**	**Staff Resources Required**
infectious	5	Radiographer/HCA -HCA if both available
noninfectious	3	Radiographer/HCA -HCA if both available

Age category	**Likelihood of Infection**	NB- For InPatients only. A table function was used.
0	0.03	
25	0.03	
28	0.04	
35	0.05	
50	0.05	
54	0.075	
63	0.13	

75	0.23	Explanation
80	0.33	@ 80 years of age 33% are infectious
95	0.34	
100	0.35	

Resource Required	**Current scenario**	**2 Scanner scenario**
CT	1	2
HCA	1	2
Radiographer	2	4
Flexible staff	4	4

Other Tasks	**Time in Minutes**	**Resource Pool Required**
Transportation delays	triangular (0,10,1.5)	NB - Only Inpatients experience this delay
Call Flexible Staff delay	triangular (0.25,3, 0.75)	NB - Flexible population used where other population not available.
Time taken to remove cannula	triangular(3,8,4)	Radiographer/HCA
Outgoing calls Duration	triangular(1,5,3)	Radiographer
Incoming calls Duration	triangular(21,57,30)	Radiographer
Paperwork	1.5	Radiographer
Post processing	1.5	Radiographer
Observation task	30	Radiographer/HCA
Removal of IV cannula	triangular(6, 10, 8)	Radiographer/HCA

No warm up time was used for the model execution, as the waiting list queue was pre-loaded or “injected” in AnyLogic parlance, into the model on start up for each exam type and for outpatients only. Patients do not remain in the department overnight and there is no continuity of work from one day to the next, owing to a model simplification which assumes inpatients are scanned on the day of ordering. To obtain metrics on resource utilisation and process performance the model ran for a period of 1 year using historic arrival times and stochastic arrival times for future performance Table 4.11. For validation a model run time of 1 year was used. For workshopping the model with staff a model run time of 5 days (1 week) period.

Table 4.11 Scenario descriptions

Scenario	Run Length	Arrivals	Purpose of scenario
Validation	1 year - 2017	Deterministic	To allow a comparison of the patient time in system between historic data and model outputs for validation.
Historical service metrics mixed IP/OP service	1 year - 2017	Deterministic	Once validated outputs used to gain insights into the current system performance and other metrics determined from model.
Mixed IP/OP scenario	1 year	Poisson arrival schedule for IP and OP	To determine how the waiting list would evolve over time given the current inflow and outflow rates.
Current mixed IP/OP scenario with 8 to 8 scheduling	1 year	Poisson arrival schedule for IP and OP	To determine how the waiting list would evolve over time given the current inflow and increased outflow rates.

2 scanner scenario: 1. IP/OP 2. OP Only	100 days	IP/OP- Poisson arrival schedule. OP- fixed time arrival schedule	Arrival time defined for OP, the model is initialised with waiting list and the decrease in the waiting list over time observed. On scanner number 1 the original Poisson arrival are used. On scanner number 2 a fixed arrival schedule is used for OP.
Workshop	1 week	Deterministic	Historic arrival times are used, staffing varied in workshop to demonstrate change in utilisation.

4.5.4 Implementation and initialisation

Anylogic modelling software was used to create the DES model, AnyLogic 8 University edition, 8.6.0. Model time units were minutes. The Initial conditions were as follows – Patients arrive into the model deterministically for OP (predefined arrival times from database created in Anylogic) and stochastically for IP based on Poisson arrival schedule. A database was created in Anylogic for the CT waiting list for each exam type and this was setup to load upon start up

Figure 4.60. A dynamic event was created named "PatientEnterWaitList". This instructed 709 Outpatients to be created based on the waiting list backlog Figure 4.60. The waiting list identified in the exploratory data analysis was used on start-up, therefore a warm-up period was not required.

Exam Type	Number of Exams
None	293
IV	107
Oral	32
IVandOral	195
Procedure	82
Total	**709**

Figure 4.60 Waiting list for Inpatients and Outpatients loaded on start-up

The model was defaulted to run with 2 radiographers and 1 HCA between 9am and 5pm for the current scenario and 1 radiographer outside of these times. A population of flexible staff are available to assist with manual handling tasks on a 24-hour basis. These parameters could be varied by the user and for the purpose of work shopping the model.

Due to the stochastic nature of the model, it was necessary to run each scenario multiple times to obtain statistically significant results. The Monte Carlo experiment method was used to obtain and display a collection of simulation outputs. A 2-d line graph was used to display simulation outputs. The run length was 365 days for each replication. A random seed value for the pseudorandom number generator was used to ensure each run was unique.

The mean and confidence intervals for the differences between means for each replication were collected with the results showing the spread of variation, see Figure 4.61 and Figure 4.62. The actual waiting list evolution is also plotted on Figure 4.61 and remains within the lower confidence interval values. The waiting list increase was affected by the removal of 100 patient requests during the Covid-19 pandemic where some scheduled work was exported to a private facility for scanning (see Figure 4.22 CT waiting list in the exploratory data analysis for further information).

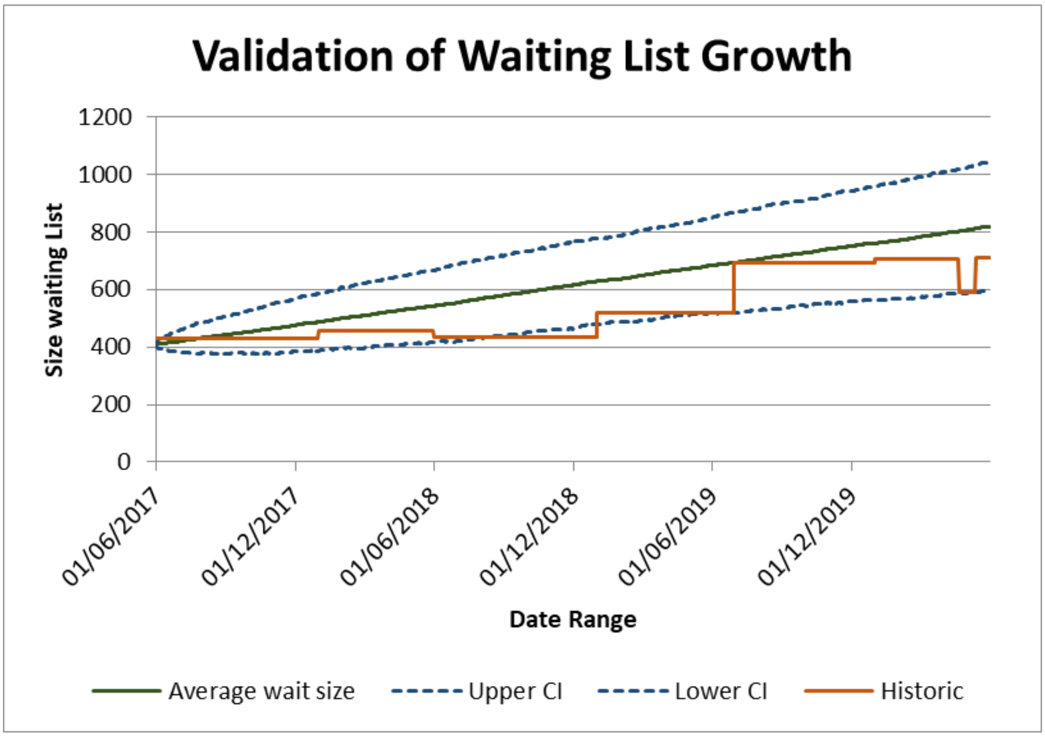


Figure 4.61 Simulated and historic growth of waiting list over 3 years

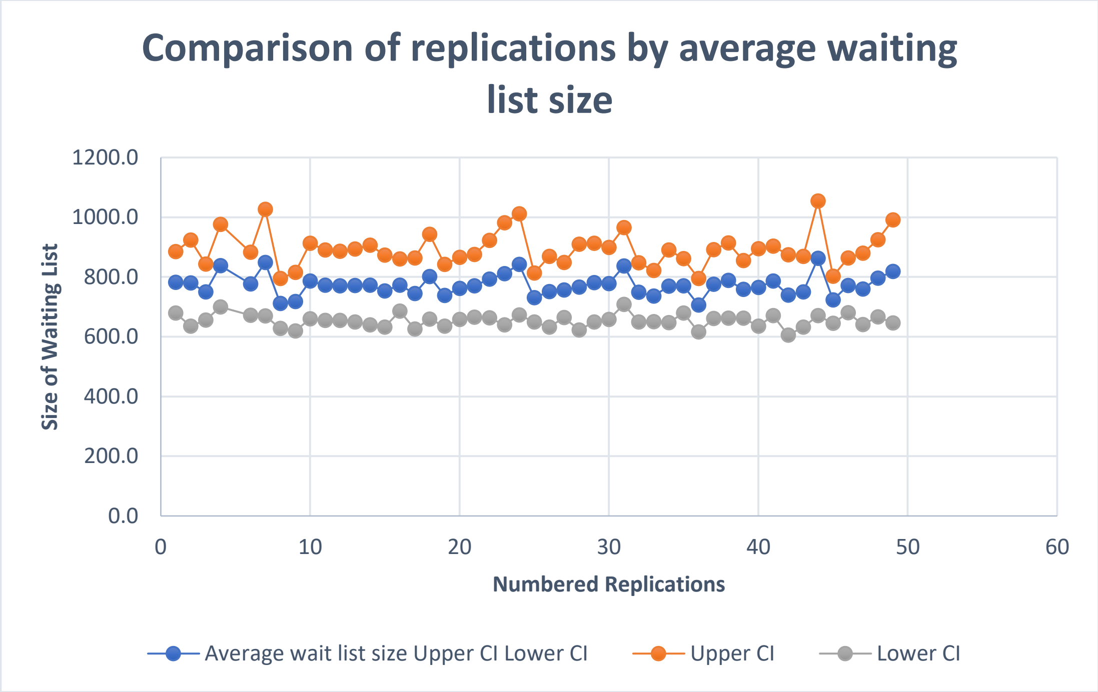


Figure 4.62 Comparison of average waiting list size for 50 replications

Towards the end of the experiment (365) there was a substantial and significant (P>0.0005) spread in average size of the waiting list 854 +/- 110. In Table 4.12 a sample of the output data from 20 of the 50 replications is demonstrated with standard deviation and upper and lower confidence intervals. It took four hours to run the 50 replications in series on an Intel® Core™ i3-3240 with 8.00GB RAM personal computer with a 64 bit operating system.

Table 4.12 Sample of data from multiple repetitions

Run number	Std Dev Wait size	Average wait list size	Upper CI	Lower CI
1	52.38142377	782.2	884.9	679.5
2	73.54366273	779.6	923.8	635.5
3	47.95722575	749.7	843.7	655.7
4	70.59792461	838.2	976.6	699.8
6	53.70247206	777.3	882.5	672.0
7	90.94835892	848.2	1026.4	669.9
8	42.84557098	711.4	795.4	627.5
9	50.11172875	717.7	815.9	619.5
10	64.43867991	786.5	912.8	660.2
11	60.34076661	772.6	890.9	654.4
12	59.12923984	770.5	886.4	654.6
13	62.21861572	771.8	893.8	649.9
14	67.88878811	773.0	906.1	639.9
15	61.56996455	753.1	873.8	632.4
16	44.71868469	772.9	860.6	685.3
17	60.71351972	744.3	863.3	625.3
18	72.48933553	801.3	943.3	659.2
19	52.8051161	738.6	842.1	635.1
20	52.85171679	761.9	865.5	658.3

4.5.5 Validation

Stakeholders were afforded an opportunity to workshop the model (4.5.5.1). The aim of this was to create support for future changes and build trust in the model. The staff (clinical and clerical) used the simulation page to vary the number of healthcare assistants and radiographers and to analyse the outputs. As part of the model verification process, model parameters were printed off and stakeholders were asked to check how realistic the assumptions and observations that lead to parameter inputs were. For statistical validation, data records from the hospital PAS were used to compare patient length of time in radiology for historical versus model data.

4.5.5.1 Workshopping the model - Stakeholder feedback

Model validation was a critical stage in the development of the simulation model. As part of the validation stakeholders were afforded an opportunity to workshop the model using historical data for one day. Staff were permitted to change simulation parameters such as the number of staff and scanners, view the model and the results as it ran see Table 4.13. This was in an effort to gain model credibility by developing user confidence in the model and information derived from it (Sargent, 2013).

Table 4.13 Workshopping the model with clinical staff

Scenario	Scanner utilisation	HCA utilisation	Radiographer utilisation	Inpatient wait time	Outpatient wait time	# Flex staff
IP/OP Scenario 2 Radiographers 1 HCA	61.3%	40.2%	54.5%	3.43mins	0.38 mins	15
IP/OP Scenario 2 Radiographers 0 HCAs	78.2%	n/a	74.6%	8.81	0.64 mins	31
OP Scenario 2 radiographer 1 HCA	55.6%	34.2%	54%	0	0.52 mins	0
OP Scenario 2 radiographer 0 HCA	63.8%	n/a	68.9%	0	0.86 mins	0

The following feedback was provided to the researcher because of the workshopping opportunity provided to staff.

1 Radiographer 1: "We are not capturing the times for HCAs when they are shadowing the radiographer and available to assist. When HCA shadow a radiographer, they assist them in some of the one person tasks by handing them alcohol wipes, taking saline syringes from a cupboard or by putting a blanket on the patient. This help is invaluable and makes

the patient experience better and alleviates pressure on radiographers. A radiographer who has gloves on should not retrieve saline from a cupboard if they need a second syringe. If a HCA is not there they must doff their gloves, hand sanitise and retrieve the syringe. This is time consuming.

2 Radiographer 1: The number of flexible staff seems high during the day but this could include a staff member accompanying a patient, or a kindly porters who stays to help as well as radiographers who are available when needed.

3 Radiographer 1: we should be allocating more time for post processing and paper work. This is a tasks we do automatically while answering phones but it is very important.

4 Radiographer 2: Staff suggested "Maybe pause all 3 radiographers while scanning is ongoing as they cannot do anything else. Also, these are the occasions when we discuss who will be scanned next and what needs to be done, don't forget staff are continuously being trained on the scanner."

5 Radiographer 2: Staff complained "The model assumes all radiographers can insert cannulas. Skill mix is hugely important and is not really included in the model. If a radiographer cannot cannulate there are delays."

An additional means of model validation was to compare observations from a specific day, with outputs from the model for that day. This day of observation was used as a means of validation and verification of the model on a patient-by-patient basis. The model arrival and start times were compared against the actual patient arrival and start times using observation notes taken on the day. The observational data provided explanations for delays and for the sequencing of patients. Verification was ongoing with the help of the CT Clinical Specialist, for each phase of the simulation model development: problem structuring, model building and evaluation. The verification process checked that:

- Patients followed the preparation path expected,
- IPs were not observed post scan,
- OPs did not require transportation,

- That OPs were not assigned any IP characteristics such as an ambulatory status of “trolley” or infectiousness,

- Scheduled work did not continue after 5pm or during lunch.

4.5.5.2 Validation using observations and model outputs – 1 day

Model data was compared for a specific day and 27 patients on that day compared case by case. Observations from a single day were used to compare model versus actual patient time in the system. These observations on delays were recorded on a spreadsheet and included patient arrival and departure time from CT. The observations helped to explain differences between model outputs and historical output. The variation in time from arrival to scan commencement was compared, the minimum difference was .46 seconds, maximum 38 minutes and average difference 13 minutes, Figure 4.63.

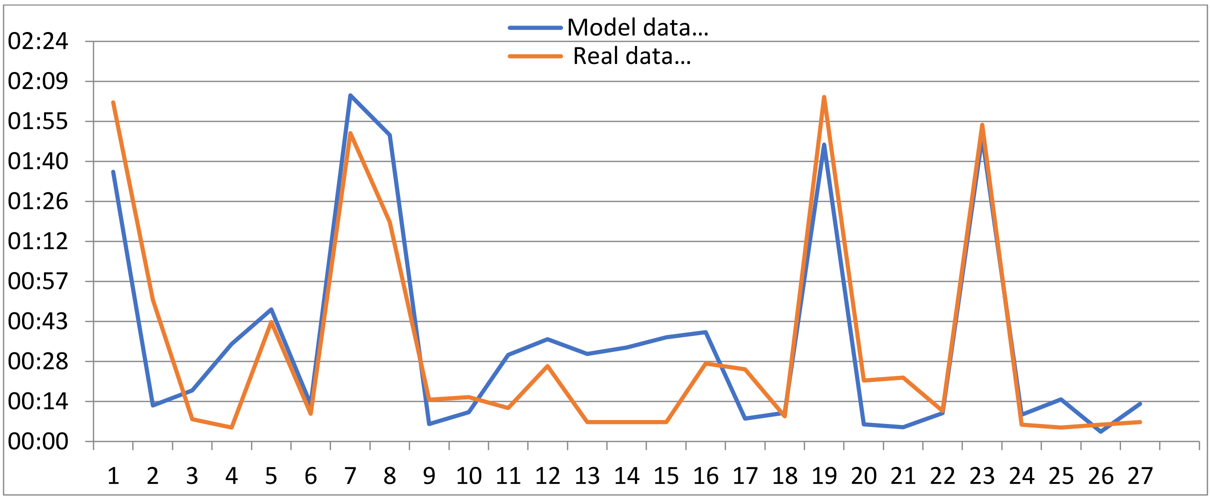


Figure 4.63 Validation using a comparison of 27 cases from a specific day

As this day was observed, explanations were provided for the greatest time differences:

- “This delay length of 31 minutes was due to a delay providing the patient with oral contrast and issues inserting a cannula.”

- “This OP exam took longer than expected - there was confusion regarding this case as to the correct protocol to use and radiologist needed to be consulted.”

- "This OP was delayed (in the model) by an infectious, high dependency cases for a CT brain scan. In reality a scheduling decision was made to deviate from the normal practice of scanning IPs first and the OP was quickly scanned between IPs."

The system queue sizes were observed for each scenario to ensure that the model behaved as intended to ensure patients did not remain overnight in the department, or arrive before 9am in the case of OP Figure 4.64.

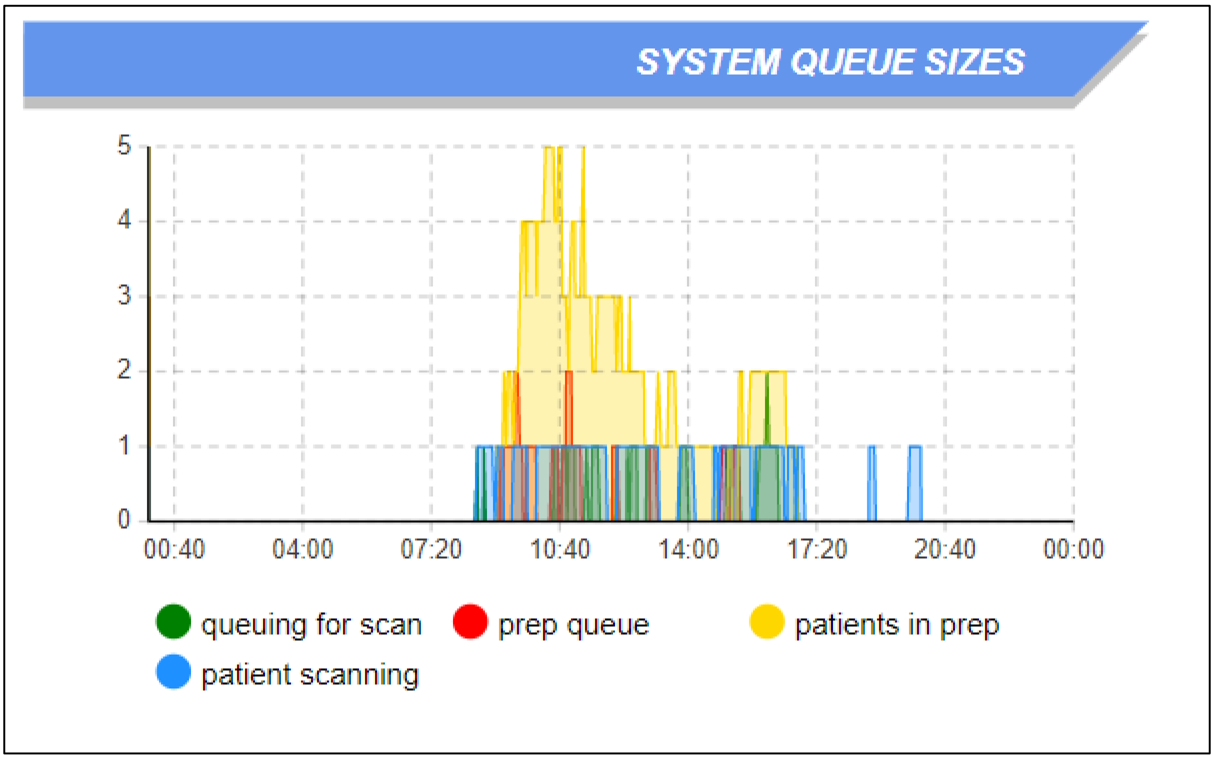


Figure 4.64 System queue sizes

4.5.5.3 Statistical Validation

After the initial model was created it was necessary to validate and adjust the model. Historic data was used for this purpose. A period of 1 year was chosen where model data was compared with historic data for the duration of time the patient spent in the department, see Table 4.14. The overall average patient time in the system from arrival to exam completion was 54.4 minutes plus or minus 1.2 minutes, the confidence interval was 3.36 minutes plus or minus 0.64.

Table 4.14 Validation of model results with historical data

Exam Categories	Mean Time in System - 95% CI	Mean Error - 95% CI
Overall	54.4±1.2	3.36±0.64
IV	33.2±1.6	-1.81±1.76
IVandOral	118.6±0.8	8.55±1.20
None	20.5±0.6	1.76±0.81
Oral	113.0±3.3	7.30±4.33
Procedure	48.7±2.7	2.81±3.01

Validation, as defined by Law (2006), is the process for determining whether the simulation model is an accurate enough representation of the system, for a particular purpose of the study. For the purpose of answering the research questions identified in Chapter 1, the model was determined to be valid.

4.5.6 Model assumptions

The following simplifications were made:

- Aall radiographers are assumed to have the same level of CT competency
- All radiographer are able to complete all tasks. (This is not always be case as some radiographers may be unable to cannulate or complete all scans)
- All exams are completed once started (in reality scans may be have to be abandoned should the patient become unstable or unable to tolerate the examination).
- A resource is considered either idle (not currently seized by a patient or other agent such as CT scanner or phone call) or not idle (seized).

A limitation of the utilisation metric is that staff activities such as teaching, learning, and other value adding communications were not captured in the model and are not reflected in this metric for staff utilisation (see Appendix A for tasks not included in the model). The term idle is not used in metrics, with this time labelled as "non scanning related activities". Additionally, while a CT scan is ongoing staff such as healthcare assistants cannot enter the CT room and must wait to assist with patient manual handling post scan. In the model this time has been captured as a time of inactivity as the resource is not seized by another agent but could have been considered as active if a different assumption had been made. This model assumption has resulted in lower levels of utilisation for healthcare assistants.

Chapter 5: Results and Analysis

Permission to carry out this research was given on the proviso that findings be shared with hospital decision makers. To date findings have been presented at various milestones in the project and on the final decision support tool outputs. Findings on CT weekend demand were presented at the biannual hospital audit day and resulted in the hiring of additional staff for the CT service provided at weekends. Simulation results were presented to hospital management to aid decision making with respect to the future of the CT service and the included as part of a business case to support the purchase of an additional CT scanner for general practitioner and outpatient demand. Findings have been presented in academic formats at various conferences in both poster and paper format.

The following simulation model results are discussed in Chapter 5:

- Simulation Results
    - Effect of interventions on waiting list in terms of time required to eliminate the waiting list.
- Current Process Findings
    - Process Metrics
- Future progression of waiting list should no action be taken
- Scenario 1 - OP only Scanner
    - Process Metrics
- Scenario 2 - 8 am to 8pm Scenario
    - Waiting List

5.1 Scenario results - effect on waiting list

For each scenario, the evolution of the waiting list was graphed, from an initial waiting list of 709 exams. In Scenario 1, no change is made and exams continue to be scheduled at the original rate. The observed increase in the waiting list is presented Figure 5.1, the waiting list was projected to increase by 14.5% over 9 months.

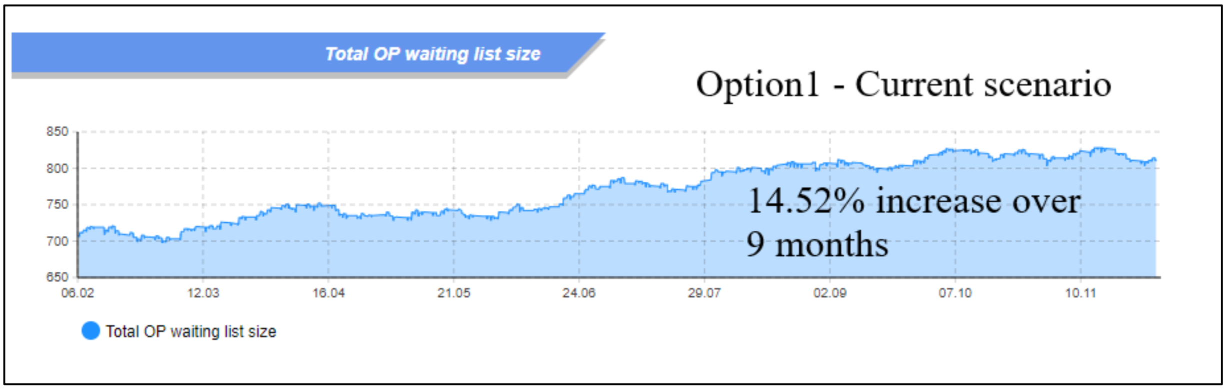


Figure 5.1 Option 1 continue with current scenario

Under Scenario 2 - the extended schedule scenario, an additional ten exams are scheduled per day. The waiting list approached zero after 4 months and 1 week, depicted in Figure 5.2.

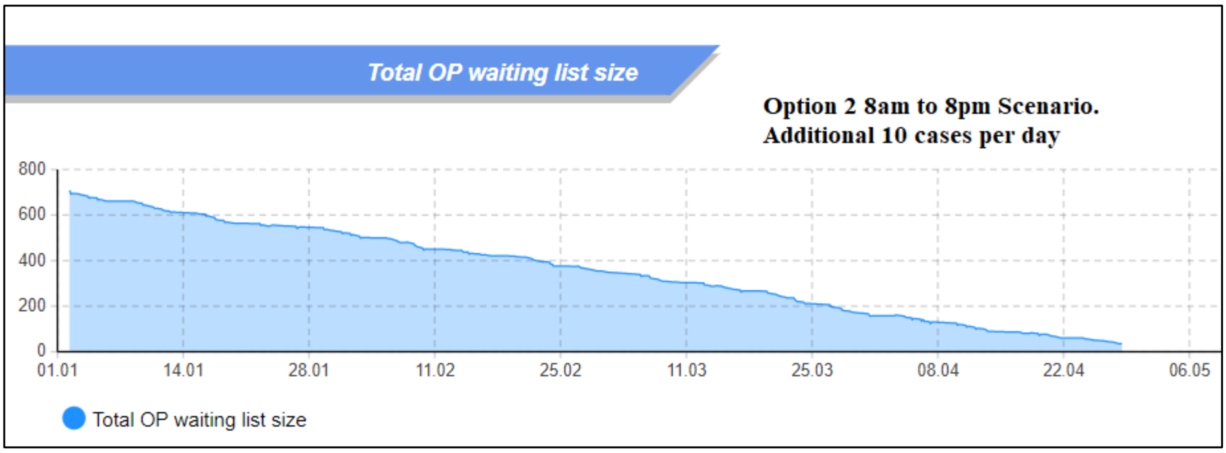


Figure 5.2 Option 2 8am to 8pm scenario

In Scenario 3 (two scanners run simultaneously) an elimination of the waiting list after 1 month and 2 weeks was seen. Scenario four is a variation of scenario three with the same results.

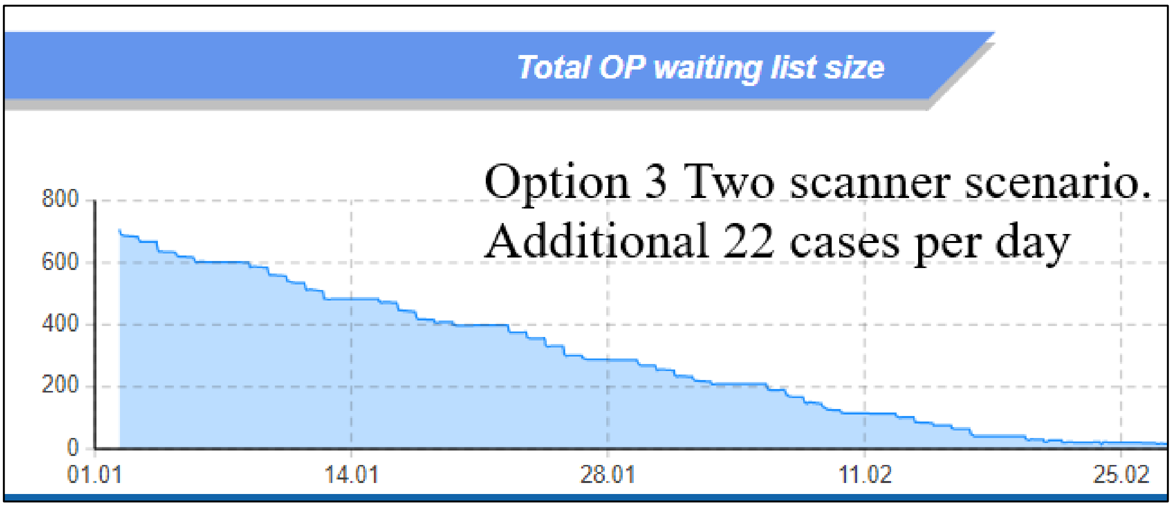


Figure 5.3 Option 3 Two scanner scenario

The results from the simulation were presented as shown in Figure 5.4, in a decision support tree for radiology management.

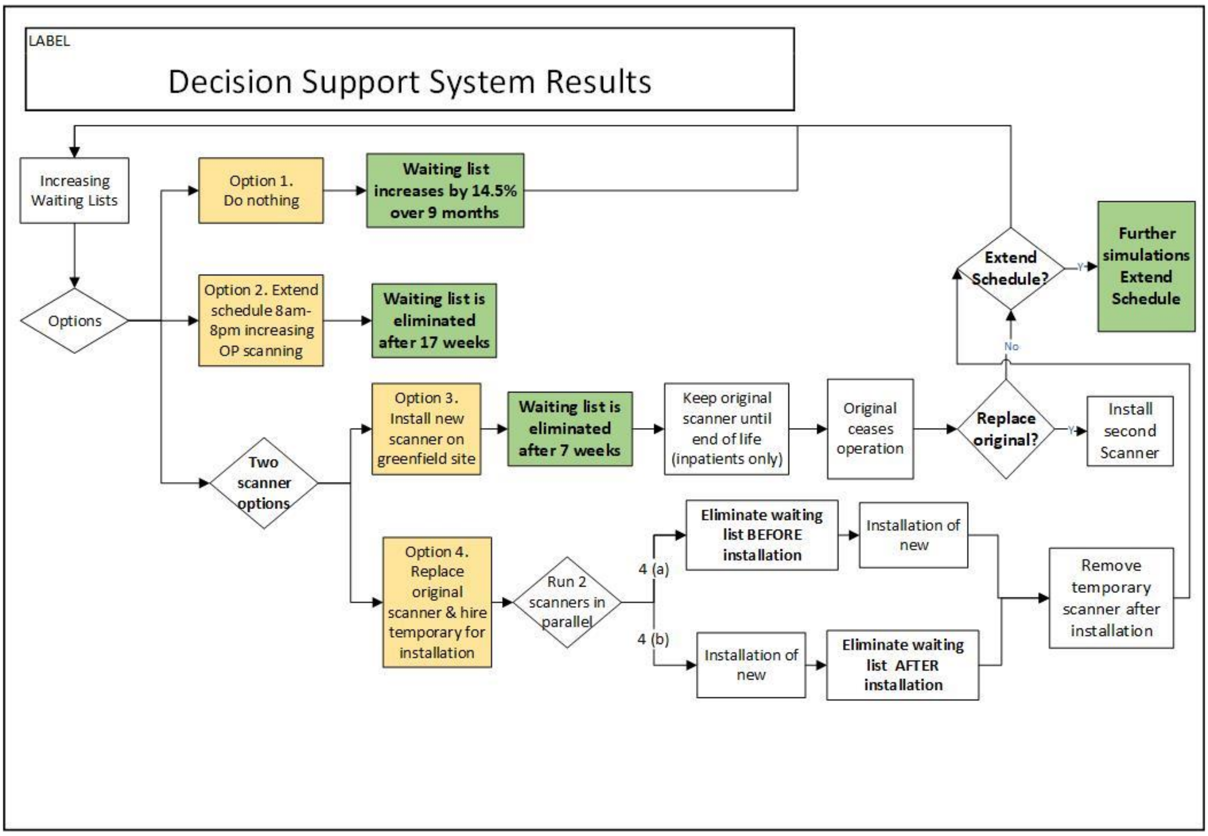


Figure 5.4 Scenario results for DSS

The simulation results were presented to decision makers along with the process metrics which were identified in conjunction with clinical and managerial staff. Option three was the scenario identified as preferred and a business case for same prepared.

5.1.1 Current scenario – Patient related metrics

This scenario represented the current system with the patient arrival times and exam type obtained from historic PAS data. The patient, process and staff metrics are presented here, providing a baseline for comparison with the OP scenario.

Table 5.1 Patient differences from model

IP/OP Comparison Metrics	**IP**	**OP**	**Explanation of Result**
MEAN_PERTURBATIONS	11.9 minutes	0.15 minutes	Perturbations are delays to process attributed to patient type. Seen to be greater for IPs.
Consumed staff minutes (CSM) for IV and Oral exams	47.05 minutes	36.5 minutes	The staff time consumed for exam preparation, scanning and manual handling, observation for IV exams. Greater for IPs by 29%
Consumed staff minutes for Non-contrast	16.5 minutes	6.2 minutes	The staff time consumed for exam preparation, scanning and manual handling, observation for IV exams. Greater for IPs by 127%
Percentage of time scanning (Scanning Time/CSM) for IV and Oral exams	18.39%	22.11%	A metric for the percentage of overall consumed time where the radiographer is involved in scanning. For OPs 3.72% more of radiographer time is spent scanning.
Percentage of time scanning (Scanning Time/CSM) for Non-Contrast exams	38.91%	61.85%	For OPs 22.94% more of radiographer time is spent scanning for non-contrast exams.

5.1.2 Current mixed IP/OP scenario – Process related metrics

The metrics determined for the process are presented in terms of utilisation of resource, the number of requests for flexible staff and the average daily number of tasks completed by the schedule resource i.e. two radiographers and 1 healthcare assistant, see Table 5.2 Process metrics for mixed IP/OP scenario Table 5.2.

Table 5.2 Process metrics for mixed IP/OP scenario

Process Metrics	**Scenario Historic**	**Explanation**
Scanner Utilisation 9-5	61.2%	Percentage of time between 9am and 5pm that the scanner was utilised. Excludes 1 hour lunch break.
Radiographers Utilisation 9-5	57%	Percentage of time between 9am and 5pm that each (of the 2) radiographers was being utilised.
HCA Utilisation 9-5	38.2%	Percentage of time 9am to 5pm that the HCA was utilised.
Average daily flexible staff requests	14.6	Daily number of additional staff called upon to assist with manual handling transfers.
Average number of Daily Tasks completed	144	Total number of individual tasks completed between three staff members.

5.1.3 Current mixed IP/OP scenario - Staff workload related metrics

5.1.3.1 Consumed staff time comparison

The metric "consumed staff time" captures the total staff time consumed for all CT process activities from patient arrival to exit from CT. For all exam types except "IV" the consumed staff time is greater for IP than OP. For the exam type "IV" the IP is cannulated in advance of coming to the CT department and does not require observation or removal of cannula Figure 5.5. The most startling difference can be observed for non-contrast exams, where OP consume 63% less resources than IP exams for the same type. Across all exam types and for all patients scanned, IPs were found to consume 23% more staff time than OP. The difference in consumption of staff time can be attributed to the manual handling and scheduling activities associated with the IP population who are less mobile and whose examinations are not scheduled by clerical staff (unlike in the case of outpatients and GP patients).

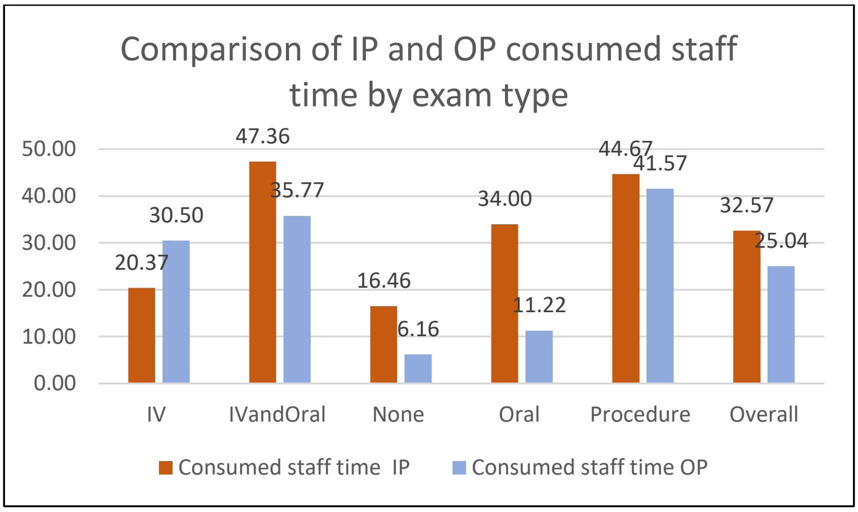


Figure 5.5 Consumed staff time for all exams

In Figure 5.6, a metric was captured in the DES model for the percentage of overall consumed time spent scanning. The decision to include this metric stemmed from the rich picture diagramming session where staff stated that the scanning was not the most onerous part of the scanning process. This is evidenced in the figure below where overall time spent scanning was shown to account for 33% and 38% of overall IP and OP consumed staff time. For "IV" and "Procedure" exams OP require greater preparation as these patients are not cannulated in advance and therefore require more preparation. The remaining two thirds of consumed staff time is spent on preparation, communications, manual handling, cleaning and other post processing/administrative activities.

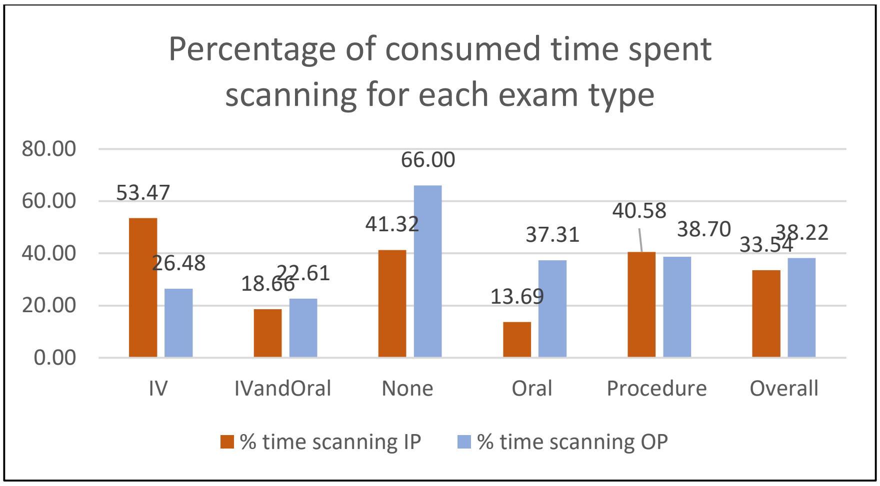


Figure 5.6 Percentage of overall consumed staff time spent scanning

Graphs were created from model output data, to depict the variation in consumed staff time for IP and OP examinations Figure 5.7, Figure 5.8, Figure 5.9. For IV exams inpatients on average less staff time was consumed owing to the fact that admitted patients and emergency department patients are generally cannulated in advance of arrival in the department and also do not require observation post scan or the removal of IV cannula post scan, unlike GP and OP.

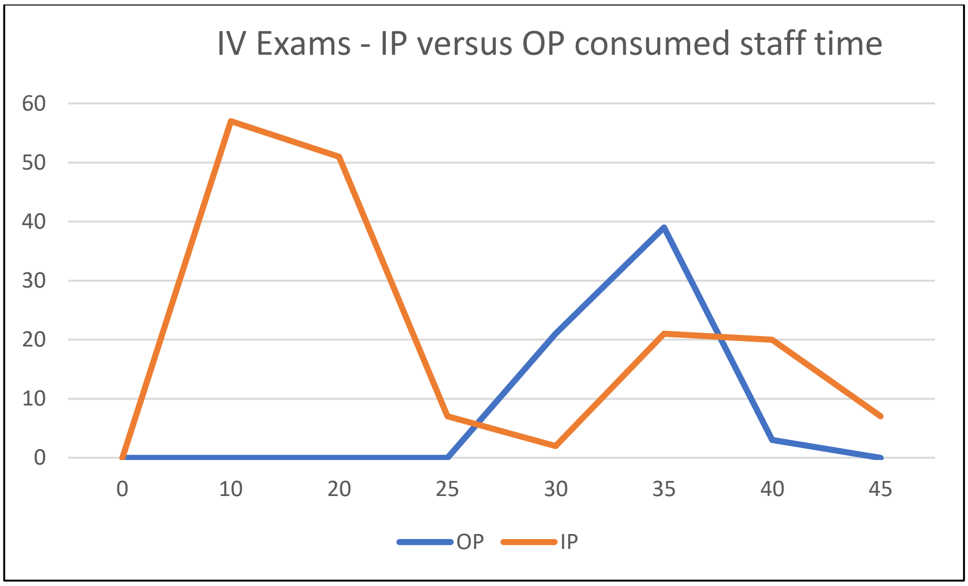


Figure 5.7 Consumed staff minutes for IV examinations

For non-contrast examinations the frequency distribution of the consumed staff time for the two patient cohorts is presented. Little variation exists in the staff time consumed for scheduled GP and OP exams represented by the blue line. Substantial variation is noted for the IP population with two peaks noticeable on the figure (Figure 5.8 and Figure 5.9). The second smaller peak can most likely be attributed to the less mobile IP population requiring transportation on a trolley and the required number of staff for manual handling.

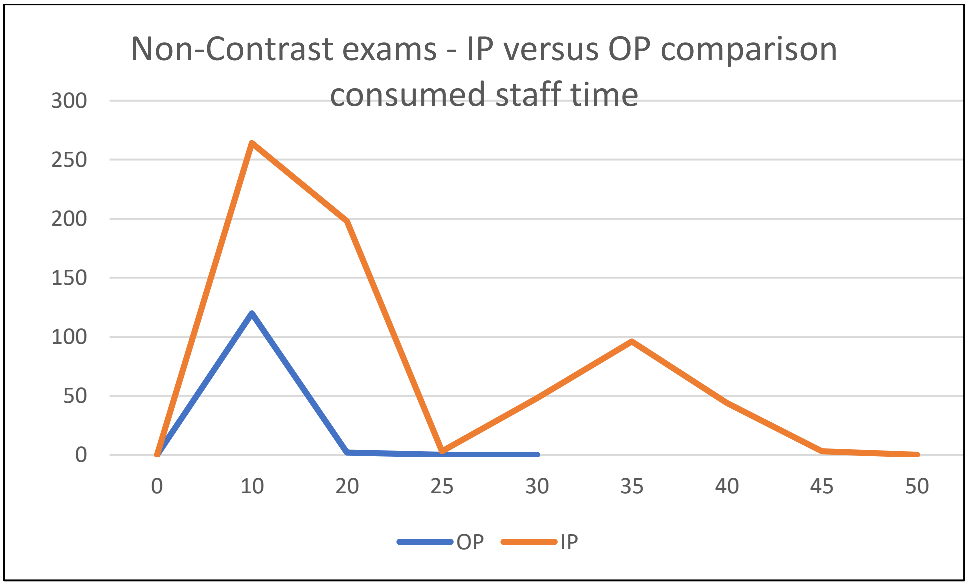


Figure 5.8 Consumed staff minutes for non-contrast examinations

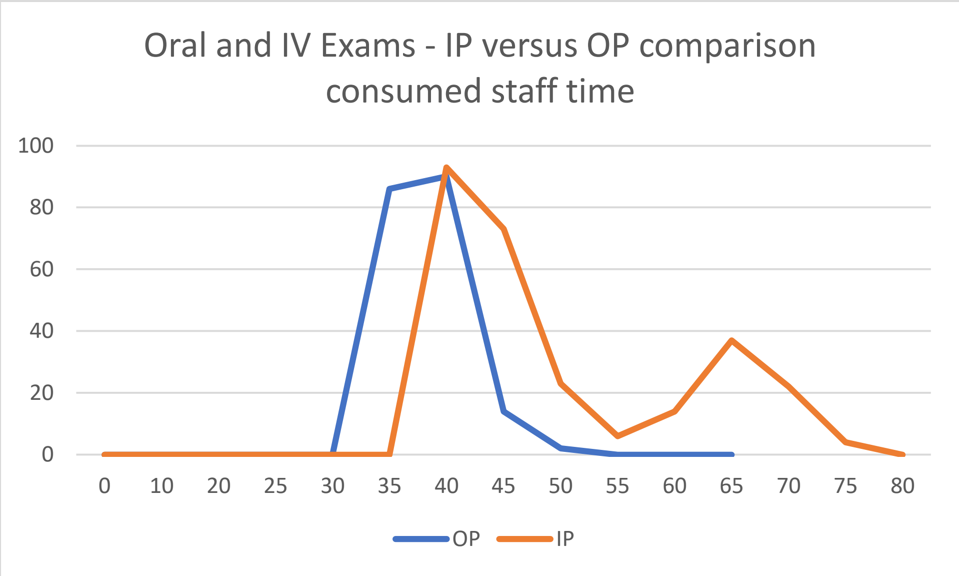


Figure 5.9 Consumed staff minutes for examinations with IV and Oral contrast

5.1.3.2 Resource utilisation in current service

A distribution frequency was plotted for radiographer and healthcare assistants and scanner utilisation and is shown in Figure 5.10. Radiographer and CT scanner utilisation are seen to be closely aligned, if the machine is operational, the radiographer is operational.

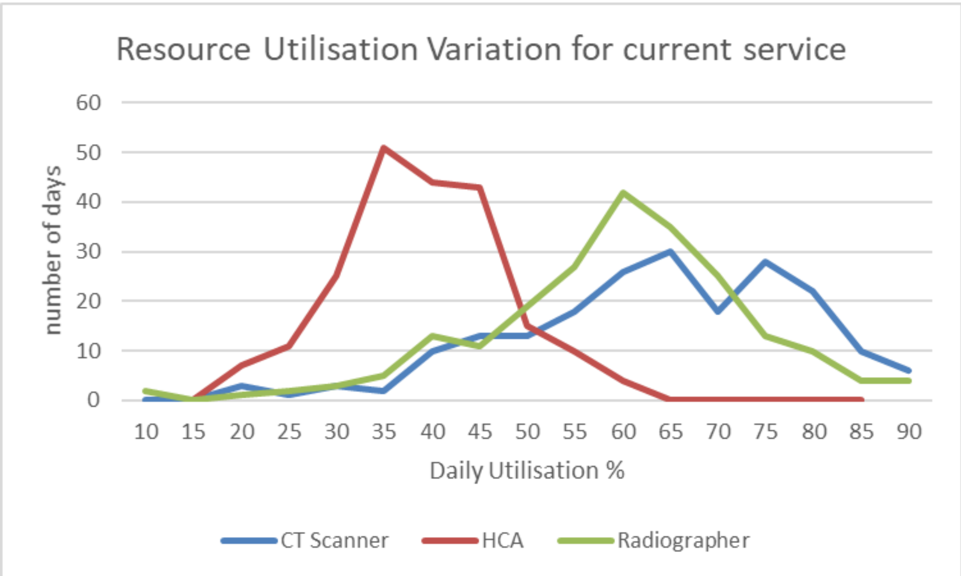


Figure 5.10 Variation in resource utilisation in mixed IP/OP scenario

Here we see that HCA utilisation lags behind the scanner and radiographer utilisation. This may well be because the HCA often assists the radiographer in whatever tasks they are undertaking at the time. This help is important to smooth workflow but not documented, as to do so would have increased the granularity of the model.

For example, while it is possible for a radiographer to flush a cannula without the assistance of a HCA, to do so would require donning and doffing of gloves or other personal protective equipment to avoid contamination of a supply cupboard where an additional saline syringe is required. The presence of a HCA negates the need for staff to take or be tempted to skip these extra steps infection control steps and represents good synergy between staff members. Such synergy is difficult to model as it would add to model granularity and take from its reusability, however further discussion will take place in Chapter 8.

5.1.3.3 Breakdown of staff utilisation under current service

Pie charts created in AnyLogic were used to present a breakdown of staff activities for weekdays for radiographers and healthcare assistants (see Figure 5.11 and Figure 5.12). A breakdown of staff utilisation by task type for radiographers and health care assistants resulted. The pie charts include all administrative, clinical and non-clinical tasks associated with scanning. As no baseline for comparison exists, the usefulness of these pie charts is in deepening the understanding for staff and decision makers of how staff time is apportioned, and this will be discussed further in Chapter 8.

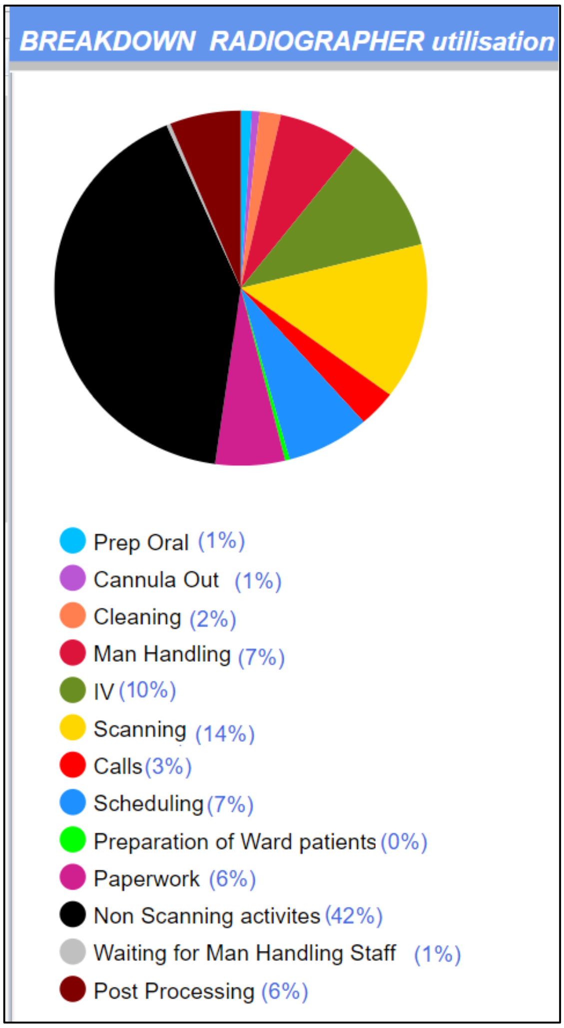


Figure 5.11 Radiographer utilisation mixed scenario

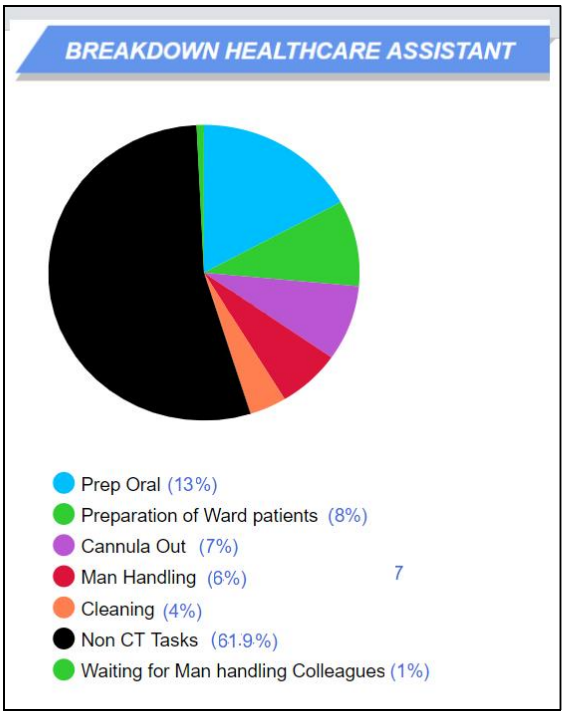


Figure 5.12HCA Utilisation mixed scenario

Average radiographer utilisation was 58%. This was broken down by activity using pie charts generated in AnyLogic. 42% of time coloured in black represents time which was unaccounted for and labelled as non-scanning related activities as per Figure 5.11. The pie chart represents the average of activities for two radiographers. The largest portion of radiographers time (14% and 10% respectively) was spent scanning and inserting IV cannulas. Paperwork, scheduling, post processing and manual handling were the next largest activities each representing approximately 6-7% of the radiographer’s time. See appendix A for tasks identified which were outside the scope of the model.

As shown in Figure 5.12, only 38.2% of the HCA time was accounted for in the model. The largest portion of HCA time was spent preparing patients for oral contrast examinations (13%) and included the time spent travelling to the wards to deliver the contrast medium (8%), the combined percentage of their time was 21%.

5.1.4 Current scenario – Radiographer utilisation KPI

Radiographer utilisation over a historic period (2017) was determined from the DES model. An over-utilisation threshold of 70% and an under-utilisation threshold of 50% was used (based on radiographer utilisation levels of 56% identified in work by (Famiglietti *et al.*, 2017). These thresholds were selected to demonstrate the potential effectiveness of using DES to monitor evidence of over and under-utilisation as departmental key performance indicators. Using an identified threshold, it is possible to identify the percentage of days on which utilisation fell above or below these values, see Figure 5.13. If a 70% threshold is used to describe over utilisation, then over-utilisation occurred on 14% of days. If a 50% threshold is used for under-utilisation, then the model evidences under-utilisation on 26% of days see Table 5.3.

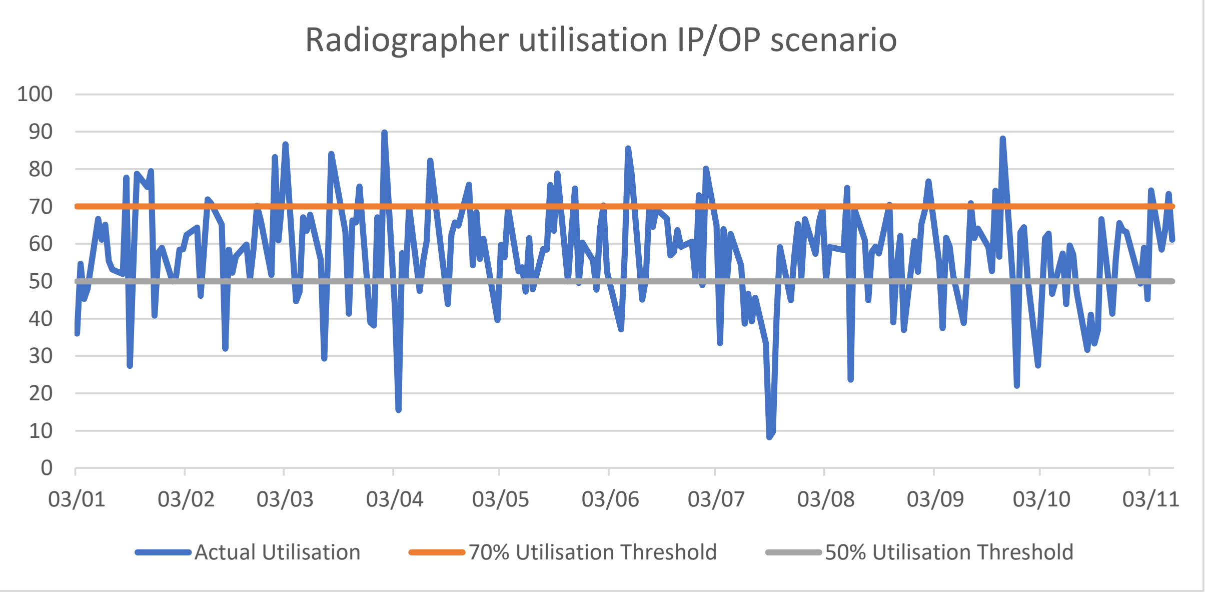


Figure 5.13 Mixed scenario measurement of radiographer utilisation KPI

Table 5.3 Cumulative Radiographer utilisation

Utilisation Range	Cumulative
10	1%
20	1%
30	4%
40	12%
50	26%
60	58%
70	86%
80	96%
90	100%

As expected, there was a strong positive correlation R^2 (210) =.68, p<0.00001 between the utilisation rate and the number of scans performed, indicating that 32% of radiographer utilisation variation is not explained by the number of scans completed per day. These findings reflect the reality of the staff experience where staff reported a high workload variation which limited the ability to schedule more outpatient work, see Chapter 0, list of issues identified during RP diagramming. Throughput and average scanner utilisation can only be increased where this variation is removed from the process, as is demonstrated next in the OP Only scenario.

5.1.5 OP Only metrics Scenario

While it is noted that the value of providing a direct comparison of the two scenarios (Mixed and OP only) is questionable, given the different patient mix and daily demand variations, a comparison between utilisation rates is made. The average scanner utilisation was found to be greater for the OP only scenario designed for the simulation where a daily total of 24 scheduled GP and OP CT examinations were scanned per day, as shown in Table 5.4. HCA utilisation was also seen to increase however the average radiographer utilisation was shown to decrease. An explanation for the increased HCA utilisation is that the HCA staff were able to perform more preparation tasks in the OP only scenario. This is not surprising considering the scenario schedules the arrival of 11 patients daily for IV and Oral contrast, which provides work for HCA staff for preparation and cannula removal post scan. In the case of the radiographer, it could be argued this decreased utilisation demonstrates that higher utilisation is not necessarily linked to higher throughput. In the OP only model staff are working "less" but are enabled to perform more value adding tasks such as inserting IV cannulas.

Table 5.4 Metrics for OP only CT scanner 24 patients per day

Process Metrics	Scenario 3 - OP Only
Scanner Utilisation 9-5	69.8%
Radiographers Utilisation 9-5	53.8%
HCA Utilisation 9-5	43.7%
Average daily flexible staff requests	1
Average Outpatient Perturbations	< 1 minute
Number of Daily Tasks completed	121
Average waiting time Out Patients	< 1 minute
Average number of scans total	24

The requirement for flexible staff was on average of 1 per day. An average of 121 individual tasks were identified per day for the CT process catering for 24 scheduled exams per day. A comparison is shown below of the comparison between the current scenario and OP only scenario as regards the number of each examination type completed per day.

Table 5.5 comparison in number of exam types completed daily

Examination type	**Current scenario**	**OP Only scenario**	**Difference**
IV	.99	3	+200%
IVandOral	2.76	10	+262%
Non-contrast	1.73	11	+535%
Procedures	2.05	0	-100%

5.1.6 OP Only staff workload

In the OP only scenario metrics a notable decrease was observed in the time spent on manual handling activities for both staff types, see Figure 5.14. Radiographers were seen to spend a greater percentage of time scanning and inserting IV cannulas, which can be considered "value-adding" activities, compared to manual handling and walking to the wards to provide oral contrast to inpatients. As expected, less time is spent on scheduling activities and phone calls as this is not required for OP and GP patients are scheduled in advance, resulting in fewer scheduling and scanning considerations as were captured in the workflow diagrams, see Figure 4.6.

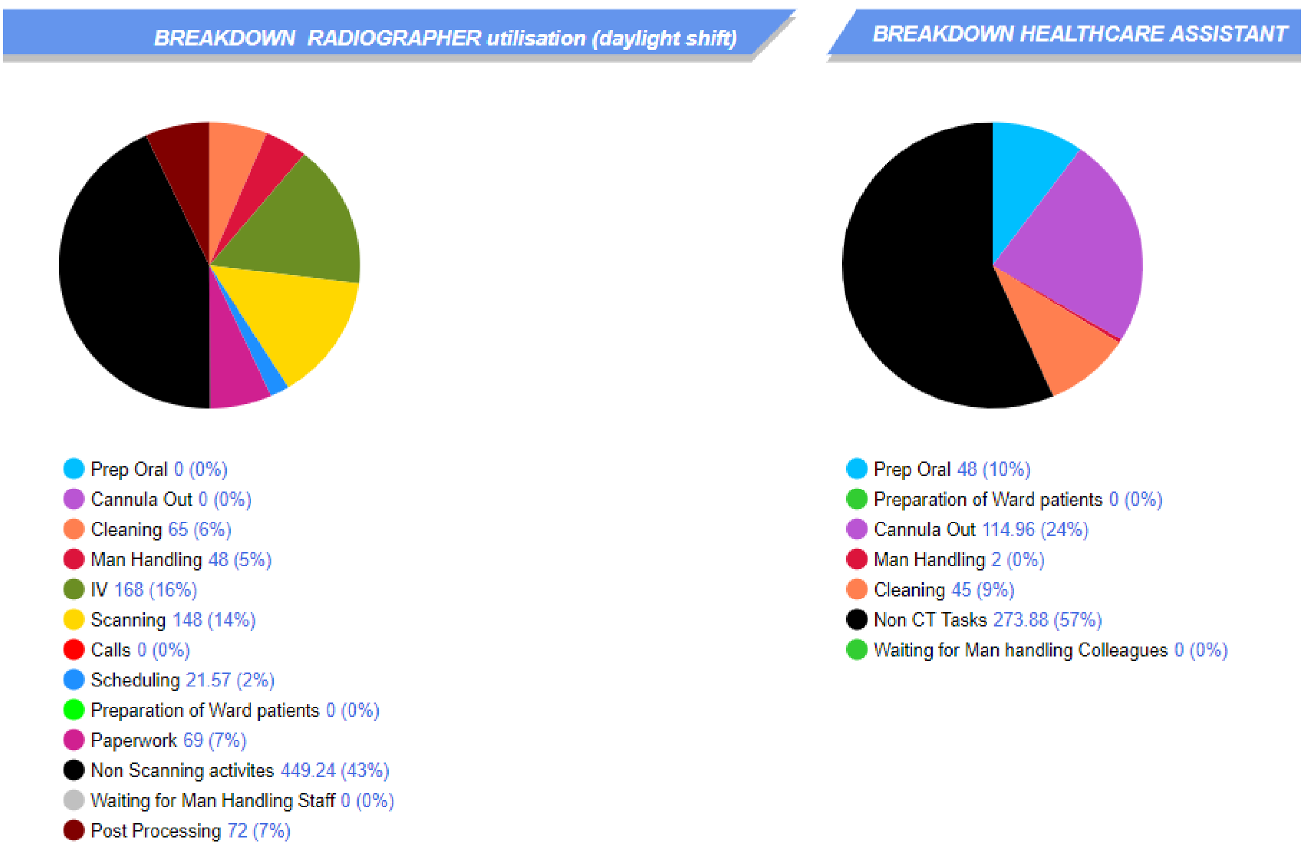


Figure 5.14 OP Only scenario staff utilisation

In the OP only scenario metrics a notable decrease was observed in the time spent on manual handling activities for both staff types. Radiographers were seen to spend a greater percentage of time scanning and inserting IV cannulas, which can be considered "value-adding" activities, compared to manual handling and walking to the wards to provide oral contrast to inpatients. As expected, there was an expected absence of scheduling activities and phone calls as all of the OP and GP patients are scheduled in advance, resulting in fewer scheduling and scanning considerations as were captured in the workflow diagrams, see Figure 4.6. HCA utilisation is greater by 8% in the OP only model, the largest change to activities being the increase between 7% and 24% of time spent removing IV cannulas.

Using DES it was possible to model the queuing of patients within the department. As can be seen from Figure *5.15*, the maximum number of outpatients being prepared at any given time is 6, this indicates that 6 preparation spaces are required for those patients who are drinking oral contrast or having an IV cannula inserted.

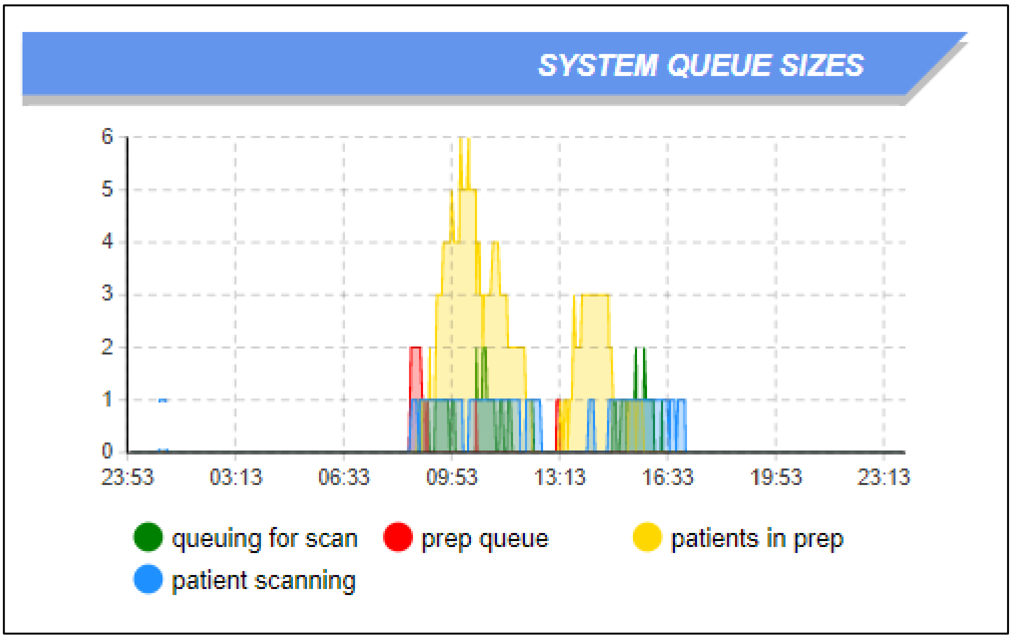


Figure 5.15 Patient queuing throughout the day

5.1.7 Scenario comparison for staff and scanner utilisation

Box plots were used to allow a comparison of resource utilisation and to summarise data, including the maximum, median, minimum, 25th and 75th percentile. In Figure 5.16 resource utilisation in the current mixed IP/OP scenario is compared with utilisation under a simulated OP Only scenario. The plus and minus error bars indicate the high variability of utilisation in the mixed IP/OP or current scenario, particularly for the CT scanner and radiographer resources. HCA utilisation was shown to vary most between scenarios. No overlap is seen between the body of the box plot for HCA (OP) and any of the other box plots. This indicates that in scenario 2 (OP ONLY) HCAs are more highly utilised, most likely due to the greater amount of preparation required for the OP examinations which are more likely to involve the administration of ORAL and IV contrast. In scenario 1 (mixed IP/OP) HCA utilisation is low as the HCA cannot do all the tasks required for patient preparation and should delays develop the Radiographers can complete tasks not attended to by the HCA in a timely manner.

Utilisation of the CT scanner varies little in the OP Only scenario from a daily minimum of 66% to a maximum of 72%, a variation of 6%. This contrasts greatly with the box plot for CT utilisation in the IP/OP scenario where variation ranges from 18% to 90%.

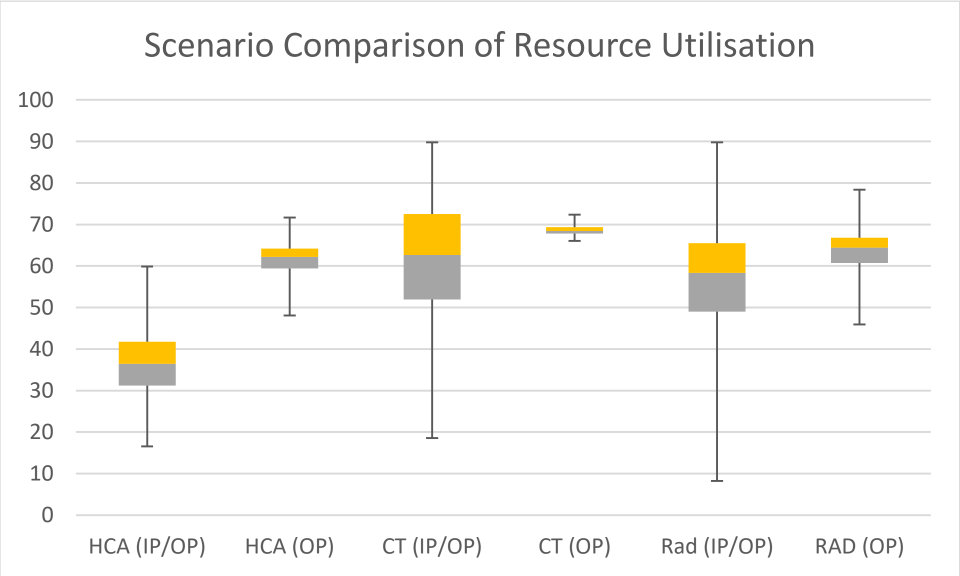


Figure 5.16 Comparison of resource utilisation for mixed IP/OP and OP only scenarios

5.2 Changes due to action research

During the many iterations of face-to-face validation and verification between researcher and Clinical Specialist, the changes which were observed to have occurred were documented. These changes include:

1. Phone calls were historically made to the clerical staff who in turn call the porters, 20 minutes prior to the IP's examination. This was identified during rich picture diagramming as an issue as the radiographers had to remember to make the call at a precise time. After discussion, the suggestion was made that the request should be made for transport at the commencement of the patient's preparation. Healthcare assistants and radiographers must pass the clerical staff as they make their way to the wards to provide oral preparation to IPs. It is at this point in the process that the change was made to put the patient's name on the list for transportation, specifying the time required. This change resulted in clerical and transport staff having more control of their work as they are aware 90 mins in advance of the task. This resulted in a reduction in the number of phone calls by 30% and eliminated the need for the radiographer to remember to call for a patient being prepared on the ward, thus reducing their cognitive workload.

2. Staff were interviewed to determine how they managed their IPs worklists, and it was identified that 3 different methods were identified. Some planned their worklist using a pre-printed paper grid, some used a white board, and some used the RIS/PACS. An initiative was undertaken to streamline how the IP list was planned and all staff were instructed to use the RIS/PACS. 30% of phone calls were identified as coming from nursing staff trying to ascertain an estimated scan time for their patients. Historically radiographers were providing verbal updates. Once all radiographers were trained on how to schedule using the RIS/PACS, staff were directed to the RIS/PACS for the estimated scan times. Plans are underway to edit the existing phone system to include an automated answering system instructing staff to check online for scan times. The number of phone calls was seen to reduce.

3. Post procedures such as CT colonoscopy and CT cardiac angiogram patients were provided with refreshments such as Tea and scone/sandwich. This required one phone

call to the canteen to be made per patient. After an analysis of workflow and nursing time involved in this process, it was decided to have a daily delivery of sandwiches and juice boxes to CT for these patients.

4. Ward staff were offered additional or refresher training on using the RIS and directed to the appropriate staff to reset their passwords. CT staff were then asked to desist from verbally providing ward staff with examination times over phone and asked instead to schedule the exam in a timely manner and ask staff to refer to the RIS for the assigned time.

5. A change took place to the process for placing a call for the porters to bring patients to radiology. Previously a call was placed ten minutes prior to the exam start time. This was altered so that healthcare assistant staff booked the porter when going to the ward to prepare the patient. The tasks was shifted to different staff and took place 90 minutes prior to the exam instead of ten minutes prior.

6. Block booking of OP slots by exam type – daily interruptions and disturbances were analysed and scheduling queries from clerical staff were observed. Clinical staff were frequently asked to consult a diary and provide advice on when to book certain exam types. A template was created and provided to clerical staff to eliminate these interruptions.

7. The CT weekend sessions was staffed by 1 radiographer. The findings from the analysis of CT demand at weekends, lead to a recommendation that a dedicated HCA for Saturday and Sunday sessions be provided. This was implemented.

8. The findings from the analysis of weekend demand recommended a dedicated CT Porter be provided for Saturday and Sunday sessions. This was implemented.

9. Recommendations from an analysis of weekend CT demand advised that additional CT radiographers be employed to increase the number of skilled radiographers available for the on-call rota. This was implemented.

10. A handover tool was created for the department because of the Rich Picture Diagramming session to improve feedback between staff on different shifts and is included in Appendix B. The handover tool remains unused.

5.3 Validation of framework with radiology decision makers

A meeting was organised to present the findings of the model to radiology and hospital with stakeholder and decision makers to determine if results could be used to inform decision making. The outputs from the scenarios identified as part of the RP building were discussed and other process metrics from the model presented.

The structure of the meeting was as follows:

- The patient profile – how workload for scheduled and unscheduled patients differ,
    - Workflow diagrams
    - Model metrics
- Discussion of OP waiting list,
    - Future projection for waiting list under different scenarios
- Identification of preferred solution by radiology decision makers

A preferred solution was identified in scenario 3 whereby outpatients were provided with a CT scanner for outpatient only scanning but which would provide redundancy and facilitate the separation of the inpatient and outpatient cohorts. The solution remains unimplemented at present though plans have been drawn up for a new CT department on the grounds of the hospital. The radiology services manager provided the following feedback, on the usefulness of the application of the framework:

"Thanks to the data analysis we initiated a CT winter initiative which has become permanent. Under this initiative we have a CT session on Saturdays and Sundays. We also obtained a HCA for the position based on the workload identified with the more complex inpatients. We needed hard data to support the decision and it was provided through the research project.

Scenario 3 is the most desirable scenario and preference, a new scanner on a greenfield site with room for a second scanner eventually. The original scanner staying in place until it expires. The time frames in weeks help support the business case."

When asked whether the department had gained from involvement in the research project the radiology service manager replied:

"The project fed into the redevelopment of the service. The department as a whole has gained from the process. We are now much more aware of how everything affects everything such as the availability of porters, the frequency of phone call interruptions, the time spent vetting OP requests. The process made us think and consider the service holistically. Where we might have previously accepted constraints, we now observe, consider, and try to eliminate or improve them. The tool may be helpful and appropriate for decision makers outside of radiology as we naturally understood patient complexity and the process complexity. It was however useful when communicating with both internal and external stakeholders."

Additionally, further applications for model use were identified by management for other areas within the department namely ultrasound and general x-ray. When asked whether the department would consider using this approach to problem solving again the radiology services manager replied:

"I would use the approach again, given the right problem and use it as part of the wider gamut of decision-making consideration. It could be used for the general x ray service. We could look at an outpatient only service. We could consider its use in a scenario where patients used an app to book appointment slots and filled out an online questionnaire about their COVID19 symptom/history. Retrospectively we could also use it to model the ultrasound service, the two streams of patients and how that service has impacted the waiting list and examine what other factors influence the successful running of a diagnostic service."

This provides an example of how the stakeholder experience of modelling has developed new inhouse expertise in problem recognition, become baked into decision making and resulted in more "intelligent" clients (Ackoff, 2010).

Chapter 6: Discussion

At the start of the manuscript the question we asked "How can we know the dancer from the dance?". The aim of this research using operational research tools, both hard and soft, was to "know" or separate out the patient complexity, the process and demand variability (see Figure 6.1). Demand for scheduled and unscheduled CT services and the different inpatient and outpatient characteristics were determined from an exploratory data analysis. Through the application of the framework additional information and previously unmeasured metrics have been ascertained. Next discussed is:

a) what has been learned about patient complexity and the resultant staff workload,
b) what has been learned about process variability resulting from patient complexity process perturbations, resource utilisation and variation of same, as well as staff workload, as shown in
c) whether the framework succeeded as a decision support tool.

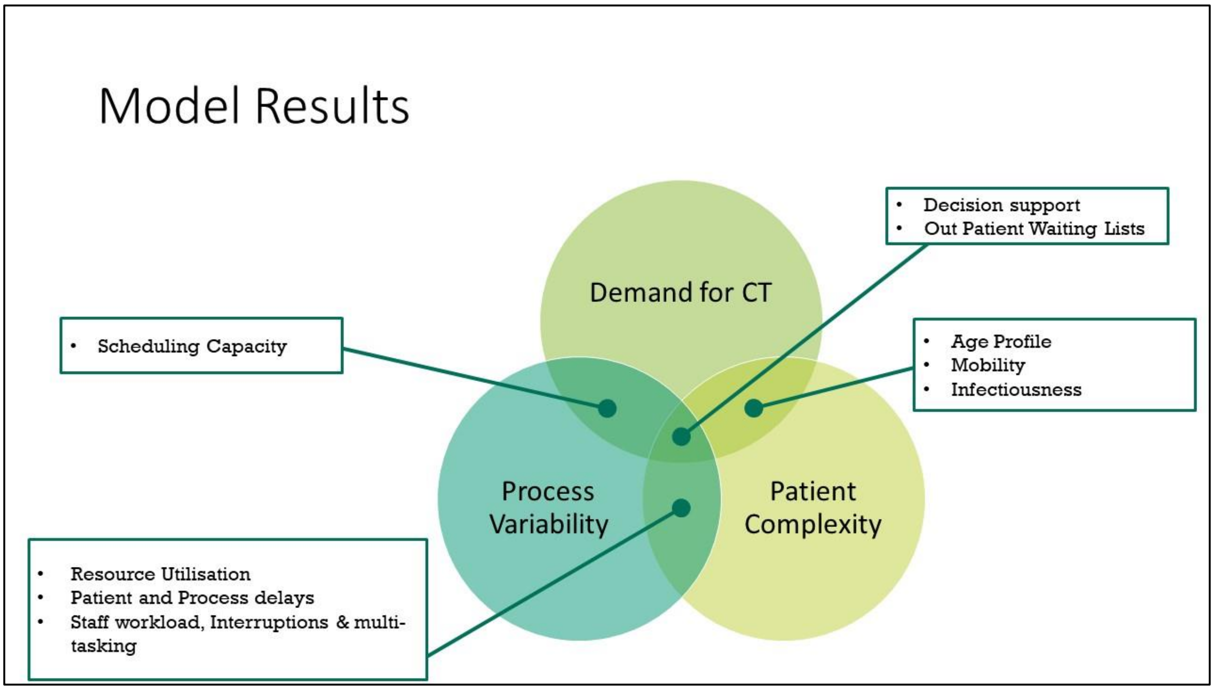


Figure 6.1 Features of service considered in DES model

6.1 Exploratory data analysis results

6.1.1 Current CT demand

The case study department provides a mixed CT service, servicing both IPs and OPs concurrently (see Figure 4.3). The results from the case study department identified an increase in the yearly number of CT examinations being completed, and significant OP and GP waiting list growth ($p>= 0.047$). The preliminary data analysis demonstrated that while the increasing demand for ED/IPs is being serviced, the demand for GP/OPs is not, see Figure 4.17.

In a conceptual SD model of the process the work identified a vicious cycle, referred to locally as "status flipping" whereby the long GP and OP waiting lists led to some patients being referred or self-referring to the ED department in a bid to circumvent the waiting lists, see Figure 4.3. The occurrence of this phenomenon is supported by the literature (O'Regan, 2015; Irish Cancer Society, 2016). Efforts are underway to offer access to diagnostics for GPs using an outsourced service model utilising private facilities for CT (HSE, 2021). The HSE and Slaintecare recognised the need for enhanced diagnostics capacity in the community and hospital in 2019 (Department of Health, 2019) .

The average number of inpatients scanned per day was found to be on 13.5 with a standard deviation of 10.5 exams per day based on 2107 data. This distribution of IP cases completed per day indicates a high variation in IP demand, Figure 4.18. A waste of resources results where the CT scanner is staffed for the highest level of production, despite the high variation in workload (Liker, 2004).

An audit of the weekend demand for CT services carried out in 2019 identified that an increase in overall CT demand coincided with improved access to the service, Figure 4.20. While the initial intention was to distribute IP demand evenly over seven days instead of the traditional five-day week, the overall number of examinations being completed was seen to increase significantly ($p>0.001$). This finding is in keeping with previous studies which identified a supplier-induced demand and highlights the need for strict clinical guidelines and regular monitoring of clinical indications as a KPI (Taylor and Dangerfield, 2005; The Royal College of Radiologists, 2017; Mildenberger *et al.*, 2020). Such system behaviour and unintended consequences are not uncommon, as to maximise one part of a system is known to result in a change in the behaviour of the overall system (Ackoff, 2010).

A later analysis of CT demand, following the start of the Covid-19 pandemic, identified that the number of CT examinations performed decreased both for scheduled and unscheduled cases, Figure 4.21. Post COVID-19 it is reasonable to expect a surge in demand and exacerbation of waiting lists, considering the number of rescheduled appointments and undiagnosed cases (Brick and Keegan, 2020; Abadal *et al.*, 2021).

6.1.2 Patient complexity

Age and infection profiles of the IP and OP cohorts were identified during RP diagramming as important factors affecting radiology staff workload and service capacity. An analysis of patient age and infectiousness data found that the likelihood of an IP being documented as infectious increased with length of stay; inferring that access to CT should not impact length of stay lest it contribute to the probability of a hospital acquired infection (Kudyba and Gregorio, 2010). Using restricted logistic regression, age and likelihood of infection were also seen to be closely related (p-value = 1.268e-07) inferring that infection control will become increasingly important as the population ages (Health Services Executive, 2015). While the infection status of GP and OPs were not available for analysis, they are generally treated with standard precaution infection control measures. When a patient is positive for, or suspected of, an infection, extra time is required to correctly don and doff personal protective equipment (PPE), isolate patients and to allow for CT scanner cleaning and drying time (Health Service Executive, 2009). Adequate staffing and time per patient should be ensured to avoid poor infection control practices and minimise scanner downtime.

A breakdown of studies by exam type for ED/IP and GP/OP showed that 64% of unscheduled (IP and ED) exams were non-contrast, compared to only 33% of scheduled exams (OP &GP). Non-contrast exams require little or no preparation and have the shortest scan times, indicating that IP exams are generally are less complex than OP exams. 33% of IP examinations were found to involve the use of IV contrast which is administered through a IV cannula. Outpatient examinations are more “complex” technically than inpatient examinations.

Data regarding patient mobility differed between that observed and that recorded on the patient information system (PAS). The (PAS) recorded that 10 percent of patients required a trolley for transportation, while that observed was 26 percent. The difference could indicate that the information system did not provide up-to-date data on the condition of the patient or that patient mobility decreases post admission. With one in four inpatients requiring four staff to assist in a patient transfer, patient mobility has implications for workload and adequate staffing should be ensured to reduce delays and decrease the risk of occupational injury (Kumar, Moro and Narayan, 2004). Previous research reported that poor manual patient handling practices can be related to time pressure and can result from coercion by other staff to complete a patient transfer without the appropriate number of staff (Ngo, Schneider-Kolsky and Baird, 2013). Huang and Marcak considered patient obesity and mobility jointly when considering four categories of mobility, where the least mobile category included patients whose weight exceeded 350kg (2013). Decision-makers should be aware of how dependence on flexible staff for manual patient handling can lead to time delays, an increased risk of unsafe practices and subsequently occupational injury.

Inpatient and outpatient profiles were found to differ significantly in terms of mobility, infectiousness, age and exam complexity and further research using modelling and simulation is warranted to measure the effect of these differences on the CT process, waiting lists and staff workload. These findings from the exploratory phase provide some of the input parameters for a simulation model of the CT process.

6.1.3 Results from survey of Irish radiographers

Irish radiographers reported in the survey that there is still a reliance on paper and white boards for management of patient worklist lists and for collating important information relevant to the patient scan. An overwhelming majority of radiographers (84%) indicated a lack of trust of blood results typed into the PACS and verified these results against the laboratory information system. Further research is advised into the usability of the information system and its effectiveness in supporting the CT workflow. Considering that an estimated 10% of radiology errors are attributed to communication issues, further investment in the information system is recommended to enhance usability and decrease the cognitive workload associated with patient scheduling and scanning (Swensen and Johnson, 2005; Gomes and Romão, 2018; Mazur *et al.*, 2019).

Only 35% of radiographers reported that they generally have sufficient staff available for patient transfers inferring that 65% experience regular delays where they must find available staff to assist with a patient transfer. Evidence of the physical nature of radiography is provided, with 60% of radiographers reporting a history of back pain or repetitive strain injury. This is supported by further work where 83% of female radiographers reported experiencing back pain (Kumar, Moro and Narayan, 2004). The daily work of radiology staff requires lifting, pulling, turning, and general moving of patients. These repetitive handling and mobility tasks put them at high risk for a musculoskeletal injury (Ngo, Schneider-Kolsky and Baird, 2013; Hallmark, Mechan and Shores, 2015). 48.33% of Radiographer who complete the survey reported that they sometimes make do with below recommended numbers of staff when carrying out manual handling. This substantiates research that suggests work related pressure to scan faster and save time may result in unsafe manual handling practices (Ngo, Schneider-Kolsky and Baird, 2013). The use of alternative means of transferring patients, for example the use of ceiling hoists, should be considered, to reduce the potential for occupational injuries.

Radiology is a dynamic working environment where the allocation of medical staff is flexible and tailored to current patient demand. Thorwarth investigated patient pathways in relation to the workflow of medical staff with the consideration of dependence on limited resources. The benefits of a flexible scheduling strategy are flexible work allocation and spontaneous adjustment of work force to demand (Thorwarth, 2011). Flexibility however incurs delays where staff are randomly required then released throughout the day.

6.2 Modelling Patient complexity

6.2.1 Age and infection

DES Model data pertaining to the pre COVID-19 service, indicated that staff spend between 3% (radiographers) and 4% (healthcare assistants) of their time involved in cleaning activities. Rich picture diagramming and workflow mapping best captured the cognitive workload associated with the scheduling of inpatient exams and increasingly so for infections such as COVID-19, as evidenced in Figure 4.6 and Figure 4.13.

As a result of the COVID-19 pandemic, additional staff idleness and scanner downtime results where thirty minutes to one hour of scanner downtime is required before a scanner may be cleaned in the case of suspected or confirmed COVID-19 cases (Health Service Executive, 2009; Mossa-Basha *et al.*, 2020; Orsi, Oliva and Cellina, 2020; Zanardo *et al.*, 2020). As the country's population ages and the COVID-19 pandemic continues, the likelihood of IPs presenting as infectious or being suspected of such is set to increase, and accordingly, the associated radiology workload for these cases and scanner downtime due to cleaning and the separation of infected and non-infected cohorts (Homer, Hirsch and Milstein, 2007; Zanardo *et al.*, 2020).

6.2.2 Mobility

Patient mobility was identified during the RP diagramming session as a factor contributing to radiographer workload and process delays. Using DES, manual handling activities were found to constitute 7% of HCA daily activities and 6% of each radiographer's daily activities. The CT scanner is staffed by two radiographers and one HCA, however four staff are required for manual handling where a patient is transported on a trolley. DES quantified the service dependence on flexible staff, indicating that on average 14.6 requests were made on a daily basis for flexible staff to assist in manual handling transfers. The time spent seeking these additional flexible staff was found to results in work perturbations. As expected, this was greater in the mixed scenario and contributed to the higher consumptions of staff time for IPs (Figure 5.5). These frequency of these requests for flexible staff provides evidence of the multitasking nature of radiography staff where staff are interrupted from their core work to assist with manual handling activities in the CT department.

With one in four IPs requiring four staff to assist in a patient transfer, patient mobility has implications for workload and adequate staffing should be ensured to reduce delays and decrease the risk of occupational injury (Kumar, Moro and Narayan, 2004). The exploratory survey of Irish radiographers revealed that 60% reported as suffering from backpain and 48% admitting to performing manual handling activities without adequate numbers of staff. This corresponds with previous research which suggested that work related pressure to scan faster and decrease the time spent per patient can lead to staff resorting to unsafe manual handling practices, (Ngo, Schneider-Kolsky and Baird, 2013). Decision-makers should be aware of how a dependence on flexible staff for manual handling, which was quantified using DES modelling, can lead to time delays, an increased risk of unsafe practices and the risk of occupational injury.

A recommendation for additional staff specifically to assist in manual handling could result in waste in the form of unevenness where the correct number of people, equipment and materials are on hand for the highest level of production though only intermittently needed (Liker, 2004). A recommendation is made for the future employment of multitask assistants (MTA) who combine the role of healthcare assistant and porter. These individuals should be trained to use the RIS and refer to the schedule to bring patients to the department at scheduled times and assist with patient preparation as well as manual handling when required. Such insights as provided by the model demonstrate the model's potential to assist in decisions pertaining to future staffing.

6.2.3 Examinations

Data from a historic run of the model indicated that in the mixed IP/OP scenario the consumed staff hours for IP CT examinations were found to be greater than those for OP examinations Table 5.1, showing a greater consumption of staff time by unscheduled (IP and ED) patients. Five categories of examination types were considered. For exams requiring IV contrast inpatients were found to consume less radiology staff hours than outpatients. This was an unexpected finding. On closer investigation it was realised that in the case of IPs cannulas are inserted in advance on the wards or in the emergency department meaning that radiology staff do not have to insert IV cannulas, thus accounting for this result. This however may not necessarily mean that these examinations are completed in a timelier manner. In a survey of Irish Radiographers 75% of respondents felt that extravasation (unintentional leakage of saline or contrast from the vein into the surrounding tissue) was more likely to occur in patients cannulated outside of the radiology department (Cleary *et al.*, 2017). Additionally, cannulas that have been in place for more than 24 h are a known risk factor for extravasation (ibid). Extravasation caused during injection results in unforeseen delays and process perturbations, and requires the completion of incident form, which was also highlighted during rich picture diagramming. Clinical consequences of contrast extravasation for the patient can vary from minor pain and swelling, to serious cases of skin ulceration and compartment syndrome (Cleary *et al.*, 2017). While IP undergoing IV examinations may require less preparation time, there is an increased cognitive workload required to schedule these exams, plus a heightened awareness that extravasation risks are increased.

The use of oral contrast is currently required for all ED cases however studies have shown that the implementation of IV only exams for CT TAP exams positively impacts both radiology and emergency medicine workflow and does not result in reduced image quality (Razavi *et al.*, 2014). This however is a clinical decision, and the current protocol includes the use of oral contrast (see appendix C). The radiographer time spent scanning as a percentage of overall consumed time was captured in the DES model in a response to feedback from radiographers who identified during RP diagramming (issue 20) that "It's not the actual scanning work, it's the planning." The information from the model clearly demonstrated than in the mixed scenario the percentage of time spent scanning is less for IP, indicating that an increased proportion of time is spent scheduling, preparing, and cleaning. Not surprisingly in the OP only scenario, radiographers were found to spend a higher proportion of time scanning, which is clearly one of the highest value adding activities in the process (Womack, Jones and Roos, 2007).

6.2.4 Future weighting of Radiology examinations

Infectiousness, mobility and exam type were demonstrated to impact staff workload in terms of consumed staff time. Therefore, their inclusion in the weighting of CT exams could provide a more weighted and nuanced measurement of staff workload. Examples have been identified in the research of the weighting of radiologist workload to provide more nuanced calculation of workload (RCSI, 2011; Cowan, MacDonald and Floyd, 2013). An example was created of a scoring system for integration with the existing information system to provide a means of weighting exams, Table 6.1. It is however recognised that providing such information incurs a time cost for staff by adding a new task to the workflow. The example is given of the "devils quadrangle" which identifies the trade-off that occurs between time, cost, quality and flexibility when introducing a redesign measure (Reijers, 2002)

Table 6.1Weighting patient examinations

Score	Minimum score	Maximum score
Infectiousness No = 1, Yes = 2	1	2
Exam Complexity No contrast = 1, IV only = 2, IV and Oral = 3, Procedure = 4	1	4
Mobility Walking = 1, Wheelchair = 2, Trolley = 3	1	3
Patient Care Normal = 1, Moderate = 2, High = 3	1	3
Complexity Range	4	27

It is recommended such data be displayed at the end of each CT exam and the radiographer asked to confirm on completion. If captured these metrics could be analysed and compared year on year and could also be used to justify staffing decision and resource allocation, providing a less reductionist representation of workload than that provided by simply the count of examinations carried out per year (Naylor, 1992; Ondategui-Parra *et al.*, 2004; Pitman and Jones, 2004; RCSI, 2011; Khan and Hedges, 2013). This could then allow comparison of workload between sites, as it would include aspects of complexity. It is finally recommended that a free text box be provided to indicate any additional patient care needs experienced during the examination. It is however recognised that providing such information incurs a time cost for staff by adding a new task to the workflow. The example is given of the "devils quadrangle" which identifies the trade-off that occurs between time, cost, quality and flexibility when introducing a redesign measure (Reijers, 2002)

6.3 Modelling Process Variability

6.3.1 Cognitive workload

A key motivation of the work was to apply DES to quantitively capture moments of high workload, in particular interruptions and multitasking, so as to improve the accuracy and efficiency of work in the CT department, which is a safety critical settings (Walter, Dunsmuir and Westbrook, 2015). To achieve this aim, the model was designed to capture evidence of the objective cognitive workload including resource utilisation, variation in resource consumption per patient type and the number of tasks completed per day. It can be claimed that the model successfully captured the objective workload of staff in terms of the number of hours spent on work and provided a detailed breakdown of these work activities using pie charts (Gregory, Russo and Singh, 2017). For radiology managers wishing to make interventions aimed to address workload-associated burnout, DES can provide evidence of the objective workload factors.

RP diagramming proved a useful tool with which to elicit staff's subjective cognitive workload by sharing their perspectives and frustrations, as well as the requirement to multitask and collate data etc. (see Figure 4.38). The list of issues which resulted from the RP diagramming process included reference to the information system suggesting that it does not support the radiographer's workflow and contributes to cognitive workload. One radiographer stated:

"*Managing the IP worklist is more of an art than a science and requires skill and experience. It's nearly a requirement to remember patient names and their bloods results so as to respond quickly enough to all of the phone calls and queries of other staff.*"

Staff identified how information regarding the patient's blood results needed to be verified on a separate laboratory information system and how at the point of scanning radiographers are required to toggle between two screens to ensure that they had visibility of the clinical history and comments and blood results/prompts. Staff cited fear or mistrust of the prompts as a reason for their verification of the blood results on the laboratory information system, Chapter 5.5.1.

"Doctors do not always fill in the prompts correctly and we have learnt not to trust them (the prompts). All lab results are verified against the laboratory system which requires moving to a different PC. You frequently get interrupted moving between PCs or have to ask someone to work with you to call over the dates of birth of patients."

As a workaround some radiographers reported using a paper schedule to organize the daily list and document the blood results and other considerations such as pregnancy and infection status on said paper schedule, thus evidencing a burdensome workflow, awkward ergonomics and a gap between how the system is used and how it was intended to be used (Unertl *et al.*, 2009; Bundschuh *et al.*, 2011; HIMSS, 2011; Mazur *et al.*, 2019).

The cognitive effort required to navigate the information systems was best captured during workflow mapping of IP scheduling and scanning (see Figure 4.6 and Figure 4.9). It is reasonable to suggest that the ability of the department to scan patients may in part be constrained by the cognitive effort required to safely organize IP exams while dealing with interruptions (Gregory, Russo and Singh, 2017; Gomes and Romão, 2018). It also seems plausible that the information system may not support the workflow or may require enhancement. Recognising the need for an IT system to evolve, Sachs and Long (2015) provided a template for radiology departments struggling to manage radiology workflow using their EHR. The template allowed to them to evaluate, prioritize, and implement staff requests for workflow repairs and improvements and additional functionality within the EHR (Sachs and Long, 2015). Findings from a King's Hospital report on shaping the future of digital technology in health and social care recommended that capability be built for continuous adaption and improvement by embedding change management processes in digital leadership development schemes and supporting the enhancement of digital skills (Maguire *et al.*, 2021).

The ability to manage the CT workflow was described during rich picture building as "*more of an art than a skill"*. Indeed workflow planning has previously been recognised as a tacit skill likely developed through unsystematic training (Zhang *et al.*, 2018). Also recognised is how an individual's perception of workload may be in part due to subjective differences at an individual level, and not solely a function of the objective work environment (Gregory, Russo and Singh, 2017). However, efforts should be made to minimise the cognitive workload associated with information system usage and should the cognitive workload of inpatient scheduling fail to be reduced through IT enhancement, additional staff are recommended to complete scheduling tasks and to allow for the phone call interruptions to be removed from the scanning service.

In conclusion the work recommends that key performance indictors be adopted by the department for regular audit which track system usability, interruptions, and user satisfaction with information systems such as RIS and PACS. Results from such audit findings could lead to opportunities for further training and requests to IT system providers to improve usability. Considering that an estimated 10% of radiology errors are attributed to communication issues, further investment in the information system is recommended to enhance usability and decrease the cognitive workload associated with patient scheduling and scanning (Swensen and Johnson, 2005; Gomes and Romão, 2018; Mazur *et al.*, 2019).

6.3.2 Radiographer Workload/Utilisation

Using historic arrival times, the model was used to provide baseline metrics for the current service and simulate alternative scenarios, see Figure 5.11. Using DES to model the difference between the IP and OP populations it was found that inpatients caused greater perturbations to the CT workflow, consumed more staff time and that a lower percentage of total consumed staff time was spent scanning than for the OP populations. Results from the DES model determined the average staff time consumed for IPs to be greater than that consumed by OP for all examination types except "IV" exams. In the case of non-contrast exams IP consumed 127% more staff time than OP (Table 5.1).

When comparing the model outputs for the mixed scenario simulation with OP only scenario higher scanner utilisation was observed for the OP only scenario. Interestingly however radiographer' utilisation was discovered to be less for the OP scenario despite a greater average number of patients being scanned (21.8 (sd = 6) compared to 24). The process perturbations owing to the scheduled population (OP and GP) in the OP only model were found to be less than one minute per patient, with OP experiencing delays of less than one minute also. The HCA utilisation was seen to increase between the mixed and OP only scenarios by approximately 5% due to the increased preparation required for the OP population. As expected, the requirement for flexible staff to assist with manual handling fell from the daily average of 24 to 1. The number of individual tasks completed per day fell from 144 to 121, despite an increase in the number of patients being completed, a result which is indicative of a decrease in multitasking in the OP only scenario. This can be attributed to the removal of phone calls related to scanning and IP enquiries which were eliminated, as well as decreased manual handling activities. While this is not broken down by individual staff member it goes some way towards evidencing the multitasking nature of the radiographer and HCA work. Several studies, particularly involving ED staff, have shown that there is information loss during interruptions, and that multitasking creates higher memory load, both of which contribute to medical error (Chisholm *et al.*, 2000; Laxmisan *et al.*, 2007; Westbrook *et al.*, 2010).

In the baseline scenario (mixed IP/OP), staff utilisation rates of 57% and 38% were found for radiographers and HCA respectively. Staff expressed concern at these apparently "low" rates, however two points must be made. Firstly, the result represents involvement in physical activities and does not include the time spent on cognitive tasks or the tasks identified in Appendix A. The second point to be made is that there was no baseline with which to compare this metric and there is no reason to consider this as underutilisation of staff resources. A comparison across radiology sites would require the same means of modelling to be used for both. A radiation oncology centre used DES to model their process as part of quality improvement initiative and reported similar utilisation rate of 56% for staff and 58% for equipment (Famiglietti *et al.*, 2017). It should be noted that no baseline for diagnostic radiographer utilisation, capturing 13 tasks in total, has previously been captured using DES and that the baseline applies to the case study hospital and its mix of Inpatients and Outpatients, its workflow and CT demand.

While DES successfully captured scanner utilisation it was less successful in capturing staff utilisation as evidenced in the list of tasks not included in the model (Appendix A). Inclusion of these tasks in a DES model would increase complexity of model design and decrease its usability across other sites. Unlike the many actions which staff undertake, the CT scanner as a resource is limited to the single tasks of producing the diagnostic images. Qualitatively during RP diagramming the staff resources required for patient preparation, manual handling, infection control, as well as physical space for patient preparation and observation were also recognised as factors which limited process capacity. DES proved useful for capturing staff workload directly related to CT service provision and has contributed to the body of knowledge on the subject by providing a baseline for utilisation in a mixed and OP only scenario and a detailed breakdown of tasks (thirteen for radiographers and seven for healthcare assistants).

The model captured metrics not previously available to managers such as the staff time spent scheduling and answering calls. Phone calls occur during scanning therefore presenting opportunities for distraction and pressure on the scanning radiographer to multitask. Results demonstrated up to a maximum of 12 calls per hours are made or received at the CT scanning console, where patients are scanned, and injections started, see Figure 4.31. The data would indicate the department and wards are heavily dependent on verbal communication with an average of 3 calls resulting from each IP examination. It is also noted that the time spent by radiology staff waiting for someone to answer the phone is not included. The work recommends that interruptions resulting from incoming calls be monitored as a KPI and if possible that the phone be removed from the area altogether. The monitoring of incoming calls is a suitable metric as it is reproducible, attributable to radiology performance, and involve events that occur in sufficient numbers to make statistical evaluation measurable (Donnelly *et al.*, 2010). While every effort was made to model the tasks involved in planning the IP list by including the phone calls made to do so, the model did not and could not include the proficiency of staff or their tacit, local knowledge which affect their abilities to run a smooth list (Zhang *et al.*, 2018).

The DES model captured radiographer workload in terms of utilisation. When this data was outputted, upper and lower thresholds were applied to identify the number of occasions these thresholds were exceeded in Figure 5.13. The research provides a benchmark for the case study department and identified a threshold with a view to inviting further work into the area of radiographer workload and stimulating debate. In conclusion, DES has evidenced that higher work perturbation times are attributable to IP as opposed to OPs (11.9 minutes versus 1 minute) thus confirming their status as "schedule busters" and the OP status as "scheduling buffers" (Reinus *et al.*, 2000; Murray, Halligan and Lee, 2017). This work recommends the elimination of the routine OP work from the IP service to allow staff to deal with the inherent complexity of IP work identified herein. Figure 6.2 summarises the nature of mixed and OP only services in relation to cognitive workload and demand variation.

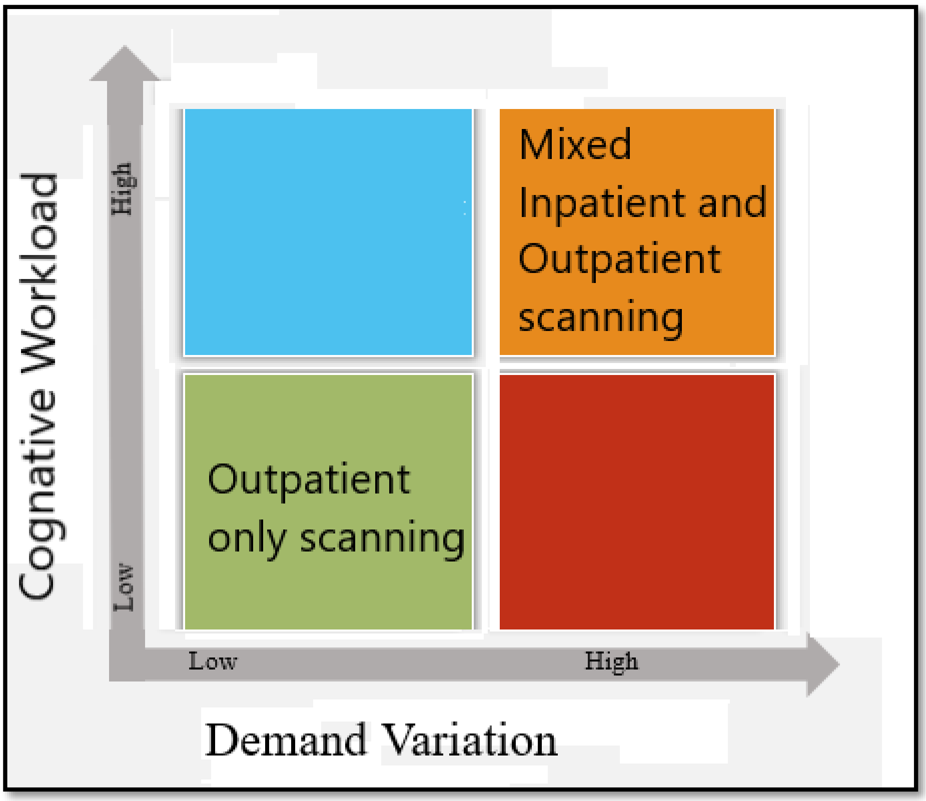


Figure 6.2 Matrix of cognitive workload versus demand and workload variation

Evidence from the DES model data supports the separation of IP and OP cohorts, evidencing that on an aggregated level the IP service limits the OP service due to the high variability in IP demand Figure 5.10 and Figure 4.18 as well as Inpatient work perturbations Table 5.2. Improved staff utilisation was identified as a potential benefit of separated OP scanning as the DES model outputs demonstrated the decreased demand variation as well as resource utilisation variation in an OP only scenario, see Table 5.4.

Mixed IP/OP CT service provision is conducive to waiting list growth, as a result of high patient complexity and high process variability limiting the OP capacity (Figure 5.5 and Figure 5.10). Diminishing returns (Cannan, 1892), can be expected from further investment, in mixed (IP and OP) model CT services as was demonstrated during the conceptual SD modelling of the service, see Figure 6.3 based on Figure 4.3 captured using system dynamics during the conceptual modelling phase.

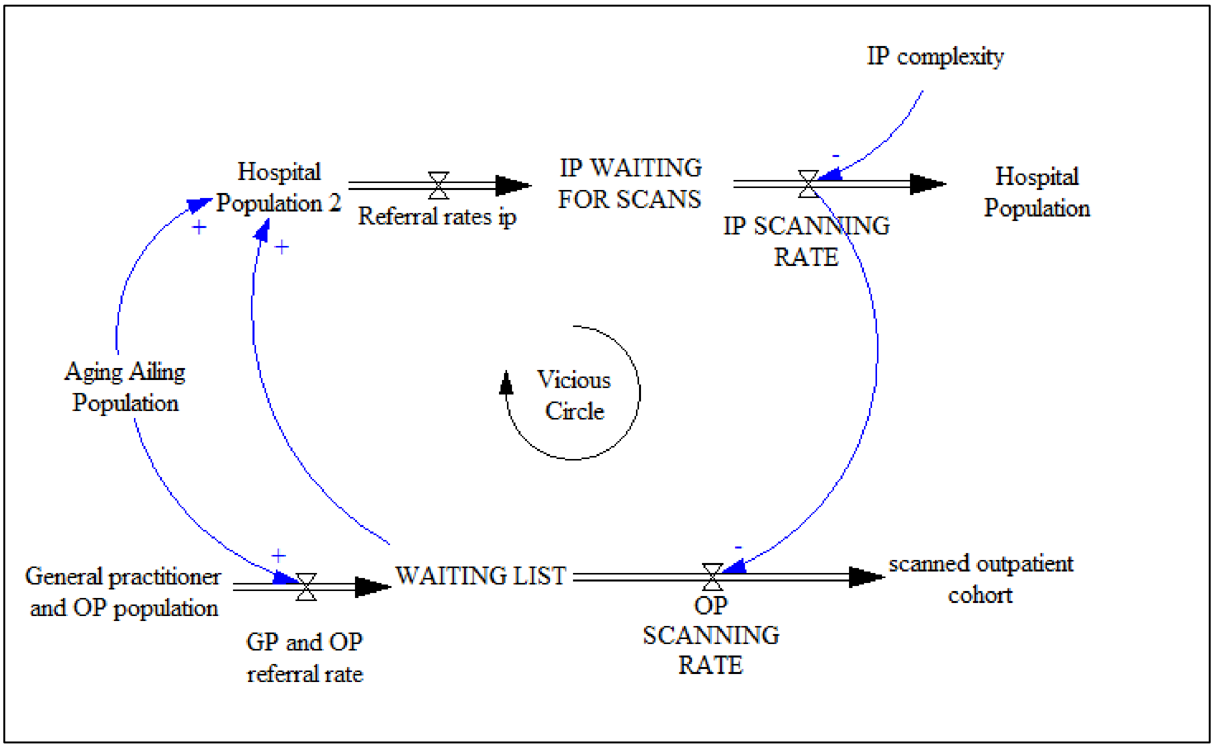


Figure 6.3 The diminishing returns of mixed IP/OP scanning

In conclusion, on an aggregated level the IP service affects the OP service where these cohorts share staff and scanner resources in two ways:

1. Delays experienced on day of examination - when attending for exams OP are subjected to the IP variability through delays related to infection control related downtime, transportation issues, manual handling delays perturbations as shown in Figure 5.5.

2. Delays experienced on waiting list – The number of OP examinations scheduled daily is limited to 8 however the demand exceeds this, see Figure 6.3.

As previously suggested in the literature, IP and OP CT services are effectively different businesses and should be operated as such (Boland, 2008). The findings from the DES model support the separation of IP and OP cohorts and confirm the research hypothesis that on an individual level, IPs utilise more resources than OPs. Separate CT scanners for IP and OP cohorts are recommended to meet the OP demand, especially considering downtime advised for positive or suspected COVID-19 patients.

In the OP only scenario fewer interruptions from phone calls and fewer requests for manual handling staff were observed. Scanner utilization was higher despite a decrease observed in radiographer utilization. Radiographers had lower utilization rates, however they were observed to spent more time scanning which can be considered a high value adding activity (Womack, Jones and Roos, 2007).

Research Question 1 asked whether "**Operational Research methods (could) be used to capture metrics for staff workload and the staff experience of providing a CT service?".** The outputs, both hard and soft, from the research methods deployed, have provided evidence of the cognitive and objective workload of staff and their experience of providing a CT service. DES proved a suitable tool for capturing information for each discrete patient and resource i.e. CT scanner and healthcare workers. Novelty lies in the granularity of detail obtained for each agent and for each of the simulations.

6.4 Recommendations and implications for practice

The following recommendations are made for the case study department, resulting from the application of the framework.

1. For infection control reasons and to maximise scheduled care, the OP and GP service should be separated from the IP service. When scheduling OP and GP patients the patient mobility and infectiousness status should be determined in advance to ensure manual handling resources are available and longer appointment slots are allocated.

2. Operational issues such as skill mix, lack of preparation space, were identified as constraining the current service and should be addressed regardless of which scenario is implemented. Other issues identified such as the poor usage of RIS provide opportunities for further development and integration of existing information systems, (RIS and PACS and Laboratory information systems) to allow more streamlined CT workflow.

3. It is recommended that staffing be provided to cover tea and lunch breaks to reduce setup times and allow load balancing throughout the day. Figure 4.19 demonstrates the decrease in patients scanned per hour as a result of preparing to go on breaks and returning from breaks, evidencing the effect of set up time (Womack, Jones and Roos, 2007)

4. A recommendation is made for the future employment of multitask assistants whose role combines both healthcare assistant and porter activities. These individuals should be trained to use the RIS and refers to the schedule to bring patients to the department at scheduled times and assist with scanning and manual handling when required. This MTA could additionally prepare patients for their scans and removed IV cannulas post scan, as well as providing transportation to and from radiology.

5. The work recommends that system usability and user satisfaction with information systems such as RIS, PACS and integrated HER be adopted as a key performance indictor for regular audit. Phone call data should be included in these KPIs as an indication of whether staff obtain data from the RIS or through making calls.

6. Coordination of the patient lists is recognised as an important, yet informal and tacit skill required for the smooth functioning of a modality worklist. A recommendation is made that training should be provided at undergraduate level to radiography students on modelling methods such as system dynamics, rich picture diagramming, process mapping to increase system thinking capabilities and problem solving skills among healthcare professionals.
7. Nationally, it is recommended that the yearly analysis of radiology volumes in terms of the number of examinations completed should be weighted to include mobility, infectiousness and examination type. This would allow a more accurate workload comparison between sites and between time periods and would better inform staffing for the department.

6.5 Review of Framework application

The framework is holistic, practical, and is applicable across other radiology modalities. The developed framework allowed for the inclusion of the quantitative and qualitative inputs for problem structuring, validation, and verification and for the identification of simulations. The main strength of the framework was its ability to engage staff. The framework accommodated the repeated returning to the problem conceptualisation stage, which in turn led to further model modification, and scenario identification.

Though a PartiSim approach was not deliberately taken, many of the hard and soft outputs of PartiSim were achieved (Tako and Kotiadis, 2015). In PartiSim terms, stages 2, 3, 4 and 5 took place in the CT department during working hours and interruptions were frequent. The framework was applied over a much longer timeframe that that recommended by PartiSim and differed by engaging and educating staff over this longer (4 year) period. High levels of complexity and granular detail were included. During this time important learning was achieved by the department through CPD sessions and improved understanding of the system (Sterman, 2001; Sanderson and Gruen, 2006; Monks, Robinson and Kotiadis, 2014, 2016; Dodds and Debenham, 2016). System dynamics models were drafted with staff using Vensim which proved a successful facilitation tool. Additionally, these conceptual models did not require coding or data to faithfully capture elements of the system increasing ease of use.

As discussed in Chapter 2, the PartiSim and SimLean approaches facilitate stakeholder involvement in all stages except coding. Proudlove (2017) suggested stakeholder involvement was possible in cases where there is low model complexity and low data-analysis complexity. The ultimate in facilitated modelling is the inclusion of stakeholders at each stage of model building, including coding. In order to decrease coding requirements, it is suggested that a tried and tested DES model such as that described herein, is deconstructed for the purpose of reconstruction during a PartiSim or other facilitated workshop. Using this approach prebuilt process blocks and agents such as patients, staff and scanners could be dragged and dropped and parameters modified by clinical staff for individual CT departments. Code could be prewritten for decision making and routing for patient preparation and scanning, thus limiting the coding required on the day of the workshop. Doing so could dissipate some of the mistrust associated with the "black box", "back office" experience of coding.

In Ireland, 68 hospitals and imaging centres use a single imaging platform called NIMIS which largely determines radiology workflow in Irish radiology departments (EHealthIreland, 2021). This similarity between departments could increase the reusability of this model allowing staff to learn how to model through "reconstructing" this model. This repurposing could introduce staff to operations research, allow learning to be internalised and ultimately improve decision making by educating future "intelligent clients" (Pitt *et al.*, 2016).

SSM and RP diagramming allowed the modelling project to incorporate knowledge elicited from a variety of stakeholders and the identification of potentially feasible and culturally desirable targeted service improvements (Crowe *et al.*, 2017). Using RP diagramming, insights were provided into radiology work conditions that contribute to stress levels and cognitive workload such as physical conditions, pressures associated with the work, the significant role of relationships and how work is organised (Raj, 2006). A by-product of the SSM approach was the list of issues identified during the Rich Picture Diagramming session, the list represents opportunities to improve departmental performance and quality of the service.

A disadvantage of the use of RP diagramming is its subjective nature and difficulty of reproducibility. Additionally, the method of recording was note taking which means some data may have been excluded and post hoc scrutiny is not possible. While recognising that the approach yielded subjective insights rather than testable results, the advantages of participant involvement included the potential to identify a greater variety of scenarios and process metrics (Rodriguez-Ulloa and Paucar-Caceres, 2005; Ackermann, 2012; Monks, Robinson and Kotiadis, 2016; Bell, Berg and Morse, 2019).

The CT service was changed in the process of researching it, and evidence for same provided in 5.1.7. Action research changes resulted from the modelling process leading to improvements in departmental performance and the quality of radiology service (Rose, 1997; Bate, 2000; Morrison and Lilford, 2001; Dodds, 2007). Gaining buy-in for the project was aided by ensuring important and relevant issues were identified, and that the work resulted in quick tangible changes and benefits to the department (Harper and Pitt, 2004).

Additionally, applications for further use of modelling and simulation in the case study department have been identified by management for other areas namely ultrasound and general x-ray. This provides a further example of how the stakeholder experience of modelling has developed new inhouse expertise in problem recognition, become baked into decision making and resulted in more “intelligent” clients. This example of model reuse demonstrated how the initial modelling project provided an introduction to the capabilities of OR and led to its becoming “baked in” as a decision support within the department (Ackoff, 2010).

In this work system dynamics was used initially to create conceptual models of the service proving a useful tool which elicited hidden theories from within the department on the behaviour of the system. Interestingly in the final presentation to management the initial conceptual models were as important as the model results in communicating recommendations. This supports further the work of Royston et al (1999) who concluded that System Dynamics is useful for rapid, intuitive understanding of a complex system (Royston *et al.*, 1999).

Research question 2 asked “**What framework, facilitating stakeholder involvement, is most appropriate to capture staff experience, identify model components and metrics, and address the problem of increasing waiting lists?”** Using the DES and SSM framework, model components as well as multiple scenarios were identified. By using DES modelling this work captured novel CT service metrics nuanced with the profiles of the IP and OP cohorts. To the best of our knowledge this is the first DES work to capture such granular data on the staff and patient experience of a service and as such contributes to knowledge in the fields of Radiology and Operations Research.

6.6 The Mangle

Pickering advocated that the modeler describe “The Mangle” of human experience and barriers encountered in the process of creating a model, so as to allow a richer, more insightful account of the project (Ormerod, 2014). A mangled description should include organizational hurdles, the changes in direction, the influences of people involved and the effect of technologies available on the path also be included. In an bid to deliver something new, knotty and substantial enough to be of interest, a description of the radiographer’s experience of modelling is included (Ormerod, 2014). Some researcher have reported that tidy descriptions of simulation projects are “completely irrelevant, if not a fantasy” (Paul, Eldabi and Kuljis, 2003). Significant events which occurred during the modelling process included:

1. 01/16 - Creation of initial models using SD approach in Vensim,

2. 12/16 -Weekend sessions were introduced for Inpatients and ED patients. Data from the exploratory data analysis was used to support this change and to support hiring of additional support staff.

3. 06/17 - CPD presentation to staff on SD, mental models and counterintuitive behaviours,

4. 09/17 - Decision to create model of the process using DES instead of SD.

5. 06/18 - CPD presentation to staff on RP diagramming and the use of soft systems methodologies to incorporate staff insights and feasible and desirable solutions,

6. 06/19 - Work shopped the model with CT and clerical staff, feedback documented resulting in additional changes,

7. 04/20 - the COVID-19 pandemic resulted in a cessation of OP work and additional infection control measures and considerations.

8. 2020 – increased downtime of CT scanner and CT service. Engineers reported increased difficulty sourcing replacement parts due to the age of the scanner,

9. 2020 – CPD presentation to staff on simulation results and evidence presented to Hospital management on IP versus OP complexity in terms of workload and work perturbations variation.

Lessons learnt during and from the project are described next.

b) Familiarity of the domain positively affected the project, due to the researchers understanding of the problem and processes (Brailsford, Churilov and Dangerfield, 2014). However, as was identified in previous research the previously established relationship between the researcher and decision makers appeared to preclude the perceived need for early involvement (Ross et al., 2003). Initially it seemed sufficient to involve only the clinical specialist for model verification and validation purposes. As the project developed the importance of including more stakeholders to reduce researcher bias became apparent. It is recommended in future work to involve a wider audience from the start when introducing the methodology and inviting perspectives and simulation scenarios.

c) Granularity – As a healthcare worker familiar with the service, the temptation to model the entire process rather than the problem was great. For example the inclusion of phone calls in the DES model was deemed necessary at the time but may be an example of over processing or using a GPS where a compass would have sufficed (Pidd, 2010). In this example it was the modeler's inexperience and fear of losing stakeholder trust that led to the high granularity approach. Choosing the right level of detail is considered important if one is to save time in the model development phase, but still convince stakeholders on the use of model (Günal and Pidd, 2010). The balance was not achieved in this project, as shown in Figure 6.4, where the motivations and worldviews of the decision makers and clinical stakeholders were at odds.

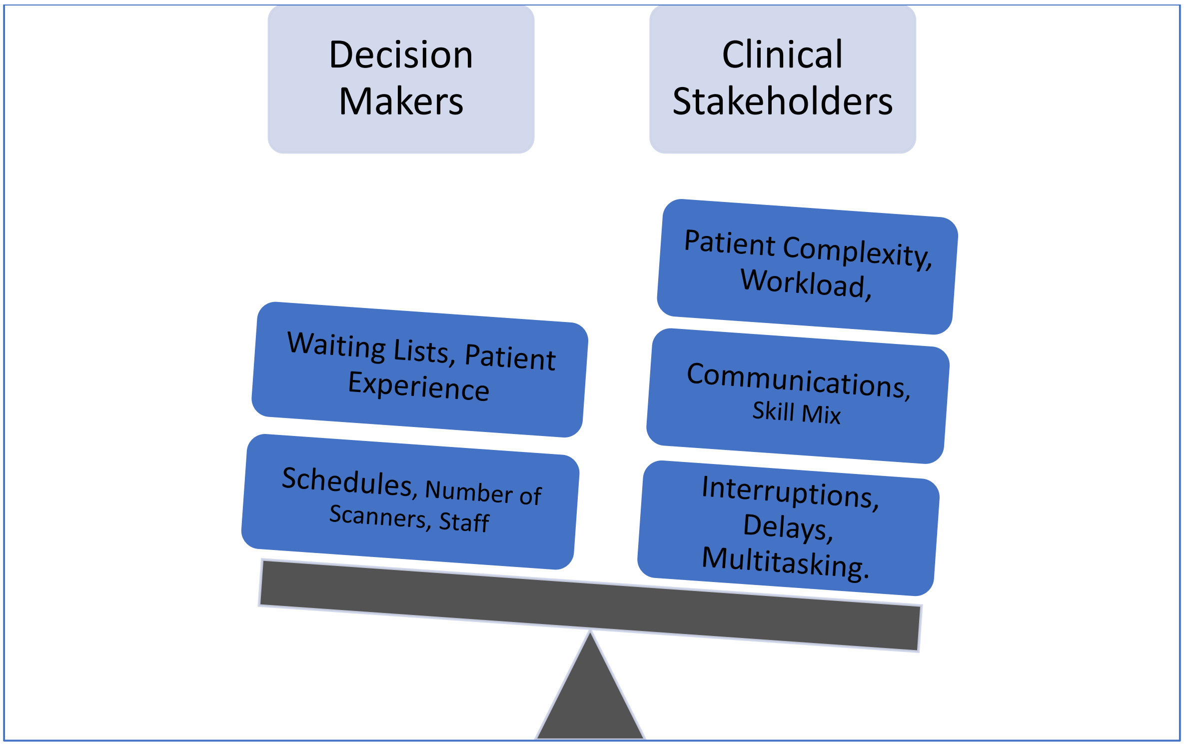


Figure 6.4 Clinical and Managerial stakeholder worldviews

d) The availability of commercial off the shelf modelling software packages, with their drag and drop user interfaces and reporting tools eliminates some barriers to modeling for the non-programmer (Brailsford, 2015). The level of model detail described above plus the clinical origins of the modeler presented many technical challenges during model building. The specialised skills, tools, experience and the requirement to switch between hard and soft paradigms presented barriers for the clinical radiographer. Prolonged exposure of clinical individuals to model building is advised to increase OR capabilities in healthcare, through involvement in multidisciplinary OR teams.

e) Great expectations – the model was designed to allow staff to use it, allowing the number of radiographers, healthcare assistants and scanners to be varied and effects on workload observed. This involved considerable time and effort to design a robust interface. While stakeholders appreciated the opportunity to workshop the model, it would have been adequate to simply present them with the results. While we can surmise that trust was gained and staff provided with an opportunity to internalise knowledge, this remains unsubstantiated.

f) The voice of the patient - Patients were not formally interviewed or involved as stakeholders and their perspectives and requirements were considered from a radiographer's perspective. Apart from the patient care related phone calls and administration, patient care remains largely unquantified. The activities around reassurance, obtaining consent, providing explanations, and ensuring preparedness and suitability of the patient take time. Clinicians and students described a "production-line" mentality and system barriers that diminished their potential for compassion, include a lack of time, support, staffing, and resources (Sinclair *et al.*, 2016). Lest it be eroded, time for patient care is an important KPI that should be acknowledged if not included in OR models.

g) Fear – Throughout the project staff admitted fearfulness on every level (managerial, radiographer and healthcare assistant) that the model would indicate low levels of utilisation and fail to include all aspects of their work. Staff considered "high" utilisation levels to be in the order of 80% and above. When verifying observed task duration times with stakeholders, caveats where frequently made to stipulate that there are exceptions to every rule and situations arise that cannot be accounted for in a model. On reflection, staff could have been reassured that no baseline for radiographer utilisation existed and that if one did exist comparison between hospitals would not be useful. This reaffirms the importance of trust in simulation studies and the relationships between modellers and stakeholders for model acceptability and result implementation (Harper, Mustafee and Yearworth, 2021).

The case study which began as an academic endeavour, gained traction over the time period, becoming an important part of the department's business case planning. In 2019 questions were asked of the model and results presented to the board of management. In this situation an academic project became an industry project at the 11th hour.

6.7 Limitations

In medicine lacunae are small spaces, containing an osteocyte in bone, in OR lacunae are gaps where deep fundamental questions remain unanswered. Ormerod (2014) asked of modelling projects whether the right people were involved and whether the voice of the affected but uninvolved was heard (Ormerod, 2014). A limitation of this study is that the voice of the affected patient was unheard, and patients were not involved in the identification of process metrics and RP diagramming. In hindsight, an assumption was made that the clinical staff represented the patient's needs. Pearson et al (2013) contend that in a democratic society it should be unthinkable that service re-design take place without the involvement of the people most directly affected, arguing that processes such as modelling that are used to inform the decision-making process should involve patients and members of the public (Pearson *et al.*, 2013).

Efforts made to reduce the possibility of bias in this mixed qualitative and quantative study were discussed in Chapter 3, Research methods. Due to the researchers dual role as staff member with local tacit knowledge and primary researcher, the potential for bias existed. The potential to overestimate the duration of tasks existed as this was considered more favourable by staff. The researcher was aware of fears expressed by staff that the study would demonstrate underutilisation of resources. This was mitigated by capturing times using a stopwatch during observation and later verifying results with stakeholders.

It is also recognised that the staff may have used the rich picture diagramming session as an opportunity to express dissatisfaction rather than satisfaction. However, it sis recognised that an objective of RPD is to identify a list of issues which is in itself a request for negative feedback. In order to minimize the risk of the radiographer researcher being solely responsible for model component identification, other radiographers and staff across a range of professions were questioned on the factors affecting service delivery.

6.8 Future research

While quality norms decay readily, they rise with more difficulty and increased work pressure resulting in a decrease in time per order (in this case CT examination) can lead to an erosion of standards (for example patient care in radiology) (Oliva and Sterman, 2001). While the research contributes to the pressures specific to the time-pressured, task-focussed, highly technical and rapid turnover environment of CT it does not address how these impact upon compassionate patient care (Bleiker et al., 2018). Further research involving the patient in an active role to measure or model KPIs of patient care and staff workload is recommended (Železnik, Kokol and Blažun Vošner, 2017).

A wider study including referring doctors such as GP and OP doctors is recommended. Lindsay et al (2011) asked how should a radiology department audit its performance? A survey of referrers determined that a more approachable radiology service was associated with improved clinician satisfaction (Lindsay *et al.*, 2011). The danger exists that greater access to CT would result in unintended consequences such as increased rates of referral, due to supplier induced demand (Taylor and Dangerfield, 2005). A widening of the scope of the RPD and involvement of additional stakeholders at a conceptual level has the potential to identify new levers for change, ensuring we do not solve the wrong problems or create new ones (Ackoff, 1979).

Further research is advised into the usability of the information system and its effectiveness in supporting the CT workflow. A comprehensive evaluation of the human computer interaction defined by the ISO standard EN ISO 9241-10 is advised using an assessment tool (Bundschuh *et al.*, 2011).

Further research into the potential "status flipping" reinforcing loop is warranted as it indicates that IP demand is reducing the OP capacity of the CT service and further fuelling IP demand, see Figure 4.3. System dynamics is identified as a suitable modelling paradigm for capturing this.

Chapter 7: Conclusions

The contributions of the work in relation to the answering of the research questions is discussed next. Research question 1 (a) asked “From the literature, what previous attempts have been made to model healthcare staff workload and patient complexity?” Little was found in the literature which estimates or quantifies the daily effort or workload of radiographers and healthcare assistants, though substantial references have been made to radiologist workload and the necessity to weight their workload and acknowledge indirect tasks such as teaching and administration for example. Where radiographer workload is addressed, it appears to be in terms of increasing volume or throughput in radiology. Examples from OR literature where radiographers and radiology staff were involved in a facilitated use of DES to measure radiology staff workload or capture their experience were not identified in the literature and herein lies the novelty of the work.

Research question 1.(b) asked “Which OR methods are most suitable to do so?”. From the literature it was determined that discrete event simulation modelling would provide a suitable tool for modelling the process-oriented nature of the CT service, once which could capture multiple tasks in high granularity for discrete patients, resources and staff. System Dynamics was identified as most suitable for macro level conceptualisation of the service and for identifying causal links and loops.

Research question 1.(c) asked “What factors (patient and other) affect staff workload and resource utilisation?” Regarding patient factors, the exploratory data analysis identified that while the demand for ED and IP exam was met, the service provided to GP and OP cohorts failed to meet demand resulting in growing waiting lists. The unscheduled IP/ED work is considered more urgent, and demand met as it arises. In short IPs demand a service while OPs wait for one. The aging and ailing patient profile coupled with the effects of current COVID-19 pandemic ensure that waiting lists are set to increase under the mixed IP/OP model of CT service provision. The variation in OPs and IPs characteristics presented when both cohorts are serviced simultaneously has been shown to manifests itself in work perturbations, service delays and uncertainty of demand. Waste results where capacity set aside for the fluctuating IP demand is not used. This work recommends the reduction of complexity through the separation of the IP and GP/OP diagnostic imaging services.

The rich picture diagramming event identified the additional factors affecting workload such as lack of preparation space, inappropriate referrals for inexperienced staff and unsuitable staff skill mix. A list of issues resulted from the process providing opportunities for process and service improvement.

DES was useful for capturing staff workload directly related to CT service provision and has contributed to the body of knowledge on the subject. The CT scanner was not found to be the limiting factor in process capacity rather RP diagramming identified the human resources for patient preparation, manual handling, as well as infection control and space for patient preparation and observation as limiting factors. A theme which emerged from the soft system methods employed was the use versus intended use of the IT system. Questions have been raised as to the extent to which workflow is supported. DES was useful for capturing staff workload directly related to CT service provision and has contributed to the body of knowledge on the subject. In conclusion, the single CT scanner availability was not found to be the limiting factor in process capacity. It was instead the human resources for patient preparation, manual handling, as well as infection control and space for patient preparation and observation combined with the high variation in demand that were identified as limiting factors. The model outputs and exploratory data analysis indicate that the number of patients scanned is not the sole indicator of staff workload.

In response to research question 2.(a) two frameworks were identified which were modified herein to address the problem of increasing waiting lists. Work carried out by Crowe et al., (2017) and Rashwan (2017) were identified as pivotal and elements from both adapted to the design of a framework for radiology. Following on from the gap identified in the literature and the findings from the exploratory analysis carried out in Phase 1, an application of DES and SSM was applied in Radiology thus achieving research objective 2(a and b). The application was novel in the richness of detail and metrics captured pertaining to the CT service.

The framework allowed decision makers to consider workload, tailored to the different patient populations (scheduled and unscheduled), in terms of resource utilisation, staff time consumption, interruptions, and the cognitive workload associated with scheduling and using the information system. Simulation modelling allowed radiology management to make decisions on operational changes using quantitative information of the impact of what-if scenarios on CT waiting lists. Based on simulation data results, a preferred scenario was identified and awaits implementation. The framework incorporates managerial and clinical stakeholders' perceptions, requirements, and experience as well as evidence of staff workload as part of the quantitative aspect of the framework.

A shared understanding of the problem was achieved and decision makers' capacity to process information extended. As well as providing insights into the current service the framework connected the modeller, clinical staff, and decision makers from its design to its end use as a decision support tool to help inform service planning and staffing, enhancing the in house decision making capabilities. Bate (2000) said learning is not only about action and an outcome of this work is the novel representation of radiology staff workload.

Finally, the work aimed to validate the framework through implementation, in a case study setting, research objective 2(a). Refection on the application was carried out to consolidate the learnings and insights obtained. While the experience of those involved is intrinsically woven into the SSM aspect of the project, direct feedback from the radiology services manager on her experience of involvement in the research project reported *"The process made us think and consider the service holistically. Where we might have previously accepted constraints, we now observe, consider and try to eliminate or improve them."*

To summarise, the SSM and DES framework proved capable of iterative refinement and continuous improvement, included stakeholder perspective and supported decision making in radiology. The decision makers within the hospital endorsed the solution framework and are currently considering the next steps for the service considering the results provided by the DST. The research hopes to encourage further research and debate on the subject of radiographer and healthcare staff workload both objective and subjective. This research contributed to both theory and practice: the framework outlined how the simulation based DSS was designed and practically applied to the case study radiology department. The work presented is a synthesis of multiple perspectives and sources of information. The data extracted from the information system, the knowledge provided by the clinical specialist, the understanding gained through RP diagramming and decision support tool should culminate in wisdom and an evaluated understanding of the right way to proceed with regard to handling the problem of increasing waiting lists and increasing workload.

Duncan (2019) engineer and novelist identified in his work, ten different categories of problems including problems that can and can't be solved, should and shouldn't be solved, aren't understood and problems that emerge from solving other problems. Duncan suggests that a person's nature is a function of their attraction to certain types of problems and if this attraction changes over the course of a person's life, and if one reflects on these changes over time, then the pattern of these changing problems offers a view onto their personality and how it might have evolved (Duncan, 2019). Healthcare provision problems unsurprisingly fall under many of these categories. Most notably relevant are the problems that can be solved, those that we do not understand and those that emerge from solving other problems. In the course of this work, a greater understanding of the system dynamics, the patient populations, the process, and the demand for the CT service was achieved for both the researcher and those involved as stakeholders.

APPENDIX A

1. Process Complications

During the observation period and in interviews with staff the following reasons for disruption to the CT scanning process or work perturbations were observed. Patient related issues or complications which result in workflow and process perturbations are listed next:

a. Patient not well enough or unavailable for scan,
b. Bloods outside of the 6 week date range or not within acceptable Creatinine and Egfr levels,
c. Patient infectious and scheduled at the end of the list or with other infectious patients,
d. No cannula or incorrect cannula in situ or cannula not working as expected,
e. Patient not prepped/fasting as per the examination protocol,
f. Instructions for preparation not followed correctly,
g. When a patient arrival is delayed due to transport or communication issues,
h. Where a female patient is outside the 10 day rule and the risk of pregnancy cannot be excluded,
i. Patient who feels unwell while in radiology,
j. Patient experiencing any reaction to IV contrast,
k. Patient who is not prepared for their scan,
l. Patient who has an allergic reaction or requires the crash team while in radiology,
m. Aggressive, confused, agitated, moving patients,
n. Resus or emergency patients requires an emergency scan i.e. Fast brain scans where immediate imaging is required.

Resource issues

a. Scanner unavailable,
b. Radiologist staff unavailable to supervise injection (protocol advises radiologists on site during injection or senior house officer)

c. Second radiographer unavailable to assist with injection (protocol advises two radiographers present for injection)

d. Porters late, unavailable, or wheelchair/trolley unavailable.

Schedule issues

a. Miscommunications between staff members resulting in a delayed start to preparation or examination.

b. Unclear clinical indications or protocol directions

Other issues such as completion of incident forms, administration duties, time for CPD etc. were deemed to be outside the scope of the model and provided in Appendix. Despite this the model was deemed sufficiently detailed to use for staff and scheduling decisions.

3. Tasks outside model scope

Not all tasks could be included in the model and those not directly relating to the CT process and those too granular to model were excluded. These tasks however are documented as they provide some explanation for activities completed during idle times. These tasks also put into context the complexity of the service provided.

Short Tasks carried out by HCA or Radiographers include:

Refilling supplies

Reordering supplies

Emptying bins or laundry bins

Fetching new laundry and blankets

Cleaning ultrasound machine after procedures

Returning procedure kits to CCSD

Refilling cannulation trays

Assisting with cannulations to improve workflow

Cleaning other rooms during quiet times

hand hygiene - 30 seconds before and after touching a patient

hand hygiene - 30 seconds before and after assisting with cannulation

Fetching tea and coffee for procedure patients post procedure

Assisting patients to dress and undress for scans

Assisting patients to toilet

Escorting patients to reception

Escorting patients to oncology

Making calls to family members regarding when scan is finished and relative is ready for collection

Logging into PC in the morning

Making phone calls to other departments when a scan is delayed

Relaying information to radiographers or queries from patients and visa versa.

Longer Tasks/projects

Audits staff may be involved in

Continuous professional development

Responding to work related email

Filling out incident forms

Attending multidisciplinary meetings

Updating policies and procedures

Training other staff

Quality improvement initiatives

Communications with other departments and wards

APPENDIX B

1. Daily handover tool for Radiographers

A daily handover tool was designed for the department, at the request of the manager. Included in the tool were items identified by radiographers as important for communication between the day and night shift.

"Feedback is critical to the well-calibrated performance of individuals and is integral to effective team functioning." Laxmisan 2007

Date	Day Night
Staff on shift	
Individual patients – overflow between shifts	
Updates - issues with information systems or downtime, keys, phones etc	• Technology status • Environmental status • Communications
Note for RSM and other staff	• Suggestion for improvement. • Interesting cases from the day • Ideas for CPD talk • Idea for journal club article

NB. Please continue to log any incidences on QPulse as normal.

2. CATWOE -

What is it? A mnemonic for systematically including information about customers, actors, transformation process, worldview, owners and environmental constraints in a definition of a service

Customers - may have more than one
Actors - those involved in delivering the service
Transformation process – what do they achieve in their job
World view/Mission also called Weltanschauung
Owners – (who can stop the service being provided if necessary)
Environmental constraints - what limit you from providing a service 100% of the time.

Root definition – what do you do, how do you do it, why do you do it?

APPENDIX C

1. CT exam protocol for Thorax Abdomen Pelvis (TAP)

Preparation	No solids x 6 hrs No liquid x 2hrs. All in patients/oncology patients cannulated 20g. Oral Contrast: 20mls Omnipaque in 1L water 1 – 11/2hr prior to scan. Bladder empty ½ hr before scan. Top up glass given prior to scan. Change into gown and remove all artifacts if possible. Check re allergies etc and cannulate out-patients. Flush with 20mls saline thro' extension tube
Patient position	Supine, head first with arms extended in comfortable position above head. Ensure patient is immobilised using Velcro strap around body. Use knee pad and blanket
Just superior to sternal notch using internal laser light in isocenter and zero	

Topogram	Craniocaudal
Scan type Scan from	Protocol name to select - 00_CAP_ONE_RANGE Apices to inferior border of symphysis pubis
Contrast	Recall STD ABDO on injector 80mls @ 3ml/s Ulrich injector: prime injector _ walking man .CT scanner and injector are NOT coupled so Press Start button on injector and scanner. Volume: 80mls of 350 mg I/ml – increase/decrease as per patient weight. Rate: 3ml/s via 20G cannula Pre delay: 65 seconds If 22G is in situ reduce flow rate to 2mls and increase delay by 5-10 seconds. Check with Radiologist.

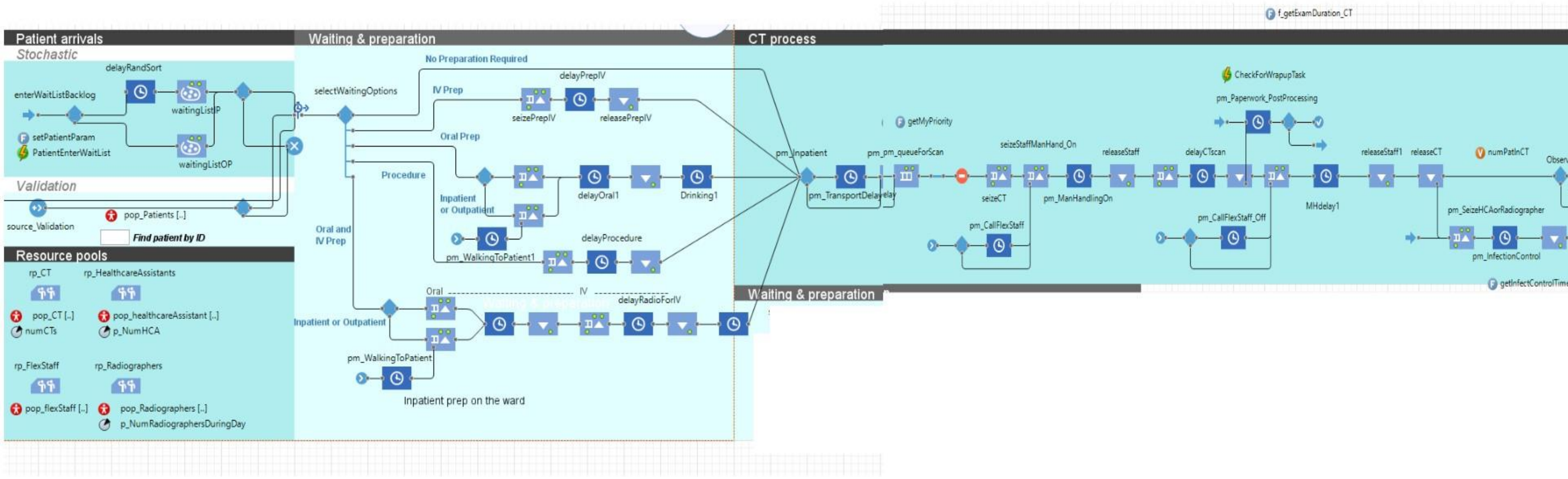
2. All Tasks to be completed with 1 Staff member

1. Read request and decide on examination required
2. Prepare room: Change headrest
3. Prepare room: Set up pump
4. Prepare room: Change sheet
5. Prepare patient: Check ID and Check allergies
7. Prepare patient: Give oral contrast
8. Prepare patient: Check Cannula
9. Prepare patient: Insert cannula
10. Prepare patient: Change patient
11. Prepare patient: Give explanation etc. (see IIRRT guidelines)
12. Scan: Put patient on bed
13. Scan: Test cannula
14. Scan: Reassure patient
15. Scan: Set up scan
16. Scan: Administer contrast
17. Scan: Reconstruct images
18. Scan: Disconnect pump
19. Scan: Remove patient from bed
20. Scan: Check for signs of reaction
21. Scan: Remove patient from room
22. Scan: Inform patient on next steps
23. Observe: Remove patient to observation area
24. Observe: Observe for 20 minutes
25. Observe: Remove cannula
26. Discharge: provide patient with information on next steps

3. Task to be completed with 3 radiographers

Radiographer 1	Radiographer 2	Radiographer 3
Read request and decide on examination required	Prepare patient: Check ID	Scan: Put patient on bed
Prepare room: Change headrest	Prepare patient: Give oral contrast	Prepare patient: Check ID
Prepare room: Set up pump	Prepare patient: Check Cannula	Scan: Reassure patient
Prepare room: Change sheet	Prepare patient: Insert cannula	Scan: Set up scan
Prepare patient: Check ID	Prepare patient: Change patient	Scan: Administer contrast
	Prepare patient: Give explanation	Scan: Reconstruct images
	Prepare patient: Bring into scanner room	Scan: Disconnect pump
	Prepare patient: Check allergies	Scan: Remove patient from bed
		Scan: Check for signs of reaction
		Scan: Remove patient from room
		Scan: Inform patient on next steps
		Scan: Test cannula

1. CT Process logical model



2. CATWOE Transportation Service

Table 7.1 CATWOE Statement for transportation services

Customers – The patient or goods etc that need to go from A to B. The radiology clerical staff who ask for transportation. The radiographers who ask for transportation.
Actors The porters carry out the tasks and are instructed by clerical and clinical staff who are helping to arrange a scan.
Transformation process – what do they achieve in their job The patient is moved from A to B so that they can get their test completed. The needs of the radiographer carrying out the test and the patient are met.
World view/Mission It is important to safely get the patient from wherever they are to radiology and back again. It is important to prioritise the urgency of the patient with how timely we respond to a request.
Owners – (who can stop the service being provided if necessary). Head of portering service and the nurse or doctor who says that patient is/is not able to go at that moment.
Environmental constraints Patient may not be able to go at the desired time. There are a limited number of trolleys/wheelchairs. We may be covering the front desk. At night we may be covering ED as well as the wards and cannot be as responsive at this time. Patient may be infectious/unwell/unavailable, and as a result timing may have to change as.
Root definition A hospital service owned by whoever cares for the patient and by those who have are responsible for carrying out a CT scan, whereby a patient must be transported to and from radiology for their scan. The service operates under time and staff resource constraints and can be limited by the number of wheelchairs and trolleys available.

APPENDIX D

1. OP scheduling tool for use in current scenario

Table 7.2 OP scheduling tool under current scheduling on mixed IP/OP scanner

	Monday	Tuesday	Wednesday	Thursday	Friday
08:30	Non con	non con & Cardiac (max 2 hour prep)	MEETING	Non con	Non con
08:45	Non con	Non con	MEETING	Non con	Non con
09:00	Non con	1/2 hour	MEETING & 1st Colon Arrives	1/2 hour	Nerve block/non con
09:15	1/2 hour	1/2 hour	MEETING	1/2 hour	Nerve block
09:30	1/2 hour	1/2 hour	1st Colon	1/2 hour	Nerve block/ 1/2 hour
09:45		Cardiac	I/P		Nerve block
10:00	90 minutes	90 minutes	2nd Colon	90 minutes	90 minutes
10:15	90 minutes	90 minutes	I/P	90 minutes	90 minutes
10:30	BREAK	BREAK & 2nd Cardiac arrives	BREAK & 3rd Colon	BREAK	BREAK
11:00	Daycare Cardiac	90 minutes	90 minutes		90 minutes
11:15	Post interview	Post interview	Post interview	Post interview	Post interview
11:30	Post interview	Post interview	Post interview	Post interview	Post interview
11:45	I/P	I/P	I/P	I/P	I/P
12:00	I/P	2nd Cardiac on table	I/P	I/P	I/P
12:15	I/P	I/P	I/P	I/P	I/P
12:30	I/P	I/P	I/P	I/P	I/P
12:45	I/P	I/P	I/P	I/P	I/P
13:00	BREAK	BREAK	BREAK	BREAK	BREAK
13:15	BREAK	BREAK	BREAK	BREAK	BREAK
13:30	BREAK	BREAK & 3rd Cardiac arrives	BREAK	BREAK	BREAK
13:45	BREAK	BREAK	BREAK	BREAK	BREAK
14:00	Emergency/PP	Non con	Nerve block/ non con	Emergency/PP	Emergency/PP
14:15		I/P	Nerve block	Non con	
14:30			Nerve block		
14:45			Nerve block		
15:00		3rd Cardiac on table	Nerve block		

BIBLIOGRAPHY

Abadal, J. M. *et al.* (2021) 'Future scenarios and opportunities for interventional radiology in the post COVID-19 era', *DDiagn Interv Radiol*, 27, pp. 263–268. doi: 10.5152/dir.2020.20494.

Ackermann, F. (2012) 'Problem structuring methods "in the Dock": Arguing the case for Soft or', *European Journal of Operational Research*, 219(3), pp. 652–658. doi: 10.1016/j.ejor.2011.11.014.

Ackoff, R. L. (1979) 'The Future of Operational Research is Past', *Journal of the Operational Research Society*, 30(2), pp. 93–104. doi: 10.1057/jors.1979.22.

Ackoff, R. L. (2010) *Systems thinking for curious managers*. Triarchy Press.

Anylogic Personal Learning Edition 8.4.0 (2019) 'Anylogic'. Oakbrook Terrace Tower: AnyLogic North America. Available at: https://www.anylogic.com/.

Arisha, A. and Rashwan, W. (2016) 'Modeling of Healthcare Systems: Past, Current and Future Trends', *Proceedings of the 2016 Winter Simulation Conference*, (ii), pp. 1523–1534. doi: 10.1109/WSC.2016.7822203.

Bate, P. (2000) 'Synthesizing research and practice: Using the action research approach in health care settings', *Social Policy and Administration*, 34(4), pp. 478–493. doi: 10.1111/1467-9515.00205.

Behzad, B., Moraga, R. J. and Chen, S. G. (2013) 'Modelling healthcare internal service supply chains for the analysis of medication delivery errors and amplification effects', 4(4), pp. 554–576.

Bell, S., Berg, T. and Morse, S. (2016) *Rich Pictures: Encouraging Resilient Communities*. Taylor \& Francis (Earthscan Tools for Community Planning). Available at: https://books.google.ie/books?id=gp%5C_DCwAAQBAJ.

Bell, S., Berg, T. and Morse, S. (2019) 'Towards an Understanding of Rich Picture Interpretation', *Systemic Practice and Action Research*, 32(6), pp. 601–614. doi: 10.1007/s11213-018-9476-5.

Berg, T. (2015) 'Rich Picture: The Role of the Facilitator', *Systemic Practice and Action*

Research, 28(1), pp. 67–77. doi: 10.1007/s11213-014-9318-z.

Bergvall-Kåreborn, B., Mirijamdotter, A. and Basden, A. (2004) 'Basic principles of SSM modeling: An examination of CATWOE from a soft perspective', *Systemic Practice and Action Research*, 17(2), pp. 55–73. doi: 10.1023/B:SPAA.0000018903.18767.18.

Bernell, S. and Howard, S. W. (2016) 'Use Your Words Carefully: What Is a Chronic Disease?', *Frontiers in Public Health*, 4, p. 159. doi: 10.3389/fpubh.2016.00159.

Bleiker, J. *et al.* (2018) '"It's what's behind the mask": Psychological diversity in compassionate patient care', *Radiography*, 24, pp. S28–S32. doi: 10.1016/j.radi.2018.06.004.

Boland, G. W. L. (2008) 'Enhancing CT productivity: Strategies for increasing capacity', *American Journal of Roentgenology*, 191(1), pp. 3–10. doi: 10.2214/AJR.07.3208.

Booker, M. T. *et al.* (2016) 'Quality Improvement with Discrete Event Simulation: A Primer for Radiologists', *Journal of the American College of Radiology*, 13(4), pp. 417–423. doi: 10.1016/j.jacr.2015.11.028.

Brailsford, S. C. *et al.* (2009) 'An analysis of the academic literature on simulation and modelling in health care', *Journal of Simulation*, 3(3), pp. 130–140. doi: 10.1057/jos.2009.10.

Brailsford, S. C. (2015) 'Hybrid Simulation in Healthcare: New Concepts and New Tools', *Proceedings of the 2015 Winter Simulation Conference*, pp. 1689–1699. doi: 10.1017/CBO9781107415324.004.

Brailsford, S. C. *et al.* (2019) 'Hybrid simulation modelling in operational research: A state-of-the-art review', *European Journal of Operational Research*. Elsevier B.V., pp. 721–737. doi: 10.1016/j.ejor.2018.10.025.

Brailsford, S., Churilov, L. and Dangerfield, B. (2014) *Discrete-Event Simulation and System Dynamics for Management Decision Making*. New York, UNITED KINGDOM: John Wiley & Sons, Incorporated. Available at: http://ebookcentral.proquest.com/lib/nuig/detail.action?docID=1666485.

Brailsford, S., Desai, S. M. and Viana, J. (2010) 'TOWARDS THE HOLY GRAIL: COMBINING SYSTEM DYNAMICS AND DISCRETE-EVENT SIMULATION IN

HEALTHCARE', *Proceedings of the 2010 Winter Simulation Conference*, 53(9), pp. 1689–1699. doi: 10.1017/CBO9781107415324.004.

Brailsford, S. and Hilton, N. (2001) 'A Comparison of Discrete Event Simulation and System Dynamics for Modelling Healthcare Systems', in Reilly, J. (ed.) *ORAHS 2000*. Glasgow, Scotland, pp. 18–39.

Brailsford, S. and Vissers, J. (2011) 'OR in healthcare: A European perspective', *European Journal of Operational Research*, 212(2), pp. 223–234. doi: 10.1016/j.ejor.2010.10.026.

Brask, K. B. and Birkelund, R. (2014) '"patient care in radiology" - The staff's perspective', *Journal of Radiology Nursing*, 33(1), pp. 23–29. doi: 10.1016/j.jradnu.2013.12.001.

Brick, A. and Keegan, C. (2020) *Paying more to wait less: Estimating the cost of reducing Ireland's public hospital waiting lists*.

Bundschuh, B. B. *et al.* (2011) 'Quality of human-computer interaction - Results of a national usability survey of hospital-IT in Germany', *BMC Medical Informatics and Decision Making*. BioMed Central Ltd, pp. 1–12. doi: 10.1186/1472-6947-11-69.

Burt, J. (2017) 'Getting to grips with the beast: The potential of multi-method operational research approaches', *BMJ Quality and Safety*, 26(8), pp. 611–612. doi: 10.1136/bmjqs-2017-006484.

Cain, B. (2007) 'A Review of the Mental Workload Literature', *Defence research and development Toronto (Canada)*, (1998), pp. 4-1-4–34. Available at: http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA474193.

Cannan, E. (1892) 'The Origin of the Law of Diminishing Returns, 1813-15', *The Economic Journal*, 2(5), pp. 53–69. doi: 10.2307/2955940.

Checkland, P. (1985) 'Achieving "Desirable and Feasible" Change: An Application of Soft Systems Methodology', *Source: The Journal of the Operational Research Society*, 36(9), pp. 821–831.

Checkland, P. (1999) *Soft systems methodology : a 30-year retrospective* . [New ed.]. Edited by P. Checkland. Chichester: Chichester : John Wiley.

Checkland, P. and Scholes, J. (1992) *Soft Systems Methodology in Action*. Edited by Wiley.

Chichester.

Chisholm, C. D. *et al.* (2000) ‘Emergency Department Workplace Interruptions Are Emergency Physicians "Interrupt-driven" and "Multitasking"?’, *Academic Emergency Medicine*, 7(11), pp. 1239–1243. doi: 10.1111/j.1553-2712.2000.tb00469.x.

Clark, K. R. (2020) ‘Drawing to Improve Learning and Comprehension.: EBSCOhost’, *RADIOLOGIC TECHNOLOGY*, 92(2), p. 181,183. Available at: http://web.a.ebscohost.com.libgate.library.nuigalway.ie/ehost/pdfviewer/pdfviewer?vid=5&sid=1158d0e4-2084-423d-8c2c-513f21cbadda%40sessionmgr4007 (Accessed: 22 February 2021).

Clarke, N. *et al.* (2019) ‘GDPR: an impediment to research?’, *Irish Journal of Medical Science*, 188(4), pp. 1129–1135. doi: 10.1007/s11845-019-01980-2.

Cleary, N. *et al.* (2017) ‘An investigation into current protocols and radiographer opinions on contrast extravasation in Irish CT departments’, *Radiography*, 23, pp. 87–92. doi: 10.1016/j.radi.2017.05.009.

Conlon, M., Molloy, O. and Zolzer-Bryce, N. (2020) ‘Driving the Bus : A Radiology Case Study Utilizing Rich Picture Diagramming and CATWOE to Capture Staff Perceptions and Inform Service Improvement Scenarios’, in *KMIS 2020*.

Cowan, I. A., MacDonald, S. L. S. and 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), pp. 558–566. doi: 10.1111/1754-9485.12092.

Crowe, S. *et al.* (2016) ‘Identifying improvements to complex pathways: evidence synthesis and stakeholder engagement in infant congenital heart disease’, *BMJ Open*, 6: e010363. doi: 10.1136/bmjopen-2015-010363.

Crowe, S. *et al.* (2017) ‘Combining qualitative and quantitative operational research methods to inform quality improvement in pathways that span multiple settings’, *BMJ Quality & Safety*, 26(8), pp. 641–652. doi: 10.1136/bmjqs-2016-005636.

Cullen, P. (2020) ‘Outpatient waiting list surpasses 600,000 for first time’, *The Irish Times*.

Available at: https://www.irishtimes.com/news/health/outpatient-waiting-list-surpasses-600-000-for-first-time-1.4330620 (Accessed: 6 January 2021).

Currie, C. S. *et al.* (2020) 'How simulation modelling can help reduce the impact of COVID-19'. doi: 10.1080/17477778.2020.1751570.

Davenport, T. H. and Short, J. E. (1990) 'The New Industrial Engineering: Information Technology And Business Process Redesign', *MIT Sloan management review*, 31(4), p. 11.

Delesie, L. (1998) 'Bridging the gap between clinicians and health managers', *European Journal of Operational Research*, 105(2), pp. 248–256. doi: 10.1016/S0377-2217(97)00232-4.

Demir, E. *et al.* (2017) 'Health Systems Demand and capacity modelling for acute services using discrete event simulation Demand and capacity modelling for acute services Demand and capacity modelling for acute services using discrete event simulation', *Health Systems*, 6(1), pp. 33–40. doi: 10.1057/hs.2016.1.

Department of Health (2019) 'Sláintecare Action Plan 2019', *Government of Ireland*, p. 58. Available at: https://www.gov.ie/en/publication/109e2b-slaintecare-action-plan-2019/.

Dickson, E. W. *et al.* (2009) 'Application of Lean Manufacturing Techniques in the Emergency Department', *Journal of Emergency Medicine*, 37(2), pp. 177–182. doi: 10.1016/j.jemermed.2007.11.108.

Dodds, S. (2007) *Three Wins: Service redesign through flow modelling*. 2nd edn. Chichester, UK: Kingsham Press.

Dodds, S. and Debenham, P. (2016) 'Learning Anti-Chaos Design in Emergency Flow', *Journal of Improvement Science*, 32, pp. 1–14. Available at: http://www.journalofimprovementscience.net.

Donnelly, L. F. *et al.* (2010) 'Quality initiatives department scorecard: A Tool to help drive imaging care delivery performance', *Radiographics*, 30(7), pp. 2029–2038. doi: 10.1148/rg.307105017.

Dubiel, B. and Tsimhoni, O. (2005) 'Integrating Agent Based Modeling Into a Discrete Event Simulation'', in *Proceedings of the Winter Simulation Conference, 2005*. IEEE, pp. 1029–

1037. doi: 10.1109/WSC.2005.1574355.

Duncan, A. (2019) *Love Notes from a German Building Site*. Lilliput Press.

EHealthIreland (2021) *NIMIS - National Integrated Medical Imaging System - eHealth Ireland, NIMIS Overview*. Available at: https://www.ehealthireland.ie/strategic-programmes/nimis-national-integrated-medical-imaging-system/ (Accessed: 2 January 2022).

Eldabi, T. *et al.* (2002) 'Quantitative and qualitative decision□making methods in simulation modelling', *Management Decision*, 40(1), pp. 64–73. doi: 10.1108/00251740210413370.

Enda Cunningham (2017) *Galway's public patients face two year wait for MRI scan - Connacht Tribune*, *Connacht Tribune*. Available at: https://connachttribune.ie/galways-public-patients-face-two-year-wait-mri-scan-276/ (Accessed: 12 February 2019).

EPA (2019) *RADIOLOGICAL PROTECTION ACT 1991 (IONISING RADIATION) REGULATIONS 2019*. Ireland: Irish Statute Book. Available at: http://www.irishstatutebook.ie/eli/2019/si/30/made/en/pdf (Accessed: 23 January 2020).

Faezipour, M. and Ferreira, S. (2013) 'A system dynamics perspective of patient satisfaction in healthcare', in *Procedia Computer Science*. doi: 10.1016/j.procs.2013.01.016.

Famiglietti, R. M. *et al.* (2017) 'Using Discrete-Event Simulation to Promote Quality Improvement and Efficiency in a Radiation Oncology Treatment Center', *Quality Management in Health Care*, 26(4), pp. 184–189. doi: 10.1097/QMH.0000000000000145.

Fone, D. *et al.* (2003) 'Systematic review of the use and value of computer simulation modelling in population health and health care delivery', *Journal of Public Health Medicine*, 25(4), pp. 325–335. Available at: http://www.jstor.org/stable/45162056.

Fougner, M. and Habib, L. (2008) 'If I had a rich picture···: Insights into the use of "soft" methodological tools to support the development of interprofessional education', *Journal of Interprofessional Care*, 22(5), pp. 488–498. doi: 10.1080/13561820802168125.

France, D. J. *et al.* (2005) 'Emergency physicians' behaviors and workload in the presence of an electronic whiteboard', *International Journal of Medical Informatics*, 74, pp. 827–837. doi: 10.1016/j.ijmedinf.2005.03.015.

Franco, L. A. and Montibeller, G. (2010) 'Facilitated modelling in operational research', *European Journal of Operational Research*, 205(3), pp. 489–500. doi: 10.1016/j.ejor.2009.09.030.

Frangeskou, M. (2018) *An exploration of standardised processes in a knowledge-intensive healthcare operation : Implementing the acute stroke care ' pathway*. University of Bath.

French, E. B. *et al.* (2017) 'End-Of-Life Medical Spending In Last Twelve Months Of Life Is Lower Than Previously Reported', *HEALTH AFFAIRS*, 36, pp. 1211–1217. doi: 10.1377/hlthaff.2017.0174.

Friesen, M. R. and McLeod, R. D. (2014) 'A survey of agent-based modeling of hospital environments', *IEEE Access*, 2, pp. 227–233. doi: 10.1109/ACCESS.2014.2313957.

Gartner, D., Zhang, Y. and Padman, R. (2018) 'Cognitive workload reduction in hospital information systems: Decision support for order set optimization', *Health Care Management Science*, 21(2), pp. 224–243. doi: 10.1007/s10729-017-9406-6.

Gleeson, C. (2021) 'Almost 400,000 fewer people scanned for cancers last year', *The Irish Times*, February. Available at: https://www.irishtimes.com/news/health/almost-400-000-fewer-people-scanned-for-cancers-last-year-1.4495164 (Accessed: 26 February 2021).

Gomes, J. and Romão, M. (2018) 'Information System Maturity Models in Healthcare', *Journal of Medical Systems*. Springer New York LLC, pp. 1–14. doi: 10.1007/s10916-018-1097-0.

De Gooyert, V. *et al.* (2017) 'Reviewing the role of stakeholders in Operational Research: A stakeholder theory perspective', *European Journal of Operational Research*, 262(2), pp. 402–410. doi: 10.1016/j.ejor.2017.03.079.

Gráinne Ní Aodha (2017) *HSE criticised for not knowing length of waiting lists for CT and MRI scans, thejournal.ie*. Available at: https://www.thejournal.ie/waiting-lists-critical-scans-3520767-Jul2017/ (Accessed: 12 February 2019).

Granja, C. *et al.* (2014) 'An optimization based on simulation approach to the patient admission scheduling problem: Diagnostic imaging department case study', *Journal of Digital Imaging*, 27(1), pp. 33–40. doi: 10.1007/s10278-013-9626-3.

Greasley, A. and Owen, C. (2018) 'Modelling people's behaviour using discrete-event simulation: a review', *International Journal of Operations & Production Managemen*, 38(5), pp. 1228–1244. doi: 10.1108/IJOPM-10-2016-0604.

Gregory, M. E., Russo, E. and Singh, H. (2017) 'Electronic health record alert-related workload as a predictor of burnout in primary care providers', *Applied Clinical Informatics*, 8(3), pp. 686–697. doi: 10.4338/ACI-2017-01-RA-0003.

Gullhav, A. N. *et al.* (2017) 'Block scheduling at magnetic resonance imaging labs', *Operations Research for Health Care*. doi: 10.1016/J.ORHC.2017.08.001.

Gunal, M. (2012) 'A guide for building hospital simulation models', *Health Systems*, 1(1), pp. 17–25. doi: 10.1057/hs.2012.8.

Günal, M. M. and Pidd, M. (2010) 'Discrete event simulation for performance modelling in health care: a review of the literature', *Journal of Simulation*, 4(1), pp. 42–51. doi: 10.1057/jos.2009.25.

Hackman, J. R. and Wageman, R. (1995) *Total Quality Management: Empirical, Conceptual, and Practical Issues, Source: Administrative Science Quarterly*. Available at: https://www.jstor.org/stable/pdf/2393640.pdf?refreqid=excelsior%3A7c18a3236f58deeb42e20cad0b95273c (Accessed: 3 July 2019).

Hallmark, B., Mechan, P. and Shores, L. (2015) 'Ergonomics: Safe patient handling and mobility', *Nursing Clinics of North America*, pp. 153–166. doi: 10.1016/j.cnur.2014.10.012.

Hammer, M. and Champy, J. (1993) 'Reengineering the corporation', *Small business report (Monterey, Calif.)*, 18(11), p. 65.

Harper, A., Mustafee, N. and Yearworth, M. (2021) 'Facets of trust in simulation studies', *European Journal of Operational Research*, 289(1), pp. 197–213. doi: 10.1016/j.ejor.2020.06.043.

Harper, P. R. and Pitt, M. A. (2004) 'On the challenges of healthcare modelling and a proposed project life cycle for successful implementation', *Journal of the Operational Research Society*, 55(6), pp. 657–661. doi: 10.1057/palgrave.jors.2601719.

Harvey, H. B. *et al.* (2016) 'Key Performance Indicators in Radiology: You Can't Manage What You Can't Measure', *Current Problems in Diagnostic Radiology*, 45, pp. 115–121. doi:

10.1067/j.cpradiol.2015.07.014.

Health Service Executive (2009) *Infection Prevention and Control Hand Hygiene for Staff*. Available at: http://www.who.int/gpsc/5may/background/5moments/en/index.html (Accessed: 30 August 2019).

Health Services Executive (2015) 'Projected Demographic Effect on Health Service Costs in 2015', (May 2014), pp. 1–88. Available at: https://www.google.ie/search?rct=j&q=projected+nuber+of+persons+living+in+nursing+homes&gws_rd=cr&ei=39vrV7m1NOWZgAaPwraIDw#q=projected+number+of+persons+living+in+nursing+homes+source+cso+population.

Health Services Executive (2017) *Review of the Clinical Radiology Medical Workforce in Ireland*. Dublin. Available at: https://www.hse.ie/eng/staff/leadership-education-development/met/plan/specialty-specific-reviews/clinical-radiology-chapter-for-web-2017.pdf (Accessed: 29 December 2020).

Hiam, L. *et al.* (2018) 'Why is life expectancy in England and Wales "stalling"?', *J Epidemiol Community Health*, 72(1), pp. 404–408. doi: 10.1136/jech-2017-210401.

HIMSS (2011) *Promoting Usability in Health Organizations: Initial Steps and Progress Toward a Healthcare Usability Maturity Model*. Chicago.

Holden, R. J. (2011) 'Lean thinking in emergency departments: A critical review', *Annals of Emergency Medicine*. doi: 10.1016/j.annemergmed.2010.08.001.

Holden, R. J. *et al.* (2015) 'Healthcare workers' perceptions of lean: A context-sensitive, mixed methods study in three Swedish hospitals', *Applied Ergonomics*, 47. doi: 10.1016/j.apergo.2014.09.008.

Holloway, I. and Wheeler, S. (2009) *Qualitative Research in Nursing and Healthcare*. Somerset, UNITED KINGDOM: John Wiley & Sons, Incorporated. Available at: http://ebookcentral.proquest.com/lib/nuig/detail.action?docID=707888.

Homer, J., Hirsch, G. and Milstein, B. (2007) 'Chronic illness in a complex health economy: The perils and promises of downstream and upstream reforms', *System Dynamics Review*, 23(2–3), pp. 313–343. doi: 10.1002/sdr.379.

HSE (2016) *Framework for Improving Quality in our Health Service*. Dublin: HSE.ie.

HSE (2020) *Portiuncula University Hospital | Saolta University Health Care Group*. Available at: https://www.saolta.ie/hospital/puh (Accessed: 1 April 2021).

HSE (2021) *GP Access to Diagnostics Radiology Outsourced Service Model*.

Hyde, E. and Hardy, M. (2021) 'Patient centred care in diagnostic radiography (Part 2): A qualitative study of the perceptions of service users and service deliverers', *Radiography*, 27(2), pp. 322–331. doi: 10.1016/j.radi.2020.09.008.

IIRRT (2010) 'Computed tomography: Best practice guidlines', *IIRRT Guidlines*, 787(November).

Irish Cancer Society (2016) *Access to Diagnostics Used to Detect Cancer*. Available at: http://health.gov.ie/future-health/financial-reform/private-health-insurance-2/ (Accessed: 12 February 2019).

Irish Cancer Society (2019) *Patients without health insurance must not be denied access to lifesaving drugs | Irish Cancer Society, cancer.ie website*. Available at: https://www.cancer.ie/about-us/news/patients-without-health-insurance-must-not-be-denied-access-lifesaving-drugs#sthash.6kj426NW.dpbs (Accessed: 23 January 2020).

Irish Institute of Radiography and Radiation Therapy (2014) *Computed Tomography Guidelines on Best Practice Fourth edition: 2014 COMPUTED TOMOGRAPHY: GUIDELINES ON BEST PRACTICE (4th edition)*. Available at: www.iirrt.ie (Accessed: 26 July 2018).

Jones, S. *et al.* (2013) 'A Business Analytics Software Tool for Monitoring and Predicting Radiology Throughput Performance', *Journal of Digital Imaging*, 29, pp. 645–653. doi: 10.1007/s10278-016-9871-3.

Karami, M. (2017) 'Development of key performance indicators for academic radiology departments', *International Journal of Healthcare Management*, 10(4), pp. 275–280. doi: 10.1080/20479700.2016.1268350.

Khan, H. A., Baig, F. K. and Mehboob, R. (2017) 'Nosocomial infections: Epidemiology, prevention, control and surveillance', *Asian Pacific Journal of Tropical Biomedicine*. Hainan

Medical University, pp. 478–482. doi: 10.1016/j.apjtb.2017.01.019.

Khan, S. H. M. and Hedges, W. P. (2013) 'Workload of consultant radiologists in a large DGH and how it compares to international benchmarks.', *Clinical radiology*, 68(5), pp. e239-44. doi: 10.1016/j.crad.2012.10.016.

King's Fund (2021) *How hospital activity in the NHS in England has changed over time | The King's Fund*. Available at: https://www.kingsfund.org.uk/publications/hospital-activity-funding-changes#diagnostics (Accessed: 27 April 2021).

Kotiadis, K. *et al.* (2013) 'Using a model of the performance measures in Soft Systems Methodology (SSM) to take action: A case study in health care', *Journal of the Operational Research Society*, 64(1), pp. 125–137. doi: 10.1057/jors.2012.21.

Kotiadis, K. and Tako, A. A. (2017) 'Facilitated post-model coding in discrete event simulation (DES): A case study in healthcare', *European Journal of Operational Research*, 266(3), pp. 1120–1133. doi: 10.1016/j.ejor.2017.10.047.

Kotiadis, K., Tako, A. A. and Vasilakis, C. (2014) 'A participative and facilitative conceptual modelling framework for discrete event simulation studies in healthcare', *Journal of the Operational Research Society*, 65(2), pp. 197–213. doi: 10.1057/jors.2012.176.

Kudyba, S. and Gregorio, T. (2010) 'Identifying factors that impact patient length of stay metrics for healthcare providers with advanced analytics.', *Health informatics journal*, 16(4), pp. 235–45. doi: 10.1177/1460458210380529.

Kumar, S., Moro, L. and Narayan, Y. (2004) 'Perceived physical stress at work and musculoskeletal discomfort in X-ray technologists', *Ergonomics*, 47(2), pp. 189–201. doi: 10.1080/00140130310001617958.

Kunc, M, Malpass, J and White, L (2016) *Behavioral Operational Research*. Edited by Martin Kunc, Jonathan Malpass, and Leroy White. London: Palgrave Macmillan UK. doi: 10.1057/978-1-137-53551-1.

Lakdawalla, D. N., Bhattacharya, J. and Goldman, D. P. (2004) 'Are The Young Becoming More Disabled?', *Health Affairs*, 23(1), pp. 168–176. doi: 10.1377/hlthaff.23.1.168.

Lamé, G., Crowe, S. and Barclay, M. (2020) '"What's the evidence?"—Towards more empirical evaluations of the impact of OR interventions in healthcare', *Health Systems*, 00(00), pp. 1–9. doi: 10.1080/20476965.2020.1857663.

Lamé, G., Jouini, O. and Stal-Le Cardinal, J. (2020) 'Combining Soft Systems Methodology, ethnographic observation, and discrete-event simulation: A case study in cancer care', *Journal of the Operational Research Society*, 71(10), pp. 1545–1562. doi: 10.1080/01605682.2019.1610339.

Law, A. and Kelton, D. (1991) *Simulation modeling and analysis*. 2nd ed. Edited by W. D. Kelton. New york: New york.

Laxmisan, A. *et al.* (2007) 'The multitasking clinician: Decision-making and cognitive demand during and after team handoffs in emergency care', *International Journal of Medical Informatics*, 76(11–12), pp. 801–811. doi: 10.1016/J.IJMEDINF.2006.09.019.

Leedy, P. D. (2021) *Practical research planning and design*. Twelfth, g. Edited by J. E. Ormrod and L. R. Johnson. Harlow, England: Harlow, England : Pearson.

Leedy, P. D. and Ormrod, J. E. (2020) *Practical Research: Planning and Design, Global Edition*. Harlow, United Kingdom, UNITED KINGDOM: Pearson Education, Limited. Available at: http://ebookcentral.proquest.com/lib/nuig/detail.action?docID=6401102.

Van Lent, W. A. M. *et al.* (2012) 'Reducing the throughput time of the diagnostic track involving CT scanning with computer simulation', *European Journal of Radiology*, 81, pp. 3131–3140. doi: 10.1016/j.ejrad.2012.03.012.

Lewis, P. J. (1992) 'Rich picture building in the soft systems methodology', *European Journal of Information Systems*, 1(5), pp. 351–360. doi: 10.1057/ejis.1992.7.

Liker, J. K. (2004) *The 14 Principles of the Toyota Way : An Executive Summary of the*, *The 14 Principles of the Toyota Way : An Executive Summary of the*. New Yoprk: McGraw-Hill.

Liker, J. K. (2007) *The Toyota way: 14 management principles from the world's greatest manufacturer*, *Action Learning: Research and Practice*. doi: 10.1080/14767330701234002.

Lindsay, R. *et al.* (2011) 'What influences clinician's satisfaction with radiology services?', *Insights into Imaging*, 2(4), pp. 425–430. doi: 10.1007/s13244-011-0099-y.

Lofland, J. (1971) *Analyzing social settings : a guide to qualitative observation and analysis*.

Belmont, Calif.: Wadsworth Pub. Co (The Wadsworth series in analytic ethnography).

Loosemore, M., Chow, V. W. and Mcgeorge, D. (2012) ‘Construction Management and Economics Modelling the risks of extreme weather events for Australasian hospital infrastructure using rich picture diagrams Modelling the risks of extreme weather events for Australasian hospital infrastructure using rich picture diagrams’. doi: 10.1080/01446193.2012.725941.

Lu, A. D. *et al.* (2021) ‘Implementation Strategies for Frontline Healthcare Professionals: People, Process Mapping, and Problem Solving’, *Journal of General Internal Medicine*, 36(2), pp. 506–510. doi: 10.1007/s11606-020-06169-3.

Lyons, G. J. and Duggan, J. (2014) ‘System dynamics modelling to support policy analysis for sustainable health care’, *Journal of Simulation*, pp. 1–11. doi: 10.1057/jos.2014.15.

Maguire, D. *et al.* (2021) *Shaping the future of digital technology in health and social care*. Available at: www.kingsfund.org.uk (Accessed: 27 April 2021).

Marshall, D. A. *et al.* (2015) ‘Applying dynamic simulation modeling methods in health care delivery research - The SIMULATE checklist: Report of the ISPOR simulation modeling emerging good practices task force’, *Value in Health*, 18(1), pp. 5–16. doi: 10.1016/j.jval.2014.12.001.

Martin, A. (2010) *Soundings : leaving certificate poetry, interim anthology*. Dublin: Gill Books.

Mays, N. and Pope, C. (1996) *Qualitative Research in Health Care*. London: BMJ Pub. Group.

Mazur, L. M. *et al.* (2019) ‘Association of the Usability of Electronic Health Records With Cognitive Workload and Performance Levels Among Physicians’, *JAMA Network Open*, 2(4), p. e191709. doi: 10.1001/jamanetworkopen.2019.1709.

McCarney, R. *et al.* (2007) ‘The Hawthorne Effect: a randomised, controlled trial’, *BMC Medical Research Methodology*, 7(1), p. 30. doi: 10.1186/1471-2288-7-30.

McDaniel, R. and Driebe, D. (2001) ‘Complexity science and health care management’, in *Advances in Health Care Management*. Emerald Group Publishing Limited (Advances in

Health Care Management), pp. 11–36. doi: 10.1016/S1474-8231(01)02021-3.

McGrath, K. *et al.* (2018) ‘Enhancing acute stroke services: a quality improvement project’, *BMJ Open Quality*, 7(3), p. e000258. doi: 10.1136/bmjoq-2017-000258.

McHugh, C., Bevans, K. and Paradis, S. (2020) ‘LADiBUG – A Communication Tool for Diagnostic Imaging’, *Journal of Medical Imaging and Radiation Sciences*, 51(4), pp. S31-S38.e1. doi: 10.1016/j.jmir.2020.07.053.

McLaughlin, N. *et al.* (2014) ‘Demystifying process mapping: A key step in neurosurgical quality improvement initiatives’, *Neurosurgery*. Lippincott Williams and Wilkins, pp. 99–109. doi: 10.1227/NEU.0000000000000360.

Meadows, D. H., Meadows, D. L. and Randers, J. (1992) *Beyond the limits: Confronting global collapse, envisioning a sustainable future*. Post Mills, Vermont: Chelsea Green Publishing Co.

Mildenberger, P. *et al.* (2020) ‘Performance indicators for radiation protection management: suggestions from the European Society of Radiology’, *Insights into Imaging*, 11(1), pp. 1–9. doi: 10.1186/s13244-020-00923-1.

Mingers, J. and Rosenhead, J. (2004) ‘Problem structuring methods in action’, *European Journal of Operational Research*, 152(3), pp. 530–554. doi: 10.1016/S0377-2217(03)00056-0.

Monks, T. *et al.* (2019) ‘Strengthening the reporting of empirical simulation studies: Introducing the STRESS guidelines’, *Journal of Simulation*, 13(1), pp. 55–67. doi: 10.1080/17477778.2018.1442155.

Monks, T., Robinson, S. and Kotiadis, K. (2014) ‘Learning from discrete-event simulation: Exploring the high involvement hypothesis’, *European Journal of Operational Research*, 235(1), pp. 195–205. doi: 10.1016/j.ejor.2013.10.003.

Monks, T., Robinson, S. and Kotiadis, K. (2016) ‘Can involving clients in simulation studies help them solve their future problems? A transfer of learning experiment’, *European Journal of Operational Research*, 249(3), pp. 919–930. doi: 10.1016/j.ejor.2015.08.037.

Morgan, J. S., Belton, V. and Howick, S. (2017) ‘Health Systems Lessons from mixing OR methods in practice: using DES and SD to explore a radiotherapy treatment planning process Lessons from mixing OR methods in practice: using DES and SD to explore a radiotherapy treatment planning process', *Health Systems*, 5. doi: 10.1057/hs.2016.4.

Morrison, B. and Lilford, R. (2001) 'How Can Action Research Apply to Health Services?', *QUALITATIVE HEALTH RESEARCH*, 11(4), pp. 436–449.

Mossa-Basha, M. *et al.* (2020) 'Radiology Department Preparedness for COVID-19: *Radiology* Scientific Expert Panel', *Radiology*, p. 200988. doi: 10.1148/radiol.2020200988.

Murray, T. E., Halligan, J. J. and Lee, M. J. (2017) 'Inefficiency, dignity and patient experience: Is it time for separate outpatient diagnostics?', *British Journal of Radiology*, 90(1080), pp. 4–6. doi: 10.1259/bjr.20170574.

Naylor, A. F. (1992) *Quantitative assessment of radiology workload and facilities requirements*, *European Journal of Radiology*.

Ngo, M., Schneider-Kolsky, M. and Baird, M. (2013) 'The attitudes of Australian radiography students towards the use of assistive transfer devices to reduce biomechanical stress in the clinical setting', *Radiography*, 19, pp. 125–129. doi: 10.1016/j.radi.2013.01.003.

Nightingale, J. *et al.* (2021) 'Retention of radiographers: A qualitative exploration of factors influencing decisions to leave or remain within the NHS', *Radiography*, 27(3), pp. 795–802. doi: 10.1016/j.radi.2020.12.008.

O'Connor, W. (2020) 'Warning as patients face increasing wait for scans as winter looms - Independent.ie', *Independent,ie* , 27 September. Available at: https://www.independent.ie/irish-news/health/warning-as-patients-face-increasing-wait-for-scans-as-winter-looms-39565014.html (Accessed: 6 January 2021).

O'Regan, E. (2015) *Two-tier waiting lists for patients seeking vital scans - Independent.ie*, *Independent.ie*. Available at: https://www.independent.ie/irish-news/health/twotier-waiting-lists-for-patients-seeking-vital-scans-30978644.html (Accessed: 12 February 2019).

O'Regan, E. (2018) *Thousands are told in A&E they have cancer - Independent.ie*, *Irish Independent*. Available at: https://www.independent.ie/irish-news/health/thousands-are-told-in-ae-they-have-cancer-37580540.html (Accessed: 3 December 2018).

O'Regan, E. (2019) *Outpatient delays worsen, but still no action plan - Independent.ie*. Available at: https://www.independent.ie/irish-news/health/outpatient-delays-worsen-but-still-no-action-plan-37117592.html (Accessed: 12 February 2019).

Office for National Statistics (2018) 'Health state life expectancies, UK: 2015 to 2017', *Office for National Statistics*, pp. 1–53.

Oh, H.-C., Toh, H.-G. and Giap Cheong, E. S. (2011) 'Realization of Process Improvement at a Diagnostic Radiology Department with Aid of Simulation Modeling', *Journal For Healthcare Quality*, 33(6), pp. 40–47. doi: 10.1111/j.1945-1474.2011.00133.x.

Olisemeke, B. *et al.* (2014) 'The Effectiveness of Service Delivery Initiatives at Improving Patients' Waiting Times in Clinical Radiology Departments: A Systematic Review', *Journal of Digital Imaging*, 27(6), pp. 751–778. doi: 10.1007/s10278-014-9706-z.

Oliva, R. (2002) 'Tradeoffs in responses to work pressure in the service industry', *IEEE Engineering Management Review*, 30(1), pp. 53–62. doi: 10.1109/EMR.2002.1022405.

Oliva, R. and Sterman, J. D. (2001) 'Cutting Corners and Working Overtime: Quality Erosion in the Service Industry', *Management Science*, 47(7), pp. 894–914. doi: 10.1287/mnsc.47.7.894.9807.

Olthof, M. *et al.* (2018) 'Actual and perceived nursing workload and the complexity of patients with total hip arthroplasty', *Applied Nursing Research*, 39, pp. 195–199. doi: 10.1016/J.APNR.2017.11.023.

Ondategui-Parra, S. *et al.* (2004) 'Essential practice performance measurement', *Journal of the American College of Radiology*, 1(8), pp. 559–566. doi: 10.1016/j.jacr.2004.03.020.

Ormerod, R. J. (2014) 'The mangle of OR practice: towards more informative case studies of "technical" projects', *Journal of the Operational Research Society*, 65(8), pp. 1245–1260. doi: 10.1057/jors.2013.78.

Oroviogoicoechea, C. and Watson, R. (2009) 'A quantitative analysis of the impact of a computerised information system on nurses' clinical practice using a realistic evaluation framework', *International Journal of Medical Informatics*, 78(12), pp. 839–849. doi: 10.1016/j.ijmedinf.2009.08.008.

Orsi, M. A., Oliva, A. G. and Cellina, M. (2020) ‘Radiology Department Preparedness for COVID-19: Facing an Unexpected Outbreak of the Disease’, *Radiology*, p. 201214. doi: 10.1148/radiol.2020201214.

Palmqvist, C. *et al.* (2019) ‘Surface Contamination of CT and MRI EquipmentdA Potential Source for Transmission of Hospital-Acquired Infections’. doi: 10.1016/j.jradnu.2019.09.002.

Parsons, H. (1974) ‘What Happened at Hawthorne?’, *JSTOR*, 183(4128), pp. 922–932. Available at: https://about.jstor.org/terms (Accessed: 14 August 2019).

Patching, D. (1990) *Practical soft systems analysis*. London: Pitman.

Paul, R. J., Eldabi, T. and Kuljis, J. (2003) ‘Simulation education is no substitute for intelligent thinking’, *Winter Simulation Conference Proceedings*, 2(January), pp. 1989–1993. doi: 10.1109/wsc.2003.1261662.

Pearson, M. *et al.* (2013) ‘Involving patients and the public in healthcare operational research—The challenges and opportunities’, *Operations Research for Health Care*, 2(4), pp. 86–89. doi: 10.1016/j.orhc.2013.09.001.

Pessôa, L. A. M. *et al.* (2015) ‘Integrating soft and hard operational research to improve surgical centre management at a university hospital’, *European Journal of Operational Research*, 245(3), pp. 851–861. doi: 10.1016/j.ejor.2015.04.007.

Pickering, A. (1997) *The Mangle of Practice: Time, Agency, and Science*, *Technology and Culture*. University of Chicago Press. doi: 10.2307/3106908.

Pidd, M. (2010) ‘Why Modelling and Model Use Matter’, *Source: The Journal of the Operational Research Society*, 61(1), pp. 14–24. doi: 10.1057/jors.2009.141.

Pitman, A. *et al.* (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), pp. 450–458. doi: 10.1111/j.1754-9485.2009.02094.x.

Pitman, A. *et al.* (2018) ‘Measuring radiologist workload: Progressing from RVUs to study ascribable times’, *Journal of Medical Imaging and Radiation Oncology*, 62(5), pp. 605–618. doi: 10.1111/1754-9485.12778.

Pitman, A. G. and Jones, D. N. (2004) ‘Radiologist workloads in teaching hospital departments: Measuring the workload’. doi: 10.1111/j.1440-1673.2005.01524.x.

Pitt, M. *et al.* (2016) ‘Systems modelling and simulation in health service design, delivery and decision making’, *BMJ Quality and Safety*. BMJ Publishing Group, pp. 38–45. doi: 10.1136/bmjqs-2015-004430.

Polgar, S. (2008) *Introduction to research in the health sciences*. 5th ed. Edinburgh ; New York: Elsevier.

Polgar, S. and Thomas, S. A. (2013) *Introduction to Research in the Health Sciences E-Book*. London, UNITED KINGDOM: Elsevier Health Sciences. Available at: http://ebookcentral.proquest.com/lib/nuig/detail.action?docID=1746284.

Proudlove, N. C. *et al.* (2017) ‘Towards fully-facilitated discrete event simulation modelling: Addressing the model coding stage’, *European Journal of Operational Research*, 263, pp. 583–595. doi: 10.1016/j.ejor.2017.06.002.

Rachuba, S., Salmon, A., *et al.* (2018) ‘Redesigning the diagnostic pathway for chest pain patients in emergency departments’, *Health Care Management Science*, 21(2), pp. 177–191. doi: 10.1007/s10729-017-9398-2.

Rachuba, S., Knapp, K., *et al.* (2018) ‘Streamlining pathways for minor injuries in emergency departments through radiographer-led discharge’, *Operations Research for Health Care*, 19, pp. 44–56. doi: 10.1016/j.orhc.2018.03.001.

Raj, V. (2006) ‘Occupational stress and radiography.’, *Radiologic Technology*, 78(2), pp. 113–122. Available at: http://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=ccm&AN=106288512&site=ehost-live&authtype=sso&custid=s6172330.

Rashwan, W. *et al.* (2015) *MODELING BEHAVIOR OF NURSES IN CLINICAL MEDICAL UNIT IN UNIVERSITY HOSPITAL: BURNOUT IMPLICATIONS*. Dublin. Available at: http://arrow.dit.ie/buschmarcon (Accessed: 17 April 2018).

Rashwan, W. (2017) *An Integrated Framework for Staffing and Shift Scheduling in Hospitals*. Dublin Institutue technology. Available at: https://arrow.dit.ie/busdoc/25/.

Rashwan, W., Abo-Hamad, W. and Arisha, A. (2015) 'A system dynamics view of the acute bed blockage problem in the Irish healthcare system', *European Journal of Operational Research*, 247, pp. 276–293. doi: 10.1016/j.ejor.2015.05.043.

Razavi, S. A. *et al.* (2014) 'The impact of introducing a no oral contrast abdominopelvic CT examination (NOCAPE) pathway on radiology turn around times, emergency department length of stay, and patient safety.', *Emergency radiology*, pp. 605–613. doi: 10.1007/s10140-014-1240-2.

RCSI (2011) *Measuring Consultant Radiologist workload in Ireland : rationale, methodology and results from a national survey*. Dublin.

Reijers, H. a. (2002) *Design and Control of Workflow Processes: Business Process Management for the Service Industry*. 1st ed. 20. Berlin, Heidelberg: Berlin, Heidelberg : Springer Berlin Heidelberg : Imprint: Springer.

Reinus, W. R. *et al.* (2000) 'A proposed scheduling model to improve use of computed tomography facilities.', *Journal of medical systems*, 24(2), pp. 61–76. Available at: http://www.ncbi.nlm.nih.gov/pubmed/10895421.

Robinson, A. S. and Robinson, S. (2001) 'Soft with a Hard Centre : Discrete-Event Simulation in Facilitation Published by : Palgrave Macmillan Journals on behalf of the Operational Research Society Linked references are available on JSTOR for this article : Soft with a hard centre : discrete-eve', *The Journal of the Operational Research Society*, 52(8), pp. 905–915.

Robinson, S. (2008) 'Conceptual modelling for simulation Part I: Definition and requirements', *Journal of the Operational Research Society*, 59(3), pp. 278–290. doi: 10.1057/palgrave.jors.2602368.

Robinson, S. *et al.* (2014) 'Facilitated modelling with discrete-event simulation: Reality or myth?', *European Journal of Operational Research*, 234(1), pp. 231–240. doi: 10.1016/j.ejor.2012.12.024.

Rodriguez-Ulloa, R. and Paucar-Caceres, A. (2005) 'Soft System Dynamics Methodology (SSDM): Combining Soft Systems Methodology (SSM) and System Dynamics (SD)', *Systemic Practice and Action Research*, 18(3), pp. 303–334. doi: 10.1007/s11213-005-4816-

7.

Rose, J. (1997) 'Soft systems methodology as a social science research tool', *Systems Research and Behavioral Science*, 14(4), pp. 249–258. doi: 10.1002/(SICI)1099-1743(199707/08)14:4<249::AID-SRES119>3.0.CO;2-S.

Ross, S. *et al.* (2003) 'Partnership experiences: Involving decision-makers in the research process', *Journal of Health Services Research and Policy*, 8(SUPPL. 2), pp. 26–34. doi: 10.1258/135581903322405144.

Royal College of Radiologists (2021) *Clinical Radiology UK Workforce Census 2020 Report, The Royal College of Radiologists*. Available at: https://www.rcr.ac.uk/system/files/publication/field_publication_files/clinical-radiology-uk-workforce-census-2020-report.pdf.

Royston, G. *et al.* (1999) 'Using System Dynamics to Help Develop and Implement Policies and Programmes in Health Care in England', *System Dynamics Review*, 15(3), pp. 293–313. doi: 10.1002/(SICI)1099-1727(199923)15:3<293::AID-SDR169>3.0.CO;2-1.

RStudioTeam (2015) 'RStudio: Integrated Development for R. RStudio'. Boston.

RTE (2018) *Public patients have cancer detected later - study, rte.ie*. Available at: https://www.rte.ie/news/2016/0426/784242-cancer-tests-health/ (Accessed: 12 February 2019).

Sachs, P. B. and Long, G. (2015) 'Process for Managing and Optimizing Radiology Work Flow in the Electronic Heath Record Environment.', *Journal of digital imaging*, pp. 43–46. doi: 10.1007/s10278-015-9819-z.

Sanderson, C. and Gruen, R. (2006) *EBOOK: Analytical Models for Decision-Making*. Berkshire, UNITED KINGDOM: McGraw-Hill Education. Available at: http://ebookcentral.proquest.com/lib/nuig/detail.action?docID=295465.

Sargent, R. G. (2013) 'Verification and validation of simulation models', *Journal of Simulation*, 7(1), pp. 12–24. doi: 10.1057/jos.2012.20.

Sauter, V. L. (2011) *Decision Support Systems for Business Intelligence*. Hoboken, UNITED STATES: John Wiley & Sons, Incorporated. Available at:

http://ebookcentral.proquest.com/lib/nuig/detail.action?docID=706599.

Saver, J. L. (2006) 'Time is brain - Quantified', *Stroke*, 37(1), pp. 263–266. doi: 10.1161/01.STR.0000196957.55928.ab.

Saville, C. E. *et al.* (2019) 'How many nurses do we need? A review and discussion of operational research techniques applied to nurse staffing', *International Journal of Nursing Studies*, 97, pp. 7–13. doi: 10.1016/j.ijnurstu.2019.04.015.

Sechrist, S. R. and Frazer, G. H. (1992) 'Identification of stressors in radiologic technology.', *Radiologic Technology*, 64(2), pp. 97–103. Available at: http://web.b.ebscohost.com.libgate.library.nuigalway.ie/ehost/pdfviewer/pdfviewer?vid=9&sid=9807add7-b08c-4af6-8198-a4d4b64900e8%40pdc-v-sessmgr03 (Accessed: 22 February 2021).

Seila, A. and Brailsford, S. (2009) *Opportunities and Challenges in Health Care Simulation.* Edited by W. J. Alexopoulos C., Goldsman D. Boston: Springer.

Seltzer, S. E. *et al.* (1997) 'Expediting the turnaround of radiology reports in a teaching hospital setting.', *American Journal of Roentgenology*, 168(4), pp. 889–893. doi: 10.2214/ajr.168.4.9124134.

Sherwood, D. (2002) *Seeing the forest for the trees : a manager's guide to applying systems thinking*. London: Nicholas Brealey Pub.

Shukla, N. *et al.* (2017) 'Modelling and simulation in health care systems', *International Journal of Systems Science: Operations & Logistics*, 4(1), pp. 1–3. doi: 10.1080/00207721.2016.1222772.

Shukla, N., Keast, J. E. and Ceglarek, D. (2014) 'Improved workflow modelling using role activity diagram-based modelling with application to a radiology service case study', *Computer Methods and Programs in Biomedicine*, 116(3), pp. 274–298. doi: 10.1016/j.cmpb.2014.05.005.

Sibbel, R. and Urban, C. (2001) 'Agent-Based Modeling and Simulation for Hospital Management', in *Cooperative Agents*. Dordrecht: Springer Netherlands, pp. 183–202. doi: 10.1007/978-94-017-1177-7_11.

Sinclair, S. *et al.* (2016) 'Compassion: a scoping review of the healthcare literature', *BMC Palliative Care*, 15(1), p. 6. doi: 10.1186/s12904-016-0080-0.

Snaith, B., Milner, R. C. and Harris, M. A. (2016) 'Beyond image interpretation: Capturing the impact of radiographer advanced practice through activity diaries', *Radiography*, 22(4), pp. e233–e238. doi: 10.1016/j.radi.2016.07.005.

Sterman, J. (1994) 'Learning in and about complex systems', *System Dynamics Review*, 10(2–3), pp. 291–330.

Sterman, J. (2007) 'A Sober Optimist's Guide to Sustainability - An interview with John Sterman', *MIT Sloan Management Review*, pp. 0–6. Available at: http://sloanreview.mit.edu/beyond-green/a-sober-optimists-guide-to-sustainability/.

Sterman, J. D. (2000) 'Business dynamics. System thinking and modeling for a complex world', *McGraw-Hill Education. Boston:* , (January 2000), p. 982 pp. doi: 10.1016/S0022-3913(12)00047-9.

Sterman, J. D. (2001) 'System Dynamics Modeling: Tools for Learning in a Complex World', *California management review*, 43(4), pp. 8–25. doi: 10.1111/j.1526-4637.2011.01127.x.

Sunshine, J. H. and Burkhardt, J. H. (2000) 'Radiology groups' workload in relative value units and factors affecting it.', *Radiology*, 214(3), pp. 815–822.

Swensen, S. J. and Johnson, C. D. (2005) 'Radiologic quality and safety: Mapping value into radiology', *Journal of the American College of Radiology*, 2(12), pp. 992–1000. doi: 10.1016/j.jacr.2005.08.003.

Tako, A. A. *et al.* (2014) 'Improving patient waiting times: A simulation study of an obesity care service', *BMJ Quality and Safety*, 23(5), pp. 373–381. doi: 10.1136/bmjqs-2013-002107.

Tako, A. A. and Kotiadis, K. (2015) 'PartiSim: A multi-methodology framework to support facilitated simulation modelling in healthcare', *European Journal of Operational Research*, 244(2). doi: 10.1016/j.ejor.2015.01.046.

Taylor, K. and Dangerfield, B. (2005) 'Modelling the feedback effects of reconfiguring health services', *Journal of the Operational Research Society*, 56(6), pp. 659–675. doi:

10.1057/palgrave.jors.2601862.

The Royal College of Radiologists (2017) *iRefer: making the best use of clinical radiology*. 8.0.1. doi: BFCR(17)2.

The World Medical Association (2000) *WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects – WMA –*. Available at: https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/ (Accessed: 6 April 2021).

Thorwarth, M. (2008) *Application of Discrete-Event Simulation in Health Care : a Review*. Dublin Institute of Technology, School of Management,.

Thorwarth, M. (2011) *A Simulation-based Decision Support System to improve Healthcare Facilities Performance – elaborated on an Irish Emergency Department*. Dublin Institute of Technology.

Trebble, T. *et al.* (2010) 'Practice pointer: Process mapping the patient journey: An introduction', *BMJ (Online)*, 341(7769), pp. 394–397. doi: 10.1136/bmj.c4078.

Unertl, K. M. *et al.* (2009) 'Describing and Modeling Workflow and Information Flow in Chronic Disease Care', *Journal of the American Medical Informatics Association*, 16(6), pp. 826–836. doi: 10.1197/jamia.M3000.

Ventana Systems, I. (2018) 'Vensim PLE Software'. Available at: www.vensim.com.

Verrier, W. and Harvey, J. (2010) 'An investigation into work related stressors on diagnostic radiographers in a local district hospital', *Radiography*, 16, pp. 115–124. doi: 10.1016/j.radi.2009.09.005.

Viana, J. *et al.* (2014) 'Combining discrete-event simulation and system dynamics in a healthcare setting: A composite model for Chlamydia infection', *European Journal of Operational Research*, 237(1), pp. 196–206. doi: 10.1016/J.EJOR.2014.02.052.

Walter, S. R., Dunsmuir, W. T. M. and Westbrook, J. I. (2015) 'Studying interruptions and multitasking in situ: The untapped potential of quantitative observational studies', *International Journal of Human-Computer Studies*, 79, pp. 118–125. doi: 10.1016/J.IJHCS.2015.01.008.

Wammes, J. D., Roberts, B. R. T. and Fernandes, M. A. (2018) 'Task preparation as a mnemonic: The benefits of drawing (and not drawing)', *Psychonomic Bulletin and Review*, 25(6), pp. 2365–2372. doi: 10.3758/s13423-018-1477-y.

Westbrook, J. I. *et al.* (2010) 'The impact of interruptions on clinical task completion', *Quality and Safety in Health Care*, 19(4), pp. 284–289. doi: 10.1136/qshc.2009.039255.

Whitley, S. and Clark, K. (2005) *Clark's positioning in radiography*. 12th ed., *Positioning in radiography*. 12th ed. London : New York, NY: London : Hodder Arnold.

Womack, J., Jones, D. and Roos, D. (2007) *The machine that changed the world*. London, England: Simon & Schuster.

Woods, A. L., Miller, P. K. and Sloane, C. (2016) 'Patient obesity and the practical experience of the plain radiography professional: On everyday ethics, Patient positioning and infelicitous equipment', *Radiography*, 22(2), pp. 118–123. doi: 10.1016/j.radi.2015.09.005.

Woznitza, N. *et al.* (2014) 'Optimizing patient care in radiology through team-working: A case study from the United Kingdom', *Radiography*, 20, pp. 258–263. doi: 10.1016/j.radi.2014.02.007.

Xu, Y. S. (2013) *An Agile Approach for Healthcare Simulation Modeling*. University of Calgary, Calgary. doi: 10.11575/PRISM/24809.

Yih, Y. (2010) *Handbook of Healthcare Delivery Systems*. Baton Rouge, UNITED STATES: Taylor & Francis Group. Available at: http://ebookcentral.proquest.com/lib/nuig/detail.action?docID=665650.

Zanardo, M. *et al.* (2020) 'Management of patients with suspected or confirmed COVID-19, in the radiology department', *Radiography*. doi: 10.1016/j.radi.2020.04.010.

Železnik, D., Kokol, P. and Blažun Vošner, H. (2017) 'Adapting nurse competence to future patient needs using Checkland's Soft Systems Methodology', *Nurse Education Today*, 48, pp. 106–110. doi: 10.1016/j.nedt.2016.09.015.

Zhang, C. *et al.* (2018) 'A systematic literature review of simulation models for non-technical skill training in healthcare logistics', *Advances in Simulation*, 3(1). doi: 10.1186/s41077-018-0072-7.