

EVALUATING THE IMPACT OF SERVICE DELIVERY  
INITIATIVES ON PATIENTS' WAITING TIMES IN DIAGNOSTIC  
RADIOLOGY: A MIXED METHODS STUDY

By

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## Abstract

This thesis describes the impact of service delivery initiatives (SDIs) on patients' waiting times within radiology departments. A systematic review of the literature (71 studies included) found the following broad type of SDIs: extended scope practice, quality management, productivity-enhancing technologies, outsourcing, pay-for-performance and multiple interventions. Ninety-six percent of the studies used either the pre- and post-intervention without control or the post-intervention only designs; but these designs are fundamentally weak and are prone to bias.

Furthermore, this thesis also described a case-study for the evaluation of the impact on patients' waiting times of a 320-slice computed tomography (CT) scanner, speech recognition reporting and extended-working-hours within the Birmingham Heartlands Hospital (Heart of England NHS Foundation Trust), Birmingham. The evaluation combined the interrupted time series (ITS) design and qualitative interviews with healthcare professionals in a mixed methods approach. The mixed methods approach leverages the strengths of the quantitative and qualitative methods, so that the triangulation of the findings of one research method might be strengthened when supported by the findings of the other research method. The thesis used a distinctive implementation of ITS segmented regression which accounts for the changing trends of patients waiting times – an approach referred to as ITS 'segmented spline' regression.

## Dedication

Dedicated to my wife, Doris and my children; Blossom, Destiny and Devine  
for their patience.

## Acknowledgement

This thesis could not have been completed without the help of some individuals. I am profoundly grateful to everyone who has helped me through the entire process. In particular, I would like to thank my supervisors; Alan Girling, Sheila Greenfield and Karla Hemming for their time, patience, advice and the overall guidance towards the successful completion of this thesis. Words cannot express the gratitude I have for all your help.

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**Olisemeke, B.,** Girling, A. and Hemming, K. (2016) The impact of a faster CT-scanner and extended-opening-hours on the waiting times for CT-scan: the experiences of an NHS Trust. **Journal of Medical Radiation Sciences**, 63: (S1): 45-85. **Abstracts from the 11th Annual Scientific Meeting of Medical Imaging and Radiation Therapy, Brisbane, Australia, 22-24 April**

**Olisemeke, B.,** Girling, A. and Hemming, K. (2015) Quantifying the impact of increasing ultrasound workload on patient waiting times using multiple time series analysis. **Proceedings of the British Medical Ultrasound Society 47th Annual Scientific Meeting 9–11 December 2015, City Hall, Cardiff, UK** Cardiff, UK 24

**Olisemeke, B.,** Chen, Y.F., Hemming, K., Girling, A. (2014) The Effectiveness of Service Delivery Initiatives at Improving Patients' Waiting Times in Clinical Radiology Departments: A Systematic Review. **Journal of Digital Imaging**, 1-28.

**Olisemeke, B.,** Chen, Y. F., Hemming, K., Girling, A. (2013) The effectiveness of service delivery initiatives at improving patients waiting times in clinical radiology departments: Protocol for a systematic review. PROSPERO: **CRD42013002092**.

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## Abbreviations

<i>A&amp;E</i>	Accident and Emergency
<i>ACF</i>	Autocorrelation Function
<i>BHH</i>	Birmingham Heartlands Hospital
<i>BO</i>	Bernard Olisemeke
<i>CBA</i>	Controlled Before and After
<i>CI</i>	Confidence Interval
<i>CINHAL</i>	Cumulative Index for Nursing and Allied Health Literature
<i>CPOE</i>	Computerised Physician Order Entry
<i>CR</i>	Computed Radiography
<i>CRIS</i>	Clinical Radiology Information System
<i>CT</i>	Computed tomography
<i>CTPA</i>	Computed Tomography Pulmonary Angiography
<i>DR</i>	Digital Radiography
<i>EMBASE</i>	Excerpta Medica dataBASE
<i>EMR</i>	Electronic Medical Records
<i>EPOC</i>	Effectiveness of Practice and Organisation of Care
<i>ER</i>	Electronic Requesting
<i>ESP</i>	Extended Scope Practice
<i>GP</i>	General Practice
<i>HEFT</i>	Heart of England Foundation Trust
<i>HIS</i>	Hospital Information System
<i>ICT</i>	Information and Computer Technology
<i>INSPEC</i>	Information Service for Physics Engineering and Computing
<i>IT</i>	Interrupted Time Series

<i>NH</i>	National Health Service
<i>MeSH</i>	Medical Subject Heading
<i>OLS</i>	Ordinary Least Squares
<i>PACF</i>	Partial Autocorrelation Function
<i>PACS</i>	Picture Archival and Communication System
<i>PETs</i>	Productivity-Enhancing Technologies
<i>PEWT</i>	Pre-examination Waiting Times
<i>PFP</i>	Pay-For-Performance
<i>PICO</i>	Population Intervention Comparison Outcome
<i>PNS</i>	Pager Notification System
<i>PRISMA</i>	Preferred Reporting Items for Systematic Review and Meta-Analysis
<i>QM</i>	Quality Management
<i>QMMs</i>	Quality Management Methodologies
<i>RCT</i>	Randomised Control Trial
<i>RIS</i>	Radiology Information System
<i>RTAT</i>	Report Turnaround Times
<i>SDIs</i>	Service Delivery Initiatives
<i>SRR</i>	Speech Recognition Reporting
<i>TR</i>	Tele-radiology
<i>TRWT</i>	Total Radiology Waiting Time
<i>WMS</i>	Workflow Management System
<i>YFC</i>	Yeng-Fu Cheng

# CHAPTER 1. INTRODUCTION AND BACKGROUND

## 1.1 Introduction

Diagnostic imaging is a key route in many patients' journeys through the healthcare system. More so because rational medical treatment depends on the establishment of a diagnosis (Foote et al., 2004; Stein, 2005; Sailer et al., 2015). It has been estimated that over 80% of hospital patients require some form of imaging (Rahimi, 2007). It is not surprising therefore that radiology departments have seen increasing demand for services in recent years (Smith-Bindman et al., 2008; Larson et al., 2011; Rohatgi et al., 2015; RCR, 2016). This is partly due to better equipment (Hendee et al., 2010), increased life expectancy (Keehan et al., 2008) and defensive medicine (Chen et al., 2015). The increasing demand for imaging has placed increased pressures on radiology departments (RCR, 2016). Many radiology departments have struggled to cope and as a consequence, waiting times have increased (Joffe et al., 2007; RCR, 2016).

The pressure on radiology services is often compounded by growing public expectations (Gahan, 2010). Waiting times have become a topical issue in the National Health Service (NHS) and have often caused passionate political debate and argument (Smith and Sutton, 2013). The political interest in waiting times has manifested itself in



the numerous policy initiatives of successive United Kingdom (UK) governments (Smith and Sutton, 2013) including guaranteeing maximum waiting times for patients (DoH, 2010). In a publicly funded healthcare system like the NHS, where access to service does not depend on the ability to pay, and waiting times are guaranteed with limited resources, there is a constant struggle to achieve a delicate balance between increasing demand, increased patients' expectations and budgetary constraints (Pandit et al., 2010).

There are also clinical pressures to reduce waiting times. There is evidence that increased waiting times might worsen patient's symptoms, deteriorate patient's condition and lead to poor clinical outcomes (Guttmann et al., 2011). A recent study has shown that increased waiting time for CT imaging is associated with increased tumour size, cancer stage and negative impact on clinical outcome for lung cancer patients (Byrne et al., 2015b). There is also anecdotal evidence from cancer patients that any reduction in time waiting for a diagnosis, even if it does not affect treatment or outcome, has a significant positive impact on psyche (DoH, 2012). Increased waiting times for imaging have also been identified as an independent predictor of increased length of hospital stay and costs (Cournane et al., 2016), thus reducing the effectiveness of the hospital.

Furthermore, it has long been argued that improved access to diagnostic imaging services has a wider implication for the overall effectiveness of the hospital (O'Kane, 1981). Although there is a significant body of literature on surgical waiting times, very little work has been done on the dynamics of waiting times in radiology

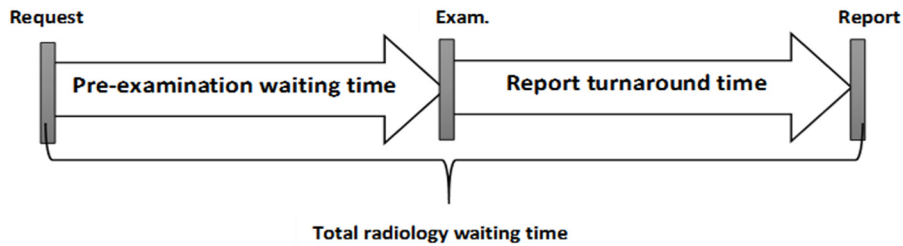
departments. It is generally believed that patients' waiting times arise when demand outstrips supply for healthcare. However, as noted by Borowitz et al. (2013), increased expenditure, and by extension increased supply, does not always guarantee low waiting times. It is now argued that increased waiting times are the result of a mismatch between the variances in capacity and demand for healthcare (Silvester et al., 2004; Gahan, 2010; Pandit et al., 2010; Borowitz et al., 2013). Healthcare systems are complex by nature, and understandably the measurement and definitions of patients waiting times are often varied and confusing (Breil et al., 2011). The next subsection briefly describes how waiting times are measured in diagnostic radiology.

### **1.1.1 Measurement of patients' waiting times in diagnostic radiology**

According to the Audit Commission (2002), there are two key measures of patients' waiting times in diagnostic radiology: a) the time between the imaging request arriving the radiology department and the patient undergoing the examination, referred to as the time 'waiting for the examination', and b) the time between the patient undergoing the examination and the finalised radiology report, referred to as the 'reporting time'. For clarity and consistency, these will be referred to as the pre-examination waiting times and the report turnaround times, respectively, in this thesis. These two components make up the total radiology waiting time (Figure 1.1). In practice, there is a wide variation in how the timelines are interpreted within the published literature (Hayt et al., 2001; Halsted and Froehle, 2008). This will be discussed further in chapter 2. Within this thesis, the terms "patients' waiting times"

and “waiting times” are broadly used to represent both the pre-examination waiting times and report turnaround times.

**Figure 1.1 Schematic presentation of patients' waiting times in clinical radiology**



### **1.1.2 Patients' waiting time management within clinical radiology departments**

Patients' waiting time management involves policies, activities and initiatives aimed at matching (the variability in) demand for and (the variability in) supply of radiology services, in order to maintain an acceptable balance between excessive resource use (costs) and excessive waiting times. Waiting time management within radiology can be broadly divided into demand-side and supply-side approaches (Durand et al., 2013). Demand-side approaches encompass all activities aimed at reducing the demand for radiology services (Duszak Jr and Berlin, 2012; Durand et al., 2013). This includes guidance issued to requesting physicians on clinical indications and appropriate use of diagnostic imaging (RCR, 2007). Supply-side management involves all initiatives aimed at meeting the extant demand effectively.

In a publicly funded healthcare system, increased waiting times may either prompt providers to intervene by implementing some initiatives to reduce waiting

times (either because providers tend to be altruistic and feel bad about increased patients' waiting times or because the measurement of their performance is based on waiting time targets) or induce government to allocate more resources to the healthcare sector (Dixon and Siciliani, 2009; Borowitz et al., 2013). In the current financial climate of budgetary constraints within the NHS, radiology departments are required to increase the efficiency of the services they provide (Grant et al., 2011). Many NHS radiology departments are therefore implementing different type of service delivery initiatives (SDIs) ranging from quality management strategies (Tiwari et al., 2014) to smart technologies such as speech recognition reporting (Hart et al., 2010) to reduce waiting times.

Despite the popularity of many SDIs currently implemented within radiology departments, there appears to be little in the form of robust, rigorous and systematic assessment of their impact on quality of service in the published literature (Ayal and Seidmann, 2009; Danton, 2010). Rather radiology has relied largely on anecdotal evidence (Hillman, 2004; Lee and Forman, 2011). SDIs in radiology should show evidence of effectiveness and added value to patients' quality of care (Hillman, 2007; Lee and Forman, 2011). This has become increasingly important especially given the current drive for efficiency savings within the NHS radiology departments (Grant et al., 2011).

The radiology department, Birmingham Heartlands Hospital (a part of the Heart of England NHS Foundation Trusts (HEFT)) recently implemented three SDIs: a) replacement of a 4- with a 320-slice computed tomography (CT) scanner, b) a switch

from manual transcription to speech recognition reporting and c) extended its working hours from 9AM – 5PM to 8AM – 8PM. This thesis aims to evaluate the impact on patients' waiting times of SDIs implemented within radiology departments and in particular, the above mentioned SDIs implemented within HEFT.

### **1.1.3 The research questions**

The research questions are:

- a. How effective at reducing patients' waiting times are currently popular SDIs implemented within diagnostic radiology departments?
- b. How have the SDIs recently implemented within the radiology department, Birmingham Heartlands Hospital impacted on patients' waiting times for CT scan?

## **1.2 Research methods and rationale**

This thesis has focused on a patient-centred outcome measure (patients' waiting times) for a few reasons: (a) there is an increasing interest in healthcare quality (Borowitz et al., 2013): waiting times are a key indicator of quality within radiology departments (Abujudeh et al., 2010); (b) waiting times are a crucial aspect of patients' experiences of radiology departments (Olofsson et al., 2014); (c) increased waiting times are associated with poor clinical outcomes for patients (Byrne et al., 2015b) and as previously mentioned, there is anecdotal evidence from cancer patients that any

reduction in time waiting for a diagnosis, has a significant positive psychological impact, even if it does not improve outcome (DoH, 2012) and d) the quest for ways to improve patients waiting times is a topical within the NHS (Ballini et al., 2016).

This thesis combines a systematic review and a case study to address the research questions listed in section 1.1.3. To address the first research question, a systematic review was performed to assess the effectiveness at reducing patients' waiting times of SDIs implemented within radiology departments. A systematic review is appropriate for addressing this type of question because it allows the researcher to gather, evaluate and synthesise all the empirical evidence that meet pre-specified criteria, using explicit methods to minimise bias (Higgins and Green, 2011).

To address the second research question, the interrupted time series (ITS) design and analysis was combined with in-depth qualitative interviews in a mixed methods approach within the framework of a case study. The ITS design and analysis is a robust quasi experimental method that can control for underlying secular and seasonal trends. Therefore, it provides a higher level of evidence compared to the simple pre- and post-intervention designs (Creswell and Clark, 2011). The ITS design and analysis is especially useful when (a) it is not feasible to perform randomisation (Shadish et al., 2002; Kontopantelis et al., 2015), (b) the investigator has no control over the implementation of the intervention (Penfold and Zhang, 2013) and (c) identification of a control a group is not practical (Grimshaw et al., 2003); as is the case with the current study.

Qualitative interviews (with healthcare professionals) allow the researcher to learn about what cannot be seen and explore alternative explanations for what can be seen (Glesne, 1999; Seidman, 2013). Qualitative information on the intervention is a powerful control for one of the biases of the ITS design: the bias of 'history' / time varying confounder; explained in detail in chapter three. When combined with a comprehensive qualitative data on the intervention, the ITS design is a powerful tool for evaluating the effectiveness of healthcare interventions (Penfold and Zhang, 2013).

A case study allows researchers to explore in detail a phenomenon demarcated by time and activity, in its real-life environment where variables and behaviours cannot be controlled, through the collection of detailed information using a variety of data collection instruments and procedures (Yin, 2009). A case study is especially useful when there is a need to understand how or why an intervention might have worked or not (Yin, 2009).

A mixed methods case study is an empirical method of enquiry designed to handle technically distinctive situation where there might be many more variables that can possibly explain the effect of interventions, than can be modelled quantitatively (Yin, 2009; O'Cathain et al., 2007). In a mixed methods study, the qualitative and quantitative methods need to be properly integrated such that the studies converge in a triangulating (Yin, 2009; O'Cathain et al., 2010) and coherent (Fetters et al. 2013) manner. The next sub-section highlights how integration can be achieved in a mixed methods case study design.

## **1.2.1 Integration in a mixed methods study**

The mixed methods research design is a powerful tool for investigating the effectiveness of complex interventions within the healthcare systems as it leverages on the strengths of the quantitative and qualitative research methods (Creswell et al., 2011). According to Fetters et al. (2013), the methods should be integrated at the design, methods and results (reporting) levels.

### **1.2.1.1 Integration at the design level**

There are three basic mixed methods designs: the exploratory sequential, convergent and explanatory sequential designs (Fetters et al., 2013). In the exploratory sequential design, qualitative data is collected and analysed, which then informs how the quantitative study is conducted. In the convergent design, both quantitative and qualitative data are collected and analysed in parallel. In the explanatory sequential design, quantitative data is first collected and analysed which then informs how the qualitative study is performed. The current study followed the explanatory sequential design. Quantitative waiting time data was first collected and analysed using the ITS design and analysis. The qualitative study was subsequently performed to explore the context within which the interventions were implemented.

Fetters et al. (2013) also noted that the three basic designs can be a part of an advanced research framework. The advanced frameworks were identified as the multistage, intervention, participatory and case study frameworks. The multistage mixed methods framework as the name implies involves multiple stages of data



collection which may include any number of the basic designs. The intervention mixed methods framework uses qualitative design to collect data which is then used to shape and design an intervention. The participatory mixed methods framework allows participants to guide the direction of the research. In a case study framework, qualitative and quantitative data are collected to build a more comprehensive understanding of the case. This thesis followed the case study framework.

### **1.2.1.2 Integration at methods level**

Fetters et al. (2013) listed four ways of integration at the methods level to include connecting, embedding, merging and building. The methods are connected when the data collection for one method is linked to the other method through the sampling frame. For example, choosing interview participants from those who responded to a survey questionnaire (Fetters et al., 2013). Integration through embedding occurs when data collection and analysis are linked at multiple points. Integration through merging occurs when the data from the two methods are brought together for analysis and comparison. Integration through building occurs when the data collection approach of the latter study is informed by the former study. In this thesis, the qualitative study was built on the quantitative study at the methods level. The qualitative study was designed to explore the contextual issues surrounding the implementation of the SDIs. As there was a need to understand the wider issues which might have shaped the interventions and why the interventions might have worked or not.

### **1.2.1.3 Integration at the results (reporting) level**

Fetters et al. (2013) listed three ways of integrating mixed methods study at the reporting level to include joint display, data transformation and the narrative approaches. The narrative approach is further subdivided into weaving, contiguous and staged approaches. The contiguous approach to narrative reporting involves presenting the findings of the quantitative and qualitative study in a single report, but dedicating different sections of the report to the qualitative and quantitative findings. The weaving approach to narrative reporting involves writing both qualitative and quantitative findings together on a “theme-by-theme or concept-by-concept basis” (Fetters et al., 2013). A staged approach to narrative reporting involves presenting the results as they become available. The current study adopted the contiguous approach of narrative synthesis by presenting the quantitative and qualitative studies in different chapters of this thesis report. The weaving narrative method was then used to synthesise the studies on an intervention-by-intervention basis, using the qualitative data to contextualise the quantitative findings. This synthesis is presented in a separate chapter. Therefore, the reporting method can be seen as a cross between contiguous and weaving approaches to narrative reporting. The next sections describe the study setting including the interventions and the conceptual framework for the case study.

## 1.3 This study setting

The case study was performed in the radiology department, Birmingham Heartlands Hospital, a part of the Heart of England NHS Foundation Trust (HEFT), Birmingham. HEFT is one of the largest acute NHS Trusts in England, comprising the Birmingham Heartlands Hospital, Good Hope Hospital, Solihull hospital and the Birmingham Chest Clinic. Its catchment area stretches from Birmingham East and North through Solihull, Tamworth, Meriden and Sutton Coldfield to South Staffordshire in the West Midlands. It has a total bed capacity of 1449 across three hospital sites: Heartlands, 692; Good Hope, 521 and Solihull, 236 (HEFT, 2013b). The radiology department is spread across the four sites. HEFT employs about 11,000 members of staff, treats about 1.2 million patients per year including about 250,000 A&E attendance per year (HEFT, 2013b).

The radiology department processes about 350,000 patients per year and offers the full suite of diagnostic imaging services including magnetic resonance imaging (MRI), computed tomography (CT), ultrasound (US), interventional radiology (IR), fluoroscopy, nuclear medicine, mammography, plain film imaging and DEXA scan (HEFT Radiology, 2015). The radiology department employs about 320 staff including 27 radiologists, 130 radiographers, 14 nurses and 70 clerical personnel (HEFT Radiology, 2015).

The following software systems were in use at the time of this study: IMPAX™ version 6.3.1 (picture archival and communication system, PACS), supplied by

the Agfa-Gevaert Group, Belgium; CRIS™ version 2.9.10 (radiology information system, RIS), supplied by the Healthcare Software Solution (HSS) Ltd., Mansfield, UK; Dragon Naturally Speaking for radiology version 9 (speech recognition reporting, SRR software), supplied by Nuance Systems Inc. USA. and an in-house computerised physician order entry system (CPOE). The SRR system is fully integrated with the PACS and CRIS systems. All three systems are also fully integrated with the hospital information systems (HIS) such that completed radiology reports are immediately available to referring clinicians through the electronic patients' records portal. However, the CPOE system was not coupled with a decision support system at the time of this study.

Patients attending the radiology department are referred from four clinical pathways: inpatient; accident and emergency (A&E); outpatient; and general practice (GP). Radiology resources (staff and equipment) are shared amongst the four clinical pathways: there are no dedicated scanners / staff for any particular clinical pathway. Some of the staff also work across the three hospital sites, when required.

### **1.3.1 The interventions**

The implemented SDIs and their effective dates are as follows: a) replacement of a 4- with a 320-slice CT-Scanner, the 21<sup>st</sup> July 2009, this will be referred to as the CT intervention henceforth; b) speech recognition reporting (SRR), 1<sup>st</sup> September 2009, referred to as the SRR intervention henceforth and c) extended-

working-hours (EWH), 3<sup>rd</sup> September 2012, this will be referred to as the EWH intervention in the rest of the thesis.

Before the implementation of the CT intervention (Aquilion ONE™, Toshiba Medical Systems Ltd), there were two CT-scanners within the Heartlands Hospital site: a 16-slice (Toshiba Medical Systems Ltd) and a 4-slice (Philips Healthcare Ltd) CT-scanners. The 4-slice system was replaced with the 320-slice system. The 320-slice scanner is a much faster scanner than the 4-slice system which it replaced. This was seen as a capacity boost meant to increase patient throughput by reducing scanning times. Reducing the scanning time meant that more patients could be scanned per day. Scanning more patients/day from the pool of waiting patients should lead to reduced pre-examination waiting times.

Before the SRR intervention, radiology reports were dictated onto digital audio files which were associated with patients' records on the CRIS™. The digital audio files were accessible to transcriptionists anywhere through the CRIS™. The transcriptionist listened to the audio file and transcribed the report onto the CRIS™. The radiologist checks the transcribed report within the CRIS™ and signs it off. Although this system has many advantages, the time delay between dictation and transcription of the reports remained an issue. In order to reduce this time delay, the radiology department implemented the SRR intervention.

SRR system converts spoken words into written text and allows radiologists to generate and edit radiology reports using real-time, continuous speech. The system comprises a microphone, a soundcard and SRR software within a computing unit. The

soundcard converts spoken words into digital audio data. The SRR software analyses the digital data using an acoustic model, comprising a library of words and a language model, comprising a library of domain-specific words and phrases, to statistically predict the most likely sequence of words dictated by the radiologist (Fox et al., 2013). The first step usually, is for the acoustic model to calculate the statistical probability of the expected words spoken by the radiologist. This is then contextualised within the statistical probability of domain-specific words and phrases calculated by the language model (Fox et al., 2013). The combined probability calculations of the acoustic and language models promote a greater level of transcription accuracy. The radiologist dictates the report; the SRR system transcribes the spoken word instantaneously, the radiologist then checks the accuracy of the transcription and signs off the report. This intervention removes the time delay between dictation and transcription and should lead to reduced report turnaround times.

Finally, before the EWH intervention, all the clinical and administrative units within the department worked 9am – 5pm (eight hours), Monday to Friday. The inpatient and A&E clinical pathways had access to 24-hour service through the on-call system: if an urgent examination was required after 5pm, a radiographer was called from home to perform the scan which was then reported by the on-call radiologist. Following the EWH intervention, some clinical units including CT, MRI, and interventional radiology changed their opening times to 8am – 8pm (12 hours), Monday to Sunday to improve access to service. This meant that more patients could be scanned per working day, seven days per week. Scanning more patients per working day should lead to reduced pre-examination waiting times. With the

implementation of the EWH intervention, routine scanning also became available to inpatient and A&E from 8AM to 8 PM, Monday to Sunday. The on-call radiographer takes over from 8 PM.

The extended-working-hours mostly applied to radiographers who performed the scans; the radiologists who reported the scans did not generally work the extended-hours. It is thought that this intervention will result in more scans being performed, especially for the outpatient and GP clinical pathways, than could be reported within the normal working hours of the radiologists. Therefore, report turnaround times were expected to increase following the EWH intervention.

### **1.3.2 Data sources**

This study was performed using data from the Heartlands Hospital site only. One important requirement of the interrupted time series design is a uniform data collection technique over the entire study period (Grimshaw et al., 2003; EPOC, 2012a). Data for the quantitative study was obtained from the CRIS™, from June 2008 to September 2013. Before June 2008, the Heartlands Hospital used a radiology information system (RIS) supplied by the IMS MAXIMS Solutions Ltd. Dublin, Ireland. RIS is a computerised database used by radiology departments to record, manipulate, and distribute patient radiological data and it contributes to electronic patient' records (Alderson, 2000). Data for the qualitative study was obtained through qualitative interviews. Qualitative interviews were conducted between 20<sup>th</sup> February and 16<sup>th</sup> July 2015 with healthcare professionals based on the Heartlands Hospital site.

### **1.3.3 Ethical review**

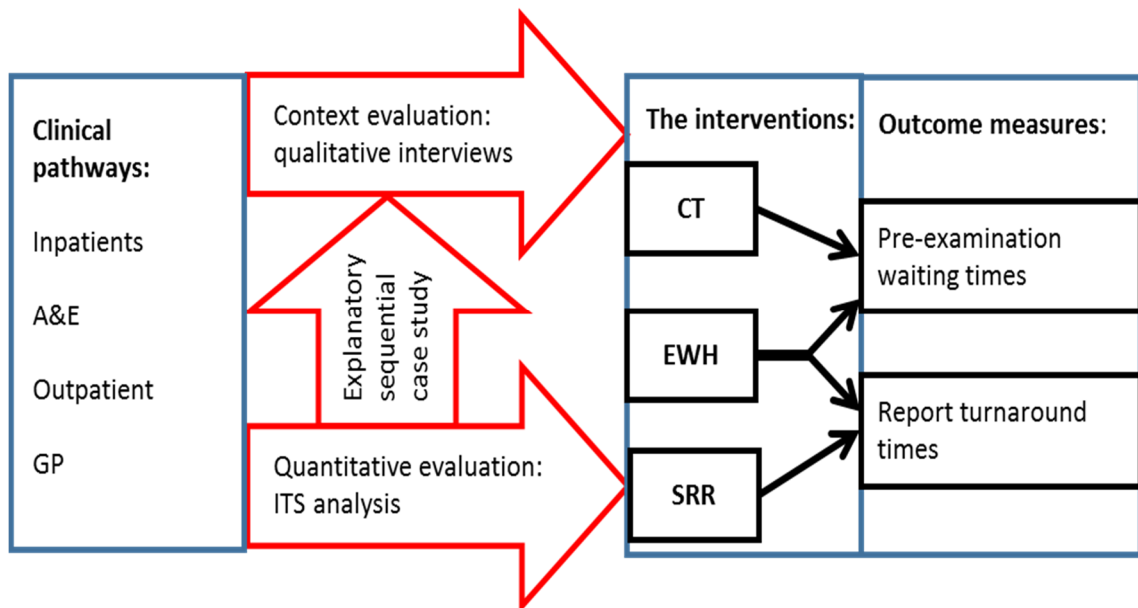
This study received a favourable ethical opinion from the Science, Technology, Engineering and Mathematics Ethical Review Committee, University of Birmingham (ref: ERN\_12-1537 dated 20<sup>th</sup> February 2013 and updated 8<sup>th</sup> September 2014) (Appendix 1). Permission was sought and obtained from the Heart of England NHS Foundation Trust for this study to be performed within its facilities. The permission letter (appendix 2) stated that NHS ethics review was not required for the studies.

## **1.4 Conceptual framework for the mixed methods case study**

The conceptual framework for the mixed methods case study is illustrated in Figure 1.2. The impact on waiting times of the three SDIs (CT-Scanner, SRR and EWH interventions) is evaluated using the mixed quantitative and qualitative methods approach as previously mentioned. The quantitative study, was performed first, using the ITS design and analysis to quantify the impact of the SDIs on waiting times. The pre-examination waiting times were used to evaluate the effectiveness of the CT intervention. The report turnaround times were used to evaluate the effectiveness of the SRR intervention. Finally, the effectiveness of the EWH intervention was evaluated using both the pre-examination waiting times and report turnaround times. The effectiveness of the three interventions was evaluated separately for each of the four clinical pathways.



**Figure 1.2 Conceptual framework for the mixed methods case study**



CT, the CT intervention; EWH, the Extended-working-hours intervention; SRR, the speech recognition reporting intervention; A&E, accident and emergency; GP, General Practice.

The quantitative study was integrated with the qualitative study using the explanatory sequential design approach (Fetters et al., 2013), as previously noted in section 1.2.1. The qualitative study was conducted at the end of the quantitative study to get an in-depth understanding of the context within which the interventions were implemented; to understand participants' perceptions of why the interventions were implemented, whether those expectations were met or not and elicit explanations for why the interventions might have worked or not.

The remainder of the thesis report comprises a systematic review performed to address research question one, presented in chapter two. Chapter three gives an overview of the ITS design and analysis, using a combination of simulated and actual datasets to demonstrate the advantages of the ITS design and analysis over the

simple pre- and post-intervention design. Chapter three also discusses the refinement of ITS analysis to accommodate datasets that violate the assumptions of the ordinary least squares (OLS) regression. The strengths and weaknesses of the ITS design are also covered in chapter three. The results of applying the ITS design and analysis to evaluate the effectiveness of the three SDIs implemented in Birmingham Heartlands Hospital are presented in chapter four. The qualitative investigation of the context within which the SDIs were implemented is presented in chapter five. Chapter six presents a synthesis of the findings of the quantitative and qualitative studies; specifically using the qualitative data to explain the results of the quantitative study on an intervention-by-intervention basis. Chapter seven summarises the main findings of the thesis. The overall conclusions and suggestions for further research are also provided in chapter seven.

# CHAPTER 2. A SYSTEMATIC REVIEW OF THE EFFECTIVENESS OF SERVICE DELIVERY INITIATIVES AT REDUCING PATIENTS' WAITING TIMES IN DIAGNOSTIC RADIOLOGY<sup>1</sup>

## Abstract

The literature was systematically reviewed for the evidence of effectiveness at reducing patients' waiting times of service delivery initiatives (SDIs) implemented within radiology departments.

The MEDLINE, EMBASE, CINAHL, INSPEC databases and The Cochrane Library were searched for relevant articles published between 1995 and June, 2016. The Cochrane Effectiveness of Practice and Organisation of Care (EPOC) Review Group

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<sup>1</sup> Materials contained in this chapter have been published: **Olisemeke, B., Chen, Y.F., Hemming, K., Girling, A. (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) 751 - 778.**

risk of bias tool was used to assess the risk of bias on studies that met specified design criteria.

Seventy-one studies (77 articles) met the inclusion criteria. Eleven (15%) of the studies were performed in the United Kingdom (UK), forty-three (61%) in the USA, eight (11%) in the European Union (EU) and nine (13%) in the rest of the world. Ten (14%) of the studies were published before year 2000, thirty-four (48%) within years 2000 to 2009, and 27 (38%) from year 2010 to June 2016. Sixty-eight (96%) of the studies used either the pre- and post-intervention without control or the post-intervention only designs. The type of SDIs implemented can be broadly classified into extended scope practice (ESP, three studies), quality management (20 studies), productivity-enhancing technologies (34 studies), multiple interventions (12 studies), outsourcing and pay-for-performance (one study each). The reporting quality was poor: for example, many of the studies did not test and / or report the statistical significance of their results.

It was not possible to pool the results in a meta-analysis due to a high level of heterogeneity between the studies, including inconsistent definitions of patients' waiting times. A narrative synthesis was therefore presented. Quality management methodologies (including Six Sigma, Lean Methodology, and continuous quality improvement), productivity-enhancing technologies (speech recognition reporting, tele-radiology and computerised physician order entry systems) and extended scope practice showed promising results. In order to make it more feasible to pool the results

of future studies in a meta-analysis, there is a need to use higher quality designs and map the definitions of patients' waiting times in radiology to a generic timeline.

## 2.1 Background

Patients' experiences of radiology services revolve around the key issues of availability and waiting times (Audit Commission, 2002; Olofsson et al., 2014).

Increasing financial, political and clinical pressures to reduce waiting times for radiology examinations have meant that many radiology departments are implementing a variety of service delivery initiatives (SDIs). The breadth of SDIs is wide, ranging from small scale inexpensive changes to practice, to large costly initiatives. There is a dearth of literature on how best to evaluate these SDIs within radiology departments, where pragmatic constraints often mean that randomised controlled trials are not feasible. Consequently, the methods and quality with which SDIs are evaluated within radiology settings is often mixed. In spite of, and perhaps even because of these constraints, a review of the type of SDIs, methods of evaluation used, and evidence of effectiveness, would be a useful addition to the literature.

There has been no synthesis of evidence of effectiveness at reducing patients' waiting times of the frequently implemented SDIs within radiology departments. A few reviews of the causes of increased hospital waiting times and the impact of various improvement strategies have been published (Hurst and Siciliani, 2003; Appleby, 2005; Masri et al., 2005). However, many of these reviews were unsystematic (Grilli et al., 2006) and they have mainly focused on the waiting lists for (elective) surgical care.

## **2.1.1 Aims and objectives**

### **2.1.1.1 Aims**

The aim of this chapter is to systematically review the literature to address the question; how effective at reducing patients' waiting times are SDIs currently being implemented within radiology departments? Evidence of this form will allow for a more effective guidance to radiology service managers who are keen to improve their services and, those designing and conducting studies evaluating the effectiveness of SDIs within radiology departments.

### **2.1.1.2 Objectives**

The objectives are to:

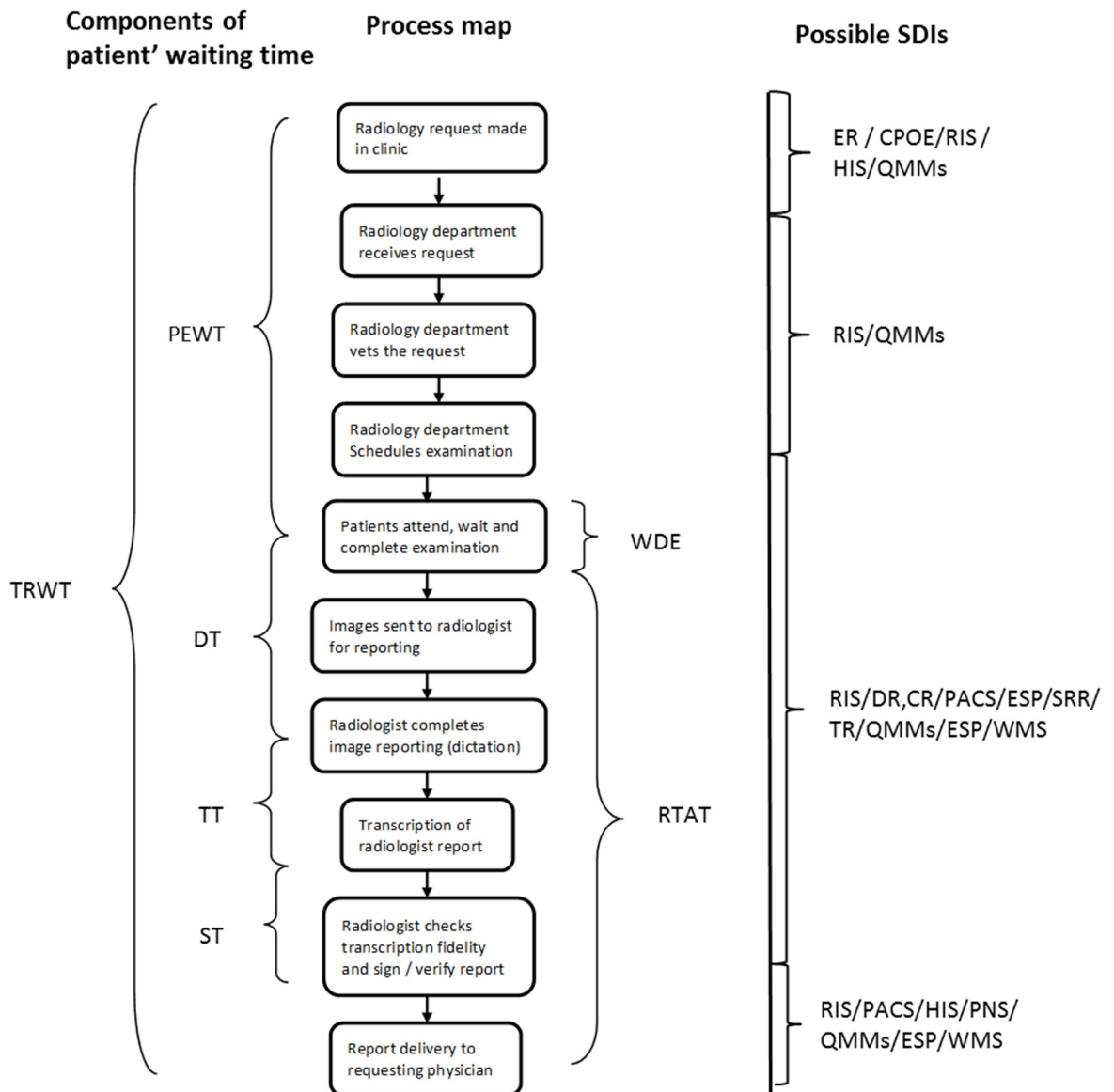
- a. Perform a literature search and apply the inclusion and exclusion criteria to the retrieved articles.
- b. Assess the risk of bias on studies that met specified design criteria.
- c. Use appropriate method to synthesis the evidence

## **2.1.2 The global radiology workflow**

It is useful to briefly explain the radiology workflow at this stage, to allow for a better understanding of how (a) the outcome measures are defined and (b) the SDIs fit into the radiology workflow processes. The radiology workflow begins with the

request for a radiology examination by a clinician and ends with a finalised radiology report (Figure 2.1).

**Figure 2.1 The global radiology workflow and possible improvement strategies**



**Legend:** RPT, radiology process time; PEWT, pre-examination waiting time; DT, dictation time; TT, transcription time; ST, signature time; WDE, waiting on the day of examination; RTAT, report turnaround time; SDIs, service delivery initiatives; ER, electronic requesting; CPOE, computerised physician order entry; RIS, radiology information system; DR, digital radiography, CR, computed radiography; PACS, picture archival and communication system; ESP, extended scope practice; TR, tele-radiology; PNS, pager notification system; QM, quality management; HIS, hospital information system; SRR, speech recognition reporting; WMS, workflow management system



Different type of SDIs can be used to optimise the radiology workflow steps, for example, the traditional hardcopy radiology images in a 'film folder', which is transported from office to office for reporting and viewing; and frequently lost in the process, can be replaced with a PACS system which makes the radiology images electronically available to multiple viewers at the same time. This should eliminate the logistic of making images physically available to clinicians. Another workflow step is the transcription of radiology reports. The human transcriptionist might be replaced with a speech recognition reporting (SRR) system which converts spoken words to written text. Intuitively, this should lead to reduced radiology report turnaround times.

## **2.2 Methods**

A systematic review is a protocol driven attempt to gather, evaluate and synthesize all the empirical evidence that meet pre-specified criteria, to address a given research question, using explicit methods to minimise bias, with an objective of producing more reliable findings that can be used to inform decision making (Higgins and Green, 2011). This review incorporates methods from the Cochrane Collaboration (Higgins and Green, 2011), Centre for Reviews and Dissemination (CRD, 2009) and the PRISMA statement (Moher et al., 2009). The general structure of this review, organisation of search and the risk of bias assessment followed the Cochrane guideline. Data synthesis followed the Centre for Review and Dissemination guideline. The reporting followed the PRISMA guideline for reporting systematic reviews. These guidelines were combined because preliminary literature search revealed diverse

study designs and settings, and the researcher did not wish to impose highly restrictive inclusion criteria.

## **2.2.1 Data sources**

The MEDLINE, EMBASE, CINAHL, INSPEC databases and The Cochrane Library were searched for relevant articles. The search was organised in line with the PICO framework: **P**opulation / **P**roblem; **I**ntervention, **C**omparison (optional) and **O**utcome. The search strategy combined Medical Subject Heading (MeSH) with free text terms. The search strategy implemented on MEDLINE (appendix 3) was adapted to suit the remaining databases. Six articles from the preliminary literature search were used to refine and validate the search strategy. The six articles are Akhtar et al. (2011), Andriole et al. (2010), Deitte et al. (2011) Hurlen et al. (2010) 2010 Krishnaraj et al. (2010) and Tavakol et al. (2011). The search strategy was fine-tuned until all six articles were retrieved from the MEDLINE database.

## **2.2.2 Inclusion and exclusion criteria**

### **2.2.2.1 Inclusion criteria**

To be included in this review, the study must (a) be published between 1995 and June, 2016, (b) clearly define what SDI was implemented, (c) report objective measures of the impact of the SDI on patients' waiting times (d) be performed within routine clinical setting. The objective measure of impact must be expressed as time waited from referral to examination or finalised radiology report; or time waited from

examination to finalised radiology report; or the number / proportion of patients that waited above or below a specified length of time.

Any type of SDI with a reported impact on patients' waiting times was included. The type of SDIs included extended scope practice (ESP), service re-design, quality management, speech recognition reporting (SRR), electronic requesting etc. (Figure 2.1). Only studies published in English language were included due to financial constrain.

### **2.2.2.2 Exclusion criteria**

The following type of publications were excluded: studies which addressed diagnostic performances without reference to impact on patients' waiting times, clinical interventions, simulation studies, opinion papers, editorials and other non-empirical studies.

### **2.2.3 Study selection process**

All identified articles were imported into EndNote X6™ and duplicates removed (Figure 2.2). The title and abstract of the retrieved articles were screened for potentially relevant studies. The full text of articles assessed as 'potentially relevant' were retrieved. The inclusion and exclusion criteria were applied to the potentially relevant articles. Any article excluded at this stage has a documented reason for exclusion. The reference lists of the included articles were also hand searched. Articles identified by hand search were added to the review database.

## 2.2.4 Data extraction

Data was extracted from the included studies into an Excel file. The extracted data included, year of publication, country of publication, study design, type of intervention, outcome measure, definition of outcome measure, effect size, population investigated, etc. The included studies were stratified by the type of SDIs, and sub-stratified by study design and the outcome measures that were reported.

## 2.2.5 Risk of bias assessment

The interpretation and conclusions drawn from a systematic review are a function of the validity of the included studies. According to (Higgins JPT et al., 2011), there are two dimensions of research validity: external and internal validity. External validity refers to the appropriateness of the research questions asked and it informs the generalisability of the findings of a study. The internal validity relates to whether the study answered the research question correctly, without bias.

*A bias is a systematic error, or deviation from the truth, in results or inferences ... meaning that multiple replication of the same study will reach the wrong answer on average (Higgins JPT et al., 2011).*

Risk of bias assessment is often confused with the assessment of quality. The study quality refers to the extent to which the researcher conducted the study to the highest possible standards (Higgins JPT et al., 2011). A study may be performed to the highest possible standard, yet have important risk of biases and conversely a study may in fact be unbiased despite a methodological flaw (Higgins JPT et al., 2011). Risk of

bias assessment addresses the key question of the extent to which the results of a study can be believed (Higgins JPT et al., 2011). The Cochrane recommends focusing on risk of bias assessment because important quality assessment criteria such as obtaining ethical approval and reporting the results of a study in line with some agreed guidelines (e.g. CONSORT) are unlikely to have a direct implication on the risk of bias (Higgins JPT et al., 2011).

Tools have been developed to assess the risk of bias in studies, however these tools are developed for studies meeting certain minimum design requirements. The Cochrane Collaboration Effectiveness of Practice and Organisation of Care (EPOC) Review Group risk of bias tool (EPOC, 2012b) was used to assess the risk of bias on studies that met the minimum criteria for inclusion in EPOC-type review: either randomised control trials (RCT), non-randomised control trials, controlled pre- and post-intervention with a minimum of two control and two intervention sites or interrupted time series (ITS) (EPOC, 2012a). Risk of bias was not assessed on studies that used either the pre- and post-intervention without control or the post-intervention only designs because these study designs are already known to be inherently susceptible to a very high risk of bias (Deeks et al., 2003; Higgins and Green, 2011; EPOC, 2012a).

## **2.2.6 Data synthesis**

Data synthesis involves the summary, collation and combination of the results of individual studies included in a systematic review. Data synthesis can be

done quantitatively using formal statistical procedures such as meta-analysis, or if formal pooling of results is unsuitable, through the narrative synthesis (CRD, 2009). Pooling of results obtained from diverse non-randomised study types is generally not recommended (Deeks et al., 2011); because meta-analysis of poor quality studies could be seriously misleading as errors or biases in individual studies would be compounded and the very act of synthesis may give credence to poor quality studies (Higgins et al., 2011).

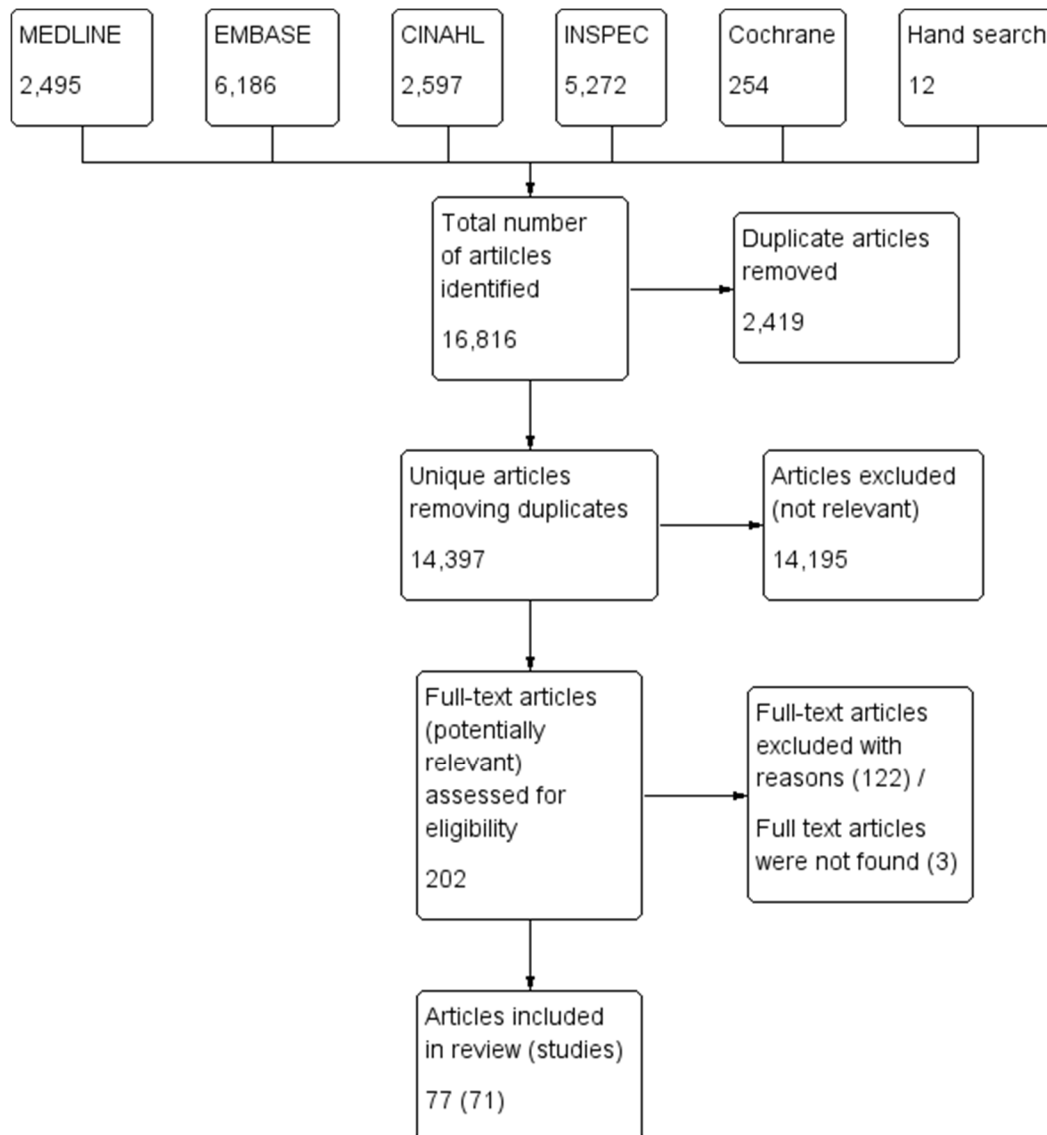
The results of the current review could not be pooled in a meta-analysis due to a high level of heterogeneity between the studies. The narrative synthesis is widely used in situations like this (McPherson et al., 2006; Hains et al., 2012). Therefore, the results of the studies are synthesised using the narrative approach. This is a word-based analysis of the relationships within and between studies and an overall assessment of the robustness of the evidence (CRD, 2009).

## **2.3 Results**

The literature search yielded 16,816 articles (Figure 2.2). After removing duplicates (n=2419), 14,397 articles were screened by titles and abstract and n=14,195 articles were excluded as not relevant leaving n=202 articles eligible for full text review. Full text for three articles could not be obtained from the British Library and were therefore excluded. One hundred twenty-two articles were excluded with reasons. The reasons included a failure to report the outcome measures of interest or

any objective measure of patients' waiting times. Other articles were excluded because they were either opinions, theoretical papers, editorial pieces or failed to report any intervention. Seventy-seven articles (71 studies) met the inclusion criteria.

**Figure 2.2 Study selection process**



**Table 2.1 Included studies stratified by type of intervention, research design and component of patients' waiting times reported (percentage in parenthesis)**

<i>Type of Intervention</i>	<b>Number of studies (percentage)</b>	<b>Study design</b>				<b>Waiting time component</b>		
		Post intervention only	Pre- and post-intervention without control	Pre- and post-intervention with control	Time series	Pre exam waiting time (PEWT)	Report turnaround time (RTAT)	Total radiology waiting time (TRWT)
<i>Extended scope practice</i>	3 (4.2)	.	2	.	1	1	2	.
<i>Quality mgt. / service re-design</i>	20 (28)	2	17	1	.	16	5	2
<i>Outsourcing</i>	1 (1.4)	1	.	.	.	1	.	.
<i>Pay-for-performance</i>	1 (1.4)	.	1	.	.	.	1	.
<i>Productivity enhancing technologies*</i>	34 (48)	5	28	1	.	4	28	3
<i>Multiple intervention</i>	12 (17)	2	10	.	.	2	7	3
<i>Total number of studies</i>	71 (100)	10 (14.1)	58 (81.7)	2 (2.8)	1 (1.4)	24 (34)	44 (62)	8 (11)

\*Productivity enhancing technologies included: speech recognition reporting (SRR), picture archival and communication system (PACS), radiology information system (RIS), computed radiographer (CR), computerised physician order entry (CPOE), digital radiography (DR). The waiting time components do not add up to 71 because some studies measured (reported) more than one component of patients' waiting times,



Most of the studies (61%: 43/71) were performed in the USA, 15% (11/71) in the UK, 11% (8/71) in the EU and 13% (9/71) in rest of the world. Fourteen percent (10/71) of the studies were published before year 2000, 48% (34/71) within years 2000 to 2009, and 38% (27/71) from year 2010 to June 2016. Eighty-two percent of studies (58/71) used the pre- and post-intervention designs without control while 14% (10/57) used the post-intervention only designs (Table 2.1). The RTAT was the most reported outcome measure; reported in 62% (44/71) of the studies while PEWT was reported in 30% (24/71) (Table 2.1). The characteristics and main findings of the included studies are summarised in appendix 4. The results of the studies by type of SDIs are summarised below.

### **2.3.1 Extended scope practice (ESP)**

ESP, also referred to as advanced practice (AP) radiographer is one who has extended his/her role to include duties that were typically performed by radiologists and accordingly has additional clinical expertise in a given area of practice (SOR, 2010) e.g. plain film reporting. Four percent (3/71) of the included studies evaluated ESP, all of which were performed in the UK. Two of the studies used the pre- and post-intervention without control designs but investigated different population (clinical pathways): A&E (Blakeley et al., 2008), inpatients and outpatients (Newman and Nightingale, 2011). The third study used time series analysis and evaluated the A&E clinical pathway (Brealey and Scuffham, 2005). Different components of patients' waiting times were reported: RTAT (Brealey and Scuffham, 2005; Blakeley et al., 2008)

and PEWT (Newman and Nightingale, 2011). All three studies reported improved patients waiting times following ESP intervention. For example, Brealey and Scuffham (2005), found that ESP was associated with 12% increase in the number of A&E plain film examinations that were reported ( $p=0.050$ ) and 36.8% reduction in RTAT for those examinations ( $p<0.001$ ). Newman and Nightingale (2011) reported a reduction in the mean PEWT of video fluoroscopy examinations for inpatient (75%) and outpatient (62%) following the implementation of ESP.

### **2.3.2 Quality management methodologies (QMMs)**

Radiology service quality management is a general approach to identify and control factors that might introduce variability into the quality of service, with a view to consistently and cost-effectively deliver high quality service (Papp, 2014). Twenty-eight percent (20/71) of the included studies investigated quality management strategies including the Lean, Six Sigma and continuous quality improvement methodologies (Laurila et al., 2001; Harmelink, 2008; Aloisio et al., 2009; Aloisio and Winterfeldt, 2010; Bucci and Musitano, 2011; Humphries et al., 2011; Mahmoud et al., 2013; Towbin et al., 2013; Steele et al., 2014; Tobey et al., 2014). Other QMMs studies evaluated process / service re-design methodologies (Hodler et al., 1999; Johal et al., 2003; Pallan et al., 2005; Hawtin et al., 2010; Steffen, 2010; Patel et al., 2012; Li et al., 2013; Mehta et al., 2013; Tiwari et al., 2014; Dang et al., 2015).

The type of study designs included the pre- and post-intervention with control (Laurila et al., 2001) and the post-intervention only designs (Pallan et al., 2005;

Dang et al., 2015). The remaining 17 studies used the pre- and post-intervention without control designs. The PEWT was reported in 15 studies (Johal et al., 2003; Pallan et al., 2005; Harmelink, 2008; Aloisio et al., 2009; Aloisio and Winterfeldt, 2010; Hawtin et al., 2010; Steffen, 2010; Bucci and Musitano, 2011; Humphries et al., 2011; Li et al., 2013; Mahmoud et al., 2013; Mehta et al., 2013; Steele et al., 2014; Tiwari et al., 2014; Dang et al., 2015). Five studies reported the RTAT (Hodler et al., 1999; Towbin et al., 2013; Tobey et al., 2014; Dang et al., 2015) and two studies reported the TRWT (Laurila et al., 2001; Patel et al., 2012). Four studies failed to define the timelines used in computing the reported outcome measures (Johal et al., 2003; Bucci and Musitano, 2011; Mehta et al., 2013; Tobey et al., 2014). The remaining studies reported RTAT.

Most of the studies reported improved outcomes (Hodler et al., 1999; Laurila et al., 2001; Johal et al., 2003; Pallan et al., 2005; Harmelink, 2008; Aloisio et al., 2009; Aloisio and Winterfeldt, 2010; Hawtin et al., 2010; Steffen, 2010; Bucci and Musitano, 2011; Humphries et al., 2011; Li et al., 2013; Mahmoud et al., 2013; Mehta et al., 2013; Towbin et al., 2013; Steele et al., 2014; Tiwari et al., 2014; Tobey et al., 2014). For example, Humphries et al. (2011) used the Lean methodology to improve the PEWT for CT-examinations in an academic trauma Centre. The changes implemented in the study included encouraging radiographers to facilitate workflow by "pulling" patients, defining CT-scanning protocol, aligning radiographers' rota with the variability in the demand for CT-examination, improved communication between radiology and A&E and performance feedback to radiographers. The study found that the mean PEWTs dropped from 56 (90% CI 54, 57) to 36 (90% CI 34, 38) minutes following the interventions. The only study that used the pre- and post-intervention

design with a control site (Laurila et al., 2001), reported that the improvements were not sustained. One study found increased waiting times following service re-design (Patel et al., 2012): TRWTs were 51 and 69 minutes for CT head; 69 and 82 minutes for body CT pre-and-post service re-design, respectively.

### **2.3.3 Outsourcing**

A situation where the radiology department (rather than the referring clinician) sub-contracts an examination or parts of it (e.g. reporting) to a third-party provider is known to as outsourcing (Tavakol et al., 2011). One study evaluated the impacts on PEWT of outsourcing radiology examinations (Tavakol et al., 2011). This study used the post-intervention only design to compare the PEWT of outsourced examinations with those performed in-house. Two sub-groups of examinations were analysed: the first sub-group are those in which the requesting physician specified a preferred time for the examination and the second sub-group are those where the requesting physician expressed no preferences. The study found no statistically significant difference between the examinations performed in-house and those outsourced, in either the number of examinations that were not performed within the preferred time or the number of days that exceeded the preferred waiting time. However, for examinations without a preferred timeframe, the waiting times were shorter for outsourced investigations compared to those performed in-house.

## **2.3.4 Pay for performance (PFP)**

PFP is a package of financial incentive designed to encourage healthcare organisations and/or individual staff to improve their performances and deliver a higher quality care (Boland et al., 2010b). A PFP programme comprising \$5,000 annual bonus payment to radiologists who met specified RTAT targets was evaluated for its impact on RTAT (Boland et al., 2010b). This study found that the mean RTATs dropped from 43 (SD 99) hours to 32 (SD 78) hours following PFP and 16 (SD 54) hours two years after PFP,  $p < 0.0001$ .

## **2.3.5 Productivity-enhancing technologies (PETs)**

PETs are an assortment of technologies intended to improve the radiology workflow. The effectiveness of PETs at reducing patients' waiting times was explored in 48% (34/71) of the included studies. The technologies evaluated comprised speech recognition reporting, picture archival and communication systems, tele-radiology, radiology information systems, computerised physician order entry systems and other.

### **2.3.5.1 Speech recognition reporting (SRR)**

The SRR system works by converting spoken words into digital signal which is then transformed into written text. SRR was evaluated in 19% (13/71) of the studies (Rosenthal et al., 1998; Wheeler and Cassimus, 1999; Lemme and Morin, 2000b; a; Whang et al., 2002; Cavagna et al., 2003; Sferrella, 2003; Koivikko et al., 2008; Hart et al., 2010; Krishnaraj et al., 2010; Akhtar et al., 2011; Kelley, 2011; Rao et al., 2013;

Prevedello et al., 2014). Two of the studies used the post-intervention only design (Whang et al., 2002; Cavagna et al., 2003) and the remaining 11 studies used the pre- and post-intervention without control design. All 13 studies evaluated different patient population and measured RTAT using different time lines. All 13 studies reported varying degrees of improvement. However, one of the studies noted that two of 30 radiologists in a practice did not experience improvement in their individual workflow following the implementation of SRR (Krishnaraj et al., 2010).

### **2.3.5.2 Picture archival and communication system (PACS)**

The PACS is an electronic system for handling, storing, organising and distributing digital images within the healthcare environment. Seven percent (5/71) of the studies evaluated the impact of PACS on patient waiting times (Hangiandreou et al., 1997; Mehta et al., 2000a; b; Redfern et al., 2000; Kuo et al., 2003; Mackinnon et al., 2008). The post-intervention design was used in one study (Kuo et al., 2003) and the pre- and post-intervention without control design was used in the remaining four studies. Different patient population were investigated: these were based on imaging modality (Mehta et al., 2000b; a; Mackinnon et al., 2008), or clinical pathway (Hangiandreou et al., 1997; Redfern et al., 2000). The definition of outcome measures also varied. The results for PACS is mixed, for example one study (Mackinnon et al., 2008) found that the mean RTAT increased from four to seven days for MRI ( $p < 0.001$ ), remained stable at two days for CT and dropped from four to three days for plain x-rays, following the implementation of PACS. However, the overall departmental RTAT dropped from six to five days ( $p < 0.001$ ). Another study found a 9% reduction in RTAT

(Mehta et al., 2000b; a). Yet another study reported that the median PEWT was significantly longer for plain x-rays following the implementation of PACS: increasing from 20 to 25 minutes for A&E patients and three to 42 minutes for intensive care patients (Redfern et al., 2000).

### **2.3.5.3 Tele-radiology**

Tele-radiology is the method for electronically transmitting digital radiology images from one location to another for the purpose of consultation and interpretation. Two (2.8% of 71) studies on tele-radiology met the inclusion criteria. The two studies used different research designs: pre- and post-intervention without control design (Kennedy et al., 2009) and the post intervention only design (Krupinski et al., 1999). Both studies measured RTAT in using different timelines. Both studies found that tele-radiology was associated with reduced RTAT. For example, the proportion of reports completed within 40 minutes increased from 34% (95% CI 29, 38) to 43% (95% CI 39, 47) with tele-radiology (Kennedy et al., 2009).

### **2.3.5.4 Radiology information system (RIS)**

RIS is a software system for managing and keeping permanent records of patients' journeys through a radiology department. Two (2.8% of 71) studies investigated RIS and both studies used the pre- and post-intervention without control design. Both studies investigated different components of patient waiting times: the TRWT for orthopaedic outpatients (Inamura et al., 1997) and the RTAT for MRI and mammography (Lahiri and Seidmann, 2009). The results were mixed. Lahiri and

Seidmann (2009) found that the mean RTAT for MRI increased from 3.11 (SD 1.87) to 3.20 (SD 1.85) hours following the implementation of RIS. These results were statistically significant at 5%. Inamura et al. (1997) found that the mean TRWT reduced from 26.8 (SD 6.8) to 3.6 (SD 2.5) hours following the implementation of RIS.

### **2.3.5.5 Computerised physician order entry (CPOE) system**

CPOE is a system for requesting radiology examinations electronically instead of using pen on paper, and sending the completed request form to the radiology department by post or fax. Seven percent (5/71) of the studies assessed the impact of CPOE on patients' waiting times. All five studies used the pre- and post-intervention without control design. Two studies measured the TRWT (Adam et al., 2005; Schneider et al., 2013) while the remaining three measured the PEWT (Mekhjian et al., 2002; Cordero et al., 2004; Thompson et al., 2004). Different patient population were investigated: patients that presented with chest pain in an A&E department and subsequently had a chest x-ray (Adam et al., 2005), patients in adult intensive therapy unit (ITU) who had urgent CT or plain film imaging (Thompson et al., 2004), patient referred for either plain chest / abdominal x-rays or abdominal ultrasound from a transplant service (Mekhjian et al., 2002), inpatients referred for MRI (Schneider et al., 2013) and very low birth weight (VLBW) babies in a neonatal intensive care unit (NICU) who had abdominal or chest x-rays (Cordero et al., 2004). Three of the studies reported improved waiting times. Thompson et al. (2004) found that median PEWT reduced from 96 to 29 minutes following intervention ( $p < 0.001$ ), with less variation around the median for adult ITU patients. The study involving patients referred from a



transplant unit found that PEWT reduced from seven to four hours (49%)  $p < 0.05$  (Mekhjian et al., 2002). It was not specified if these were mean or median values. The VLBW study reported reduced mean order-to-image-display time from 42 to 32 minutes (Cordero et al., 2004). The fourth study reported no improvement in patient waiting times: TRWT remained stable at 80 minutes, ( $p = 0.49$ ) despite increased volume of requests (Adam et al., 2005). Two of the five studies (Mekhjian et al., 2002; Cordero et al., 2004) were from the same institution.

### **2.3.5.6 Other technologies**

The remaining seven PETs studies (10% of 71) investigated a wide range of PET ranging from paging-systems for alerting attending radiologists of examinations awaiting report (Andriole et al., 2001b; a; Oguz et al., 2002) through digital imaging (Langlois et al., 1999; Olteanu and Gaetano-Klosek, 2013), the use of radiology reporting template (Hundt et al., 1998), workflow management system (Halsted and Froehle, 2008) to computer aided diagnosis (Kao et al., 2015). Two studies used the post-intervention only design (Hundt et al., 1998; Langlois et al., 1999). The remaining five studies used the pre- and post-intervention without control design (Andriole et al., 2001a; b; Oguz et al., 2002; Halsted and Froehle, 2008; Olteanu and Gaetano-Klosek, 2013; Kao et al., 2015). All seven studies measured the RTAT with different timelines and included different patient population as well. Most of the studies reported improved patients' waiting times (Hundt et al., 1998; Andriole et al., 2001a; b; Oguz et al., 2002; Halsted and Froehle, 2008), however one study noted that the gains were not sustained beyond one-week after the implementation of a pager-notification-

system (Andriole et al., 2001a; b). Mixed results were reported on a digital radiography system (Langlois et al., 1999; Olteanu and Gaetano-Klosek, 2013).

### **2.3.6 Multiple interventions**

Seventeen percent (12/71) of the studies evaluated more than one type of interventions. Most of these studies combined multiple PETs (Mattern et al., 1999a; b; Horii et al., 2000; Langer, 2002a; b; Marquez and Stewart, 2005; Nitrosi et al., 2007; Ayal and Seidmann, 2008; 2009; Van-Lom, 2009). The remainder combined QMMs with PETs (Seltzer et al., 1997; Hayt et al., 2001; DeFlorio et al., 2008; Hurlen et al., 2010; Clarke et al., 2013). The studies used varied research designs including the post-intervention only design (Langer, 2002a; b) and the pre- and post-intervention without control design. Three studies reported TRWT (Mattern et al., 1999a; b; Nitrosi et al., 2007; Clarke et al., 2013). One study reported PEWT (Horii et al., 2000). The remaining eight studies reported RTAT (Seltzer et al., 1997; Hayt et al., 2001; Langer, 2002a; b; Marquez and Stewart, 2005; Ayal and Seidmann, 2008; DeFlorio et al., 2008; Van-Lom, 2009; Hurlen et al., 2010).

Most of the studies found that waiting times improved following intervention (Seltzer et al., 1997; Hayt et al., 2001; Marquez and Stewart, 2005; Nitrosi et al., 2007; Ayal and Seidmann, 2008; 2009; Van-Lom, 2009; Hurlen et al., 2010). For example, the average RTAT dropped from 115 to 23 minutes following multiple interventions (Ayal and Seidmann, 2008; 2009). Again, one study reported that the improvements were not sustained (Hurlen et al., 2010). Two studies reported

increased patients' waiting times following multiple interventions (Horii et al., 2000; Clarke et al., 2013). Clarke et al. (2013) found that following the implementation of a weekly A&E radiology group meeting, authorisation of A&E CT head requests by radiographers, an escalation policy, immediate transfer of A&E patients to the CT unit, and the provision of radiology registrars reporting hub next to the A&E CT-Scanners, the TRWT for CT abdomen increased from 69 to 82 minutes. Horii et al. (2000) reported that PEWT increased from 0.12 to 0.27 hours following the implementation of PACS and automated scheduler. Three studies reported mixed results (Mattern et al., 1999a; b; Langer, 2002a; b; DeFlorio et al., 2008). For example, DeFlorio et al. (2008) evaluated a combination of interventions and found that better staffing level, PET (adoption of SRR) were associated with reduced RTAT while staff education on the need to comply with RTAT requirements and proposed sanctions for non-compliance with RTAT targets did not lead to reduced RTAT.

### **2.3.7 Risk of bias assessment**

Only one study (Brealey and Scuffham, 2005) fully met the minimum design standard for a Cochrane-type review. Two other studies (Laurila et al., 2001; Kennedy et al., 2009) used the controlled pre- and post-intervention design; but with a single intervention site and a single control site instead of the recommended minimum of two intervention and two control sites, thereby only partially meeting the standard specified in EPOC (2012b). The Cochrane EPOC risk of bias tool (EPOC, 2012b) was used to assess the risk of bias on these three studies (Table 2.2). Risk of bias assessment was

not performed for the remaining studies for two reasons: (a) as earlier stated, there is empirical evidence that the pre- and post-intervention without control and the post-intervention only designs are inherently susceptible to a very high risk of bias (Matowe et al., 2002; Deeks et al., 2003; Higgins and Green, 2011), and (b) no risk of bias assessment tool for these study designs was found.

**Table 2.2 Risk of bias assessment on the three studies that met the minimum design requirement for the Cochrane EPOC risk of bias tool**

	<i>Controlled pre-and-post (CBA) studies</i>		<i>Time series (ITS) study</i>	
<b>CBA Domains</b>	Laurila et al. (2001)	Kennedy et al. (2009)	<b>ITS Domains</b>	Brealey and Scuffham (2005)
<i>Quality management</i>	Quality management	Tele-radiology		ESP
<i>Was the allocation sequence adequately generated?</i>	<b>High risk of bias</b> All CBA studies are considered high risk on this domain	<b>High risk of bias</b> All CBA studies are considered high risk on this domain	Was the intervention independent of other changes	<b>High risk of bias</b> The study is silent on the medical informatics and other productivity-enhancing technologic environment of the department / any changes within the time period
<i>Was the allocation adequately concealed?</i>	<b>High risk of bias</b> All CBA studies are considered high risk on this domain	<b>High risk of bias</b> All CBA studies are considered high risk on this domain	Was the shape of intervention effect pre-specified?	<b>Low risk of bias</b> Time of intervention was specified
<i>Were the baseline outcome measures similar?</i>	<b>Low risk of bias</b> Number of chest x-rays performed on the two sites were similar	<b>Low risk of bias</b> Differences were adjusted for by analyzing percentage drop in RTAT	Was intervention unlikely to affect data collection?	<b>Low risk of bias</b> Radiographers reporting should not affect data retrieval from the RIS.
<i>Were baseline characteristics similar?</i>	<b>High risk of bias</b> The two sites have different workflow processes	<b>Low risk of bias</b> The same site as control	Was the knowledge of the allocated intervention adequately prevented during the study?	<b>Low risk of bias</b> Objective outcome data
<i>Were incomplete data adequately addressed?</i>	<b>Unclear</b> Not discussed	<b>Unclear</b> Not discussed	Were incomplete data adequately addressed?	<b>Unclear</b> Not discussed
<i>Was the knowledge of the allocated intervention adequately prevented during the study?</i>	<b>Low risk of bias</b> Objective outcome data	<b>Low risk of bias</b> Objective outcome data	Was the study free from selective outcome reporting?	<b>Low risk of bias</b> No evidence of selective reporting
<i>Was the study adequately protected against contamination?</i>	<b>Low risk of bias</b> Based on institution which were far apart	<b>Low risk of bias</b> Based on episodes of care	Freedom from other risk of bias?	<b>Low risk of bias</b> None detected
<i>Was the study free from selective outcome reporting?</i>	<b>Low risk of bias</b> No evidence of selective reporting	<b>Low risk of bias</b> No evidence of selective reporting		
<i>Freedom from other risk of bias?</i>	<b>High risk of bias</b> Different methods of data collection on both sites, Data obtained from the RIS on one site (OUH) and by questionnaire at the other site (HUCH)	<b>Low risk of bias</b> None detected		

## 2.4 Discussion

Patients' waiting times are a major indicator of the quality within radiology departments (Ondategui-Parra et al., 2004; Abujudeh et al., 2010). The current review has highlighted the broad range of interventions being implemented and evaluated with regards to waiting time management in diagnostic radiology departments. The interventions have been broadly grouped into extended scope practice, outsourcing, pay-for-performance, productivity-enhancing technologies, quality management and multiple interventions. The studies are highly heterogeneous and most (96%) of them used study designs that can potentially lead to biased estimates of intervention effect. The reporting quality is also poor.

Recent systematic reviews have examined the impact of a single SDI on a range of outcome measures. For example, computerised physician order entry (CPOE) system was found to impact on imaging requesting behaviours, adherence to guidelines, length of hospital stay, mortality, readmission rates and radiology turnaround times (Georgiou et al., 2011); PACS within the intensive care setting was found to impact on image availability, image viewing patterns, clinical decision etc. (Hains et al., 2012). These reviews have not focused on the topical issue of patients' waiting times. To address that imbalance, the current review has adopted a different approach: that of exploring the impact of a range of SDIs implemented within radiology on patients' waiting times.

The next sub-sections discuss the different type of interventions in terms of how they work, why they might work for which type of organisations, the results and relationships between the studies with a focus on the three studies with lower risk of bias. The subsequent sub-sections examine the robustness of the evidence, causes of heterogeneity in the studies, the limitations of this study and implications for future research.

### **2.4.1 Extended scope practice (ESP)**

ESP allows radiographers to extend their roles to include some duties that were conventionally performed by radiologists (e.g. plain film reporting), as means of increasing reporting capacity (DoH, 2000a; RCR, 2012). ESP/AP radiographer reporting has been implemented to manage report turnaround times by NHS organisations experiencing increased demand and a shortage of radiologists (RCR, 2012). McPherson et al. (2006) reviewed the evidence on the effectiveness of ESP and found that most of the reviewed studies explored the acceptance of ESP by other professional colleagues; nevertheless, the impacts of ESP on services were not evaluated. The current review found three ESP studies, all of which were performed within the UK. This is not surprising because the NHS is one of the first healthcare systems to implement ESP (DoH, 2000a; b). Only one of the three studies (Brealey and Scuffham, 2005) used a research design that meets the design criteria for inclusion in a Cochrane-type review. Risk of bias assessment shows that Brealey and Scuffham (2005) has a moderate to low risk of bias (Table 2.2). The remaining two studies used the pre- and post-intervention

design and risk of bias assessment was not performed on studies that used this design as previously noted. All three ESP studies reported improved patients waiting times, suggesting that where appropriate, ESP might be an effective strategy to combat increasing RTAT for A&E plain film and video fluoroscopy examinations. However, amongst other considerations for implementing EPS, an assessment must be made that increasing RTAT is due to shortfall in reporting capacity, rather than a shortage of transcriptionists.

## **2.4.2 Quality management methodologies (QMMs)**

The main aim of QMMs is to identify and eliminate non-value adding processes from a system and reduce variability in the outcome measure to an acceptable level. The potential for the existence of non-value adding processes in a system is closely associated with the number of workflow steps within that system. The radiology workflow process, illustrated in Figure 2.1 has many steps which can be improved with QMMs. QMMs, especially when combined with PETs appear to have a considerable potential to improve the global radiology workflow (Seltzer et al., 1997; Hayt et al., 2001; Hurlen et al., 2010). Implementing PETs without QMMs is unlikely to yield the optimum results (Nitrosi et al., 2007; Hurlen et al., 2010; Kelley, 2011). It is not surprising therefore that the NHS is paying a greater attention to QMMs such as the Lean and Six Sigma methodologies (NHS Improvement, 2010; 2012).

Most of the studies found that QMMs is associated with improved patients' waiting times. Only one (Laurila et al., 2001) of the 20 included studies



partially met the design requirement for a Cochrane-type review. This study implemented a seven-step continuous quality improvement (CQI) on the intervention site and a 'traditional management technique' on the control site. The seven steps included using expert team to map the process, identify and understand the problems, select, design, implement and monitor the process improvement. This led to an 18% reduction in the proportion of chest x-ray examinations breaching the two-hour target. However, the study was not clear on what the 'traditional management technique' involved. On the other hand, Patel et al. (2012) reported a deteriorated waiting time following the implementation of QM. These two studies differ; in terms of the study population (clinical pathway / imaging modality investigated), research design and type of intervention: Patel et al. (2012) appears not to have followed a problem identification procedure before implementing a host of intervention within the A&E setting. This might explain the difference in results between the two studies. The radiology workflow is particularly suited to process improvement; it is therefore reasonable to expect that any radiology department can potentially benefit from QMMs. However sufficient time must be invested into identifying, understanding the problem and designing appropriate intervention.

QMMs are mostly based on the "Lean Concept" used by the Japanese Motor Company (Toyota) and the "Six Sigma" of the Motorola Corporation (USA). The simple mathematical concepts and theories underpinning the QMMs are not well discussed in the published literature (Reed et al., 2000; Pandit et al., 2010). Many of the QMMs studies lack a clear and rational explanation of the mechanism of impact of the implemented interventions. Not only does this make a scientific assessment of the

studies very difficult, also it potentially makes any attempts to generalise their findings extremely difficult.

### **2.4.3 Productivity-enhancing technologies (PETs)**

Of the 34 PETs studies, only Kennedy et al. (2009) partially met the minimum design standard for a Cochrane-type review. This study investigated the impact of tele-radiology on report turnaround times. Tele-radiology is used by hospitals for outsourcing radiology reporting to cover shortfalls in reporting capacity and to provide cover for remote community hospitals (RCR, 2010). The results of Kennedy et al. (2009) and Krupinski et al. (1999) suggest that tele-radiology might improve RTAT. However, reduced RTAT must be balanced against other quality parameters such as costs and satisfaction of the referring clinicians (RCR, 2010). Especially as there are indications that referring physicians feel that outsourced radiology services are poorer in quality compared to in-house services (Olofsson et al., 2016).

The importance of SRR is limited to addressing the time delay between dictation and transcription of radiology report. Theoretically, SRR should improve the speed of radiology report production because spoken words (dictated report) are instantly transcribed into text (written reports). Therefore, the SRR intervention might only be useful to an establishment having difficulties with its transcription workload, as opposed to a shortfall in its reporting capacity. All 13 SRR studies included in this review reported varying levels of improvements in RTAT. Some studies reported cost

savings as well (Rosenthal et al., 1998; Kelley, 2011), others reported that SRR had not improved the RTAT of some radiologists within the study setting (Krishnaraj et al., 2010). It is therefore thought that human behaviour might play a significant role on the extent of improvements that can be gained with SRR. All 13 studies used designs with high inherent risk of bias. However, the results suggest that a 'total' (100%) SRR implementation might be more effective than partial implementation (Hart et al., 2010) and even better when combined with QMMs (Kelley, 2011). However, 100% SRR adoption might be a tough arrangement for a teaching-type establishment (Koivikko et al., 2008), because radiology registrars cannot not sign off their reports immediately after production as they need to be checked by a consultant radiologist.

The results obtained by Rao et al. (2013) is very instructive in deciding what type of problem to address with SRR. In this particular study, the implementation of SRR was associated with a 14 (SD 25) to 1 (SD 5) hours drop in dictation time (time from dictation to availability of final reports); whereas the report turnaround time (time from completion of examination to final report) increased from 12 (SD 18) to 21 (SD 82) hours. This suggests that a shortfall in reporting capacity is contributing to the delay in this particular system, hence, despite the reduction in dictation turnaround time the report turnaround time doubled. The only possible explanation being that the examinations have been waiting to be reported.

Despite the extensive implementation of SRR within radiology departments (including within the UK), there are persisting worries about high error rates, productivity and cost-effectiveness. Some researchers have maintained that SRR

merely shifted the problem of transcription to the radiologists with negative impact on their productivity. This might result in higher cumulative costs of transcribing radiology reports (Pezzullo et al., 2008; Strahan and Schneider-Kolsky, 2010). Other researchers are concerned about high error rates (Strahan and Schneider-Kolsky, 2010) and the brevity of reports generated with SRR (24 – 39% shorter in length) compared to conventional dictation (Ramaswamy et al., 2000; Pezzullo et al., 2008). I believe that SRR has a potential to improve report turnaround times if properly implemented by an institution that is experiencing a shortfall in transcription capacity, rather than a shortfall in reporting capacity.

PACS and RIS are the bedrocks of any modern radiology department. Both technologies impact patients' waiting time by improving process flow; reducing time wasted on tracking films, patients' records and optimising appointments. The impact of PACS on patient waiting times is mixed. One study reported mixed results depending on referral sources (Mackinnon et al., 2008). Other studies observed no impact on waiting times (Mehta et al., 2000a & b), deteriorated waiting times (Redfern et al., 2000) and improved waiting times (Hangiandreou et al., 1997; Kuo et al., 2003). The situation is similar with the RIS: two studies with mixed results. The evidence of the impact on patients' waiting times of PACS and RIS is both inconsistent and insufficient. A previous review reached similar conclusions (Hains et al., 2012). However, I feel that the overall importance of these two systems to any large radiology department might outweigh any considerations of their empirical effectiveness at reducing patients' waiting times. The dynamics might be different for small departments processing only a few hundred examinations per year.

The current review found a few other promising PETs such as electronic requesting (Nitrosi et al., 2007), CPOE (Mekhjian et al., 2002; Cordero et al., 2004; Thompson et al., 2004; Adam et al., 2005; 2005; Schneider et al., 2013), computer aided diagnosis (Kao et al., 2015). CPOE can improve waiting time by not only ensuring that radiology requests do not get lost, but are received almost instantaneously. Again this technology might be useful to large departments having problems with lost request forms and / or not receiving them in a timely manner. The earlier the requests are received; the sooner the examinations can be arranged. Of the five CPOE studies, only Adam et al. (2005) reported no improvement in waiting times. This is probably because the study examined chest x-ray requests in the A&E settings. Care in the A&E is fast paced, usually with x-rays performed in adjacent rooms. Therefore, CPOE might not be expected to make a drastic impact on such setting.

#### **2.4.4 Pay for performance and outsourcing**

There is only one study each evaluating pay-for-performance (PFP) (Boland et al., 2010a) and outsourcing (Tavakol et al., 2011). PFP might be useful when routine QMMs fail and an organisation decides that staff needed additional incentive to improve performance. Boland et al. (2010a) reported significant improvement in RTAT, but this is a single study estimate. The implications of PFP are a current topic for debate in many health economies (Reiner and Siegel, 2006; Serumaga et al., 2011). Some researchers believe that there are too many obstacles for it to work in radiology

departments (Swayne, 2005), others feel that it can be easily abused (Pentecost, 2006) but most importantly there are insufficient outcome studies (Seidel and Nash, 2004).

Tavakol et al. (2011) evaluated the impact of outsourcing on report turnaround times and found no difference in waiting times between outsourced examinations and those performed in-house. A predictable consequence of the development of tele-radiology is the potential for outsourcing of radiology reporting. By 2009, 37% of UK radiology department were already outsourcing parts of radiology reporting as a means of increasing reporting capacity (RCR, 2010). As previously mentioned, there are suggestions that referring clinicians are concerned with the quality of outsourced radiology reporting (Olofsson et al., 2016). The current review has found insufficient evidence that either PFP or outsourcing of radiology examinations improved patients' waiting times.

## **2.4.5 Quality of the included studies**

Of the 71 studies reviewed, only Brealey and Scuffham (2005) fully met the minimum design standard for a Cochrane-type review while Laurila et al. (2001) and Kennedy et al. (2009) partially met the minimum design criteria specified in EPOC (2012a). The pre- and post-intervention without control and the post-intervention only designs were adopted in 96% (68/71) of the studies (Table 2.1). As previously stated, the above study designs have very high inherent risk of bias.

The reporting quality was generally poor. For example, many of the studies that reported improved outcomes did not test and / or report the statistical

significance of their findings (Hangiandreou et al., 1997; Krupinski et al., 1999; Mehta et al., 2000a; b; Cavagna et al., 2003; Johal et al., 2003; Marquez and Stewart, 2005; Harmelink, 2008; Van-Lom, 2009; Aloisio and Winterfeldt, 2010; Steffen, 2010; Bucci and Musitano, 2011; Newman and Nightingale, 2011). Only three studies reported confidence intervals on their results (Pallan et al., 2005; Kennedy et al., 2009; Humphries et al., 2011). Many of the studies did not define the timelines used in computing patient waiting times (Wheeler and Cassimus, 1999; Lemme and Morin, 2000b; a; Johal et al., 2003; Brealey and Scuffham, 2005; Blakeley et al., 2008; Bucci and Musitano, 2011; Mehta et al., 2013; Tobey et al., 2014). Virtually all the included studies failed to give any information on the technical features of the implemented systems, the information technology (IT) infrastructure and the levels of integration within the study settings. The IT systems and the level of integration have a significant impact on the effectiveness of radiology SDIs (Ayal and Seidmann, 2008; 2009; Krishnaraj et al., 2010). The results of the studies must be viewed with the above quality issues in mind.

## **2.4.6 Exploration of heterogeneity**

The results of the studies could not be pooled in a meta-analysis due to a high level of heterogeneity. Heterogeneity in this context refers to the differences between the studies in terms of research their designs, the breadth / combination of SDIs evaluated, the study settings, the definition of the outcome measures and the populations investigated. For example, the study population included patients who

had specific examinations e.g. chest x-rays (Laurila et al., 2001), CT pulmonary angiogram (Kennedy et al., 2009); patient referred from specified clinical pathways like A&E (Brealey and Scuffham, 2005) or patients examined using a particular imaging modality like ultrasound (Hawton et al., 2010). These differences are shown in the characteristics of the included studies (appendix 4). As previously mentioned in section 2.2.6, pooling of results obtained from heterogeneous non-randomised studies is not recommended (Deeks et al., 2011), as the result could be seriously misleading (Higgins et al., 2011).

In addition, the IT environment within which the evaluated systems were implemented and the levels of integration were either different or not discussed in many of the studies. In addition, many studies failed to define the timelines used in computing patients' waiting times (Wheeler and Cassimus, 1999; Lemme and Morin, 2000b; a; Johal et al., 2003; Brealey and Scuffham, 2005; Blakeley et al., 2008; Bucci and Musitano, 2011).

Many of the studies did not define the timeline used for computing the outcome measure (patients' waiting times). For the studies that defined the timeline, there was a large inconsistency in the definitions of the outcome measures. The importance of consistent outcome measure definition has been highlighted (Breil et al., 2011; Hains et al., 2011). For example, the RTAT which is the time interval between the examination and the finalised report was variously defined as the time interval between the time a patient arrived the x-ray reception desk (Langlois et al., 1999), start of examination (Hangiandreou et al., 1997; Hayt et al., 2001), completion of



image acquisition (Andriole et al., 2001a; b; Oguz et al., 2002), completion of the examination on the RIS (Mehta et al., 2000b; a), the time the image became available on the PACS (Halsted and Froehle, 2008) and the time of final radiology report.

The time interval between the completion of image acquisition and completion of the examination on the RIS is frequently more than 1 hour (Gregg et al., 2010). Given that many of the studies reported improvements in minutes (Kennedy et al., 2009; Kelley, 2011), it is easy to see how inconsistent outcome measure definitions might affect the results of any comparison. A generic timeline for defining patients' waiting times in clinical radiology is therefore proposed (Table 2.3).

**Table 2.3 Proposed generic timeline for defining patients waiting time in clinical radiology**

<i><b>Outcome measure</b></i>	<i><b>Definition</b></i>
<i>Pre-examination waiting time (PEWT)</i>	The time elapsed from the moment a request for radiology investigation is received on the RIS to the time when the examination was completed on the RIS.
<i>Report turnaround time (RTAT)</i>	The time elapsed from when the radiology examination was completed on the RIS to the time when the final radiology report was available on the RIS or PACS.
<i>Total radiology waiting time (TRWT)</i>	The time elapsed from the moment a request for radiology investigation is received on the RIS to the time when the finalised radiology report was available on the RIS or PACS.

## **2.4.7 Limitations of the study**

It is possible that the implemented search strategy has missed articles indexed under different MeSH headings or key words. Non-English language papers were excluded. This might lead to language bias. Sources of grey literature were not searched. This might lead to publication bias. Data extraction was completed by the researcher (BO), due to limited resources. This could also be seen a limitation. However, independent double data extraction was performed by BO and YFC for the first ten articles and notes compared. YFC was satisfied that all relevant data have been extracted and BO completed data extraction for the remaining articles.

## **2.5 Conclusions**

This review has highlighted the type of SDIs implemented to improve patients' waiting times within radiology departments. Most of the studies used either the pre- and post-intervention without control or the post intervention only designs. These designs are prone to overestimating intervention effect. It is therefore not surprising that majority of the studies reported improved patients waiting times.

### **2.5.1 Implications for practice**

The studies were highly heterogeneous. The study designs and reporting quality was poor. Some SDIs within radiology departments will impact on more than one quality measure. Therefore, it is recommended that interested parties should

critically appraise the studies for their designs, results, and explanation of the basic features of the evaluated interventions that they (interested parties) think are critical to achieving their objectives.

## **2.5.2 Implications for future research**

Evidence of effectiveness is clearly paramount in the implementation of appropriate SDIs within radiology departments, as a means to improve the patients' experiences. Studies to date have been mostly of low quality. Future studies need to be of higher quality. Higher quality study design might consist of interrupted time series, mixed methods or, randomised designs. As there is obviously a need for pragmatism, one possible appealing randomised design might be the stepped wedge design (Brown and Lilford, 2006; Hemming et al., 2015). The stepped wedge is a cluster study design, and so would involve multiple sites or modalities, which would sequentially (be randomised to) receive an SDI.

There is a need to harmonise the definitions of the timelines used in computing patients' waiting times to reduce the level of heterogeneity in future studies. It is hoped that future studies would adopt the definitions proposed in the current review. It will be of considerable help if future studies included basic details of the IT infrastructure within the study setting and the levels of integration. The above suggestions should make both the comparison and / or meta-analysis of future studies less restrictive.

# CHAPTER 3. INTERRUPTED TIME SERIES DESIGN AND ANALYSIS: AN INTRODUCTION

## Abstract

A systematic review of the type and effectiveness of interventions implemented to reduce patients' waiting times in diagnostic radiology departments (reported in chapter two) found that 96% of the 71 studies included in the review used either the pre- and post-intervention without control or the post-intervention only designs. These study designs are prone to biased effect estimates. The interrupted time series (ITS) is a robust design that can be used to strengthen the simple pre- and post-intervention design and it is especially useful when it is not feasible to perform a randomised study.

A simulated waiting time dataset was used to describe the basic principles of the ITS design and demonstrate its advantages over the simple pre- and post-intervention design. The dataset was also used to demonstrate the pitfalls in the implementation of the ITS design and analysis, such as a failure to control for autocorrelation, which could lead to biased estimate of intervention effect. Further refinements of the basic ITS design including multiple interventions and especially the use of 'segmented spline' regression to model non-linear trends are described. Other statistical issues such seasonality, outliers and the options to control for these are

highlighted. The different types of intervention effect encountered in the ITS design, as well as the quality criteria for a well implemented ITS study are also highlighted.

## 3.1 Introduction

The ultimate aim for the evaluation of healthcare interventions is to produce a valid estimate of effectiveness (Deeks et al., 2003). The validity of a study is a function of the research design. A research design is the framework within which data collection, analyses and conclusions are linked with the research question (Yin, 2009). The randomised control trial (RCT) is widely regarded as the best design for evaluating the effectiveness of healthcare interventions. However, due to practical / pragmatic constraints, it is not always feasible to perform an RCT of policy interventions.

It is not surprising therefore that a systematic review of the effectiveness of interventions to reduce patients' waiting times within radiology departments (presented in chapter two) found that 96% of the 71 studies included in the review used either the pre- and post-intervention without control or the post-intervention only designs. As previously mentioned (in chapter two), a review of the impact of speech recognition reporting systems on productivity and error rates in radiology reports also found that all 20 studies included in the review used either the pre- and post-intervention without control or the post-intervention only designs (Hammana et al., 2015).

The pre- and post-intervention designs are prone to biased effect estimates (Matowe et al., 2002; Deeks et al., 2003; Higgins JPT et al., 2011). The Cochrane

Effectiveness of Practice and Organisation of Care (EPOC) Review Group recommends that studies which used either the pre- and post-intervention without control or the post-intervention only designs should not be included in systematic reviews of the effectiveness of healthcare interventions (EPOC, 2012a).

The interrupted time series (ITS) design is a robust alternative to randomisation, which can be used to strengthen the pre- and post-intervention design (Wagner et al., 2002) and it is considered to be the “next best” approach when randomisation is not feasible (Kontopantelis et al., 2015). This chapter describes the basic principles of the ITS design and analysis including some refinements that allow for appropriate analysis of datasets that violate the assumptions of the ordinary least squares (OLS) regression. A demonstration of the appropriate implementation of the ITS design and analysis is necessary as it has been noted that over 65% of the studies included in a review of the methodological quality of ITS studies were inappropriately implemented (Ramsay et al., 2003). More recently, Svonoros et al. (2015) noted that two recent papers published in the British Medical Journal (BMJ Quality & Safety) (Morgan et al., 2015a & b) were described as ITS studies by the authors, whereas they did not perform ITS analysis.

Section 3.2 discusses the basics of the ITS design and analysis, and demonstrates its advantages over the simple pre- and post-intervention design using a simulated dataset. Section 3.3 covers the refinement of the basic ITS analysis to accommodate autocorrelation, non-homogenous variance, multiple interventions and non-linear trends. Refinement of the basic ITS analysis is demonstrated using a

combination of simulated and actual datasets. Section 3.4 summarises the strengths and potential biases of ITS analysis. The quality criteria for a well implemented ITS study are also summarised in section 3.4. Discussions and conclusions are presented in sections 3.5 and 3.6 respectively.

### **3.1.1 Aims and objectives**

#### **Aims**

The aim of this chapter is to present a general introduction to the ITS design and illustrate how it can be appropriately analysed.

#### **Objectives**

The objectives are to demonstrate:

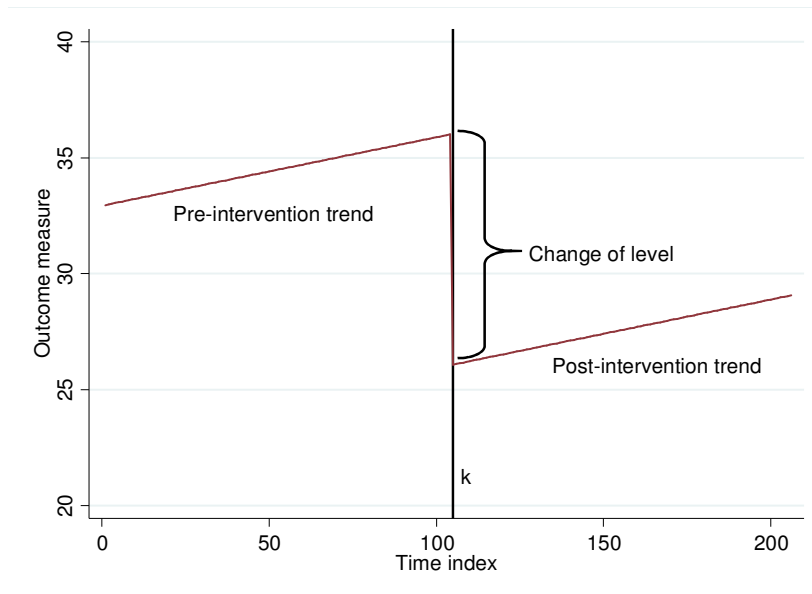
- a. That the effect estimates obtained with the simple pre- and post-intervention design could be biased by trend;
- b. The appropriate implementation of ITS analysis on datasets that violate the assumptions of the OLS regression; especially
- c. The use of 'segmented spline' regression to model non-linear trends, and
- d. To summarise the quality criteria that differentiate a well implemented from a poorly implemented ITS study.



## 3.2 The basic ITS research design

A time series is a variable measured repeatedly over time, usually at equally spaced intervals. The ITS design attempts to determine whether an intervention has had an effect on a time series, which is significantly greater than any underlying trend over time (Lagarde, 2011; Reeves et al., 2011). ITS analysis (a subset of time series analysis) is a statistical tool used to analyse the ITS design. Time series analysis refers to a wide range of statistical methods developed to analyse variables that are time dependent. In the ITS design, it is assumed that the intervention occurs at a known point in time (Figure 3.1). The type of effect that the intervention is expected to have on the outcome measure, if it were effective, should be specified before the onset of data collection and analysis (Box et al., 2008; EPOC, 2012b). The aim of ITS analysis therefore, is to determine if a change in the outcome measure, of the expected type is associated with the intervention under investigation (Box et al., 2008). The basic principles of ITS analysis will be demonstrated with a simulated dataset in the following sub-sections.

**Figure 3.1 The basic ITS design**



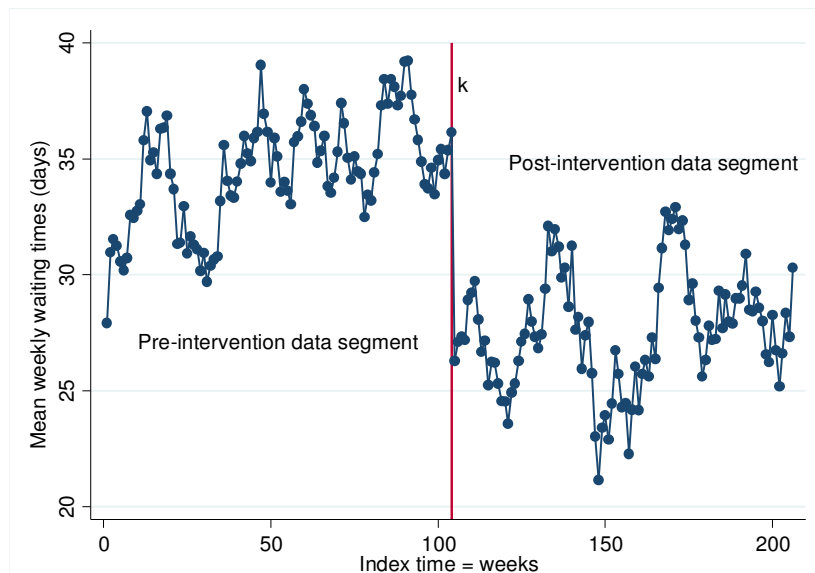
$k$ , the intervention point. The intervention effect is measured by a change in level and a change in trend

### **3.2.1 How the dataset for illustrating ITS analysis was simulated**

ITS analysis can be conceptualised within the framework of the OLS regression and its assumptions. This can be illustrated with a simulated dataset. A four-year waiting time series with an initial waiting time of 30 days and an increasing trend of 0.07 days per-week was simulated to follow a first order autoregressive process with an AR(1) parameter of 0.9. The simulated dataset also included a 10 days reduction in the level of waiting times (change in level) and a change in trend of waiting times of 0.03 days per-week following a policy intervention at the end of the second year (week 105) (Figure 3.2). The simulated dataset is summarised in (Table 3.1). The codes for simulating this hypothetical time series are shown in appendix 5.

The simulation and all subsequent data analyses were performed on STATA™ 13 (STATA Corporation USA).

**Figure 3.2 Time plot of the simulated dataset**



K, the point of intervention

**Table 3.1 Summary of the simulated dataset**

<i>Data segment</i>	<i>Number of observations</i>	<i>Mean waiting time (SD)</i>
<i>Whole dataset</i>	206	31.06 (4.23)
<i>Pre-intervention</i>	104	34.49 (2.38)
<i>Post-intervention</i>	102	27.57 (2.48)

### 3.2.2 The basic principle of ITS analysis

According to Wagner et al. (2002), the series should be divided into a pre-intervention and post-intervention data segments (Figure 3.2) and the intervention effect modelled using the segmented regression approach. This is done by regressing

the outcome variable (waiting times),  $Y$  on the intervention variable  $H(t-k)$  (Model 3.1).

Model 3.1 has one predictor variable (the intervention variable),  $H(t-k)$ , a 'Heaviside step function' which is coded '0' for all times before  $k$  and '1' for all times after  $k$ .

$$Y_t = a_0 + b_1H(t - k) + \varepsilon_t \quad \text{Equation 3.1 (Model 3.1)}$$

The regression coefficient,  $b_1$  is the change in the level of waiting time following the intervention (the intervention effect), and  $a_0$  is the intercept, the waiting time at time zero, also interpreted as the mean pre-intervention waiting time (in model 3.1). Model 3.1 is the regression equivalent of the simple pre- and post-intervention design (analysed with the t-test) and it compares the mean pre-intervention waiting time to the mean post-intervention waiting time. The regression equivalent of the t-test is used here to allow for easy comparison with subsequent models. Model 3.1 assumes; that the errors are random (uncorrelated) and have the same variance in each observation (Krzanowski, 1998). These assumptions will henceforth be referred to as the ordinary least squares, OLS assumptions.

The results of analysing the simulated dataset with Model 3.1 suggest that waiting times dropped by 6.92 days (95% CI 6.25, 7.58) (change in level) following the intervention (Table 3.2). The results are graphically presented in Figure 3.3. Model 1 does not account for the increasing trend within the simulated dataset. It is possible that the lower mean level of the post-intervention waiting times could be explained by a decreasing underlying trend during the pre-intervention phase. On the other hand, Model 3.1 could have underestimated the effect size, if the underlying trend was increasing during the pre-intervention phase. This is because the model would have

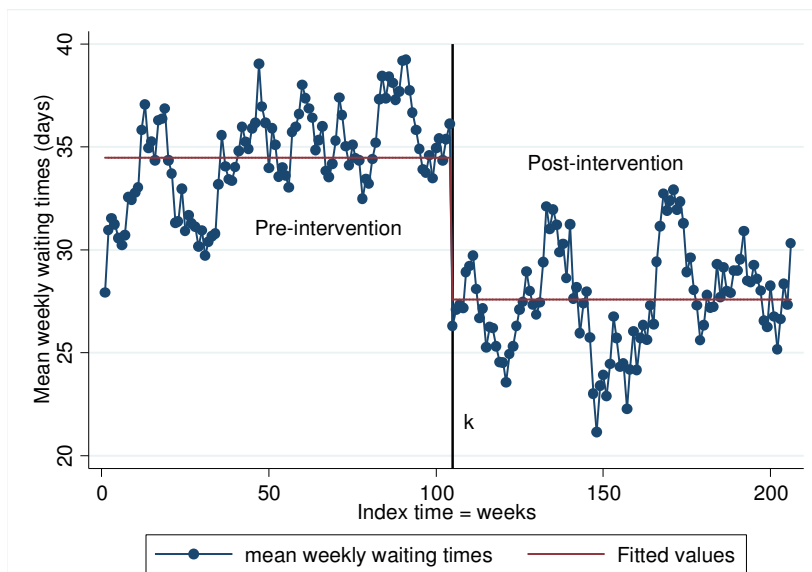
ignored what the post-intervention level would have been had the intervention not taken place and the pre-intervention trend had continued. In summary, the effect size estimated with Model 3.1 could be biased by trend.

**Table 3.2 Effect size estimated by analysing the simulated dataset with Model 3.1**

<i>Interpretation of the regression coefficients</i>	<i>Effect size (95% CI)</i>	<i>Simulation parameters</i>
<i>Mean pre-intervention waiting time (<math>a_0</math>)</i>	34.49 (34.02, 34.96)	34.49*
<i>Change in level of waiting times after the intervention (<math>b_1</math>)</i>	-6.92 (-7.58, -6.25)	10

\*The simulated initial level is 30 (see Figure 3), with an increasing trend. But Model 3.1 ignores the trend and estimates the mean of the pre-intervention data segment, which is 34.49 (Table 3.1)

**Figure 3.3 A graphical presentation of the results obtained with Model 3.1**



k, the intervention time. Model 1 ignores the increasing underlying trend in the simulated dataset

### 3.2.3 Accounting for the underlying trend

By adding a trend variable to Model 3.1, it becomes possible to account for the underlying trend within a regression framework. Such regression model would then have two predictor variables; the intervention variable,  $H(t-k)$  and a time variable,  $t$ . The time variable is the same as the time index time,  $t$ . It starts at '1' and increases linearly up to week 206 (Model 3.2).

$$Y_t = a_0 + a_1 t + b_1 H(t - k) + \varepsilon_t \quad \text{Equation 3.2 (Model 3.2)}$$

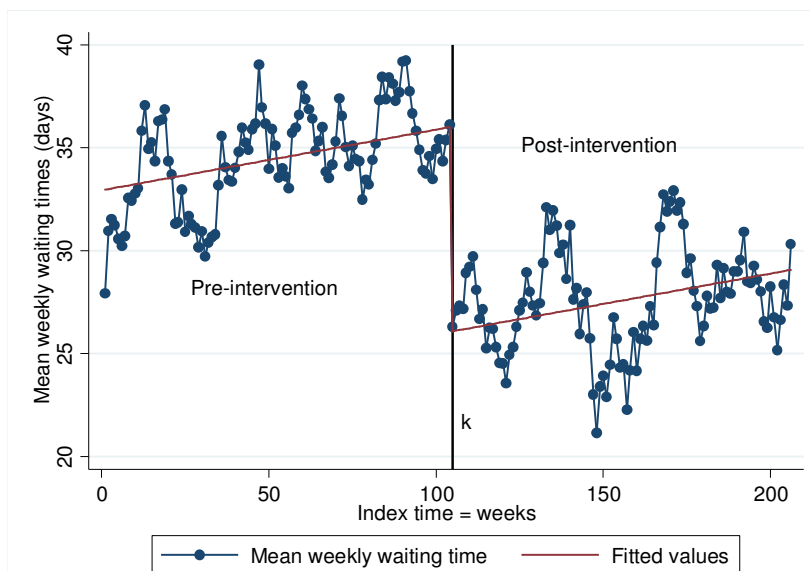
In addition to the earlier OLS assumptions, Model 3.2 assumes a linear relationship between waiting times,  $Y$  and time,  $t$ . The regression coefficient,  $a_1$  measures the slope (underlying trend) of waiting times. The interpretation of the regression coefficient  $a_0$  changes from the mean pre-intervention waiting time to the process intercept, which is now interpreted as the initial waiting time (the waiting time at time zero), due to the addition of a trend variable. Similarly, the interpretation of  $b_1$  becomes the difference between the last pre-intervention and the first post-intervention observations. Table 3.3 are the results of analysing the simulated dataset with Model 3.2. The value of  $a_1$  suggests that waiting times were increasing at the rate of 0.03 (95% CI 0.02, 0.04) days per-week before the intervention. The regression coefficient,  $b_1$  suggests that waiting times dropped by 9.96 (95% CI 8.71, 11.21) days following the intervention. The results are presented graphically in Figure 3.4.

**Table 3.3 Effect size estimated by analysing the simulated dataset with Model 3.2**

<i>Interpretation of the regression coefficients</i>	<i>Effect size (95% CI)</i>	<i>Simulation parameters</i>
<i>Initial level of waiting times (<math>a_0</math>)</i>	32.94 (32.23, 33.65)	30
<i>The trend of waiting times (<math>a_1</math>)</i>	0.03 (0.02, 0.04)	0.07
<i>Change in level after intervention (<math>h_1</math>)</i>	-9.96 (-11.21, -8.71)	-10

Model 3.2 accounts for the underlying trend but ignores the change in trend following the intervention

**Figure 3.4 A graphical presentation of the results obtained with Model 3.2**



In Model 3.2, the pre- and post-intervention trends are the same (0.03 days-per-week) because the model ignores the change in trend following the intervention.

Note that the drop in the level of waiting times estimated with Model 3.2 is larger than is previously estimated with Model 3.1. More importantly, the 95% CI of the change in level ( $b_1$ ) estimated with Model 3.1 and Model 3.2 does not overlap. This shows that Model 1 might have underestimated the impact of the intervention

because it has not accounted for the underlying trend. In this example, waiting times would have continued to increase had the intervention not been implemented.

### 3.2.4 Accounting for a change in trend after the intervention

One might also wish to determine if the trend of waiting times has changed following the intervention. This can be done by adding a trend-change variable,  $(t-k)_+$  to Model 3.2 (Model 3.3). The trend-change variable,  $(t-k)_+$  is coded '0' for all times before  $k$  and is identical to  $t-k$  for all times after  $k$ . The coefficient of the trend-change variable,  $b_2$  measures the difference between the pre- and post-intervention trends. Model 3.3 now contains three predictor variables: the intervention variable,  $H(t-k)$ ; the trend variable,  $t$  and the trend-change variable,  $(t-k)_+$ . Model 3.3 makes the same OLS assumptions noted earlier

$$Y_t = a_0 + a_1 t + b_1 H(t - k) + b_2 (t - k)_+ + \varepsilon_t \quad \text{Equation 3.3 (Model 3.3)}$$

Table 3.4 shows the results of analysing the simulated dataset with Model 3.3. The value of the coefficient  $a_1$  suggests that before the intervention, waiting times were increasing at the rate of 0.04 days per-week. The rate at which waiting times were increasing was reduced by 0.03 (95% CI 0.05, 0.06) days per-week following the intervention (change in trend) as suggested by the value of  $b_2$ . The post-intervention trend therefore =  $a_1 - b_2 = (0.04 - 0.03) = 0.01$  days-per-week.

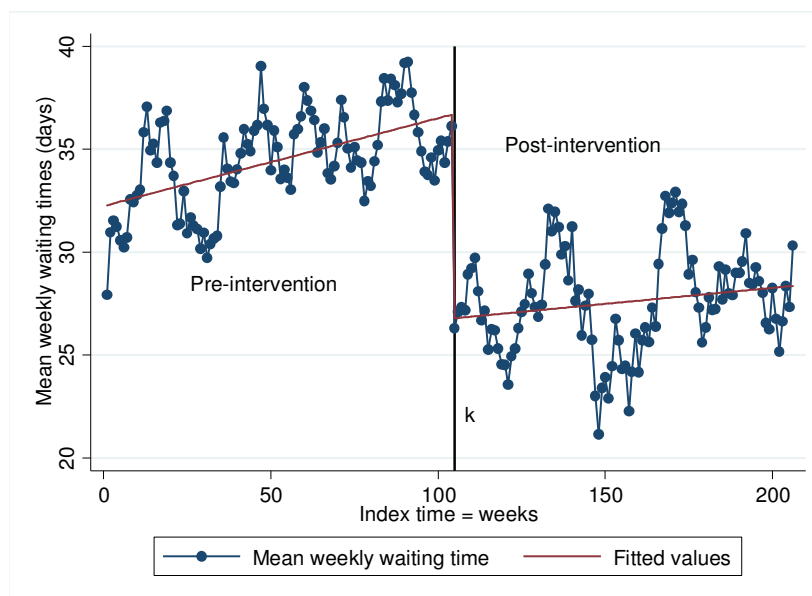


**Table 3.4 Effect size estimated by analysing the simulated dataset with Model 3.3**

<i>Interpretation of the regression coefficients</i>	<i>Effect size (95% CI)</i>	<i>Simulation parameters</i>
<i>Initial level of weekly waiting times (<math>a_0</math>)</i>	32.24 (31.36, 33.12)	30
<i>The trend of waiting times (<math>a_1</math>)</i>	0.04 (0.03, 0.06)	0.07
<i>Change in level times after the intervention (<math>b_1</math>)</i>	-9.92 (-11.13, -8.68)	-10
<i>The change in trend of waiting times after the intervention (<math>b_2</math>)</i>	-0.03 (-0.05, -0.06)	-0.03

Model 3.3 captures the simulation parameters better than all the previous Models. However, it does not account for autocorrelation.

**Figure 3.5 A graphical presentation of the result obtained with Model 3.3**



k, time of intervention. Model 3.3 accounts for different pre- and post-intervention trends, but does not account for autocorrelation.

The result suggests that in addition to 9.92 days reduction in the level of waiting times, the rate of increase has dropped from 0.04 to 0.01 days per-week following the intervention. The results are graphically presented in Figure 3.5. Model

3.3 captures the simulation parameters better than the previous two models.

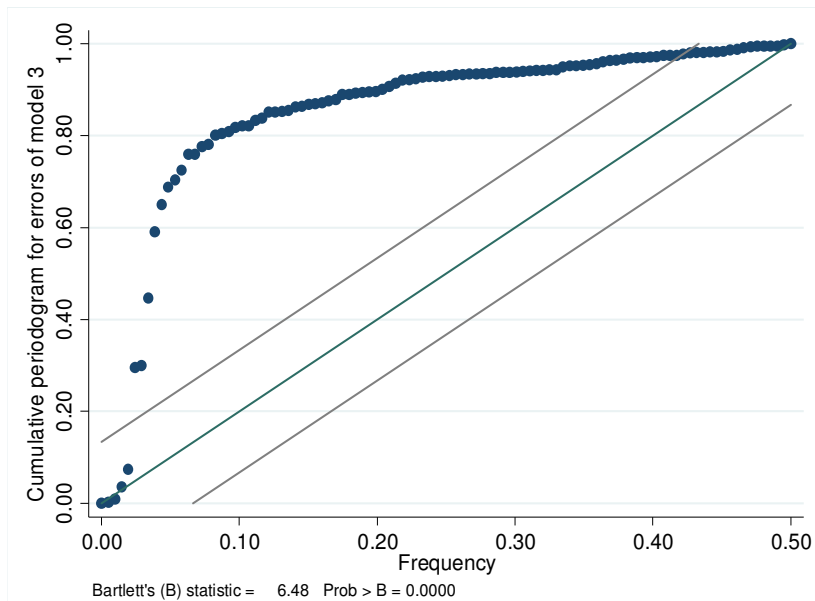
However, it fails to account for autocorrelation within the simulated dataset. The inadequacy of this model can be detected by diagnostic checks; which are described in the next sub-section.

### **3.2.5 Diagnostic tests on Model 3**

All the models discussed so far assume random errors, homogenous variance and linearity (OLS assumptions). These assumptions are often violated by time series, which is the case with the simulated dataset. When the models discussed above are used to analyse datasets that violate the OLS assumptions, the models may fail diagnostic tests, but more importantly, the effect estimates will be distorted.

Two diagnostic tests were performed on Model 3.3. The Bartlett's periodogram tests and the autocorrelation function (ACF) plot. A periodogram is a graphical display of the calculated periodic frequencies to identify any significant intrinsic periodic signals in a time-series. Figure 3.6 is the result of the Bartlett's cumulative periodogram test. The periodogram steps wildly out of the 95% CI band, indicating the presence of non-random periodicity in the errors of the Model 3.3. The cumulative periodogram for a white-noise process remains close to the 45° line (Beckett, 2013), as will be demonstrated latter.

**Figure 3.6 Results of the Bartlett's cumulative periodogram test on Model 3.3.**



The ACF plot displays exponential decays (Figure 3.7), suggesting that the errors are autocorrelated. A white-noise process does not have any significant spike (a spike reaching outside the 95% CI band) (Box et al., 2008). In summary, Model 3.3 has failed diagnostic tests, suggesting that it is inadequate to describe the simulated dataset. Certain refinements are required of Model 3.3 before it can be used to describe the simulated dataset (autocorrelated dataset), if valid inferences are to be drawn from the results of such analysis. These refinements are discussed in the following sections.

### **3.3 Refining the basic ITS regression model**

This section discusses the necessary refinements of Model 3.3 in terms of accommodating autocorrelation, inhomogeneous variance, multiple interventions and

non-linear trends. The impact of a failure to control for autocorrelation will be demonstrated with the simulated dataset. Inhomogeneous variance, multiple interventions and non-linear trend will be illustrated with actual datasets.

### **3.3.1 Autocorrelation**

Autocorrelation is the correlation of a random variable with its past and future values. Instead of fluctuating randomly from one period to the next, neighbouring observations tend to be closer to each other. Autocorrelation could also occur due to seasonality. For example, in a monthly time series, the value of the series at a point might be correlated with its past values at intervals of 12, 24, 36 or 48 months. This type of correlation violates the classical statistical assumption of random errors. One consequence of violating the random errors assumption is that the sampling variances (standard error) obtained with OLS based models are biased (Wagner et al., 2002; Huitema, 2011). Therefore, the statistical test of significance is also biased. The standard errors may be under-estimated (caused by positive autocorrelation) or over-estimated (caused by negative autocorrelation) (Biglan et al., 2000). Under-estimation of the standard error leads to an overestimation of the statistical significance of an observed relationship or estimate of intervention effect and vice versa (Biglan et al., 2000; Wagner et al., 2002). The general direction of bias tends to be that of underestimating the standard error (Becketti, 2013).

The type of autocorrelation within a time series can be broadly grouped into the autoregressive (AR) and moving average (MA) processes as described in Box et

al. (2008). In an autoregressive process, the value of  $Z$  at time,  $t$  comprises a white noise component ( $\varepsilon_t$ ) and a proportion of the previous values of  $Z$  ( $Z_{t-1}, Z_{t-2} \dots$ ) up to order  $p$ . This proportion is represented by the parameter  $\phi$ . A first order autoregressive process, AR(1) with zero mean can be written as

$$Z_t = \phi Z_{t-1} + \varepsilon_t \quad \text{Equation 3.4}$$

(see Chatfield (2004)) while an order ' $p$ ' autoregressive process (AR( $p$ )) can be written as

$$Z_t = \phi_1 Z_{t-1} + \phi_2 Z_{t-2} + \dots + \phi_p Z_{t-p} + \varepsilon_t \quad \text{Equation 3.5}$$

In a moving average (MA) process, the value of  $Z$  at time,  $t$  comprises the white noise component at the current time point and a proportion of the white noise component at previous points ( $\varepsilon_{t-1}, \varepsilon_{t-2} \dots$ ) up to order  $q$ . This proportion is represented by the parameter  $\theta$ . A first order MA process can be written as

$$Z_t = \varepsilon_t + \theta_1 \varepsilon_{t-1} \quad \text{Equation 3.6}$$

An order ' $q$ ' moving average process can be written as

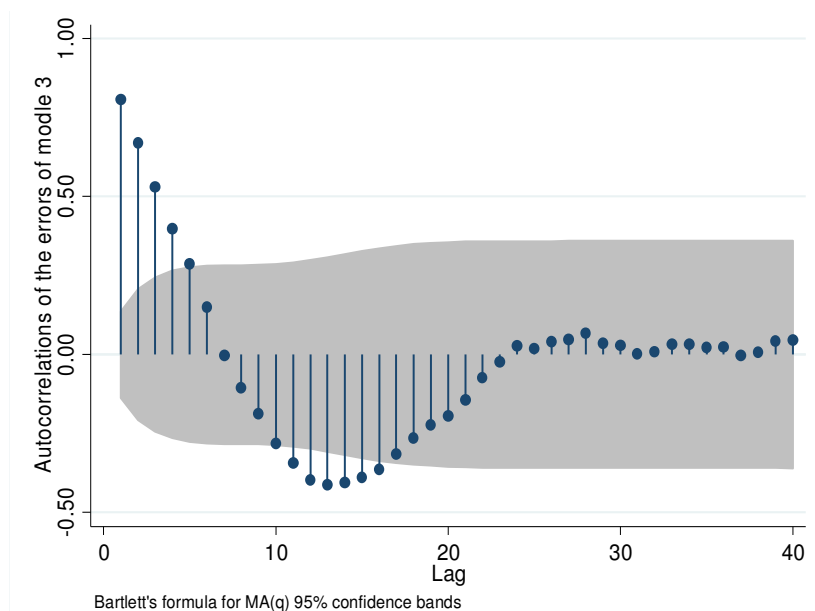
$$Z_t = \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \dots + \theta_q \varepsilon_{t-q} \quad \text{Equation 3.7}$$

(see Chatfield (2004)). Having noted that autocorrelation can potentially bias the intervention effect estimated with the ITS design, highlighted the two broad type of autocorrelation found in time series, the following sub- section describes how to detect autocorrelation within time series.

### 3.3.1.1 Determination of the type and order of autocorrelation in a time series

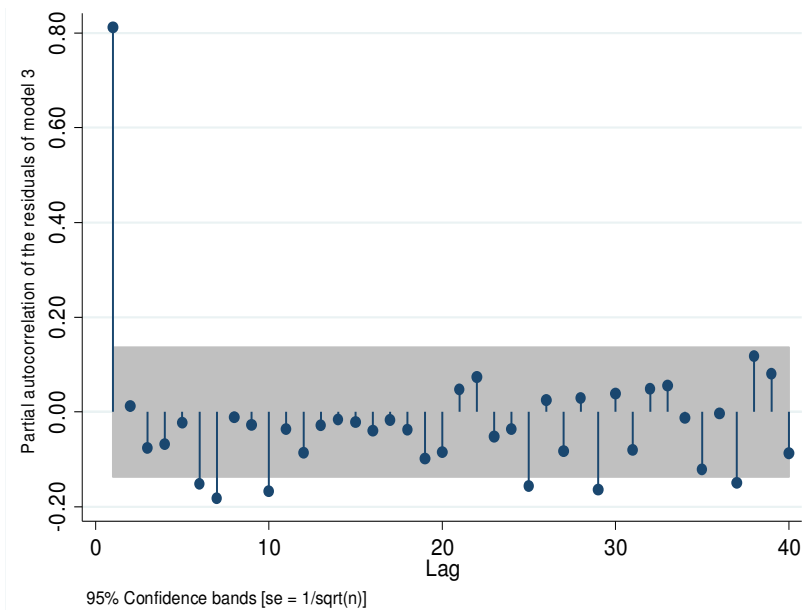
A correlogram is a very useful instrument for determining the presence, type and order of autocorrelation within a time series. A correlogram is a plot of the average correlation between observations at successive time lags. Two types of correlogram are particularly important for determining the type and order of autocorrelation within a time series: the ACF and the partial autocorrelation function (PACF) plots. The ACF plot demonstrates the average correlation between successive data points within a series (Box et al., 2008). The ACF plot of the errors of Model 3.3 (Figure 3.7) shows a high positive average correlation of 0.84 between successive data points. The ACF plot also shows that autocorrelation decreases exponentially with lag length.

**Figure 3.7 The ACF of the errors of Model 3**



The ACF of the errors of Model 3.3 decays exponentially suggesting that the errors follow an autoregressive process

**Figure 3.8 The PACF plot of the errors of Model 3.3**



The PACF plot demonstrates the extent of autocorrelation between data points after adjusting for the values at the intervening lags (Box et al., 2008). Thus if the PACF has a significant spike at lag 1 only, higher-order correlations are fully explained by the lag 1 autocorrelation. Figure 3.8 shows the PACS plot of the errors of Model 3.3 with a significant spike at lag 1.

The type and order of autocorrelation present within a time series can be determined from the characteristics of the ACF and PACF plots using the guideline summarised in Table 3.5. For example, the ACF of an AR(1) process decays exponentially while the PACF shows a significant spike only at lag 1 (Table 3.5). These recommendations are equally applicable to seasonal autocorrelation. For example, if there is seasonal autoregressive autocorrelation in a monthly time series, there should be an exponential decay of the ACF, while the PACF will show significant spikes at lags 1, 12, 24 and 36 with no significant spikes at intervening lags. Nevertheless, the

guidelines do not represent exact science hence the process of identifying an appropriate error model using the ACF and PACF plots is necessarily iterative. Using the guidelines in Table 3.5, the ACF (Figure 3.7) and PACF (Figure 3.8) plots suggest that the errors of Model 3.3 follow an autoregressive process of the first order, AR(1) which is consistent with the simulation parameters (appendix 5).

Formal statistical tests for autocorrelation include the Durbin-Watson alternative test for first order autocorrelation and the Ljung-Box Q-test. These tests and their applications are described in detail in Box et al. (2008) and Becketti (2013). However, in terms of testing for higher-order autocorrelation or detecting the type and order of autocorrelation present within a time series, the ACF and PACF plots are most useful (Wagner et al., 2002; Ramsay et al., 2003; Becketti, 2013).

**Table 3.5 Guideline for identifying the type and order of autocorrelation in a time series using the ACF and PACF plots**

<i>Process (order)</i>	<i>Pattern of ACF plots</i>	<i>Pattern of PACF plots</i>
<i>AR(1)</i>	Exponential decay	Significant spike at lag 1, no significant spikes at any other lags
<i>AR(2)</i>	A sine-wave shape or a set of two exponential decays	Significant spikes at lags 1 and 2, no significant spikes at any other lags
<i>MA(1)</i>	Significant spike at lag 1, no significant spikes at any other lags	Exponential decay.
<i>MA(2)</i>	Significant spikes at lags 1 and 2, no significant spikes at any other lags	A sine-wave shape or a set of two exponential decays.
<i>AR(1) &amp; MA(1)</i>	Exponential decay starting at lag 1	Exponential decay starting at lag 1

Adapted from (Becketti, 2013; Hill and Lewicki, 2013)



### 3.3.2 Segmented regression with autocorrelated errors

If autocorrelation is detected within the errors of an OLS-based ITS regression model, an expanded model that accommodates autocorrelation is required. Figure 3.7 and Figure 3.8 suggest the presence of first order autocorrelation in the errors of Model 3.3. The expanded version of Model 3.3, referred to as segmented regression with autocorrelated errors can be written as

$$Y_t = a_0 + a_1 + b_1H(t - k) + b_2(t - k)_+ + \varepsilon_t \quad \text{Equation 3.8 (Model 3.4)}$$

where the residual term  $\varepsilon_t$  is generated by an AR(p) process.  $p = 1$  is taken for illustrative purposes.

$$\varepsilon_t = \phi_1\varepsilon_{t-1} + u_t$$

In which  $u$  constitute a random sequence with mean zero mean and constant variance.

This type of model is usually fitted in three stages (Wagner et al., 2002; Huitema, 2011):

- a. An OLS-based ITS regression model is initially fitted (as already demonstrated with Model 3.3);
- b. Residual diagnosis is performed to determine if the errors are autocorrelated. If so, the type and order of autocorrelation present within the errors, as described in section 3.2.5;

- c. The tentative error model identified in step *b* above, is then incorporated into a re-fitted ‘regression model with autocorrelated errors’ (Model 3.4) and re-diagnosed in an iterative process until a suitable error model is found.

Such model can be estimated using a routine that provides maximum-likelihood estimates (Wagner, et a., 2002; Huitema, 2011). The parameter estimates obtained by analysing the simulated dataset with Model 3.4 are more consistent with the simulation parameters (Table 3.6). In addition, Model 3.4 passes diagnostic tests as shown in the next sub-section. This demonstrates that Model 3.4 is more suitable for describing the simulated dataset compared to Model 3.3.

**Table 3.6 Effect size estimated by analysing the simulated dataset with Model 3.4**

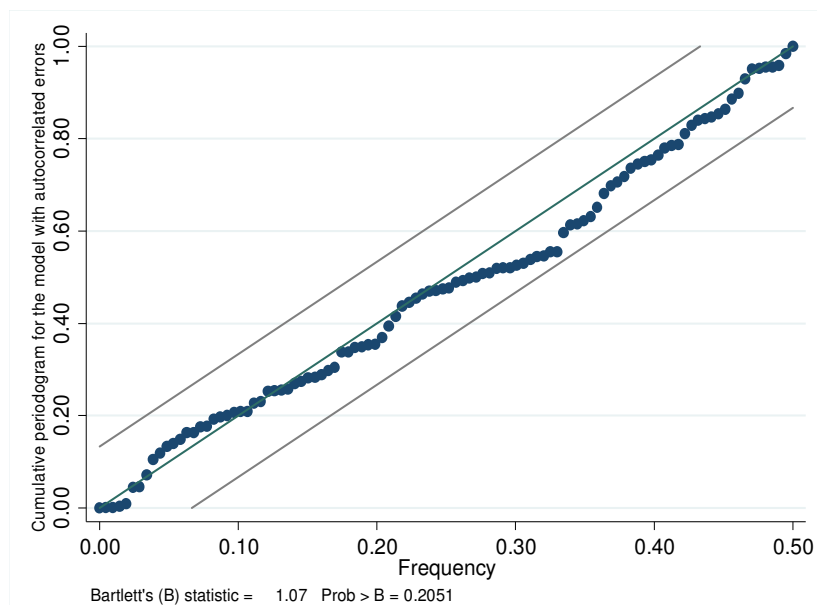
<i>Interpretation of the regression coefficients</i>	<i>Effect size (95% CI)</i>	<i>Simulation parameters</i>
<i>Initial level of waiting times (<math>a_0</math>)</i>	31.63 (29.57, 33.68)	30
<i>The trend of waiting times (<math>a_1</math>)</i>	0.05 (0.01, 0.09)	0.07
<i>Change in level of waiting times after intervention (<math>b_1</math>)</i>	-10.06 (-14.44, -5.69)	-10
<i>The change in trend of waiting times after the intervention (<math>b_2</math>)</i>	-0.03 (-0.09, 0.03)	-0.03
<i>Autoregressive parameter, AR(1)</i>	0.82 (0.74, 0.90)	0.90

Model 3.4 captures the simulation parameters better than all the previous models.

### 3.3.2.1 Diagnostic tests on regression model with autocorrelated errors (Model 3.4)

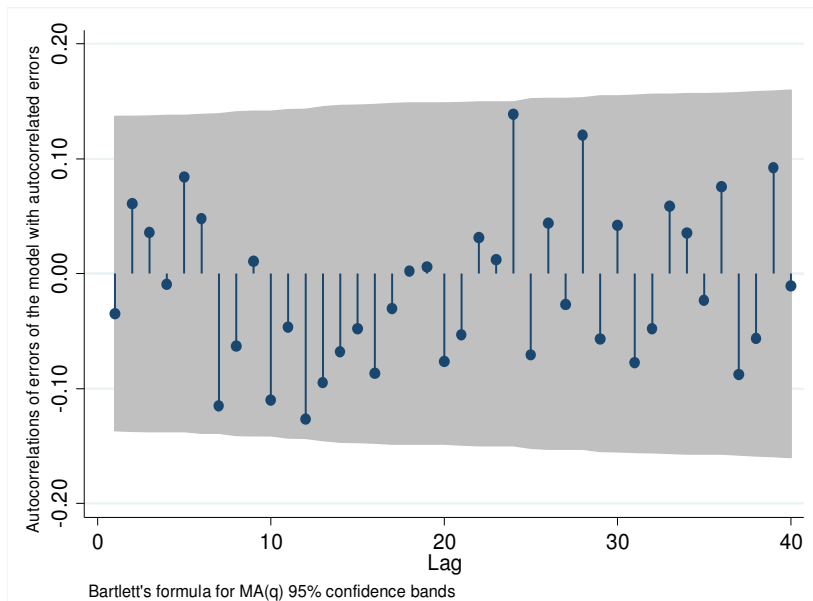
The diagnostic tests performed on the errors of Model 3.3 (section 3.2.5) were repeated on the errors of Model 3.4. The results of the Bartlett's cumulative periodogram test (Figure 3.9) shows that the periodogram is well lined up at 45° with no value appearing outside the 95% CI band. The ACF plot of the errors of Model 3.4 (Figure 3.10) shows no spike outside the 95% CI band, suggesting that Model 3.4 is most appropriate for describing the simulated dataset, compared to all the previous models. It accounts for trend, trend-change and autocorrelation within the dataset. Actual datasets were used to illustrate inhomogeneous variance, multiple interventions and non-linear trends in the next subsections.

**Figure 3.9 Result of the Bartlett's cumulative periodogram test on Model 3.4**



The periodogram is well lined up at 45° showing that all non-random periodicity has been removed

**Figure 3.10 The ACF plot of the errors of Model 3.4**

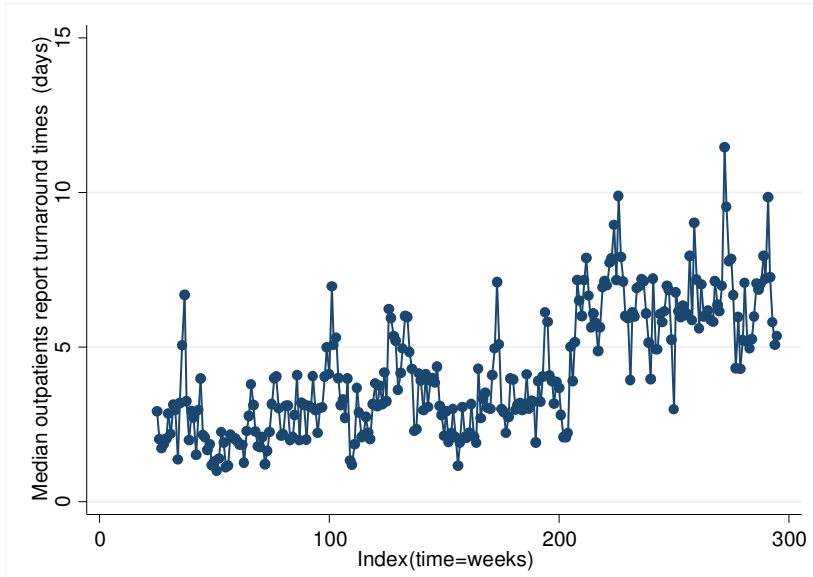


### 3.3.3 Homogeneity of variance

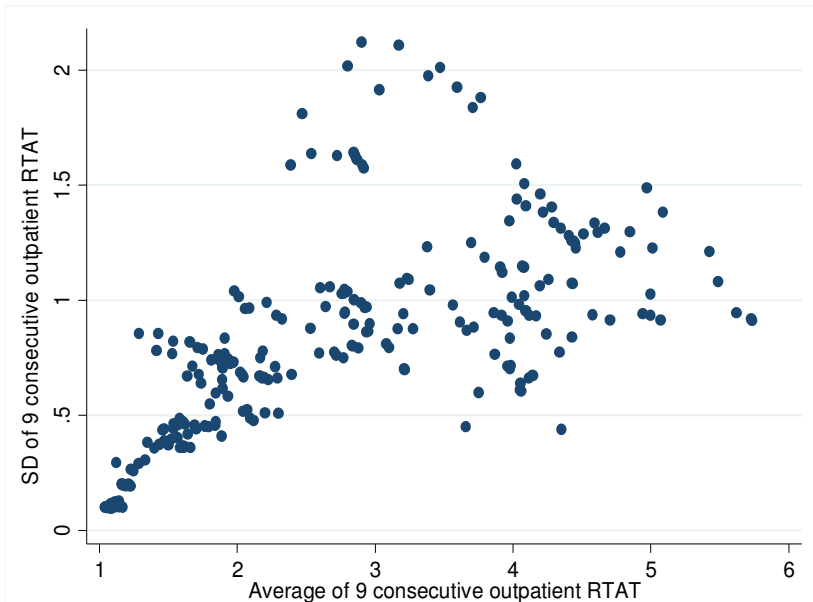
All the models discussed so far (including Model 3.4) assume that each observation is subject to the same variance (homogenous variance). This assumption does not always hold true with time series. Figure 3.11 is a time plot of the outpatient report turnaround times (one of the series evaluated in this thesis). Looking at Figure 3.11, it appears that the variances of the series are greater when the level of the series is higher. This can be examined by plotting the local means of (nine) consecutive observations against their standard deviation (SD) (Figure 3.12). This shows a clear relationship between SD and the level of the series which will invalidate many statistical models, including all the models discussed so far. This relationship is best explored by plotting both axis on a log-scale and fitting a straight line to the data (Figure 3.13). The slope of the OLS regression line is 1.03 for the logged series, implying that  $SD \propto (\text{mean})^{1.03}$  or  $SD \propto \text{mean}$  (approximately). In this case, it can be shown that a

logarithmic transformation can be used to (approximately) stabilise the variance of the series prior to ITS analysis as described in Box et al. (2008).

**Figure 3.11 Time plot of outpatient report turnaround times (RTAT)**

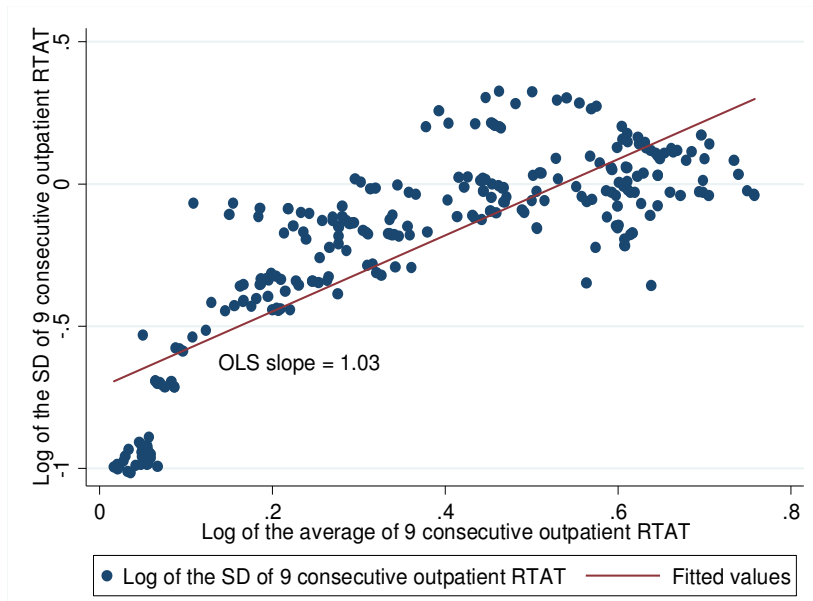


**Figure 3.12 Transformation plot of outpatient report turnaround times**



RTAT, report turnaround times

**Figure 3.13 Transformation plot of logged outpatients report turnaround times**



### 3.3.4 Multiple interventions with linear trend

Often times two or more interventions are implemented serially. Figure 3.14 is a time plot (log-transformed) of the inpatient pre-examination waiting times (PEWT) (one of the datasets evaluated in this thesis). The first and second interventions ( $k_1$  and  $k_2$  respectively) are separated by a time gap of 162 weeks (data points). Model 3.4 can be expanded to accommodate a second intervention,  $H(t-k_2)$  and a second trend-change variable  $(t-k_2)_+$ . The expanded model (Model 3.5) can be written as

$$Y_t = a_0 + a_1 t + b_1 H(t - k_1) + b_2 (t - k_1)_+ + c_1 H(t - k_2) + c_2 (t - k_2)_+ + \varepsilon_t$$

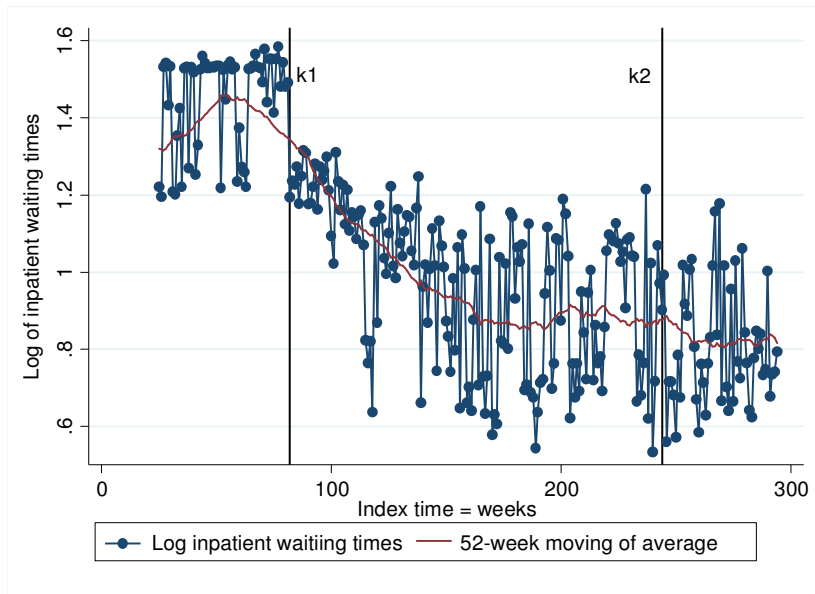
Equation 3.9 (Model 3.5)

where the residual term  $\varepsilon_t$  is generated by an AR(p) process, p=1 is taken for illustrative purposes.

$$\varepsilon_t = \phi_1 \varepsilon_{t-1} + u_t$$

In which  $u$  constitute an uncorrelated sequence with zero mean and constant variance.

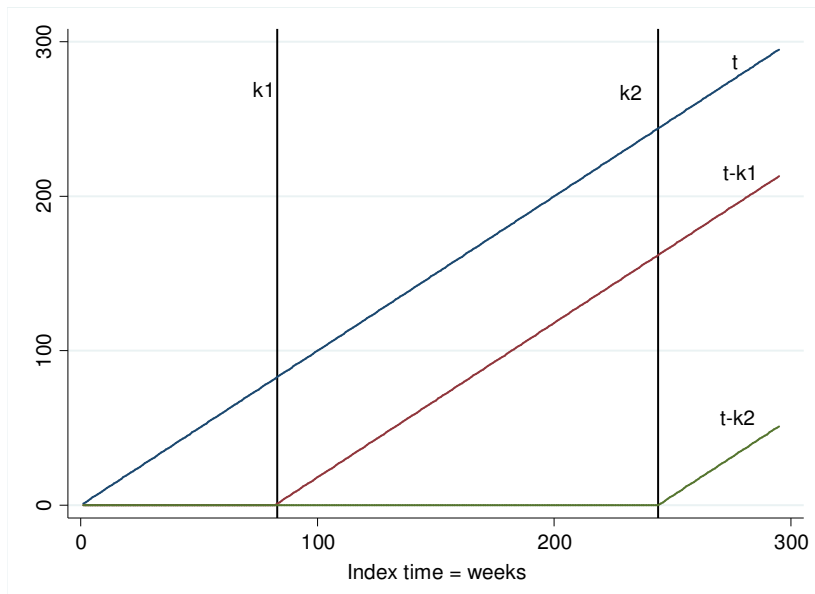
**Figure 3.14 Time plot of the log-transformed inpatient pre-examination waiting times**



K1 = the first intervention, K2= the second intervention

Model 3.5 then has three trend variables  $t$ ,  $(t-k_1)_+$  and  $(t-k_2)_+$  (Figure 3.15).  $(t-k_2)_+$  is coded '0' for all times before  $k_2$  and is identical to  $t-k_2$  for all times after  $k_2$  (Figure 3.15). The regression coefficients  $c_1$  and  $c_2$  measure the change in level and change in trend associated with the second intervention. Table 3.7 shows the effect estimates obtained by analysing the inpatient PEWT with Model 5. The results are graphically presented in Figure 3.16.

**Figure 3.15 A graphical illustration of the linear trend variables in a regression model with two interventions (Model 3.5)**



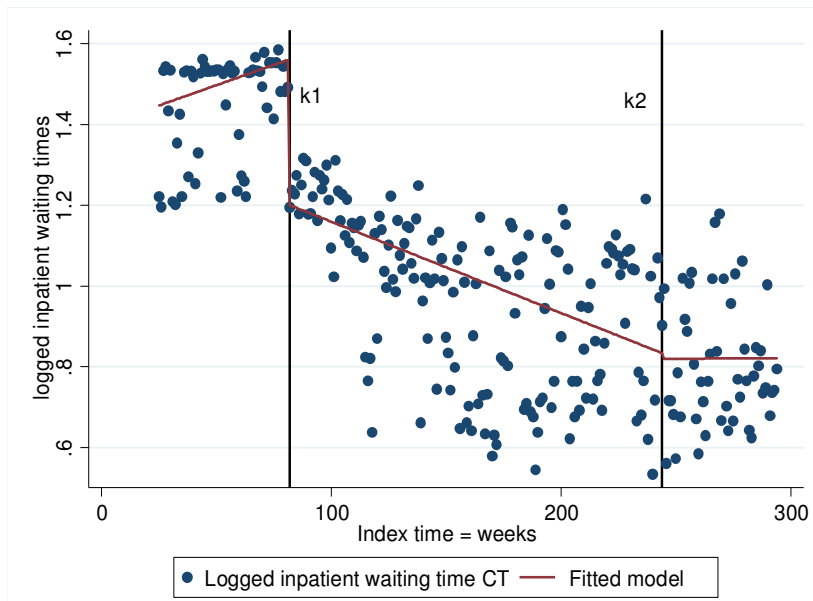
$k_1$ , the first intervention;  $k_2$ , second intervention;  $t$ , underlying trend also known as the pre-intervention trend;  $t-k_1$ , trend following the first intervention and  $t-k_2$ , trend following the second intervention

**Table 3.7 Effect size estimated by analysing the inpatient PEWT with Model 3.5**

<i>Parameters</i>	<i>Estimates</i>
<i>Initial level of waiting times (<math>a_0</math>)</i>	1.02 (0.70, 1.33)
<i>Pre-intervention trend of waiting times (<math>a_1</math>)</i>	0.19 (-0.03, 0.42)
<i>Change in the level of waiting times after <math>k_1</math> (<math>b_1</math>)</i>	-36.18 (-45.26, -27.11)
<i>Change in trend of waiting times after the first intervention (<math>b_2</math>)</i>	-0.43 (-0.68, -0.18)
<i>The trend after first intervention = the trend before the second intervention</i>	-0.23 (-0.29, -0.16)
<i>Change in mean weekly waiting times after the second intervention (<math>c_1</math>)</i>	1.37 (-14.60, 11.87)
<i>The change in trend of waiting times after the second intervention (<math>c_2</math>)</i>	0.26 (-0.11, 0.64)



**Figure 3.16 A graphical illustration of the trends fitted to the inpatient pre-examination waiting times data using model using Model 3.5**



$k_1$ , the first intervention,  $k_2$ , the second intervention. This model does not accommodate non-linear trends. The post  $k_1$  and pre-  $k_2$  trend are the same (linear trend).

### 3.3.5 Regression model with multiple interventions and non-linear trend

It is apparent from Figure 3.14 that a linear model may not capture the temporal pattern of pre-examination waiting times between the two interventions. Some form of polynomial spline function (e.g. cubic spline) is required for this purpose. Splines are smooth curved lines. Knots give the curved line the freedom to bend and follow the trend within the data more closely (Rutherford et al., 2013). Splines with fewer knots are generally smoother than splines with many knots, however increasing the number of knots usually increases the fit of the spline function to the data (Hansen and Kooperberg, 2002). Spline regression is a less biased and more efficient way to describe data containing trends (Howe et al., 2011). In extending Model 3.5 to a

‘segmented spline’ model (Model 3.6), the linear trends before the first intervention and after the last intervention were preserved and a polynomial function (without knots) added between the two interventions. In contrast to classic ‘natural’ and ‘restricted/constrained’ spline models, ‘segmented spline’ models allow for a changes in level and a change in trend at the intervention points to be assessed.

It is convenient to parameterise the cubic polynomial so that it does not change the interpretation of the existing components of Model 3.5. This can be achieved by using two piece-wise polynomial functions:

$$P_1(t) = (t - k_1)_+^2 - 2(t - k_2)_+^2 \quad \text{Equation 3.10}$$

and

$$P_2(t) = (t - k_1)_+^3 - 2(t - k_2)_+^3 - 3(t - k_2)_+^2 (t - k_1)_+ \quad \text{Equation 3.11}$$

where  $k_1$  and  $k_2$  denote the intervention time-points. The functions  $P_1$  and  $P_2$  are (a) continuous in time over the whole data range; and (b) linear in time outside the interval between the two interventions. The ‘segmented spline’ regression model with autocorrelated errors (Model 3.6) can be written by adding terms to Model 3.5 as follows

$$Y_t = a_0 + a_1 t + b_1 H(t - k_1) + b_2 (t - k_1)_+ + c_1 H(t - k_2) + c_2 (t - k_2)_+ + d_1 P_1(t) + d_2 P_2(t) + \varepsilon_t \quad \text{Equation 3.12 (Model 3.6)}$$

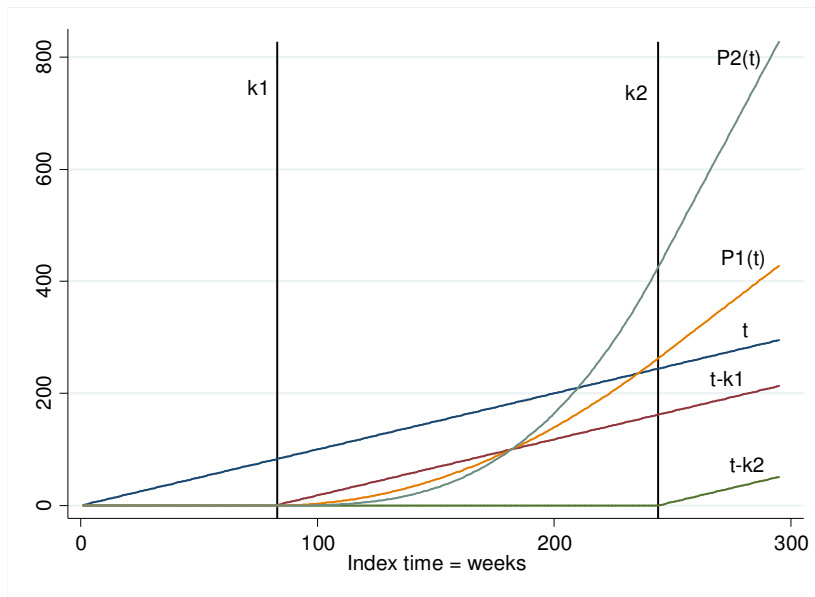
where the residual term  $\varepsilon_t$  is generated by an AR(p) process, p=1 is taken for illustrative purposes.

$$\varepsilon_t = \phi_1 \varepsilon_{t-1} + u_t.$$

In which  $u$  constitute an uncorrelated sequence with zero mean and constant variance.

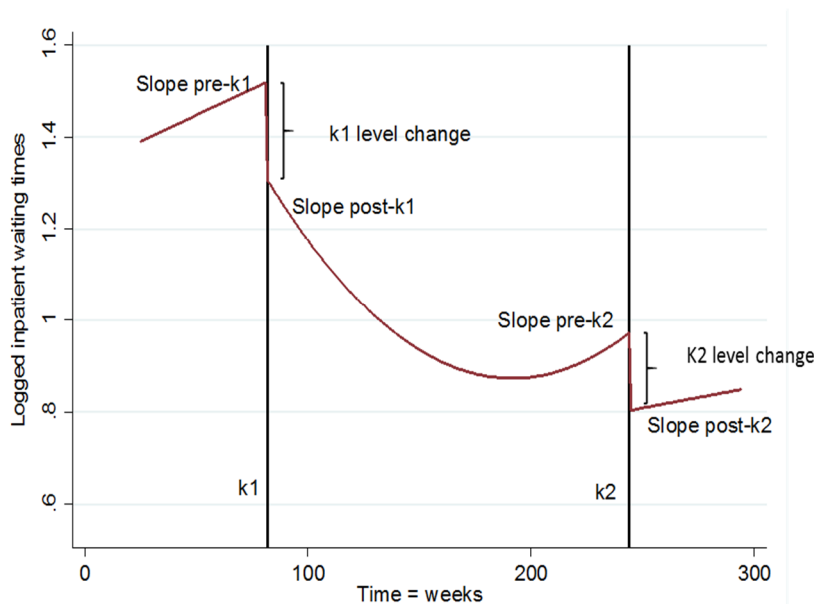
It is convenient to fit Model 3.6 using  $P_1/100$  and  $P_2/10000$  instead of  $P_1$  and  $P_2$ , to generate a more appropriate scaling of the parameters. This does not alter the fitted model. The trend components of Model 3.6 are illustrated in Figure 3.17 and the fitted model in Figure 3.18. Table 3.8 compares the estimates obtained by fitting a linear model (Model 3.5) and a non-linear model (Model 3.6) to the inpatient pre-examination waiting times. Model 3.6 estimates that the trend is significantly increasing just before the second intervention, which appears more consistent with a visual inspection of the time plot (Figure 3.14), compared to Model 3.5 which estimated a reducing trend. In addition, Model 3.6 estimates a significant drop in pre-examination waiting times following the second intervention, in contrast to Model 3.5 (Table 3.8). The confidence intervals of the change in trend estimated by models 3.5 and 3.6 for the second interventions,  $k_2$  do not overlap (table 3.8).

**Figure 3.17 A graphical illustration of the trend components of Model 3.6**



$k_1$ , the first intervention;  $k_2$ , the second intervention;  $t$ , the underlying trend;  $t-k_1$ , trend following the first intervention;  $t-k_2$ , trend following the second intervention;  $P_1$ , the quadratic polynomial and  $P_2$ , the cubic polynomial

**Figure 3.18 A graphical illustration of the trends fitted to the inpatient pre-examination waiting times data using model using Model 3.6**



$k_1$ , the first intervention;  $k_2$ , the second intervention;  $H(t-k_1)$ , level change after  $k_1$ ;  $H(t-k_2)$ , level change after  $k_2$ . With a spline model slope is constantly changing: hence pre- and post  $k_1$  and  $k_2$  slopes respectively.

**Table 3.8 A comparison of the estimates obtained using Model 3.5 and 3.6 to analyse the inpatient pre-examination waiting times**

<i>Parameters</i>	<i>Estimates</i>	
	<i>Linear trend (Model 3.5)</i>	<i>Non-linear trend (Model 3.6)</i>
<i>Waiting time at time '0'</i>	1.02 (0.70, 1.33)	1.02 (0.70, 1.33)
<i>The trend before <math>k_1</math> (<math>a_1</math>)</i>	0.19 (-0.03, 0.42)	-0.19 (-0.03, 0.42)
<i>Change in level after <math>k_1</math> (<math>b_1</math>)</i>	-36.18 (-45.26, -27.11)	-21.58 (-30.52, -12.63)
<i>The change in trend of <math>k_1</math> (<math>b_2</math>)</i>	-0.43 (-0.68, -0.18)	-0.96 (-1.27, -0.65)
<i>The trend just before <math>k_2</math></i>	-0.23 (-0.29, -0.16)	0.32 (0.05, 0.59)
<i>Change in level after <math>k_2</math> (<math>c_1</math>)</i>	1.37 (-14.60, 11.87)	-16.51 (-30.93, -2.09)
<i>The change in trend after <math>k_2</math> (<math>c_2</math>)</i>	-0.26 (-0.11, 0.64)	-0.26 (-0.68, 0.16)

In summary, the OLS-based ITS regression model (Model 3.3) can be refined to: (a) account for autocorrelation (Model 3.4); (b) accommodate multiple interventions with linear trend (Model 3.5) and (c) account for non-linear trend (Model 3.6). In addition, data transformation (e.g. log-transformation) can be used to (approximately) stabilise variance if necessary. Table 3.9 is a summary of the parameters included in the models and the interpretation of their coefficients. Other statistical considerations in ITS analysis are considered in the next sub-section.

**Table 3.9 A summary of the terms and the interpretation of their coefficients**

<i>Terms</i>	<i>coefficient</i>	<i>Interpretation of coefficient</i>	<i>Model 3</i>	<i>Model 4</i>	<i>Model 5</i>	<i>Model 6</i>
$1$	$a_0$	Level at time '0'	√	√	√	√
$t$	$a_1$	Initial Slope	√	√	√	√
$H(t-k_1)$	$b_1$	Change in Level due to the Intervention at $k_1$	√	√	√	√
$(t-k_1)_+$	$b_2$	Change in Slope due to the Intervention at $k_1$	√	√	√	√
$\varepsilon_{t-1}$	$\phi$	Autocorrelation parameter		√	√	√
$H(t-k_2)$	$c_1$	Change in Level due to the Intervention at $k_2$			√	√
$(t-k_2)_+$	$c_2$	Change in Slope due to the Intervention at $k_2$			√	√
$P_1(t)$	$d_1$	First polynomial (quadratic component), spline				√
$P_2(t)$	$d_2$	Second polynomial (cubic component), spline				√

### 3.3.6 Outliers and seasonality

In ITS analysis, the presence of outliers and seasonal patterns can potentially bias the estimate of intervention effect (Wagner et al., 2002; Box et al., 2008; Beckett, 2013). These two statistical issues are considered below.

#### 3.3.6.1 Seasonality

Time series often display strong periodic patterns, which may be at seasonal intervals. For example, the level of the outcome measure of interest might be

higher during certain seasons. It is very important that the periodicity of the dataset is kept in mind while considering seasonality. For example, monthly data have a seasonal period of 12 months; 52 for weekly data. A simple way to adjust for seasonality within the regression framework is by using deterministic seasonal variables (Wagner et al., 2002): one variable for each month. This method provides fully fitted values for all time points within the series, and it also has the ability to quantify the seasonal components at those time points (Huitema, 2011). This approach has a few disadvantages. One of which is that the fitted line of the structural component of the model appears serrated making interpretation of the underlying trend rather difficult. Deterministic seasonal modelling could potentially over parameterise the model if the time series is very short.

Other approaches to modelling seasonality in time series analysis include the stochastic method, the decomposition method and seasonal modelling in the frequency domain. A detailed treatment of seasonality in relation to time series analysis is outside the scope of this thesis. Further details on the subject could be found in Chatfield (2004) and Box et al. (2008).

### **3.3.6.2 Outliers**

Outliers can be thought of as anomalous observations, which are incoherent with, and differ noticeably from adjacent data points. An observation might be an outlier because it is either wrong or truly exceptional. The first step in dealing with an outlying observation is to exclude data entry errors. If the outlying observation

is truly exceptional, then decide how to deal with it. Methods for detecting outliers within time series can be broadly divided into automated procedures and graphical methods. The automated procedures use algorithms to determine which observation is an outlier (Weber, 2010). The graphical methods are guided by expert knowledge of the subject and experience. Graphical methods include visual examination of the time plot, box plot, and the capping & flooring technique (Tiwari et al., 2007).

There are various methods for dealing with outliers in ITS analysis. If the outlier appears in the middle of the series, it can be replaced with imputed values (Beckett, 2013). But if outliers appear at the beginning or at the end of the series, and the time series is long enough, they can be omitted from the analysis (Box et al., 2008; Beckett, 2013). Another method of dealing with an outlier is retaining it in the regression model with a pulse code (Tsay, 1988). The outlying observation could also be replaced with the value of the nearest neighbour (Ismail, 2008). For a review of the methods for detecting and handling outliers see, Tiwari et al. (2007).

### **3.4 The strengths, potential biases and quality criteria for the ITS design**

#### **3.4.1 Strengths of the ITS design**

One big asset of the ITS design, as previously demonstrated is that it can control for the underlying trends in a time series of outcome measures (Box et al., 2008). Another key strength is that the ITS design can be used to estimate two very



important forms of intervention effect: a change in level and change in trend of the series (Box et al., 2008). Change in trend is a useful indication of the longer term effect of the intervention. The ITS design and analysis provides clear and very easy to interpret graphical results. The graphical results can be used to convey a potent message to policy makers, with high audience impact, even in the absence of the statistical output of a corresponding regression model (Penfold and Zhang, 2013).

The ITS design can easily be used to assess the differential effect of an intervention on different strata of the population of interest (Wagner et al., 2002). For example, the impact of an intervention on patients' waiting times can easily be assessed for its differential effect on different clinical pathways (e.g. outpatients and inpatients). ITS analysis can also be very useful for evaluating the unintended consequences of an intervention (Shadish et al., 2002; Penfold and Zhang, 2013). For example, the unintended impact of speech recognition reporting intervention on error rates in radiology reports. A time series of error rates can easily be constructed if the researcher is interested in assessing whether the intervention has had an unintended effect on the error rates. Although the ITS design has many strengths, it is important to acknowledge that it also has potential biases which researchers need to be aware of.

### **3.4.2 Potential biases of the ITS design**

The four major potential biases and threats to internal validity of the ITS design and analysis are: history, instrumentation, selection and cyclical patterns (Shadish et al., 2002). The threat of 'history' refers to the possibility that the observed

effect may be due to some other confounding factor which happened at the same time as the intervention under investigation. This is referred to as time varying cofounder if the value of the confounder changes with time (Platt et al., 2009). There are several design features to control for the bias of 'history'. The best option is probably adding a control time series. However, this is not always possible. Another possibility is to construct a series with a shorter unit of measurement (if the data allows), e.g. weekly instead of quarterly or yearly intervals. It is then easier to place the historical event in context. In the absence of a control series, a powerful option to control for the bias of 'history' is the combination of ITS analysis with a qualitative method of enquiry (Shadish et al., 2002; Penfold and Zhang, 2013).

The threat of 'instrumentation' refers to a change, over time, in how records are kept and/or the definition of the outcome measure (Shadish et al., 2002) and represent a major threat to internal validity in ITS analysis. It is therefore important that the instrument used to measure the outcome and/or the definition of the outcome variable remain consistent throughout the entire study period. Any change in the procedure for the data collection and/or definition of the outcome variable must be carefully documented by the investigator.

The third threat to internal validity of the ITS design identified by Shadish et al. (2002) is the 'selection' bias. This refers to the probability of the composition of the series changing at the time of intervention. For example, in a clinical trial, if a significant proportion of the group exited the trial due to side effects, the validity of the study will be undermined. The bias of 'selection' can be controlled by using

stratified analysis based on the units that were measured over all the time periods. For this particular reason, Ramsay et al. (2003) recommends that dataset should comprise at least 80% of the total number of participants in the study at each data point. Any missing data should be addressed and carefully documented by the researcher.

The fourth threat to validity is the cyclical/seasonal effects (Shadish et al., 2002). As previously mentioned, it might be that the value of the outcome variable is usually higher at a certain time of year. Researchers should be open to the impact of seasonality and implement appropriate seasonal adjustment to the model. A good ITS study should have design features to address the potential biases listed above.

### **3.4.3 Quality standard for ITS analysis**

In view of the above potential biases, and a previous report by Ramsay et al. (2003) that over 65% of the studies included in their review of the methodological quality of ITS studies failed to address the potential biases of the ITS design, it is useful to briefly highlight the criteria that distinguish a well implemented from a poorly implemented ITS study. These quality criteria are drawn from Shadish et al. (2002), the Cochrane's Effective Practice and Organisation of Care Review Group, EPOC (2012b) and Ramsay et al. (2003). A well implemented ITS study must have the following features:

- a. A clear specification of the intervention time and other potential confounding factors ruled out or controlled for. This criterion addresses the effect of "history" / time varying confounders.

- b. The study is analysed appropriately using time series technique (autoregressive integrated moving average, ARIMA or time series regression model). The wide range of statistical issues that arise in time series analysis including autocorrelation, non-homogenous variance and non-linear trends were discussed in section 3.3. This criterion addresses the effect of “history” and seasonal/cyclical biases.
- c. A clear specification of the type of effect the intervention is expected to have on the outcome measure, if it was effective, with a logical explanation. This criterion also addresses the effect of “history”.
- d. A standardised and consistent method of data collection and/or definition of the outcome measure of interest throughout the study period: the same for the pre- and post-intervention periods. This criterion addresses instrumentation bias.
- e. A reliable measurement of the primary outcome: either the outcome is objectively measured or when qualitatively measured, there must be two or more raters with an inter-raters agreement  $\geq 90\%$  or kappa  $\geq 0.8$ . This criterion addresses the effect of instrumentation bias.
- f. A well implemented ITS design must adequately address incomplete or missing data. This criterion addresses the effect of selection bias.
- g. The study must have sufficient data points. This criterion addresses the effect of seasonality/cyclical patterns data.

- h. All relevant outcomes in the study must be reported. This criterion addresses the effect of selection bias

## **3.5 Discussion**

The basic ITS design and the necessary refinements to accommodate autocorrelation, multiple serial interventions and especially the use of ‘segmented spline’ regression to model non-linear trends were described. Analysis of the simulated waiting time dataset showed that the estimate of intervention effect obtained with the regression equivalent of the t-test might be biased by pre-intervention trend. The use of the t-test to analyse time series data is a common analytical error in ITS studies (Ramsay et al., 2003). However, as was explained in section 3.2.2, the lower post-intervention level could potentially be explained by a decreasing pre-intervention trend. This pitfall can be avoided with the addition of a trend variable to the regression model.

Many time series exhibit autocorrelation. It is also very important that autocorrelation is accounted for in ITS analysis, to avoid a situation where the null hypothesis is erroneously rejected. This could potentially lead researchers to make wrong inferences about the intervention effect with serious policy consequences. In addition, Time series often exhibits non-linear trend pattern. Fitting a linear model to a non-linear dataset can also lead to erroneous attribution of a change that is due to the

trend pattern in the data, to the intervention, or underestimation of the intervention effect as illustrated in section 3.3.5.

ITS analysis requires data to be in regular equally spaced time intervals. Incomplete or missing data must be adequately addressed and carefully documented. However, missing data will be unlikely to affect the analysis if either the proportion of missing data is similar in the pre- and post-intervention periods or the proportion of missing data is less than effect size, in which case it is unlikely to overturn the results of the study (EPOC, 2012b). Recommendations on the minimum number of data points required for the ITS design and analysis vary.

The Cochrane Effective Practice and Organisation of Care (EPOC) Review Group recommends that the series should have at least three observations before and after the intervention (EPOC, 2012a). In line with the above recommendation, one of the three subjects reported in Scherrer and Wilder (2008) recorded only three pre-intervention observations. Whereas Penfold and Zhang (2013) recommends a minimum of eight data points before and after the intervention. But these recommendations are unlikely to allow for accurate modelling of seasonal pattern. A more appropriate recommendation when using monthly dataset is a minimum of 12 data points prior to and 12 data points after the intervention (Wagner et al., 2002; Serumaga et al., 2011). And in cases of multiple interventions, there should be sufficient number of data points between the interventions for their impact to be evaluated independently. The above recommendation is not about ensuring adequate power for the study, but to allow seasonal component to be estimated.

Power calculation for the ITS design are not fully developed (McLeod and Vingilis, 2005; McLeod and Vingilis, 2008; Zhang et al., 2009). As a rule of thumb, a study with 10 pre- and 10 posts-intervention data points has at least 80% power to detect a change in level of five standard deviations of the pre-intervention data, if autocorrelation is greater than 0.4 (Ramsay et al., 2003). However, Huitema (2011) recommends that the dominant concern in ITS analysis should be the adequacy of model rather than power calculation. This is because power analysis is dependent on the characteristic of the series such as the process sampled (Huitema, 2011), the degree of autocorrelation (Zhang et al., 2009), the number and type of parameters to be estimated etc. (Huitema, 2011). Unfortunately, most of this information can only be obtained from analysing the dataset; rather than be available at the design stage. This helps to understand why Shadish et al. (2002) states that the number of data points (sample size) required for ITS analysis cannot be fully specified in advance.

According to Shadish et al. (2002) there are three types of intervention effect in ITS analysis. The first type is the form of effect, which might include a (a) change in the level of the series, (b) change in the trend pattern of the series, (c) change in the variance around each mean and (d) change in the cyclical pattern of the series. The second and third types are the nature of onset and the duration of the effect (Shadish et al., 2002). The onset of the effect could be immediate or delayed while the duration of effect can be permanent or temporary. Although change in level and trend are most commonly reported in the literature (Brealey and Scuffham, 2005; Oliver W. Morgan et al., 2007; Hawton et al., 2009; Siström et al., 2009; Serumaga et

al., 2011), investigators should be open to other possible types of effect such as a change in variance.

Researchers should also be aware that the result of ITS analyses cannot be used to make inferences about individual patient-level outcomes if the series used in the analysis is the aggregate values for a population (Penfold and Zhang, 2013). The implication is that if a series of median waiting times was analysed, the results cannot be used to make inferences about the effect of the intervention on an individual patient' waiting time.

## **3.6 Summary and conclusions**

The interrupted time series (ITS) design is a robust design that can be used to strengthen the simple pre- and post-intervention design and is especially useful when it is not feasible to perform a randomised study. The basic principles of the ITS design and analysis were demonstrated, especially the refinements to accommodate (a) autocorrelation, (b) inhomogeneous variance (c) multiple interventions and (d) non-linear trends. A failure to account for autocorrelation can potentially distort the statistical test of significance which might lead to a wrong inferential statistic with serious policy consequences. The OLS-based ITS regression model can be refined to accommodate serial dependency. If the variance of the series is inhomogeneous, the data can be log-transformed to (approximately) stabilise variance. Spline functions can be used to capture non-linear trend. Seasonal variability is another potential source of



bias in the ITS design. The deterministic seasonal modelling is a simple and effective option for seasonal adjustment in the ITS design. A well implemented ITS study must include design features to address the potential biases of “history” / time varying confounders, instrumentation, selection and seasonal/cyclical changes.

Given the availability of appropriate data, in a situation where an RCT is not feasible, the ITS design is a robust alternative to randomisation for evaluating the effectiveness of health care interventions. The results of using the ITS design and analysis to evaluate the effectiveness of healthcare interventions (as part of a mixed methods case study) are presented in chapter four of this thesis.

# CHAPTER 4. AN INTERRUPTED TIME SERIES EVALUATION OF THE IMPACT ON PATIENTS' WAITING TIMES OF THREE SDIs IMPLEMENTED WITHIN BIRMINGHAM HEARTLANDS HOSPITAL

## Abstract

**Background:** Chapter four presents the results of using the ITS design to evaluate the impact on waiting times for CT-scan of three SDIs implemented in the radiology department of the Birmingham Heartlands Hospital. The initiatives were (a) 320-slice CT-Scanner (CT), (b) speech recognition reporting (SRR) and (c) extended-working-hours (EWH). The outcome measures were the pre-examination waiting times (for the CT & EWH interventions) and report turnaround times (for the SRR and EWH interventions).

**Methods:** Patient-level waiting times and workload data were retrieved from the clinical radiology information system (CRIS™) from June 2008 to September 2013. The data was summarised, separated into four clinical pathways (inpatient, outpatient, GP and A&E) and collapsed into median weekly waiting times. ITS analysis was performed

using the 'segmented spline' regression approach. The models included terms to estimate (a) the underlying trend, (b) a change in level and (c) a change trend of waiting times following the interventions. The models were adjusted for seasonality and workload.

**Results:** For the CT intervention, the level of pre-examination waiting times reduced for inpatient, 22% (13, 31) and increased for outpatient, 14% (5, 24) and GP, 15% (9, 21). For the SRR intervention, the level of report turnaround times reduced for A&E, 26% (11, 41) and increased for outpatient, 20% (3, 37) and GP, 21% (4, 38). For the EWH intervention, the inpatient clinical pathway had a 17% (2, 31) reduction in the level pre-examination waiting times and a 3.92% (0.07, 7.77) increase in the level of report turnaround times. 95% confidence intervals in parenthesis.

**Conclusions:** Reduced waiting times for the inpatient and A&E clinical pathways appear to be gained at the expense of increased waiting times for the outpatient and GP clinical pathways. For the EWH intervention, reduced pre-examination waiting times appears to come with increased report turnaround times for the inpatient clinical pathway. Therefore, it was impossible to be certain of the overall effectiveness of the interventions.

## 4.1 Introduction

Chapter three described how the ITS design can be used to strengthen the pre- and post-intervention design. Appropriate implementation of the ITS design and analysis, especially the use of 'segmented spline' to model non-linear trends were also discussed in chapter three. This chapter presents a case study using the ITS design to evaluate the impact on patients' waiting times of three SDIs implemented within the radiology department of the Birmingham Heartlands Hospital site of the Heart of England NHS Foundation Trust (HEFT). The three SDIs were (a) the replacement of a 4- with a superfast 320-slice CT-scanner, (b) switching from manual transcription to speech recognition reporting (SRR) and (c) extended-working-hours (EWH).

In order to address the challenging issues of financial constraints, increasing cost pressure, manpower shortages, growing public expectations and increased waiting times, effective service delivery initiatives are required (Li et al., 2013). Earlier studies have shown that; the use of a faster CT-scanner can improve the productivity of a CT department by 13% (Jhaveri et al., 2001), the adoption of SRR increased the proportion of CT-examinations reported within 24 hours from 64% to 71% (Akhtar 2011). There are a number of reports linking the lack of out-of-hour CT-scan provision (and therefore increased patients' waiting times), to poor clinical outcomes and increased mortality in the United Kingdom (Gray et al., 2005; Martin et al., 2007; Stewart et al., 2009; Cournane et al., 2016). However, there is as yet no study

within the published literature on the impact of extended-working-hours on the waiting times for CT-examinations.

## **4.1.1 Aims and objectives**

### **Aims**

The aim of this chapter is to present a case study on the use of ITS ‘segmented spline’ regression to evaluate the effectiveness of healthcare interventions within a radiology department. It is hoped that this will help to promote the use of the ITS design in radiology service evaluation research.

### **Objectives**

The objectives are to determine, for each of the four clinical pathways (inpatient, outpatient, GP and A&E), the impact of the;

- a. CT intervention on pre-examination waiting times,
- b. Speech recognition reporting intervention (SRR) on report turnaround times,
- c. Extended-working-hours (EWH) intervention on pre-examination waiting times and report turnaround times.

## **4.2 Methods**

### **4.2.1 Study setting**

This study was performed in the radiology department of the Birmingham Heartlands Hospital site of the HEFT. The HEFT comprises three hospitals (Birmingham Heartlands, Good Hope and Solihull hospitals) and the Birmingham Chest Clinic. HEFT is one of the largest acute hospital Trusts in England. Patients are referred to the radiology department through four clinical pathways: inpatient, outpatient, General Practice (GP) and Accident and Emergency (A&E). Each clinical pathway has a different waiting time expectation (the waiting time target). For example, A&E has the most clinically urgent cases and their examinations are usually performed and reported within four hours. Examinations for the inpatient clinical pathway are usually performed within 48 hours of request and reported the same day. Examinations for the outpatient and GP clinical pathways are usually performed within six weeks of request and reported within two weeks of examination.

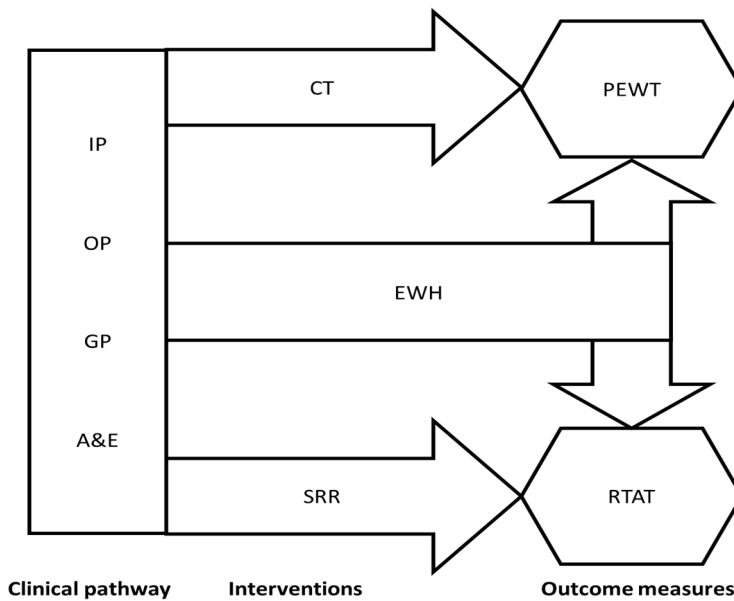
Within the study setting, radiology resources are shared amongst the four clinical pathways: there is no dedicated CT-scanner or reporting framework for any of the clinical pathways; every request goes into a single waiting list that operates like a priority queueing system. Patients are booked from the waiting list based on clinical priority and time waited on the list. The clinical priority of a given request is generally a function of its referral pathway. The clinical priority status of the four referral pathways in descending order is A&E, inpatient, outpatient and GP. Therefore, there is

a possibility that the interventions might have a differential effect on the clinical pathways.

## **4.2.2 The interventions and logic model for the analysis**

The interventions evaluated in this study were implemented on the following dates: 320-slice CT-scanner, 21<sup>st</sup> July 2009; SRR system, 1<sup>st</sup> September 2009 and EWH, 3<sup>rd</sup> September 2012. Figure 1.2 is the logic model for the quantitative evaluation of the impact on waiting times of the above three interventions. As previously mentioned in chapter three, the ITS design requires a specification and rational explanation of the nature of the expected intervention effect, before data analysis (Box et al., 2008). The aim of ITS analysis therefore, is to determine if the intervention has had the expected effect. Within this context, the 320-slice CT-scanner, a much faster scanner compared to the 4-slice system which it replaced, was expected to increase productivity by speeding up the scanning process such that more patients can be scanned per-day. Scanning more patients per-day from the waiting list should logically lead to reduced pre-examination waiting times. Therefore, the pre-examination waiting times were used to assess the effectiveness of the CT intervention.

**Figure 4.1 Logic model for the quantitative study**



CT, CT intervention; SRR, speech recognition reporting intervention; EWH, extended-working-hour intervention; PEWT, pre-examination waiting time; RTAT, report turnaround times; IP, inpatients; OP, inpatients; GP, general practice; A&E, accident and emergency

Following a CT-scan (image acquisition), the images are interpreted to produce a formal radiology report. SRR software converts spoken words into text and allows radiologists to generate and edit radiology reports using real-time, continuous speech. Before the SRR intervention, radiology reports were dictated into computer audio file that can be listened to and transcribed by secretaries/transcriptionist and returned to the radiologist for checking and sign off. There can be delay between report dictation and transcription. The SRR intervention was expected to reduce (or eliminate) the time delay between dictation and transcription of radiology reports. This should translate into reduced report turnaround times. Therefore, report turnaround times were used to assess the effectiveness of the SRR intervention.



The EWH intervention involved extending the department's operating hours from 9 AM – 5 PM (8 hours) to 8 AM – 8 PM (12 hours), a 50% increase in operating hours. The EWH generally applied to radiographers who perform the scans. The radiologists who report the scans did not generally do EWH. The EWH intervention was expected to increase access to CT-scan, which will lead to more scans that will need to be reported. Therefore, the EWH intervention was expected to reduce the pre-examination waiting times. The report turnaround times were expected to increase because there will be more scans needing reporting than could be reported with the existing reporting capacity. Therefore, the effectiveness of the EWH intervention is evaluated using both the pre-examination waiting times and report turnaround times. As shown in Figure 4.1, the interventions were evaluated separately for each of the four clinical pathways.

### **4.2.3 The outcome measures**

The outcome measures were the: (a) pre-examination waiting times (PEWT), defined as the time elapsed between the request for, and the completion of CT-examination on the clinical radiology information system (CRIS™) and (b) report turnaround times (RTAT), defined as the time elapsed between the completion of the examination and time of the final radiology report on the CRIS™.

#### **4.2.4 Data source**

The study data was collected from the radiology information system (RIS) of the radiology department, HEFT. RIS is a software and hardware system used by radiology departments to record, manipulate, and distribute patients' radiological data and it contributes to electronic patient records (Alderson, 2000). RIS is designed to support the operational workflow, business analysis and quality assurance systems within radiology departments. All interactions between users and RIS are date and time stamped, making it a very useful tool for radiology service evaluation research. Almost all recent radiology service evaluation studies including Shinagare et al. (2014) and Byrne et al. (2015b) have sourced their study data from RIS.

#### **4.2.5 The data**

Patient-level waiting times and workload data were retrieved from the clinical radiology information system (CRIS™) of HEFT from June 2008 to September 2013. Each record contains the hospital site, clinical pathway, referrer's department and specialty, the examination(s) performed, date & time of request, date & time of examination and date & time of the final radiology report. The pre-examination waiting times and report turnaround times were computed from the information contained in the retrieved records, as defined in section 4.2.3. The pre-examination waiting time equals the time the examination was completed on the CRIS™ minus the time of request. The report turnaround time equals the time of final radiology report minus the time the examination was completed on the CRIS™.

## **4.2.6 Workload**

Workload is defined as the number of patient episodes per week. Each of the retrieved records is a patient episode. If a patient had a CT neck, chest, abdomen and pelvis on a single visit, all the examinations are counted as one episode of care rather than four different examinations. This method has previously been used to compute radiology workload (Sistrom et al., 2009).

## **4.2.7 Ethical considerations**

As previously stated in chapter one section 1.3.3, favourable ethical opinion was received from the University of Birmingham (appendix 1). Local NHS organisation' permission was obtained from the Heart of England NHS (appendix 2).

## **4.2.8 Analytical methods**

### **4.2.8.1 Summary statistics**

The patient-level waiting time data was separated into the four clinical pathways and summarised. Waiting times that were deemed too high to be realistic within the study setting were excluded as outliers using the capping technique (Tiwari et al., 2007). This was done by establishing a maximum pre-examination waiting time / report turnaround time value above which observations were excluded. This method of excluding outliers has previously been used by Halsted and Froehle (2008) and Cowan et al. (2013) in radiology waiting times analysis.

The choice of capping value was guided by the statistical summary of the data and clinical experience. Pre-examination waiting times were capped at roughly twice the maximum expected waiting time (waiting time targets) for the respective clinical pathways with the exception of A&E. The target waiting time is the waiting time that no patient is expected to exceed. A recent study found that the waiting time target for outpatients CT-scan in Canada is 60 days (McCafferty et al., 2015), but this varies within and between countries. The current study used a waiting time target of six weeks (42 days) which is the waiting time target in operation for the outpatient and GP clinical pathways within the study setting. The applied capping values for pre-examination waiting times (waiting time target in parenthesis) are as follows: outpatient and GP, 90 (42) days; inpatient, 96 (48) hours and A&E 48 (4) hours.

The A&E pre-examination waiting times were capped at 48 hours because the researcher is aware that a small proportion of A&E patients within the study setting follow a sub-pathway that allows them to be discharged and come back the following day for their CT-scan. A similar observation; that A&E patients do not all have identical pathways was made in a recent Canadian study (Wang et al., 2015). The report turnaround times were capped as follows: outpatient and GP, 30 (14) days, inpatient 48 (24) hours and A&E, 48 (4) hours; the target report turnaround times in parenthesis. Again, CT-examinations for the small proportion of A&E patients that follow different sub- pathways, were not necessarily reported within the same time constraint as the regular A&E patients, hence A&E report turnaround times were also capped at 48 hours.

Another important consideration in choosing the capping values was the proportion of data excluded by the chosen capping value. The capping values were chosen such that no more than 5% of the raw data was excluded. The excluded (outlying) observations were also summarised. A random sample of 20 patient-episodes was taken from the outliers for a detailed investigation on the CRIS™ (the equivalent of patients' note analysis). The purpose of which was to check for possible reasons for the exceptionally high recorded waiting times. A free random number generator for android phones, Random™ developed by UX App, obtained from Google™ Play was used for selecting the sample of 20 patient episodes for detailed examination on the CRIS™.

#### **4.2.8.2 Interrupted time series (ITS) analyses**

After excluding the outliers, the data was summarised again, and aggregated (collapsed) into median weekly waiting times for ITS analysis: two series (pre-examination waiting times and report turnaround times) for each of the four clinical pathways; making eight series in total. ITS analyses were performed to evaluate the impact of the; CT intervention on pre-examination waiting times, SRR intervention on report turnaround times, and the EWH intervention on pre-examination waiting times and report turnaround times. ITS analysis was implemented using the 'segmented spline' regression technique. The series were log transformed to (approximately) stabilise variance. The models included terms to estimate the (a) underlying trend, (b) change in level and (c) change in trend of the series following the

interventions as described in Wagner et al. (2002), Huitema (2011) and outlined in chapter 3 section 3.3.

The fitted model (Model 4.1) is the same as Model 3.6 described in chapter 3 (section 3.3.5), plus terms for seasonality and workload. Segmented spline was achieved by computing and entering into the regression model, two piece-wise polynomial functions (quadratic and cubic) in addition to the linear (time) function. This allowed for a preservation of the linear trends at the beginning (before the first intervention) and end (after the last intervention) of the series, and added a polynomial spline (without knots) between the interventions, as described in chapter 3 (section 3.3.5).

If the contribution of the polynomial function is not significant at 0.100 (10%), it was removed from the model. The significance level of 10% was arbitrarily chosen. A similar approach was used by Schneider et al. (2013) to exclude non-significant terms in their analysis of the impact on waiting times of computerised physician order entry system. The models were adjusted for seasonality and workload. Seasonal adjustment was done by creating and entering into the regression model one variable for each month.

$$Y_t = a_0 + a_1t + b_1H(t - k_1) + b_2(t - k_1)_+ + c_1H(t - k_2) + c_2(t - k_2)_+ + d_1(P_1(t))/100 + d_2(P_2(t))/10000 + s_1m + l_1W + \varepsilon_t$$

Equation 4.1 (Model

4.1)

where

$$P_1(t) = (t - k_1)_+^2 - 2(t - k_2)_+^2$$

$$P_2(t) = (t - k_1)_+^3 - 2(t - k_2)_+^3 - 3(t - k_2)_+^2 (t - k_1)_+$$

$m$  is the month of observation for  $m = 1, \dots, 11$

and  $\varepsilon_t$  is generated by an autocorrelated process e.g. AR(p),  $p=1$  is used for the purposes of illustration.

$$\varepsilon_t = \phi_1 \varepsilon_{t-1} + u_t$$

In which  $u$  constitute an uncorrelated sequence with zero mean and constant variance.

The interpretation of the coefficients of the terms in Model 4.1 are summarised in

Table 4.1

**Table 4.1 Interpretation of the coefficients of the terms in Model 4.1**

<i>Term</i>	<i>coefficient</i>	<i>Interpretation of coefficient</i>
$1$	$a_0$	Initial Level
$t$	$a_1$	Initial Slope
$H(t-k_1)$	$b_1$	Change in Level due to Intervention at $k_1$
$(t-k_1)_+$	$b_2$	Change in Slope due to Intervention at $k_1$
$\varepsilon_{t-1}$	$\phi$	Autocorrelation parameter
$H(t-k_2)$	$c_1$	Change in Level due to Intervention at $k_2$
$(t-k_2)_+$	$c_2$	Change in Slope due to Intervention at $k_2$
$P_1(t)$	$d_1$	First polynomial component (quadratic)
$P_2(t)$	$d_2$	Second polynomial component (cubic)
$m$	$S_1$	Seasonal component; one variable for each month
$W$	$l_1$	Workload

The ITS models were fitted in the following stages: (a) an OLS-based model was initially fitted; (b) residual diagnosis was performed to check if the errors of the OLS-based model were autocorrelated and to identify the type and order of autocorrelation; (c) where autocorrelation is identified, the regression model was expanded to accommodate autocorrelation as described in chapter 3; (d) the refitted 'segmented spline' regression model with autocorrelated errors (Model 4.1) was re-diagnosed to assess the goodness of fit. These steps were repeated until a suitable error model was found. Model 4.1 is fitted using the maximum likelihood estimation procedure (Hamilton, 1994; Box et al., 2008).

The residuals of the OLS -based models and the models with autocorrelated errors (Model 4.1) were examined for the presence of autocorrelation using the Bartlett cumulative periodogram test and the autocorrelation function (ACF) plot. The ACF and PACF plots were used to identify the type and order of autocorrelation present within the errors of the OLS-based model as described in Becketti (2013), Hill and Lewicki (2013) and summarised in chapter 3 section 3.3.1. Model 4.1 was assessed for goodness of fit using residual plots and the Ljung-Box Q-test, as described in Box et al. (2008) and Becketti (2013). All analyses were performed on STATA™ 13 (STATA Corporation USA).

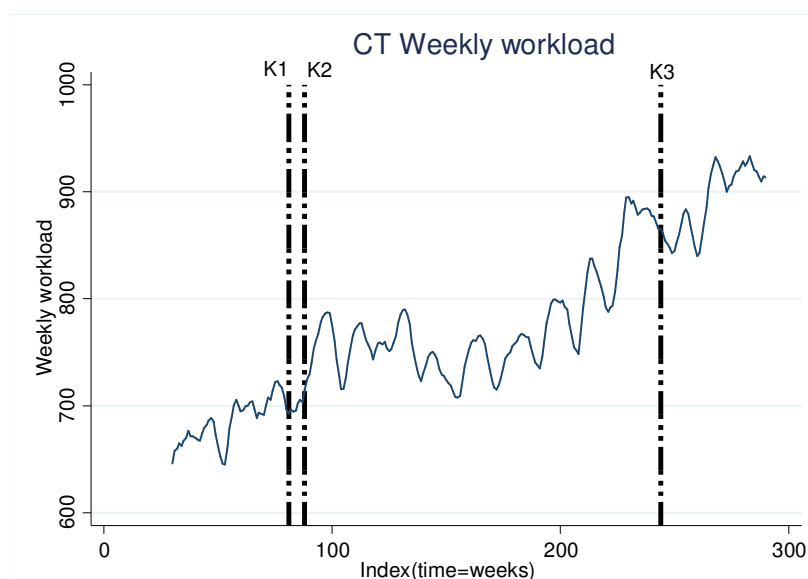


## 4.3 Results

### 4.3.1 Summary of patient level data

A total of 211,572 patient-level records (patient episodes) were retrieved from the CRIS™. The steady increase in the total weekly workload over the study period is summarised in a time plot (Figure 4.2). The mean weekly workload increased by 40% from 646 (SD 58) in the first year of the study period (2008) to 904 (SD 26) patients per-week in the last year of the study period (2013) (Table 4.2). Over the study period, the number of referrals per-week increased for inpatient (51%), A&E (57%), GP (133%) and outpatient 15% (Table 4.2). The proportion of the total weekly workload attributable to the outpatient clinical pathway dropped from 47% to 39%, but increased for GP (from 6% to 10%), inpatients (33% to 36%) and A&E (14% to 16%), over the study period (Table 4.2).

**Figure 4.2 A time plot of the total weekly workload within the study period**



K1, the CT intervention; K2, the SRR intervention; K3 the EWH intervention

**Table 4.2 Workload by clinical pathways**

<i>Clinical pathway</i>	<i>Total number of patient episodes</i>	<i>Mean weekly workload (SD) for 2008</i>	<i>Mean weekly workload (SD) for 2013</i>	<i>Percentage change from 2008 to 2013</i>
<b><i>Inpatients</i></b>	77,372	214 (12)	324 (10)	51.40
	36.57	33.13	35.84	
<b><i>Outpatient</i></b>	87,106	303 (37)	348 (15)	14.85
	41.17	46.90	38.50	
<b><i>GP</i></b>	17,154	39 (3)	91 (7)	133.33
	8.11	6.04	10.07	
<b><i>A&amp;E</i></b>	29,940	90 (15)	141 (8)	56.67
	14.15	13.93	15.60	
<b><i>Grand total</i></b>	<b>211,572</b>	<b>646 (58)</b>	<b>904 (26)</b>	<b>39.94</b>
	<b>100</b>	<b>100</b>	<b>100</b>	

The second line of each row is the percentage of the workload attributable to each clinical pathway. The last column of the table shows the percentage change in weekly workload from the first to the last year of the study period

The patient-level pre-examination waiting times and report turnaround times are summarised in Table 4.3 and Table 4.4 respectively. Table 4.3 shows pre-examination waiting times up to 20,188 hours (over two years) for inpatient and up to 730 days (two years) for outpatient. Waiting times up to two and half years for inpatient are clearly abnormal: it is impossible for an inpatient to wait over two years for a CT-scan within the study setting. Similarly, Table 4.4 shows report turnaround times up to 32,631 hours (over three years) for A&E and 1,054 days (close to 3 years) for GP. Again, report turnaround times up to 3 years for A&E are clearly not possible in the study setting. From personal experiences of the researcher, these extremely high

recorded waiting time values are inconsistent with the range of waiting times obtainable in the study setting and were excluded as outlier using the capping technique as previously described. The results of the detailed examination of the excluded records are presented latter in section 4.3.1.1

**Table 4.3 Summary of the patients' level pre-examination waiting times before excluding outliers**

<i>Clinical pathway (unit of measurement)</i>	<i>Number of records</i>	<i>Range of PEWT</i>	<i>Median (IQR)</i>	<i>Mean (SD)</i>
<i>Inpatients (hours)</i>	77,372	0 – 20,188	14.36 (2.77-24.54)	27.41 (148.70)
<i>A&amp;E (hours)</i>	29,940	0 – 7,329	14.13 (10.02-18.06)	21.48 (84.75)
<i>Outpatient (days)</i>	87,106	0 – 730	20.82 (12.67-30.05)	29.03 (44.23)
<i>GP (days)</i>	17,154	0 – 3,656	21.39 (12.77-29.71)	29.94 (31.56)

PEWT, pre-examination waiting times

**Table 4.4 Summary of the patient-level report turnaround times before excluding outliers**

<i>Clinical pathway (unit of measurement)</i>	<i>Number of records</i>	<i>Range of RTAT</i>	<i>Median (IQR)</i>	<i>Mean (SD)</i>
<i>Inpatients (hours)</i>	77,372	0 – 33,854	1.86 (1.17-3.02)	13.96 (412.91)
<i>A&amp;E (hours)</i>	29,940	0 – 32,631	1.31 (0.80-2.93)	23.50 (618.49)
<i>Outpatient (days)</i>	87,106	0 – 1,369	3.94 (1.02-7.97)	5.80 (15.76)
<i>GP (days)</i>	17,154	0 – 1,054	3.60 (0.99-7.16)	5.44 (17.31)

RTAT, report turnaround times

The pre-examination waiting times and report turnaround times are summarised in Table 4.5 and Table 4.6 respectively, after excluding outliers. The mean and median pre-examination waiting times for the inpatient clinical pathway before excluding outliers were 27.41 and 14.36 hours respectively (Table 4.3). After excluding outliers, the median value remained virtually unchanged at 13.73 hours while the mean dropped substantially from 27.41 to 17.05 hours for the inpatients clinical pathway (Table 4.5).

**Table 4.5 A summary of the patient-level pre-examination waiting times after excluding outliers**

<i>Clinical pathways</i>	<i>Capping value</i>	<i>Frequency (centile)</i>	<i>Median (IQR)</i>	<i>Mean (SD)</i>
<i>Inpatients</i>	96hours	75,055 (97.01)	13.73 (2.66-23.48)	17.05 (17.91)
<i>A&amp;E</i>	48hours	29,248 (97.69)	13.95 (9.90-17.69)	13.71 (6.92)
<i>Outpatient</i>	90 days	83,351 (95.69)	19.97 (12.17-29.00)	21.35 (14.00)
<i>GP</i>	90 days	17,099 (99.68)	21.38 (12.76-29.66)	21.27 (11.71)

The centile in parenthesis is the percentage of the whole data (frequency) retained for analysis after excluding the outliers.

The mean and median report turnaround times for the inpatient clinical pathway before excluding outliers were 13.96 and 1.86 hours respectively (Table 4.4). Again, the median report turnaround time remained virtually unchanged at 1.82 hours while the mean dropped substantially from 13.96 to 3.16 hours after excluding outliers (Table 4.6). The waiting times for the other clinical pathways follow the same pattern. Table 4.5 shows that 97% of inpatient pre-examination waiting time data was retained after excluding waiting times above 96 hours. Table 4.6 also shows that 98% of the

inpatient report turnaround time data was retained after removing waiting times above 48 hours. Figure 4.3 and Figure 4.4 are the histograms of the patient-level pre-examination waiting times and report turnaround times, respectively, after excluding much of the outliers. The results of the summary statistics clearly show that the median values were less sensitive to outliers compared to the mean values. Therefore, the patient-level waiting times were collapsed into 271 median weekly waiting times (data points) for ITS analysis after excluding outliers.

**Table 4.6 A summary of the patient-level report turnaround times after excluding outliers**

<i>Clinical pathways</i>	<i>Capping value</i>	<i>Frequency (centile)</i>	<i>Median (IQR)</i>	<i>Mean (SD)</i>
<i>Inpatients</i>	48hours	75,607 (97.72)	1.82 (1.17-2.91)	3.16 (5.21)
<i>A&amp;E</i>	48hours	29,288 (97.82)	1.27 (0.76-2.18)	2.59 (4.92)
<i>Outpatient</i>	30 days	86,609 (99.43)	3.91 (1.01-7.92)	5.30 (5.29)
<i>GP</i>	30 days	17,084 (99.59)	3.42 (0.98-7.13)	4.85 (4.81)

The centile (in parenthesis) is the percentage of the data retained for analysis after excluding the outliers.

**Figure 4.3 Histogram of pre-examination waiting times after excluding outliers**

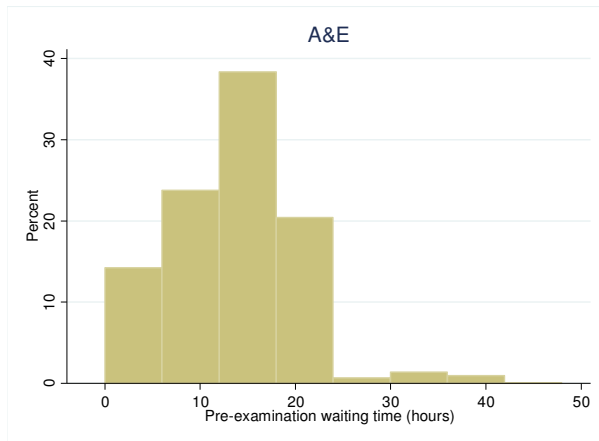
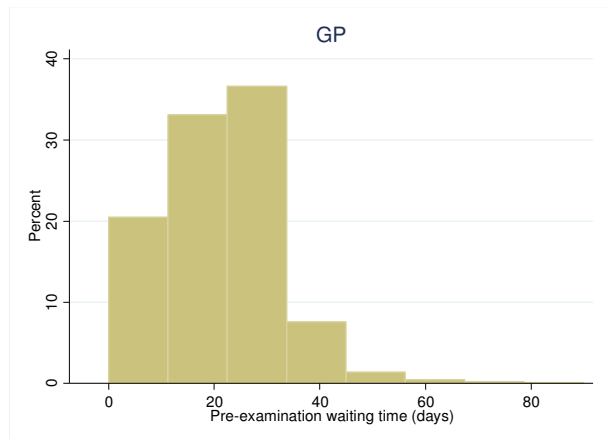
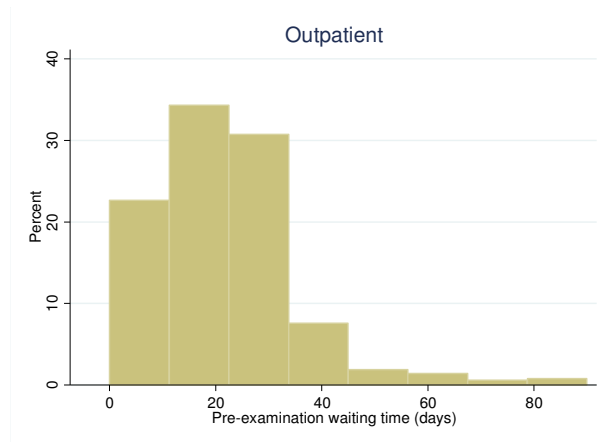
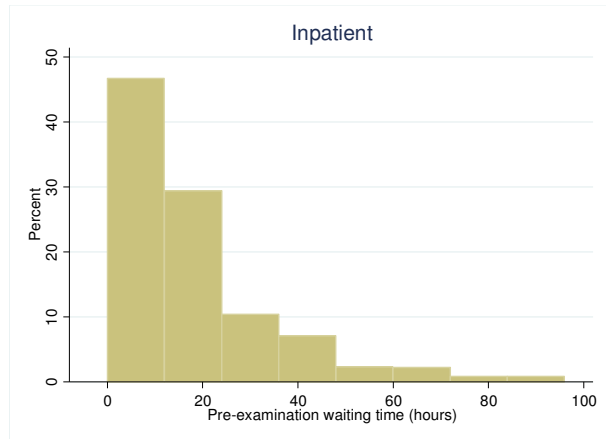
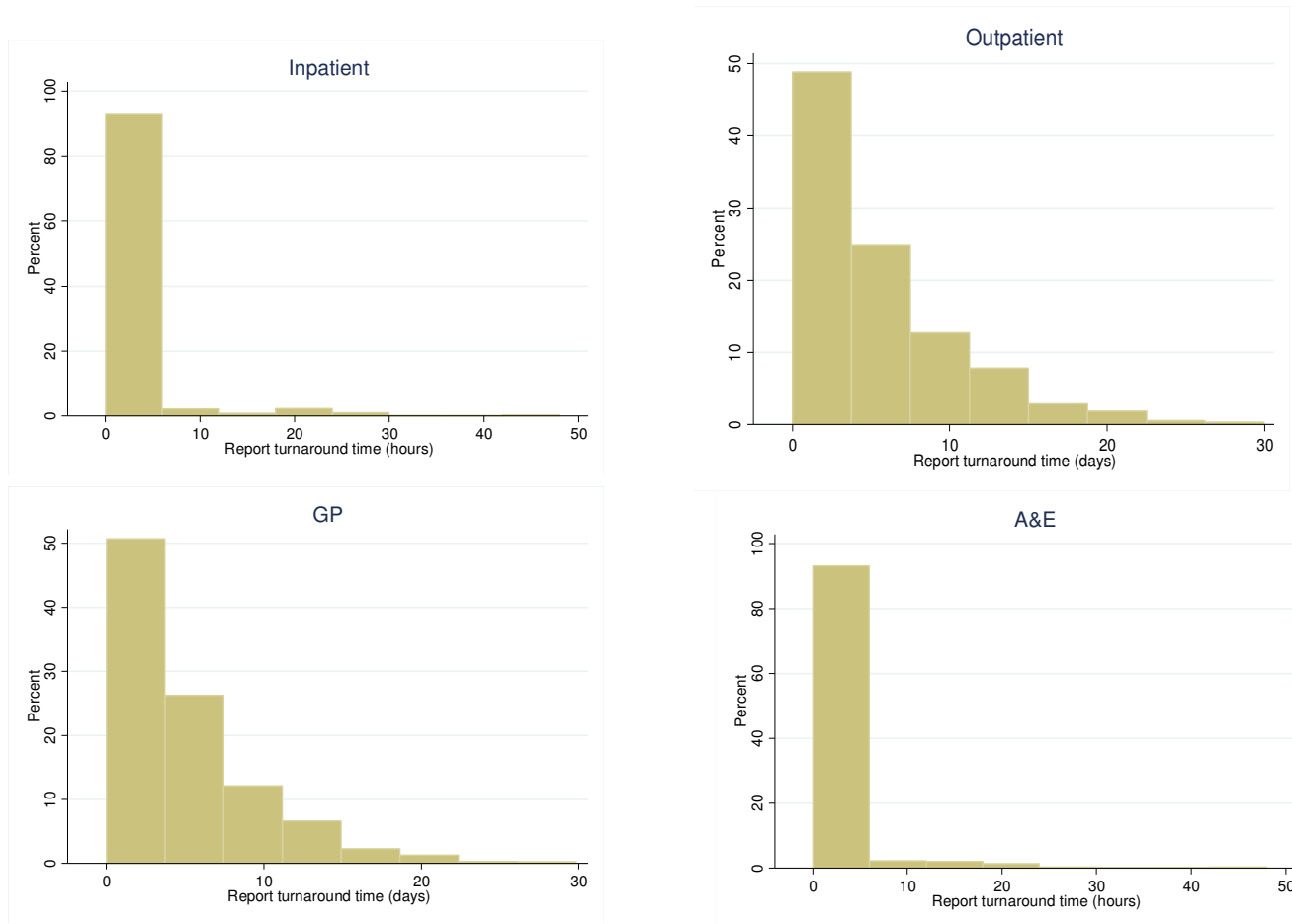


Figure 4.4 Histogram of report turnaround times after excluding outliers



### 4.3.1.1 The outliers

Of the 77,372 inpatient observations, 2,317 (3.04%) have pre-examination waiting times over 96 hours and were excluded as outliers (Table 4.7). One thousand one hundred and fourteen (1.44%) have waiting times between 96 and 180 hours, 598 (0.77%) have waiting times over 180 but less than 360 hours and 605 (0.78%) have waiting times over 360 hours (Table 4.7). Table 4.7 also shows the distribution of the excluded pre-examination waiting times for the remaining three referral pathways. Table 4.8 shows the distribution of the excluded report turnaround time observations.

**Table 4.7 Summary of the excluded patient-level pre-examination waiting times**

<i>Clinical pathway (unit of measurement)</i>	<i>Capping value, frequency, (centile of excluded PEWT)</i>	<i>Distribution of excluded pre-examination waiting times; frequency (centile)</i>			
<i>Inpatients (Hours)</i>	Total >96 2317 (3.04%)	>96 & ≤180 1114 (1.44%)	>180 & ≤360 598 (0.77%)	>360 605 (0.78%)	
<i>A&amp;E (Hours)</i>	Total >48 692 (2.31%)	>48 & ≤100 261 (0.87%)	>100 & ≤200 83 (0.28%)	>200 348 (1.16%)	
<i>Outpatient (Days)</i>	Total >96 3755 (4.31%)	>90 & ≤180 1909 (2.19%)	>180 & ≤360 1334 (1.53%)	>360 512 (0.59%)	
<i>GP (Days)</i>	Total >90 55 (0.32%)	>90 & ≤180 33 (0.19%)	>180 & ≤360 16 (0.09%)	>360 6 (0.03%)	

PEWT, pre-examination waiting times



**Table 4.8 Summary of the excluded patient-level report turnaround times by clinical pathways**

<i>Clinical pathway (unit of measurement)</i>	<i>Capping value, frequency (centile) of excluded RTAT</i>	<i>Distribution of excluded report turnaround times Absolute number (percentage)</i>			
<i>Inpatients (Hours)</i>	Total >48 1765 (2.28%)	>48 & <=100 1051 (1.36%)	>100 & <=200 424 (0.55%)	>200 290 (0.37%)	
<i>A&amp;E (Hours)</i>	Total >48 652 (2.18%)	>48 & <=100 293 (0.98%)	>100 & <=200 203 (0.68%)	>200 156 (0.52%)	
<i>Outpatient (Days)</i>	Total >30 497 (0.61%)	>30 & <=60 381 (0.44%)	>60 & <=120 57 (0.07%)	>120 59 (0.07%)	
<i>GP (Days)</i>	Total >30 70 (0.41%)	>30 & <=60 50 (0.29%)	>60 & <=120 3 (0.02%)	>120 17 (0.10%)	

RTAT, report turnaround times

Of the 20 outlying observations randomly selected for a detailed investigation of the possible reasons for the exceptionally high recorded waiting times, 16 were due to coding errors (Table 4.9). The patients' dates of birth were wrongly entered into the space for the date of request (or just a typographical error) on CRIS™. In two other cases, an addendum (modification) was added to the radiology report long after it was initially finalised. The date of the addendum became the date of the final radiology report on the CRIS™. The remaining two cases had requests that were superseded by clinical events. In one of these, a CT abdomen was requested through the outpatient clinical pathway. The patient was subsequently admitted into hospital before having the outpatient CT. The patient then had a CT thorax and abdomen as inpatient but the previous outpatient request was not cancelled on the CRIS™. One

and half year later, the outpatient request was removed from the CRIS™ without following due process: the date of removal from the CRIS™ was wrongly recorded as date of examination instead of an outright cancellation. The results of the detailed investigation show that the exceptionally high recorded waiting times were data entry errors and justify their exclusion.

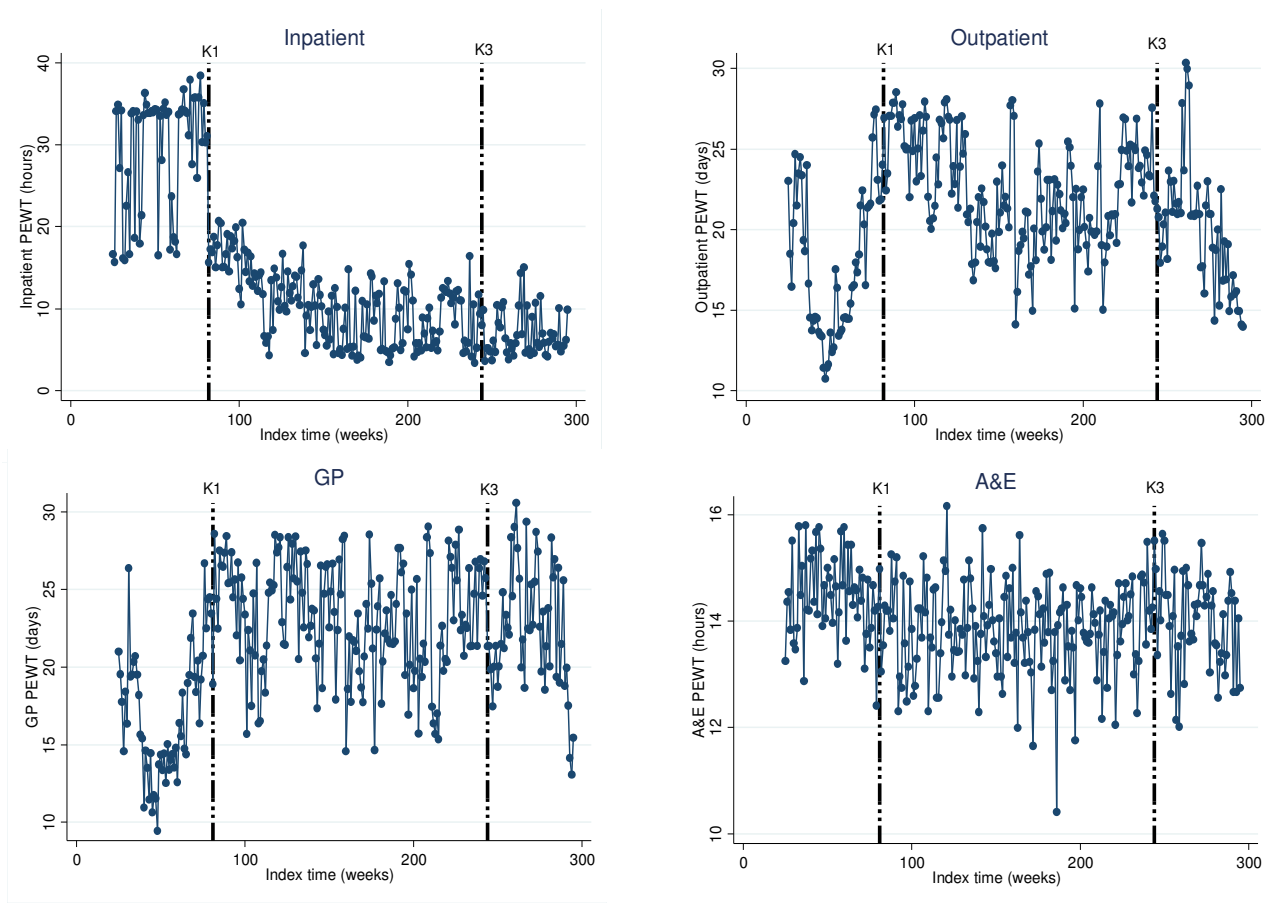
**Table 4.9 Reasons for the exceptionally high recorded waiting times**

<i>Reasons</i>	<i>Occurrence</i>
<i>Coding error</i>	16
<i>Addendum appended to radiology report</i>	2
<i>Request was overtaken by clinical event</i>	2

### 4.3.2 Interrupted time series analysis

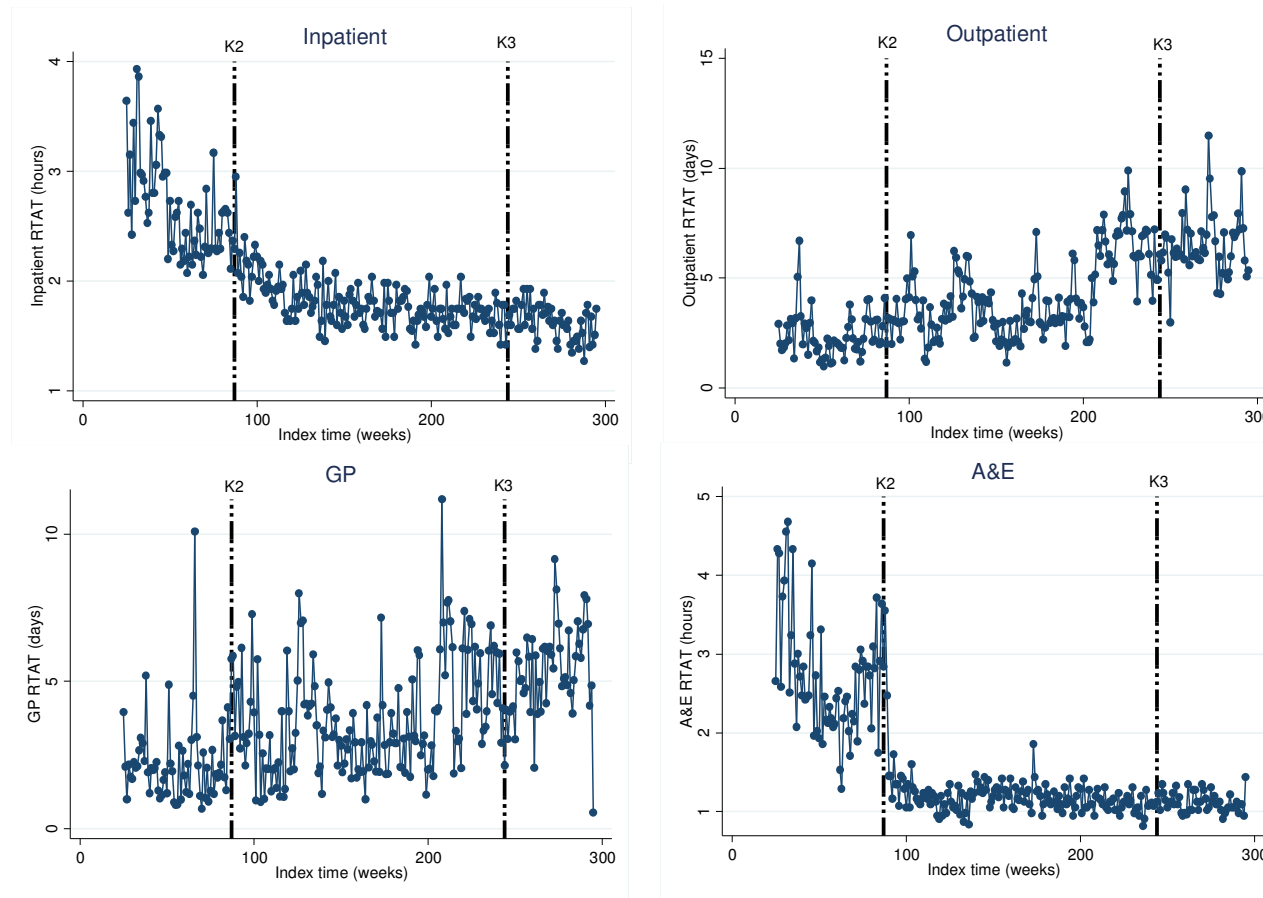
There were 271 weekly data points for ITS analysis; starting from week 25 in 2008 to week 295 in 2013. Figure 4.5 is a time plot of the pre-examination waiting times by clinical pathways showing the intervention times: CT week 82 (K1) and (EWH) week 244 (K3). Figure 4.6 is a time plot of the report turnaround times by referral pathways showing the SRR intervention at week 88 (K2) and EWH intervention at week 244 (K3). There are 57 data points before K1, 63 data points before K2, and 52 data points after K3. That is roughly one-year data before the first and after the last interventions for each series.

**Figure 4.5 Time plots of pre-examination waiting times (PEWT)**



K1 represents the time of the CT intervention (week 82) and K3 represents the time of the extended-working-hour intervention (week 244)

Figure 4.6 Time plot of report turnaround times (RTAT)



K2 represents the time of the speech recognition intervention (week 88) and K3 represents the time of the extended-working-hour intervention (week 244)

It is apparent that the trend of waiting times between the two interventions; K1 & K3 (Figure 4.5) for pre-examination waiting times and K2 & K3 (Figure 4.6) for the report turnaround times are not linear, and that variances appear to be higher when the level of the series is higher. The series were therefore log-transformed to (approximately) stabilise the variances and the 'segmented spline' regression models were fitted to capture non-linear trend.

OLS-based models were initially fitted and the results of the diagnostic tests show that the errors of the OLS-based models were not random, as suggested by the Bartlett cumulative periodogram test for the pre-examination waiting times (appendix 6) and the report turnaround times (appendix 7) but were rather autocorrelated, as suggested by the ACF plots for the pre-examination waiting times (appendix 8) and report turnaround times (appendix 9). The PACF plots of the errors of the OLS models for the pre-examination waiting times (appendix 10) and report turnaround times (appendix 11) also suggest that the errors are autocorrelated. The characteristics of the ACF and PACF plots appears to suggest that the errors of the OLS-based models follow an autoregressive process of the first order (AR (1)), with the exception of the A&E pre-examination waiting times and report turnaround times. The guideline for using the ACF and PACF plots to identify the type and order of autocorrelation in time series was described earlier in chapter three (Table 3.5).

Table 4.10 shows the error models which were identified by examining the ACF & PACF plots of the errors of the OLS-based models for the eight series. The identified error models were then incorporated into expanded 'segmented spline'

regression models that accommodate autocorrelation (Model 4.1) for each of the eight series. The errors of the OLS-based model for A&E pre-examination waiting times did not show any evidence of autocorrelation (appendices 6 & 8). However, for consistency it was refitted as an AR (1). The AR (1) error model fitted the dataset better than the OLS-based model, as suggested by the Akaike information criteria.

The results of the diagnostic tests on Model 4.1 are shown in appendices 12 – 15): The Bartlett’s cumulative periodogram tests and ACF plots for the pre-examination waiting time series (appendices 12 & 13 respectively) and for the report turnaround times series (appendices 14 and 15 respectively). Appendices 12 – 15 suggest that there is no residual autocorrelation and all non-random periodicity including seasonality has been accounted for, in the errors of the model with autocorrelated errors (Model 4.1) for all eight series.

**Table 4.10 Error models identified using the ACF and the PACF plots of the errors of the OLS-based ITS model**

<i>Clinical pathways</i>	<i>Pre-examination waiting times</i>	<i>Report turnaround times</i>
<i>Inpatients</i>	AR (1)	AR (1)
<i>Outpatient</i>	AR (1)	AR (1)
<i>GP</i>	AR (1)	AR (1)
<i>A&amp;E</i>	NA	ARMA (1 1)

NA, the errors of the OLS model for A&E pre-examination waiting times is not significantly autocorrelated, however it was re-fitted as AR(1) for consistency

The results of the Ljung-Box Q-test on the errors of Model 4.1 (Table 4.11) shows that the  $p$ -values are above 0.05 for all eight series, suggesting that Model 4.1 describes the data adequately for all eight series. The residual plot for the pre-examination waiting times (Figure 4.7) and report turnaround times (Figure 4.8) show only minimal residual variances, which might suggest a small inadequacy of log-transformation at stabilising variances for these datasets. This is an acceptable compromise between a more complex transformation and the need for easy interpretation of the results.

**Table 4.11 Results of the Ljung-Box Q-test for Model 4.1 showing the Q-statistic and p-value in parentheses**

<i>Clinical pathways</i>	<i>Pre-examination waiting times</i>	<i>Report turnaround times</i>
<i>Inpatients</i>	37.94 (0.534)	51.86 (0.099)
<i>Outpatient</i>	44.75 (0.279)	36.52 (0.628)
<i>GP</i>	52.26 (0.093)	7.46 (0.195)
<i>A&amp;E</i>	39.44 (0.495)	4.96 (0.272)

The  $p$ -values are all above 0.05 showing that the models fit the data adequately.  $H_0$ : The model does not exhibit any lack of fit

Figure 4.7 Residual plots of pre-examination times for Model 4.1

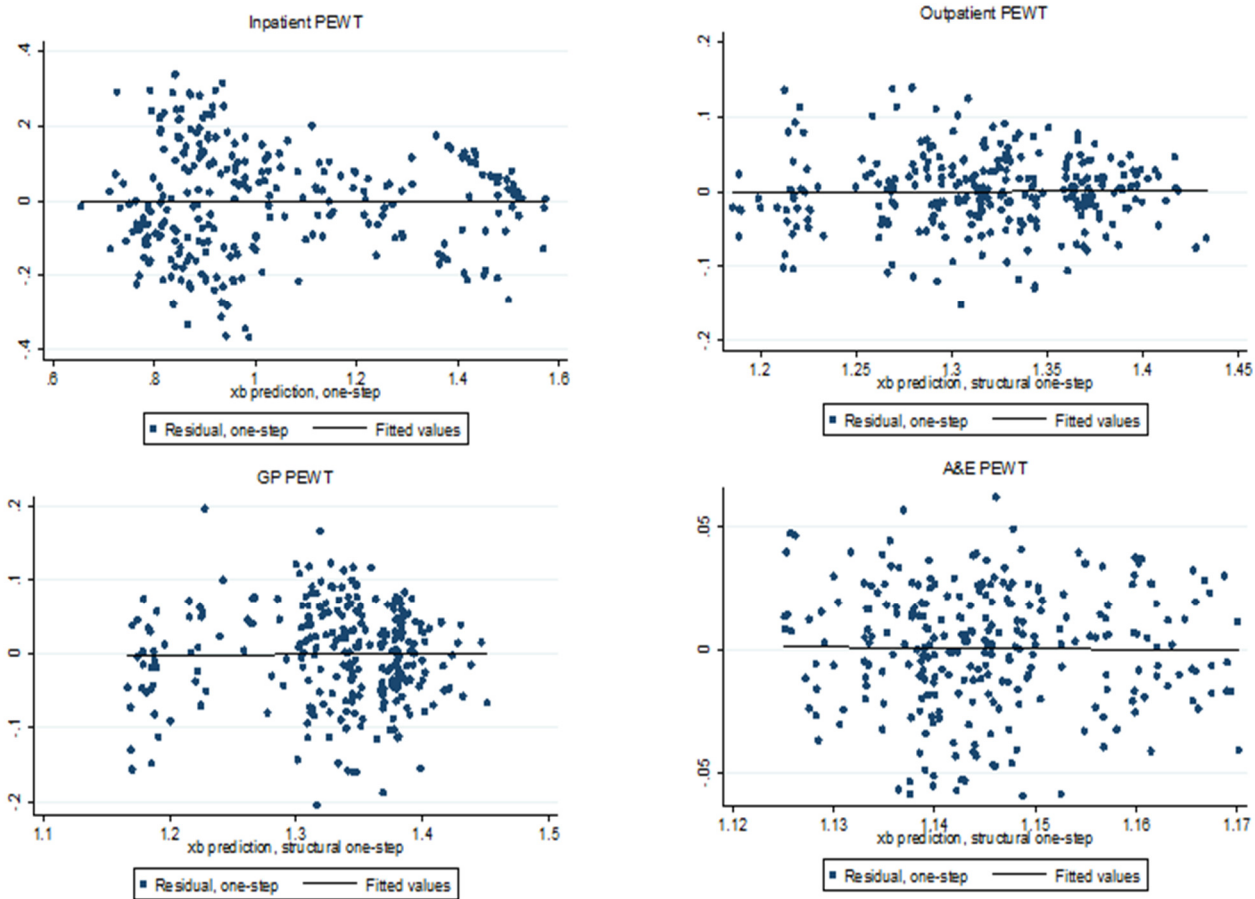
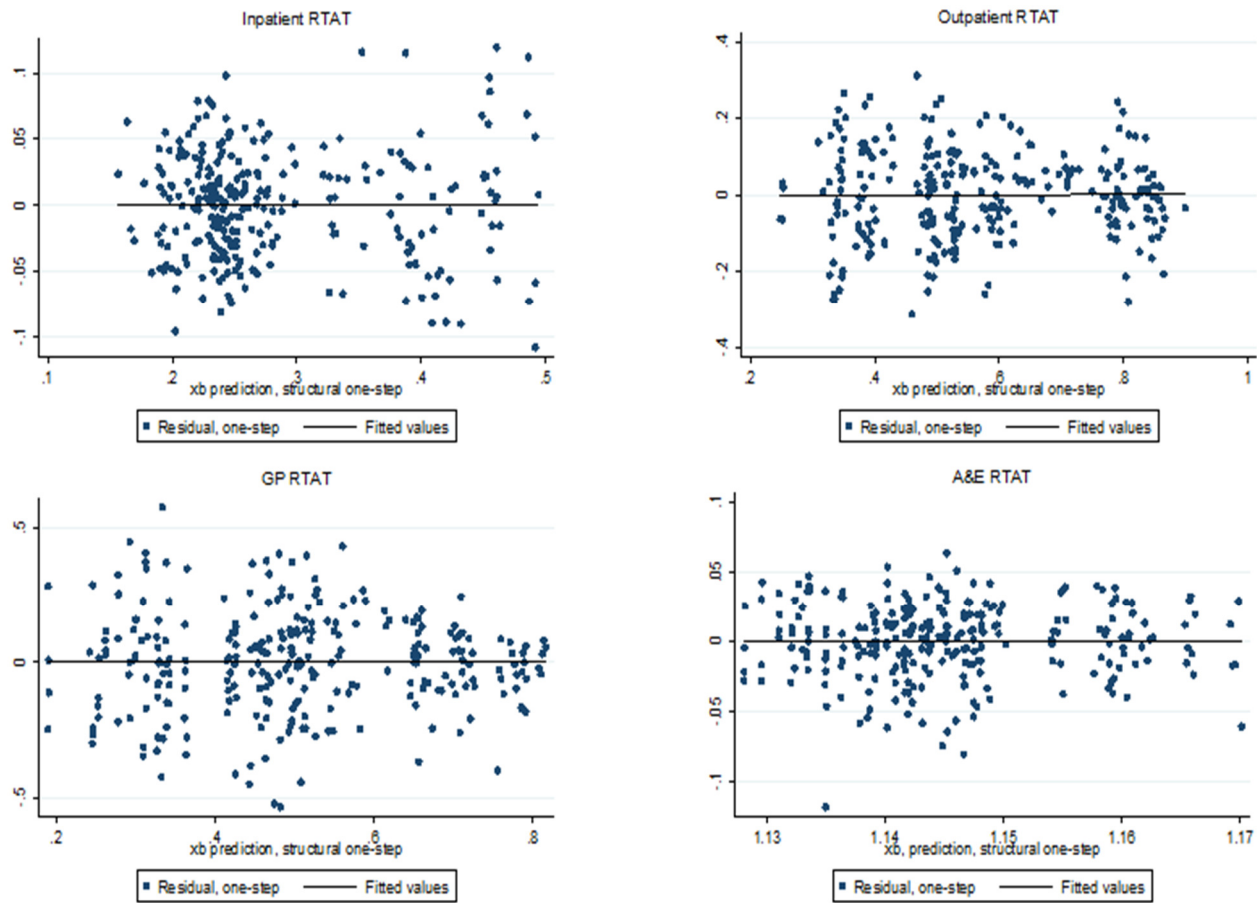




Figure 4.8 Residual plots of report turnaround times for Model 4.1



Results of the ITS analyses of the impact on pre-examination waiting times and report turnaround times of the CT, SRR and EWH interventions using Model 4.1 are presented by clinical pathways in the next sub-sections. The coefficients of the models are interpreted as percentage change because the analyses were performed on log-transformed values. The un-adjusted, seasonally adjusted and workload & seasonally adjusted estimates of intervention effect (95% confidence intervals in parenthesis) are presented in tables for each series. However, within the text, references are made to the workload & seasonally adjusted estimates. The workload & seasonally adjusted results are also graphically presented for each series. The coefficients of all incidental terms included in the models are reported with the results of the inpatient pre-examination waiting times. Subsequently, only the coefficients of the terms for underlying trends, change in level and change in trend are reported due to space constraints.

### **4.3.2.1 Results for the inpatient clinical pathway**

#### **4.3.2.1.1 Pre-examination waiting time**

Figure 4.9 (top pane) shows a visually perceptible drop in the level and variability of pre-examination waiting times following the CT intervention. On the other hand, there are no visually perceptible changes in the level and variability of pre-examination waiting times following the EWH intervention (Figure 4.9, top pane). The results of the ITS analysis of the impact on pre-examination waiting times for inpatient of the CT and EWH interventions are presented in Figure 4.9 (bottom pane) and Table 4.12.

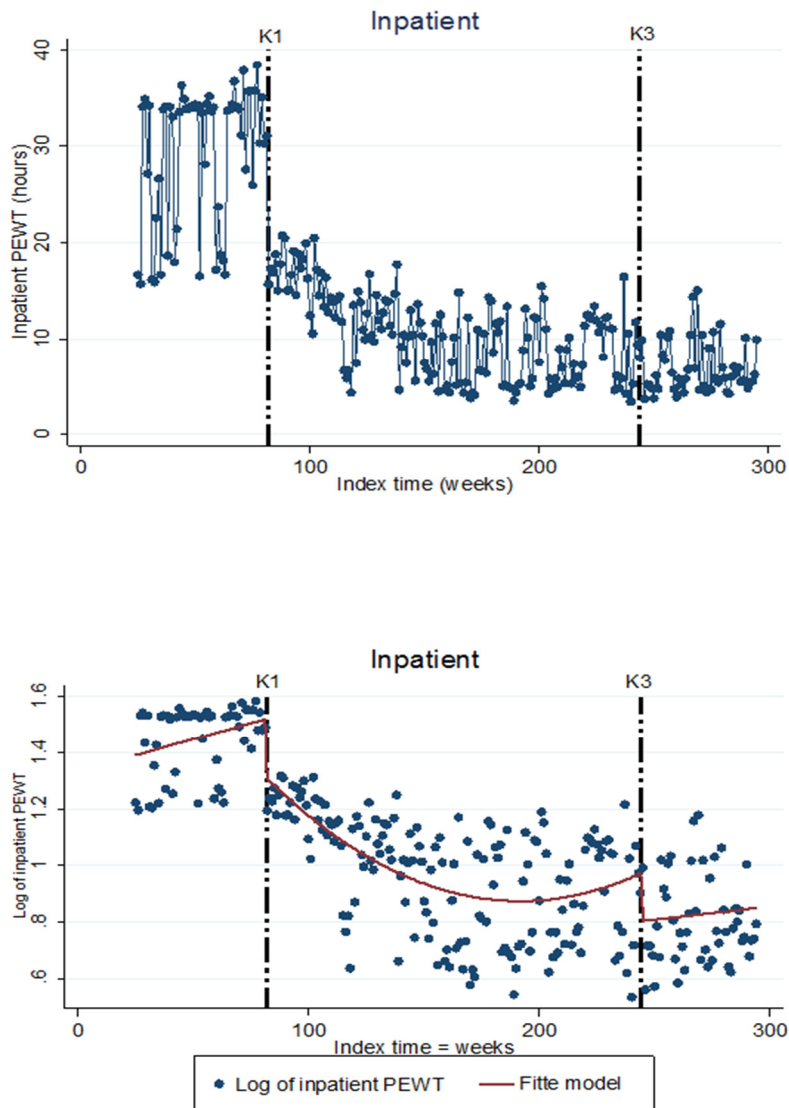
### ***CT intervention***

There was no significant underlying trend of pre-examination waiting times before the CT intervention, after adjusting for seasonality and workload (Table 4.12). The CT intervention was associated with a 21.58 % (12.58 , 31.52) reduction in level (change in level) of pre-examination waiting times for inpatient (Table 4.12). The pre-examination waiting times for inpatient was reducing (change in trend) at the rate of 0.96 % (0.65, 1.27) per-week following the CT intervention (Table 4.12). The results suggest an immediate and continued improvement of pre-examination waiting times for the inpatient clinical pathway following the CT intervention. The values for the incidental terms included in the model; seasonality, workload and autocorrelation etc. are also shown in Table 4.12. The results suggest that the effect of the CT intervention is not significantly affected by seasonality and workload. However, autocorrelation was positive at 0.36 (0.22, 0.51). The contribution of the cubic polynomial was not significant at -0.00 (p=0.832) and was dropped leaving only the quadratic polynomial.

### ***EWH intervention***

Just before the EWH intervention, the underlying trend of pre-examination waiting times for inpatient was increasing at the rate of 0.32% (0.06, 0.59) per-week (Table 4.12). Following the EWH intervention there was a 16.51% (2.09, 30.93) reduction in the level of pre-examination waiting times (change in level) for inpatient, with no significant change in trend (Table 4.12). The results suggest an immediate and sustained improvement in pre-examination waiting times for the inpatient clinical pathway following the EWH intervention.

**Figure 4.9 Time plot and graphical presentation of the fitted trend of pre-examination waiting times for the inpatient clinical pathway**



Time plot, top pane (extracted from Figure 4.5); fitted model, bottom pane; K1, time of the CT intervention; K3, time of the EWH intervention. PEWT, pre-examination waiting times.

**Table 4.12 Impact on pre-examination waiting times for the inpatient clinical pathway of the CT and EWH interventions**

<i>Interventions</i>	<i>Type of effect</i>	<i>Non-adjusted</i>	<i>Adjusted for seasonality</i>	<i>Adjusted for seasonality and workload</i>
<i>CT</i>	Underlying trend ( $a_1$ )	0.26 (0.05, 0.48)	0.23 (0.01, 0.45)	0.19 (-0.03, 0.42)
	Change in level ( $b_1$ )	-23.07 (-31.67, -14.47)	-21.57 (-30.58, -12.56)	-21.58 (-30.52, -12.63)
	Change in trend ( $b_2$ )	-1.08 (-1.64, -0.53)	-1.02 (-1.32, -0.71)	-0.96 (-1.27, -0.65)
<i>Extended working-hours</i>	Underlying trend*	0.57 (-1.64, 2.78)	0.36 (0.01, 0.63)	0.32 (0.06, 0.59)
	Change in level ( $c_1$ )	-12.40 (-30.54, -5.74)	-16.90 (-31.43, -2.36)	-16.51 (-30.93, -2.09)
	Change in trend ( $c_1$ )	-0.27 (-1.08, 0.54)	-0.29 (-0.71, 0.13)	-0.26 (-0.68, 0.16)
	Initial waiting time ( $a_0$ )	1.31 (1.17, 1.44)	1.24 (1.11, 1.38)	1.02 (0.70, 1.33)
	Autocorrelation parameter ( $\phi$ )	0.41 (0.27, 0.54)	0.36 (0.21, 0.50)	0.36 (0.22, 0.51)
	Quadratic polynomial ( $d_1$ )	0.00 (0.00, 0.01)	0.00 (0.00, 0.01)	0.00 (0.00, 0.00)
	Cubic polynomial ( $d_2$ )**	NA	NA	NA
	Seasonality ( $s_1$ )			
	January	NA	0.09 (-0.00, 0.18)	0.08 (-0.02, 0.17)

February	NA	0.11 (0.00, 0.23)	0.10 (-0.01, 0.21)
March	NA	0.01 (-0.10, 0.12)	-0.01 (-0.12, 0.10)
April	NA	0.09 (-0.03, 0.20)	0.07 (-0.04, 0.19)
May	NA	0.15 (0.05, 0.25)	0.12 (0.02, 0.23)
June	NA	0.09 (-0.01, 0.19)	0.06 (-0.04, 0.17)
July	NA	0.09(-0.04, 0.19)	0.07 (-0.02, 0.17)
September	NA	0.11 (0.02, 0.20)	0.09 (-0.02, 0.18)
October	NA	0.09 (-0.02, 0.19)	0.07 (-0.04, 0.18)
November	NA	0.15 (0.05, 0.26)	0.14 (0.03, 0.24)
December	NA	0.05(-0.06, 0.15)	0.04 (-0.06, 0.15)
Workload (I <sub>1</sub> )	NA	NA	0.00 (-0.00, 0.00)

\*The underlying trend before the second intervention is not a term in the model but rather calculated separately using a STATA command.

\*\* The contribution of the cubic polynomial is not significant at -0.00 (-0.00, 0.00) p = 0.832 and was excluded. 95% confidence intervals in parenthesis.

#### **4.3.2.1.2 Report turnaround time**

The variability in report turnaround times appeared to reduce for the inpatients clinical pathway following the SRR intervention (Figure 4.10, top pane). There was a visually perceptible reducing underlying trend of report turnaround times for inpatient which continued after the SRR intervention (Figure 4.10, top pane). There was no visually perceptible change in the variability of report turnaround times for inpatient following the EWH intervention (Figure 4.10, top pane). The results of the ITS analysis of the impact on report turnaround times for inpatient of the SRR and EWH interventions are presented in Figure 4.10 (bottom pane) and Table 4.13.

##### ***SRR intervention***

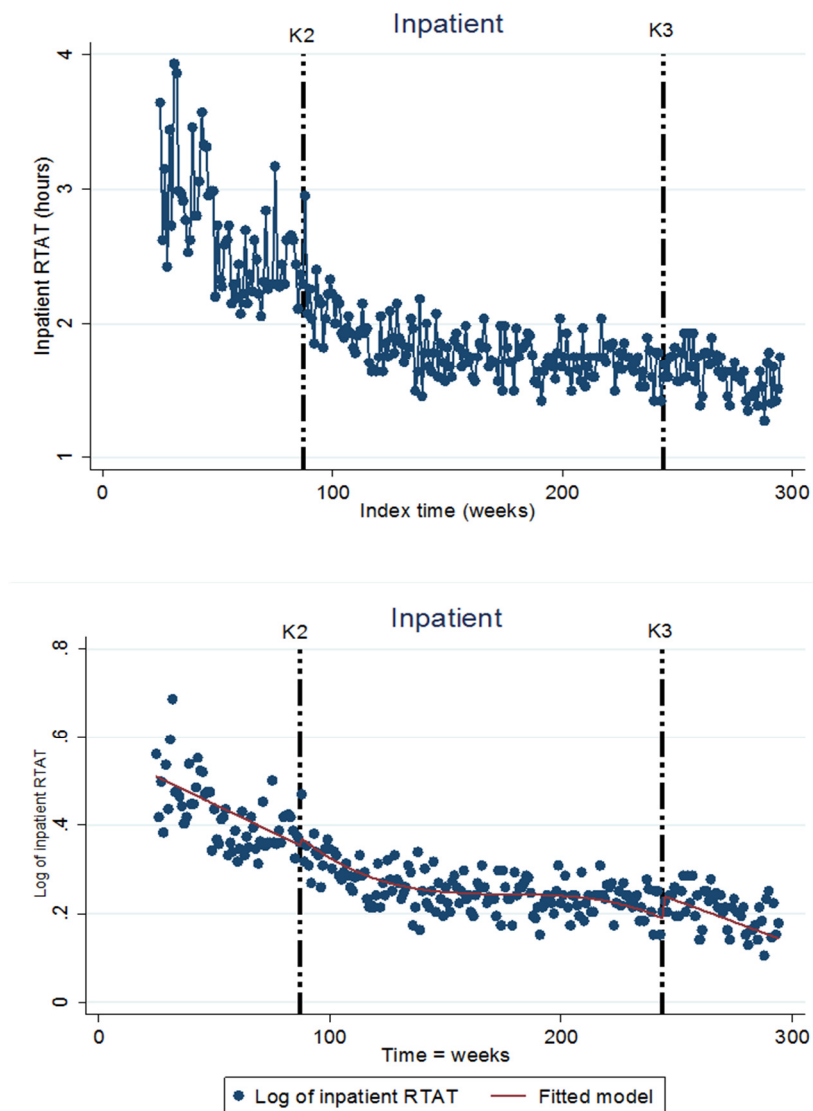
The underlying trends of report turnaround times for inpatient was reducing at the rate of 0.21% (0.12, 0.30) per-week before the SRR intervention (Table 4.13). There was no significant change in either the level or trend of report turnaround times for inpatient following the SRR intervention (Table 4.13). This suggests that the SRR intervention did not have any impact (immediate or longer term) on the report turnaround times for the inpatient clinical pathway.

##### ***EWH intervention***

Just before the EWH intervention the underlying trend of report turnaround times was reducing at the rate of 0.17% (0.02, 0.31) per-week for inpatient (Table 4.13). The level of report turnaround times for inpatient increased by 3.92% (0.07, 7.77) (change in level) following the EWH intervention, however, there was no

significant change in trend (Table 4.13). This suggests an immediate and sustained deterioration in the level of report turnaround times for the inpatient clinical pathway following the EWH intervention.

**Figure 4.10 Time plot and graphical presentation of the fitted trend of report turnaround times for the inpatient clinical pathway**



Time plot, top pane (extracted from Figure 4.6); fitted model, bottom pane; K2, time of the SRR intervention; K3, time of the EWH intervention. RTAT, report turnaround times.



**Table 4.13 Impact on report turnaround times for the inpatient clinical pathway of the SRR and EWH interventions estimated using Model 4.1.**

<i>Interventions</i>	<i>Type of effect</i>	<i>Non-adjusted</i>	<i>Adjusted for seasonality</i>	<i>Adjusted for seasonality and workload</i>
<i>Speech recognition reporting</i>	Underlying trend	-0.21 (-0.30, -0.12)	-0.20 (-0.29, -0.12)	-0.21 (-0.30, -0.12)
	Change in level	-1.38 (-5.24, 2.48)	-1.56 (-5.92, 2.80)	-1.53 (-5.92, 2.85)
	Change in trend	-0.10 (-0.28, 0.08)	-0.11 (-0.27, 0.01)	-0.10 (-0.26, 0.06)
<i>Extended working-hours</i>	Underlying trend	-0.13 (-0.29, 0.02)	-0.14 (-0.29, 0.01)	-0.17 (-0.31, -0.02)
	Change in level	3.35 (-0.03, 6.74)	3.57 (-0.37, 7.52)	3.92 (0.07, 7.77)
	Change in trend	-0.01 (-0.19, 0.15)	-0.02 (-0.18, 0.14)	0.00 (-0.15, 0.16)

Estimated percentage change (95% confidence interval).

## **4.3.2.2 Results for the Outpatient clinical pathway**

### **4.3.2.2.1 Pre-examination waiting time**

The level and variability of pre-examination waiting times for the outpatient clinical pathway appeared to increase following the CT intervention (Figure 4.11, top pane). On the other hand, there was no visually perceptible change in either the level or variability of pre-examination waiting times following the EWH intervention (Figure 4.11, top pane). The results of the ITS analysis of the impact of the CT and EWH interventions on pre-examination waiting times for the outpatient clinical pathway are presented in Figure 4.11 (bottom pane) and Table 4.14.

#### ***CT intervention***

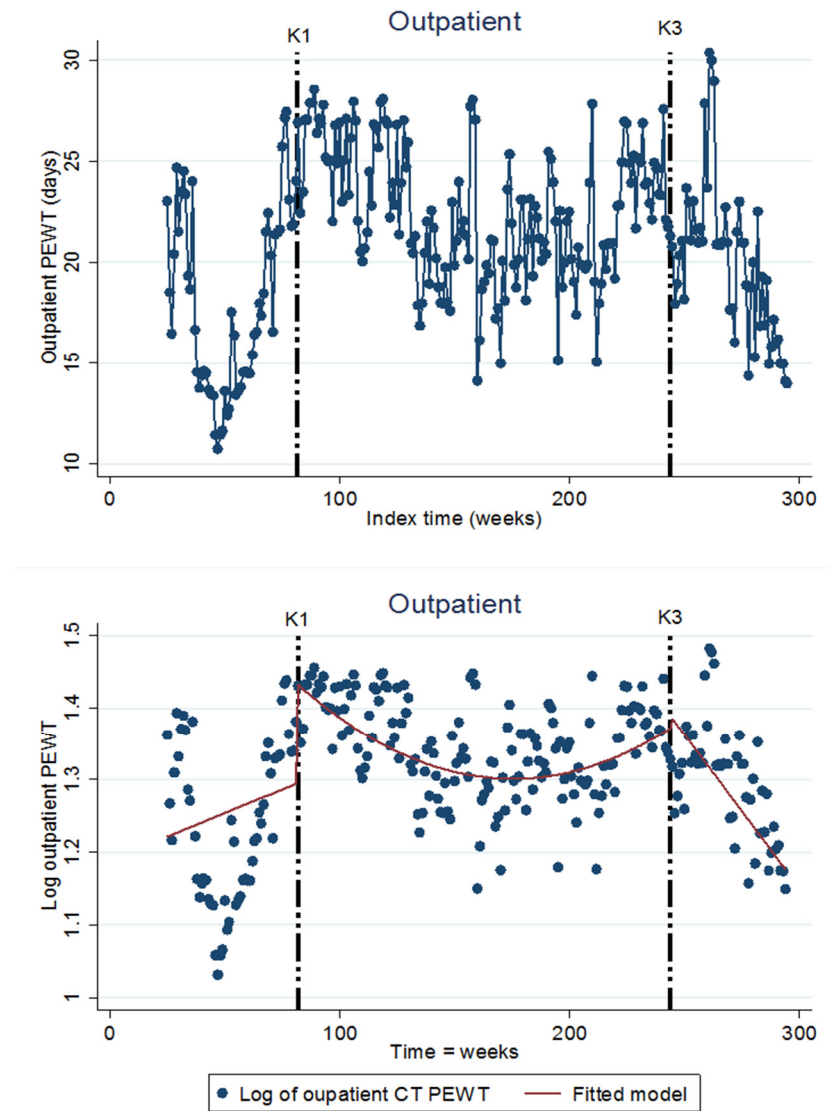
There was no significant underlying trends of pre-examination waiting times for outpatient before the CT intervention (Table 4.14). The CT intervention was associated with a 14.46% (4.94, 23.98) increase in the level (change in level) of pre-examination waiting times for outpatient (Table 4.14). The trend of pre-examination waiting times was reducing at the rate of 0.38% (0.08, 0.68) per-week following the CT intervention (Table 4.14). This suggests an immediate deterioration followed by a longer term improvement of pre-examination waiting times for the outpatient clinical pathway following the CT intervention.

#### ***EWH intervention***

The underlying trend of pre-examination waiting times for the outpatient clinical pathway was increasing at the rate of 0.19% (0.03, 0.35) per-week just before

the EWH intervention (Table 4.14). The EWH intervention was not associated with a significant change in level but rather a reducing trend (change in trend) of pre-examination waiting times at the rate of 0.57% (0.21, 0.94) per-week (Table 4.14). The results suggest that the impact on pre-examination waiting times of the EWH intervention for outpatient was a gradual rather than an immediate improvement.

**Figure 4.11 Time plot and graphical presentation of the fitted model for pre-examination waiting times for the outpatient clinical pathway**



Time plot, top pane (extracted from Figure 4.5); fitted model, bottom pane; K1, time of the CT intervention; K3, time of the EWH intervention. PEWT, pre-examination waiting times.

**Table 4.14 Impact on pre-examination waiting times for the outpatient clinical pathway of the CT and EWH interventions estimated using Model 4.1.**

<i>Interventions</i>	<i>Type of effect</i>	<i>Non-adjusted</i>	<i>Adjusted for seasonality</i>	<i>Adjusted for seasonality and workload</i>
<i>CT</i>	Underlying trend	0.16 (-0.12, 0.44)	0.13 (-0.10, 0.36)	0.12 (-0.11, 0.36)
	Change in level	12.56 (4.62, 20.49)	14.71 (5.15, 24.27)	14.46 (4.94, 23.98)
	Change in trend	-0.40 (-0.77, -0.04)	-0.39 (-0.69, -0.01)	-0.38 (-0.68, -0.08)
<i>Extended working-hours</i>	Underlying trend	0.19 (0.03, 0.36)	0.19 (0.03, 0.35)	0.19 (0.03, 0.35)
	Change in level	-0.06 (-6.1, 5.99)	1.48 (-5.80, 8.76)	1.40 (-5.96, 8.77)
	Change in trend	-0.54, (-0.84, -0.23)	-0.58 (-0.94, -0.22)	-0.57 (-0.94, -0.21)

Estimated percentage change (95% confidence interval).

#### **4.3.2.2.2 Report turnaround time**

The variability of report turnaround times for the outpatient clinical pathway appeared to increase following the SRR intervention (Figure 4.12, top pane). There was no visually perceptible change in the variability of report turnaround times following the EWH intervention (Figure 4.12, top pane). The results of the ITS analysis of the impact on report turnaround times of the SRR and EWH interventions for the outpatient clinical pathway are presented in Figure 4.12 (bottom pane) and Table 4.15.

##### ***SRR intervention***

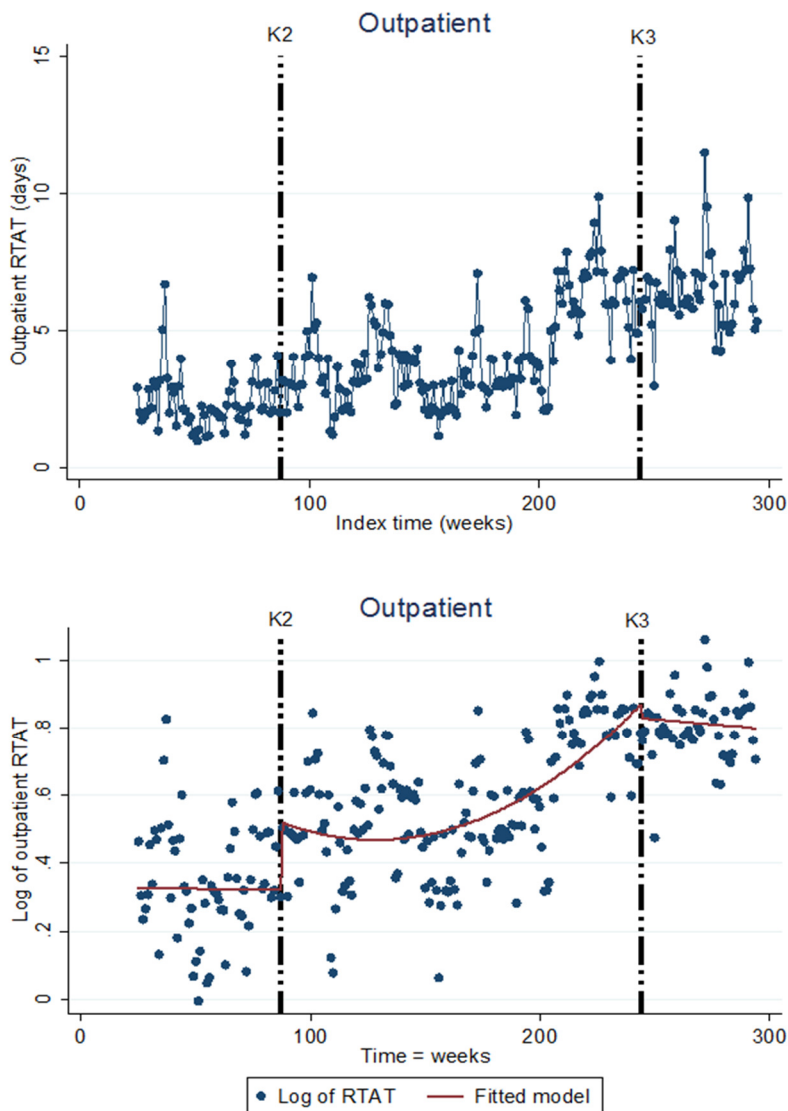
Following adjustment for workload and seasonality, there was no significant underlying trend of report turnaround times for the outpatient clinical pathway (Table 4.15). The SRR intervention was associated with a 19.90% (2.78, 37.02) increase in the level (change in level) of report turnaround times for outpatient (Table 4.15). The SRR intervention was associated with a reducing but non-statistically significant change in trend of report turnaround times for the outpatient clinical pathway (Table 4.15). The results suggest an immediate and sustained deterioration of report turnaround times for the the outpatient clinical pathway following the SRR intervention.

##### ***EWH intervention***

Just before the EWH intervention the underlying trend of report turnaround time was increasing at the rate of 0.66% (0.35, 0.96) per-week for the outpatient clinical pathway (Table 4.15). The EWH intervention was not associated with a significant change in level or trend of report turnaround times for the

outpatient clinical pathway (Table 4.15). This suggests that the EWH intervention had no impact (immediate or longer term) on the report turnaround times for the outpatient clinical pathway.

**Figure 4.12 Time plot and graphical presentation of the fitted trends of report turnaround times for the outpatient clinical pathway**



Time plot, top pane (extracted from Figure 4.6); fitted model, bottom pane; K2, time of the SRR intervention; K3, time of the EWH intervention. RTAT, report turnaround times.

**Table 4.15 Impact on report turnaround times for the outpatient clinical pathway of the SRR and EWH interventions estimated using Model 4.1.**

<i>Interventions</i>	<i>Type of effect</i>	<i>Non-adjusted</i>	<i>Adjusted for seasonality</i>	<i>Adjusted for seasonality and workload</i>
<i>Speech recognition reporting</i>	Underlying trend	-0.01 (-0.40, 0.38)	0.00 (-0.35, -0.36)	0.00 (-0.36, 0.34)
	Change in level	19.74 (5.32, 34.16)	20.21 (3.05, 37.38)	19.90 (2.78, 37.02)
	Change in trend	-0.22 (-1.15, 0.71)	-0.26 (-1.18, 0.66)	-0.24 (-1.15, 0.67)
<i>Extended working-hours</i>	Underlying trend	0.42 (-2.52, 3.35)	0.55 (-2.3, 3.40)	0.66 (0.35, 0.96)
	Change in level	-7.06 (-20.04, 5.92)	-4.08 (-17.58, 9.42)	-3.97 (-17.51, 9.58)
	Change in trend	-0.76 (-25, 1.78)	-0.71 (-0.02, 1.44)	-0.68(-0.06, 1.42)

Estimated percentage change (95% confidence interval).

### **4.3.2.3 Results for the GP clinical pathway**

#### **4.3.2.3.1 Pre-examination waiting time**

The level and variability of pre-examination waiting times for the GP clinical pathway appeared to increase following the CT intervention (Figure 4.13, top pane). There was no visually perceptible change in either the level or variability of pre-examination waiting times for GP following the EWH intervention (Figure 4.13, top pane). The results of the ITS analysis of the impact on pre-examination waiting times of the CT and EWH interventions for the GP clinical pathway are presented in Figure 4.13 (bottom pane) and Table 4.16.

#### ***CT intervention***

There was no significant underlying trend of pre-examination waiting times for the GP clinical pathway before the CT intervention (Table 4.16). The CT intervention was associated with a 15.5% (9.26, 21.45) increase in the level (change in level) of pre-examination waiting times for GP (Table 4.16). The CT intervention was also associated with a 0.26% (0.01, 0.47) per-week reducing trend (change in trend) of pre-examination waiting times for GP (Table 4.16). The results suggest an immediate deterioration followed by a gradual improvement of pre-examination waiting times for the GP clinical pathway following the CT intervention.

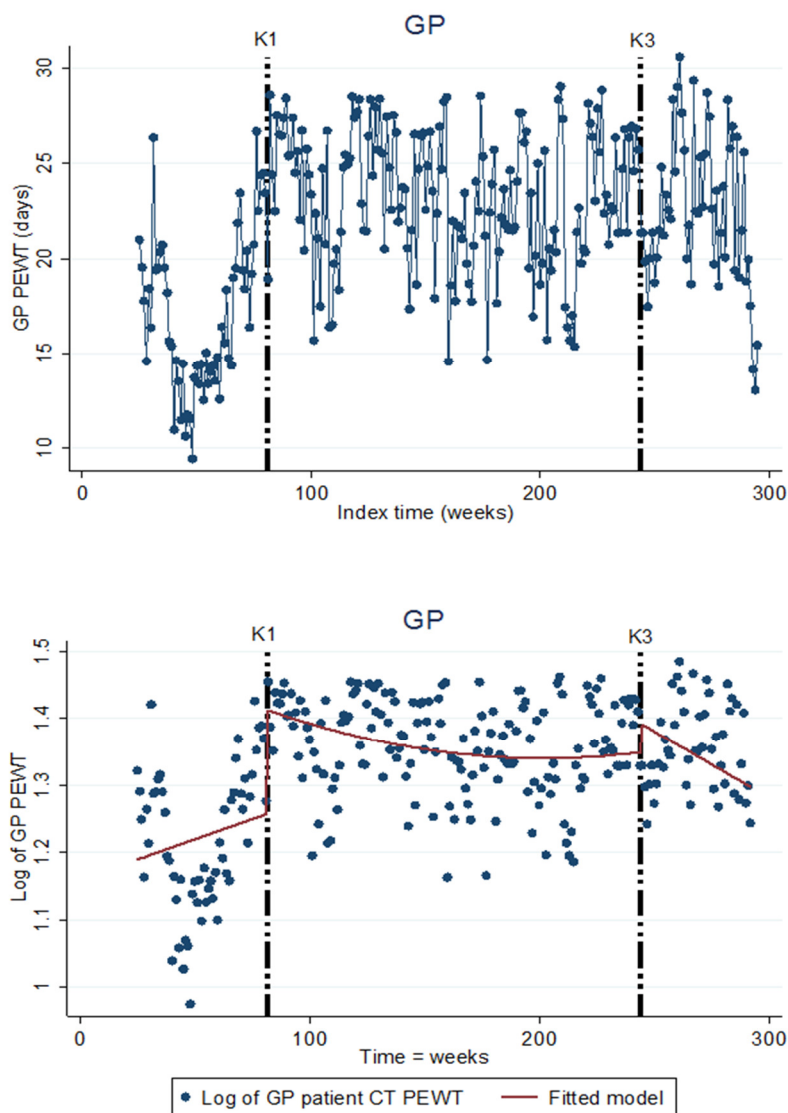
#### ***EWH intervention***

There was no significant underlying trend of pre-examination waiting times for GP just before the EWH intervention (Table 4.16). The EWH intervention was not



associated with a significant change in level, but rather a 0.25% (0.01, 0.49) per-week reducing trend of pre-examination waiting times for GP (Table 4.16). The results suggest that the impact of the EWH intervention on the pre-examination waiting times for the GP clinical pathway is a gradual rather than an immediate improvement.

**Figure 4.13 Time plot and graphical presentation of the fitted model for pre-examination waiting times for the GP clinical pathway**



Time plot, top pane (extracted from Figure 4.5Figure 4.6); fitted model, bottom pane; K1, time of the CT intervention; K3, time of the EWH intervention. PEWT, pre-examination waiting times.

**Table 4.16 The impact on pre-examination waiting times for the GP clinical pathway of the CT and EWH interventions estimated using Model 4.1.**

<i>Interventions</i>	<i>Type of effect</i>	<i>Non-adjusted</i>	<i>Adjusted for seasonality</i>	<i>Adjusted for seasonality and workload</i>
<i>CT</i>	Underlying trend	0.14 (-0.19, 0.36)	0.12 (-0.06, 0.31)	0.14 (-0.03, 0.30)
	Change in level	14.50 (7.11, 21.89)	15.05 (8.74, 21.36)	15.35 (9.26, 21.45)
	Change in trend	-0.27 (-0.55, 0.01)	-0.24 (-0.48, -0.00)	-0.26 (-0.47, -0.01)
<i>Extended working-hours</i>	Underlying trend	0.09 (-0.04, 0.22)	0.06 (-0.01, 0.17)	0.07 (-0.04, 0.18)
	Change in level	-1.29 (-7.36, 4.79)	4.34 (-2.57, 11.25)	4.29 (-2.46, 11.03)
	Change in trend	-0.11 (-0.38, -0.16)	-0.24 (-0.49, 0.12)	-0.25 (-0.49, -0.01)

Percentage change (95% confidence interval).

#### **4.3.2.3.2 Report turnaround time**

The level and variances of report turnaround times for the GP clinical pathway appeared to increase following the SRR intervention (Figure 4.14, top pane). There was no visually perceptible change in the level and variability of report turnaround times for GP following the EWH intervention (Figure 4.14, top pane). The results of the ITS analysis of the impact of the SRR and EWH interventions on report turnaround times for the GP clinical pathway are presented in Figure 4.14 (bottom pane) and Table 4.17.

##### ***SRR intervention***

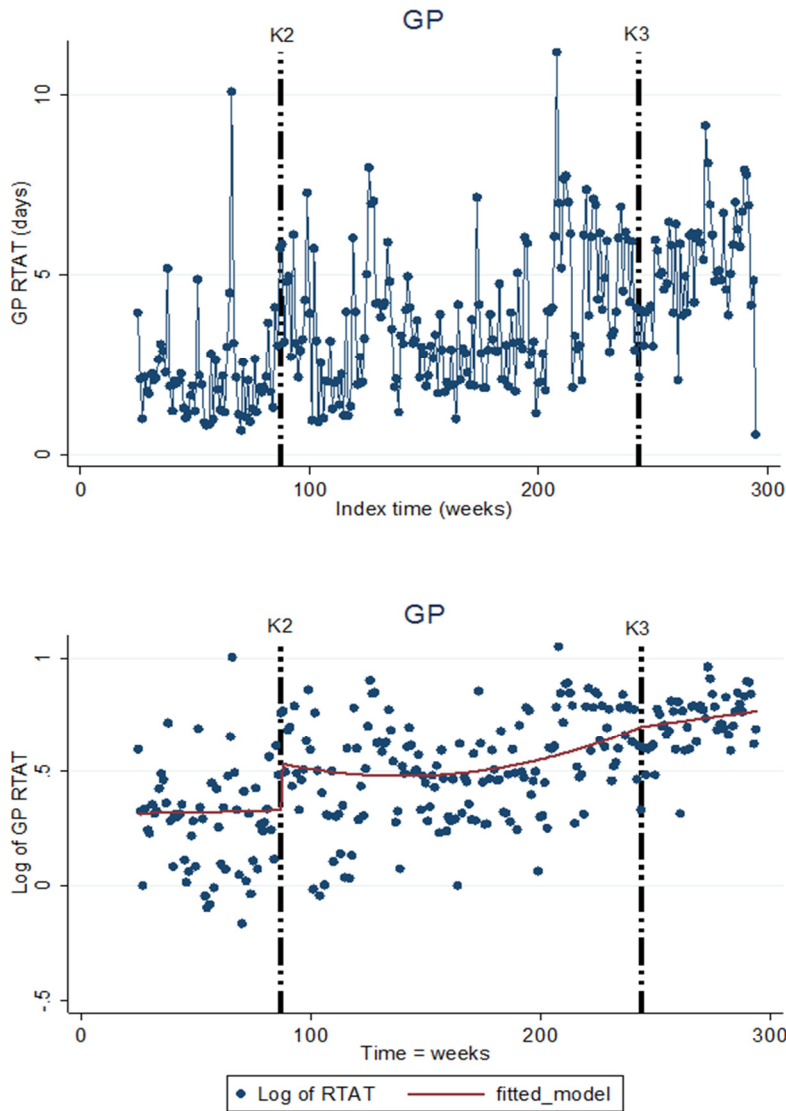
There was no significant underlying trend of report turnaround times for the GP clinical pathway before the SRR intervention (Table 4.17). Following the SRR intervention, there was a 20.59% (3.54, 37.6) increase in the level (change in level) of report turnaround times for GP (Table 4.17). The SRR intervention was associated with a reducing but non-statistically significant change in trend of report turnaround times for GP (Table 4.17). The results suggest an immediate and sustained deterioration in report turnaround times for the GP clinical pathway following the SRR intervention.

##### ***EWH intervention***

Just before the EWH intervention, the underlying trend of report turnaround times for the GP clinical pathway was increasing at the rate of 0.47% (0.05, 0.89) per-week (Table 4.17). The EWH intervention was associated with neither a change in level nor a change in trend of report turnaround times for GP (Table 4.17).

This suggests that the EWH intervention had neither an immediate nor a longer term impact on report turnaround times for the GP clinical pathway.

**Figure 4.14 Time plot and graphical presentation of the fitted trend of report turnaround times for the GP clinical pathway**



Time plot, top pane (extracted from Figure 4.6); fitted model, bottom pane; K2, time of the SRR intervention; K3, time of the EWH intervention. RTAT, report turnaround times.

**Table 4.17 The impact on report turnaround times for the GP clinical pathway of the SRR and EWH interventions estimated using Model 4.1**

<i>Interventions</i>	<i>Type of effect</i>	<i>Non-adjusted</i>	<i>Adjusted for seasonality</i>	<i>Adjusted for seasonality and workload</i>
<i>Speech recognition reporting</i>	Underlying trend	0.02 (-0.31, 0.35)	0.03 (-0.32, 0.38)	0.03 (-0.32, 0.37)
	Change in level	19.66 (4.17, 35.15)	20.63 (3.68, 37.58)	20.59 (3.54, 37.65)
	Change in trend	-0.26 (-0.76, 0.25)	-0.25 (-0.75, 0.24)	-0.25 (-0.75, 0.26)
<i>Extended working-hours</i>	Underlying trend	0.50 (0.09, 0.91)	0.47(0.05, 0.88)	0.47 (0.05, 0.89)
	Change in level	-7.08 (-30.56, 22.40)	-3.84 (-30.99, 23.32)	-3.82 (-31.04, 23.40)
	Change in trend	-0.19 (-1.29, 0.91)	-0.25 (-0.75, 0.24)	-0.24 (-1.31, 0.82)

Estimated percentage change (95% confidence interval).

## **4.3.2.4 Results for the A&E clinical pathway**

### **4.3.2.4.1 Pre-examination waiting time**

Figure 4.15 (top pane) shows no visually perceptible change in the level and variability of pre-examination waiting times for the A&E clinical pathway following the CT and EWH interventions. The results of the ITS analysis of the impact of the CT and EWH interventions on pre-examination waiting times for the A&E clinical pathway are presented in Figure 4.15 (bottom pane) and Table 4.18.

#### ***CT intervention***

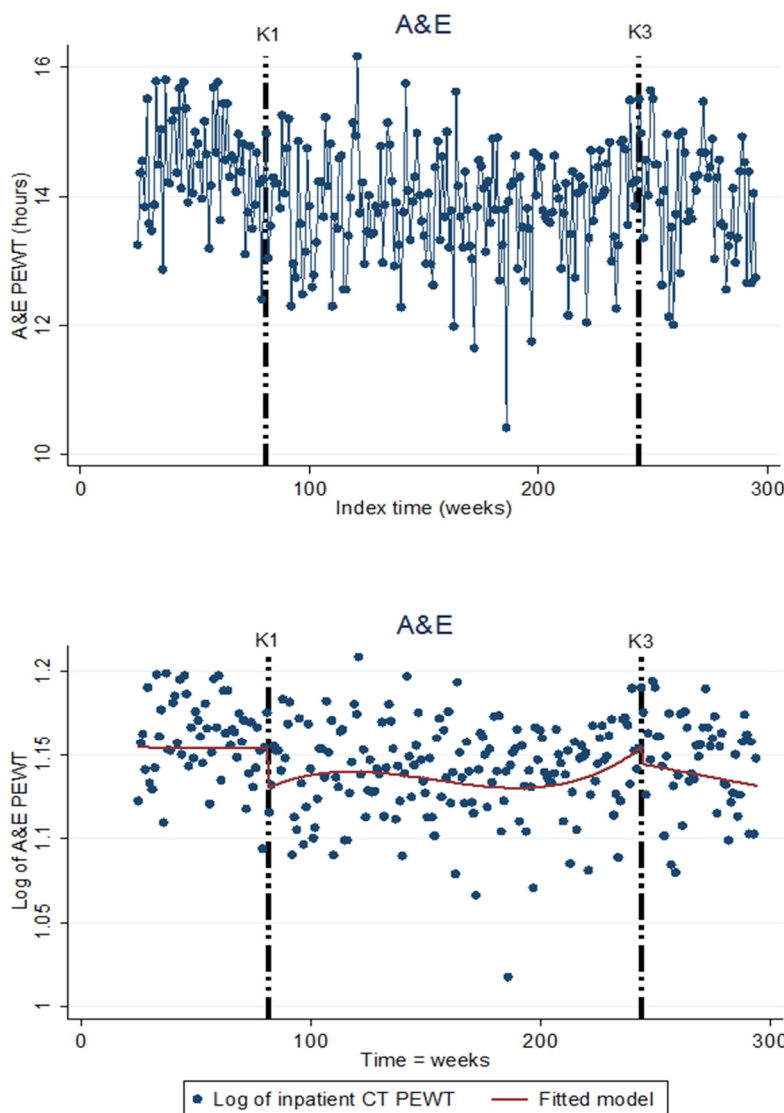
There was no significant underlying trend of pre-examination waiting times for the A&E clinical pathway before the CT intervention (Table 4.18). The CT intervention was associated with a 2.59% (0.55, 4.63) reduction in the level (change in level) of pre-examination waiting times for A&E (Table 4.18). There was no significant change in the trend of pre-examination waiting time for A&E following the CT intervention (Table 4.18). The results suggest an immediate and sustained improvement of pre-examination waiting times for the A&E clinical pathway following the CT intervention.

#### ***EWH intervention***

Table 4.18 shows that just before the EWH intervention the trend of pre-examination waiting times for the A&E clinical pathway was increasing at the rate of 0.11% (0.03, 0.20) per-week (underlying trend). The EWH intervention was not associated with a significant change in level, but rather a reducing trend (change in

trend) of pre-examination waiting times at the rate of 0.13% (0.04, 0.23) per-week for A&E (Table 4.18). The results suggest that the impact of the EWH intervention on pre-examination waiting times for the A&E clinical pathway was a gradual rather than an immediate improvement.

**Figure 4.15 Time plot and graphical presentation of the fitted trends of pre-examination waiting times for the A&E clinical pathway**



Time plot, top pane (extracted from Figure 4.5Figure 4.6); fitted model, bottom pane; K1, time of the CT intervention; K3, time of the EWH intervention. PEWT, pre-examination waiting times.

**Table 4.18 The impact on pre-examination waiting times for the A&E clinical pathway of the CT and EWH interventions estimated using Model 4.1.**

<i>Interventions</i>	<i>Type of effect</i>	<i>Non-adjusted</i>	<i>Adjusted for seasonality</i>	<i>Adjusted for seasonality and workload</i>
<i>CT</i>	Underlying trend	-0.01 (-0.05, 0.03)	-0.01 (-0.05, 0.03)	-0.01 (-0.05, 0.04)
	Change in level	-2.11 (-4.17, -0.04)	-2.53 (-4.56, -0.50)	-2.59 (-4.63, -0.55)
	Change in trend	0.06 (-0.03, 0.16)	0.07 (-0.01, 0.16)	-0.07 (-0.02, 0.16)
<i>Extended working-hours</i>	Underlying trend	0.09 (0.01, 0.19)	0.11 (0.02, 0.19)	0.11 (0.03, 0.20)
	Change in level	-0.36 (-2.66, 1.94)	-0.84 (-3.21, 1.53)	-0.93 (-3.29, 1.43)
	Change in trend	-0.13 (-0.23, -0.03)	-0.13 (-0.22, -0.03)	-0.13 (-0.23, -0.04)

Estimated percentage change (95% confidence interval).



#### **4.3.2.4.2 Report turnaround time**

Figure 4.16 (top pane) shows a visually perceptible drop in the level and variability of report turnaround times for the A&E clinical pathway following the SRR intervention. There was no visually perceptible change in the level and variability of report turnaround times for A&E following the EWH intervention (Figure 4.16, top pane). The results of the ITS analysis of the impact on report turnaround times for the A&E clinical pathway of the SRR and EWH interventions are presented in Figure 4.16 (bottom pane) and Table 4.19.

##### ***SRR intervention***

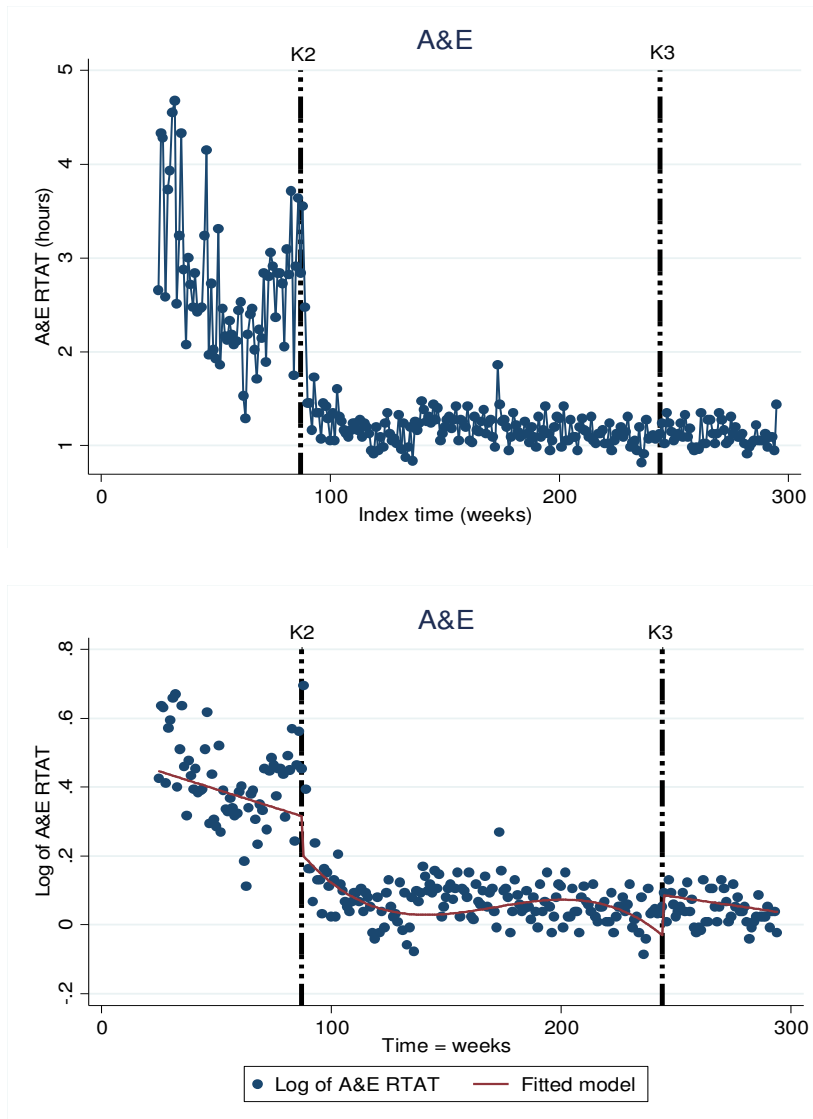
Table 4.19 shows that the underlying trend of report turnaround times for the A&E clinical pathway was reducing at the rate of 0.21% (0.01, 0.41) per-week before the SRR intervention. There was a 26.03% (10.72, 41.35) drop in the level of report turnaround times (change in level) for A&E following the SRR intervention (Table 4.19). There was no significant change in trend of report turnaround times for A&E following the SRR intervention (Table 4.19). The results suggest an immediate and sustained improvement in report turnaround times for the A&E clinical pathway following the SRR intervention.

##### ***EWH intervention***

There were neither a significant underlying trend of report turnaround times before the EWH intervention nor a significant change in level and trend of report turnaround times for A&E following the EWH intervention (Table 4.19). The results

suggest that the EWH had no impact (immediate or otherwise) on report turnaround times for the A&E clinical pathway.

**Figure 4.16 Time plot and graphical presentation of the fitted trends of report turnaround times for the A&E clinical pathway**



Time plot, top pane (extracted from Figure 4.6); fitted model, bottom pane; K2, time of the SRR intervention; K3, time of the EWH intervention. RTAT, report turnaround times.

**Table 4.19 Impact on report turnaround times for the A&E clinical pathway of the SRR and EWH interventions estimated using Model 4.1**

<i>Interventions</i>	<i>Type of effect</i>	<i>Non-adjusted</i>	<i>Adjusted for seasonality</i>	<i>Adjusted for seasonality and workload</i>
<i>Speech recognition reporting</i>	Underlying trend	-0.15 (-0.22, -0.07)	-0.14 (-0.21, -0.06)	-0.21 (-0.41, -0.01)
	Change in level	-22.90 (-28.30, -17.50)	-22.10 (-27.76, -16.44)	-26.03 (-41.35, -10.72)
	Change in trend	-0.22 (-0.56, 0.12)	-0.27 (-0.61, 0.07)	-0.20 (-0.89, 0.49)
<i>Extended working-hours</i>	Underlying trend	-0.34 (-0.77, 0.08)	-0.41 (-0.84, 0.01)	-0.33 (-0.72, 0.06)
	Change in level	6.84 (-5.36, 19.05)	8.67 (-3.24, 20.57)	5.60 (-2.78, 13.98)
	Change in trend	0.25 (-0.31, 0.81)	0.30 (-0.21, 0.82)	0.24 (-0.19, 0.68)

Estimated percentage change (95% confidence interval)

## 4.4 Discussion

The ITS design provides a superior level of evidence compared to the simple pre- and post-intervention design (Shadish et al., 2002; Kontopantelis et al., 2015). In this thesis, ITS analysis was implemented with the 'segmented spline' regression model, adjusted for workload and seasonality. Seasonal adjustment was done by creating and entering into the regression model, one variable for each month which meant adding extra 11 degrees of freedom to the model. However, with 271 data points, the ratio of data points to the parameters to be estimated in the model (14:1) is more than the ratio of 10:1 that conventional statistical wisdom suggests.

The models were adjusted for workload. This is justified by the fact that workload grew by 40% within the study period (Table 4.2). However, adjustments for seasonality and workload made no significant difference to the estimates of intervention effect. This is probably due to the fact that the NHS constitution guarantees maximum waiting times (DoH, 2010) and NHS organisations are often penalised for breaching those targets (Davies et al., 2014). Therefore, NHS organisations often provide surge capacity usually in the form of agency/locum staff to cope with added pressure during periods of peak demand with a view to keeping waiting times within the limits guaranteed by the NHS constitution/government guidelines. The effectiveness of each intervention is summarised and discussed in the next sub-sections.

#### 4.4.1 320-slice CT-Scanner

The clinical applications of 320-slice CT-scanner is widely investigated, especially in the areas of neuro- and cardio-vascular imaging (Siebert et al., 2009; Mingchen et al., 2011; Sato et al., 2013; Speciale and Pasceri, 2013; Sugiura et al., 2013; Funabashi et al., 2014). However, its impact on patients' waiting times has received very little research attention. A recent post-intervention only study compared the time taken to administer treatment to potential candidates for thrombolysis in a system that used 64- and 320-slice CT-scanners, and found the time taken to administer treatment to be comparable (Chakraborty et al., 2015). It should be noted though, that the waiting time for CT-scan is only one small component of the time taken to administer treatment to potential thrombolysis patients. A recent large Australian audit of thrombolysis in acute stroke (Lau et al., 2016) stressed the need for a timely administration of treatment. A reduced waiting time for CT-examination should contribute to early treatment of thrombolysis candidates. It is still not certain, how a 320-slice CT-scanner impact on the waiting times for patients referred from the A&E and other clinical pathways.

The current study found that the CT intervention is associated with an immediate deterioration of pre-examination waiting times for the outpatient (14%/3.5 days) and GP (15%/3.8 days) (non-acute clinical pathways) and an immediate improvement in pre-examination waiting times for inpatient (22%/7.5 hours) and A&E (3%/0.4 hours) (acute clinical pathways). In the longer term (reducing trend), the pre-examination waiting times improved for three of the four clinical pathways (inpatient,

outpatient and GP). The explanation for this pattern of impact is not certain and will be explored in the qualitative study (chapter 5). However, it is possible that the pre-examination waiting times for the A&E clinical pathway are already quite low and there is very little room for improvement (“ceiling effect”). However, the observed immediate (initial) improvement was sustained.

Earlier studies have suggested that multi-slice CT-scanner (Jhaveri et al., 2001) and multiple technologists attached to a scanner (Boland et al., 2008) might improve the productivity of a CT-scanner. Roos et al. (2002) argued that other factors such as patient flow management and well trained operators were more important than the speed of the scanner for improving productivity of a CT-scanner. This view is supported by the results of queueing analyses of the impact on productivity of different staffing models and what-if scenarios within a CT department (Wang et al., 2012). Wang et al. (2012) found that upgrading the workstation computers improved workflow more than any other factors considered. However, the above studies have looked at productivity as an outcome measure. There is as yet no evidence to suggest that increased productivity leads to reduced patients’ waiting times within radiology departments. On the contrary, there are suggestions that increased radiology capacity (such as the introduction of a faster scanner) is often associated with increased demand (Campbell et al., 2014) which could potentially lead to increased waiting times.

Workflow optimisation with quality management strategies has been used to improve CT waiting times. For example, Steffen (2010) found that waiting times

dropped from 12hours to 33minutes, following a quality improvement intervention, without a substantial increase in productivity. The average number of scans performed per-day increased marginally from 61 to 63 (Steffen, 2010); a 3% change. Confidence intervals and p-values were not reported. The quality improvement intervention consisted of creating a central scheduling system for CT and other radiology imaging modalities. Again, Aloisio et al. (2009) used the Six Sigma methodology to improve patients' waiting times in a CT-scanning unit. The intervention involved re-designing the technical work space to reduce the distances that staff had to travel between work locations and 'revamping' the scheduling process. The study does not specify what was done to 'revamp' the scheduling process. The study found that following the intervention, the mean examination turnaround times for inpatient, defined as time elapsed between the request and final radiology reports, dropped from 21 hours (SD 23) to 12 hours (SD 15). This uncontrolled pre- and post-intervention study was performed in a small hospital that processes 68,000 examinations per-year. Patel et al. (2012) audited the combined effect of installing a dedicated CT-Scanner for A&E, employing a dedicated CT porter and introduction of wireless telephone to call specialist radiology registrars on-call. This very small study compared "report request interval" (RRI) using three-weeks pre- and three-weeks post-intervention data. The study included only 210 and 340 patients during the pre- and post-intervention periods respectively. The study found that the RRI increased from 51 to 69 for A&E patients having 'CT body' and from 69 to 82 minutes for those having CT head. The study did not report confidence interval, p-values or any technical information about the CT system. All three studies evaluated a heterogeneous mix of interventions, used the

pre- and post-intervention design without control and failed to provide any information on the CT-scanner's involved in the studies (especially in terms of speed; slice number), thus making any meaningful comparison impossible. However, there are indications that workflow might play a more critical role in CT productivity and waiting times compared to scanning speed. This will be explored in the qualitative study (chapter five).

#### **4.4.2 Speech recognition reporting (SRR)**

The current study found that SRR is associated with increased level and variability of report turnaround times for the non-acute clinical pathways (outpatient and GP) (Figure 4.6). Interestingly, the reverse pattern was noted for the inpatient and A&E (acute clinical pathways) (Figure 4.6). This is most probably related to the context within which the SRR intervention was implemented. The underlying trend of report turnaround times were decreasing (improving) for the acute clinical pathways (inpatient and A&E), but stable for the non-acute clinical pathways (GP and outpatient) prior to the SRR intervention. The level of report turnaround times improved for A&E (26%/0.7 hours) and deteriorated for outpatient (20%/0.5 days) and GP (21%/0.5 days) following the SRR intervention. Two factors might be responsible for the observed pattern of impact: (a) learning curve; clinicians have to be trained on the SRR software. It is natural that productivity might be low during the training and adaptation periods (Kauppinen et al., 2013), therefore, waiting times might be expected to increase briefly for all four clinical pathways. (b) However, the patient priority system operated within



the hospital meant that examinations for the acute clinical pathways (A&E and inpatient) might be prioritised for reporting. It is then possible that during the training period and its attendant reduced productivity, attention was naturally focused on reporting the examinations for the A&E and inpatient clinical pathways which will inevitably mean that less of outpatient and GP are reported. As clinicians build up their competence on the SRR system, productivity might begin to improve. Improvements of this type will most likely be gradual and more evident in the report turnaround times for the outpatient and GP clinical pathways where more scope for improvement existed. The models did estimate a reducing trend (gradual improvement) in the report turnaround times for outpatient and GP clinical pathways, but these were not statistically significant.

SRR is widely investigated. However, a significant proportion of the published literature on SRR are opinions and editorials; with a few empirical studies (Danton, 2010). The current study is compared with Hart et al. (2010) which was performed in an NHS Trust in London, UK. Hart et al. (2010) evaluated the impact of a 100% switch over to SRR using monthly 'time to completion' data (11 months pre- and 15 months' post-intervention). 'Time to completion' was defined as the time from image acquisition to the final radiology report. The study was analysed using the two sample (pre-and post-intervention) t-test. Hart et al. (2010) reported sustained improvement of report turnaround times for all four referral pathways (inpatient, A&E, outpatient and GP) evaluated in the study. For example, the mean 'time to completion' for outpatient dropped from 8.72 days (SD 1.29) to 2.75 days (SD 1.14) following the implementation of SRR. There are two key differences between these two studies: (a)

Hart et al. (2010) used the t-test (pre- and post-intervention design) which ignores the underlying trend in the data. As noted earlier, the pre- and post-intervention design is prone to biased effect estimates (Matowe et al., 2002; Higgins JPT et al., 2011); generally, in the direction of overestimated effect size (Beckett, 2013), (b) The Trust reported in Hart et al. (2010) implemented a 100% switchover to the SRR system. These differences in study design and context of implementation might account for the differences in the results of the two studies.

Speech recognition reporting system is becoming an inherent part of many radiology departments in the UK, however, little evidence exists about its impact on report turnaround times, error rates, productivity and cost-effectiveness (Strahan and Schneider-Kolsky, 2010). Some authors argue that SRR is associated with cost savings (Kelley, 2011). But errors within reports generated with SRR continue to be a major source of concern (Chang et al., 2014; Towbin et al., 2014). Some researchers have argued that, due to high error rates, SRR systems lead to dissatisfaction (du Toit et al., 2015) and reduced radiologists' productivity, making the system non-cost-effective for radiology reporting (Strahan and Schneider-Kolsky, 2010; du Toit et al., 2015). It is possible that spending more time to edit reports might reduce productivity. But there is as yet no definitive link between SRR errors and reduced productivity (Hammana et al., 2015). At any rate, there is an expectation that as the SRR technology matures, error rates and productivity might improve (Najran et al., 2015).

It has been acknowledged that the benefits obtainable from SRR systems depended not only on technical factors such as accuracy and user friendliness, but also

on the context within which it is implemented (Alapetite et al., 2009; Hart et al., 2010; Hammana et al., 2015; Lyons et al., 2015). The context within which the SRR intervention was implemented in the current study is investigated in a qualitative study reported separately in chapter five of this thesis.

### **4.4.3 Extended-working-hours (EWH) intervention**

The results of the current study suggest that the EWH intervention is associated with a gradual rather than an immediate improvement in pre-examination waiting times for the outpatient, GP and A&E clinical pathways. On the other hand, it is associated with an immediate and sustained improvement in pre-examination waiting times for the inpatient clinical pathway. Possible explanations for the above pattern of effect might include poor initial uptake of the service by the outpatient and GP clinical pathways, probably coupled with a lack of sensitisation of the clinicians referring patients from both clinical pathways regarding the availability of EWH service. It is then possible that as awareness and/or acceptance of the service improved, its impact on pre-examination waiting times began to manifest. The EWH intervention had no immediate impact on the pre-examination waiting times for A&E most probably because A&E already had access to 24-hour service. However, contrary to expectations, the pre-examination waiting times for A&E improved gradually over the longer term.

An immediate and sustained increase in the report turnaround times for inpatient was noted following the EWH intervention. It was expected that the EWH

intervention might lead to more scans being performed than could be reported on time. Therefore, the report turnaround times were expected to increase, especially for the outpatient and GP clinical pathways. The turnaround times for the inpatient clinical pathway did increase, but there was no significant immediate or longer term impact on the report turnaround times for the GP and outpatient clinical pathways. Possible explanations for these findings might include, the possibility that some of the outpatient and GP scans were reported outside of contractual hours, in what is known as 'initiative lists' (surge capacity), or reported by locum /agency staff. A detailed explanation for these findings will be explored in the qualitative study of the context within which the interventions were implemented; reported in chapter five of this thesis.

EWH within the healthcare system has been extensively investigated. However, most of the studies are outside the discipline of radiology and are limited to (a) acceptance of EWH by patients (Brown et al., 2009; Morgan and Beerstecher, 2011), (b) patients' satisfaction with EWH (Tan and Mays, 2014), (c) influence of EWH on patients' healthcare behaviour (Lasserson et al., 2008) and (d) the impact of EWH on the health of workers (Bannai and Tamakoshi, 2014). Studies of EWH within clinical radiology are limited to its impact on the clinical performance of the individuals working extended-hours (Krupinski et al., 2010; Krupinski et al., 2012) and the training of resident radiologists (Ruutiainen et al., 2013).

Kielar et al. (2010) found a substantial reduction in the waiting times for MRI and CT-examinations in the Ontario Health Region, Canada following a national

programme that included EWH and acquisition of more scanners amongst many other interventions. The average waiting times for CT dropped from 81 days in 2005 to 47 days in 2009. It is not certain how much of this improvement is attributable to the EWH component of the complex intervention. Hauptfleisch et al. (2013) investigated the models for MRI scan provision in the UK and concluded that there is a dearth of information on the provision and impact of out-of-hour (EWH) MRI services. The situation is the same for CT and other radiology imaging modalities, particularly in the area of impact on patients' waiting times. However, the provision and utilisation of out-of-hour CT service is increasing and according to Culleton and Torreggiani (2014), the utilisation of out-of-hour CT increased by 210% in an Irish hospital between 2001 and 2010.

#### **4.4.4 Strengths and limitations of this study**

The interrupted time series design is one of the most robust quasi experimental designs (Shadish et al., 2002). The current study was analysed using the ITS 'segmented spline' regression model with autocorrelated errors. Spline regression model is a less biased and more efficient alternative to linear models for describing data containing trends (Howe et al., 2011). A spline model is particularly important so that changes in level and trend due to inherent curves within the data are not wrongly attributed to intervention effect. ITS 'segmented spline' regression model has not previously been used to evaluate the effectiveness of interventions to reduce waiting times within diagnostic radiology.

An important consideration in this study is the use of patient-centred outcome measure. Patients' waiting times are a current and topical issue within the NHS. The patient-level data used in this study was obtained directly from the radiology information system (RIS). The study also adjusted for seasonality and workload. However, even a well implemented ITS study has limitations, and the current study does have some limitations.

Patient -level data obtained from the CRIS<sup>TM</sup> contained some exceptionally high recorded waiting times which were inconsistent with the range of waiting times within the study setting and were thought to be outliers. A range of outliers' detection tools including automated algorithm and the capping technique were tried. However, the capping technique yielded the best results. The automated methods (Buis, 2006; Weber, 2010) were found to exclude waiting times that were totally reasonable; even waiting times that were close to the median values were excluded by the automated methods. Detailed investigation of a random sample of 20 cases taken from the outliers revealed data entry errors, which justified their exclusion from further analyses. One of the observed reasons for the exceptionally high recorded waiting time was the addition of addendum to a previously finalised report. This is a recognised problem in the analysis of radiology report turnaround times (Baccei et al., 2015). Radiology reports including differential diagnoses are occasionally modified in the light of new clinical information (e.g. post-mortem findings).

HEFT migrated to a new RIS system just over a year before the first (CT) intervention. It is possible that the pre-CT intervention data has not sufficiently

stabilised. The effect of this is probably most noticeable on the time plots of pre-examination waiting times for the outpatient and GP series (Figure 4.5). The waiting times trend appeared to dip and rise again over a very short period. The estimates of intervention effect obtained from the analysis is a function of the both the data and the type of model used. The current study used a spline model, but this was only applied to the time interval between the two interventions in each series. It is possible that the results might be slightly different if a more complex spline model was implemented, especially to capture the odd trend pattern (before the first intervention) for the GP and outpatient pre-examination waiting times.

Another possible limitation of this study is that no control series were used, because finding a suitable control series was not feasible in this situation. However, this is not always necessary in the ITS design (Shadish et al., 2002). The study does not account for the possible changes in staffing level during the study period (a possible time-varying confounder). This could be a source of variation. However, the failure to account for possible changes in staffing levels equally applied to the pre- and post-intervention periods, therefore unlikely to overturn the results.

Finally, this is a single centre study. The study setting has a specific set of local circumstances that might have shaped the impact of the interventions. The findings of this study and its generalisability need to be seen within that context.

## 4.5 Summary and conclusions

### 4.5.1 How the current study meets the quality criteria for a well implemented ITS study

Chapter 3 (section 3.4.3) highlighted the criteria that differentiate a well implemented from a poorly implemented ITS study. The criteria were drawn from Ramsay et al. (2003), EPOC (2012b) and Shadish et al. (2002). Table 4.20 lists the criteria and outlines the corresponding features of the current study that meet those criteria.

**Table 4.20 How the current study meets the criteria for a well implemented ITS design**

<i>Number</i>	<i>Criteria</i>	<i>Features of the current study</i>
<i>a.</i>	Was the study analysed appropriately using time series techniques (ARIMA / time series regression model)?	<ul style="list-style-type: none"> <li>i. ITS ‘segmented spline’ regression model with autocorrelated errors was implemented.</li> <li>ii. Models were adjusted for seasonality.</li> <li>iii. Residual diagnostic tests were performed on the models.</li> </ul>
<i>b.</i>	Was the intervention independent of other changes?	<ul style="list-style-type: none"> <li>i. The dates of interventions were clearly specified.</li> <li>ii. No other interventions that could affect patients waiting times were implemented within the weeks that the evaluated interventions were implemented.</li> </ul>



c.	Was the shape of the intervention effect pre-specified?	<ul style="list-style-type: none"> <li>iii. Models were adjusted for workload and seasonality.</li> <li>i. The nature of the expected impact of the interventions on patients waiting times were specified with rational explanation in section 4.2.2 (the interventions and logic model for the analysis).</li> </ul>
d.	Was the intervention unlikely to affect data collection methods?	<ul style="list-style-type: none"> <li>i. Objective outcome data was obtained from the CRIS™ database which is independent of the interventions.</li> <li>ii. A uniform data collection technique was used throughout the study period; one database (CRIS™) was used.</li> <li>iii. Uniform outcome measure definition within the study period.</li> </ul>
e.	Is the primary outcome measure reliably or objectively measured?	<ul style="list-style-type: none"> <li>i. Objective outcome data was obtained from the CRIS™.</li> </ul>
f.	Were incomplete outcome data adequately addressed? / Is the data composition at least 80% of the total number of participants in the study?	<ul style="list-style-type: none"> <li>i. There were no missing data points</li> <li>ii. Less than 5% of the patient-level data was excluded as outliers for each of the eight series; rational explanation was given for the exclusion.</li> </ul>
g.	Is the study free from selective outcome reporting	<ul style="list-style-type: none"> <li>i. The study reported the key measures of patients waiting time that it sets out to investigate</li> </ul>

<p>h. Is the rationale for the number and spacing of data points provided?</p>	<ul style="list-style-type: none"> <li>i. All available data was used for the study.</li> <li>ii. The data points were spaced in line with the format for reporting radiology patients' waiting time data within the NHS (weekly averages).</li> <li>iii. The available data points were sufficient for seasonal adjustment.</li> </ul>
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ARIMA, autoregressive integrated moving averages.

## 4.5.2 Summary

The results suggest that the replacement of a 4- with a 320-slice CT-scanner might lead to an immediate and continued improvement of pre-examination waiting times for the inpatient clinical pathway; an immediate deterioration followed by a gradual improvement of pre-examination waiting times for the outpatient and GP clinical pathways and an immediate and sustained improvement of pre-examination waiting times for the A&E clinical pathway.

The SRR intervention is associated with an immediate and sustained deterioration in the report turnaround times for the outpatient and GP clinical pathways; an immediate and sustained improvement in the report turnaround times for the A&E clinical pathway and no impact on the report turnaround times for the inpatient clinical pathway.

The study also found that the EWH intervention is associated with a gradual rather than immediate improvement of pre-examination waiting times for the outpatient, GP and A&E clinical pathways. The EWH intervention had no impact on the report turnaround times for outpatient, GP and A&E clinical pathways. For the inpatient clinical pathway, reduced pre-examination waiting times comes with increased report turnaround times following the EWH intervention. The possible explanations for these pattern of effect are investigated in a qualitative study which is reported in chapter five of this thesis.

### **4.5.3 Conclusions**

Table 4.20 suggests that this is a well implemented ITS study. The results of this study suggest that for all three interventions, an improvement in waiting times for the inpatient and A&E clinical pathways comes with a deterioration of waiting times for the outpatient and GP clinical pathways. It is therefore difficult to be certain of the overall effectiveness of the interventions.

# CHAPTER 5. QUALITATIVE EVALUATION OF THE IMPACT ON PATIENTS' WAITING TIMES OF THREE SDIs IMPLEMENTED WITHIN BIRMINGHAM HEARTLANDS HOSPITAL

## Abstract

Chapter five presents the findings of the qualitative study performed to assess the context within which the CT, speech recognition reporting (SRR) and extended-working-hour (EWH) interventions were implemented within the radiology Department of Birmingham Heartlands Hospital.

Face-to-face semi-structured interviews with healthcare professional (staff and clients of the radiology department) were conducted by BO between 20<sup>th</sup> February and 16<sup>th</sup> July 2015. The interviews were recorded, transcribed (by BO) and the data stored and managed in Nvivo10<sup>TM</sup>. Favourable ethical opinion and local NHS permission were obtained for this study.

Thematic analysis of the interview data identified five themes: expectations, context of implementation, perceived outcomes & alternative explanations for the perceived impact of the SDIs, suggestions for further

improvement and other. Participants felt that limited hospital resources were geared towards facilitating patients flow through the acute clinical pathways (A&E and inpatient), by necessity, with very little resources left to cope with the non-acute clinical pathways (outpatients and GP). The participants felt that for the CT intervention, workflow changes and clinical priority system were more likely to account for any observed improvement in waiting times for the acute pathway, rather than the speed of the scanner. For the SRR intervention, poor quality of the software, a piecemeal implementation coupled with a shortage of radiologists, increased workload, workflow changes and clinical priority system were thought to be the drivers for the perceived increase in the level and variability of waiting times for the non-acute clinical pathways (GPs and outpatients). The EWH intervention was perceived to have stopped waiting times from spiralling out of control. In the words of a participant, “... *not letting the waiting time slip in the NHS radiology, is as good as ... shortening it. ... being able to stand still is an achievement*” (009, radiologist). Equally important, referring clinicians felt that the EWH intervention allowed them to make clinical decisions earlier and discharge patients sooner.

The results of this study suggest that interventions to improve waiting times within a radiology department with shared limited resources and clinical pathways of varying clinical priority levels, might lead to improvement in waiting times for the A&E and inpatients (acute) clinical pathways and deteriorated waiting times for the outpatient and GP (non-acute) clinical pathways.

## 5.1 Background

Chapter four of this thesis presented the results of the interrupted time series (ITS) study performed to quantify the impact on patients' waiting times of the three service delivery initiatives (SDIs) recently implemented in the Birmingham Heartlands Hospital: the replacement of a 4- with a superfast 320-slice CT-Scanner, speech recognition reporting (SRR) and extended-working-hours (EWH) interventions. The qualitative study reported in this chapter was designed to explore the context within which the interventions were implemented and the impact of the interventions on the quality of service as perceived by clients of the radiology department. The clients of a radiology department have been defined to include the referring clinicians and staff of the department (Alderson, 2000; Yanci, 2006).

As previously noted, waiting times are a major quality indicator in clinical radiology (Abujudeh et al., 2010). A quality service is the one that meets or exceeds clients' expectations, making the client happy and satisfied (Hoe, 2007). According to Lehtinen and Lehtinen (1991), there are two dimensions of quality: the process quality and the output/outcome quality. The process quality encompasses the clients' subjective evaluation of his/her participation in the service delivery process. The output quality is the clients' subjective evaluation of the results of the service delivery process. It is natural for staff of the radiology department to have subjective evaluation of their involvement in the process of implementing the SDIs as well as the outcomes, and for the referring clinicians to have subjective evaluation of the outcome of the SDIs. Literature is scant on the perceptions of referring clinicians on quality of

service provisions within diagnostic radiology departments (Lindsay et al., 2011). Expensive SDIs within radiology are hardly justifiable if referring clinicians do not perceive these as adding value to the quality of care they (clinicians) provide to their patients or do not use the services.

### **5.1.1 Aims and objectives**

#### **Aims**

The aim of this study is to understand the context within which the SDIs were implemented, and their perceived effectiveness.

#### **Objectives**

The study objectives are to;

- a. Explore participants' understanding of why and how the SDIs were implemented and what the expected outcomes were,
- b. Explore participants' perceptions of the effectiveness of the SDIs,
- c. Explore participants' explanations of why the SDIs might have worked or not,
- d. Elicit suggestions for further improvement of the radiology service.

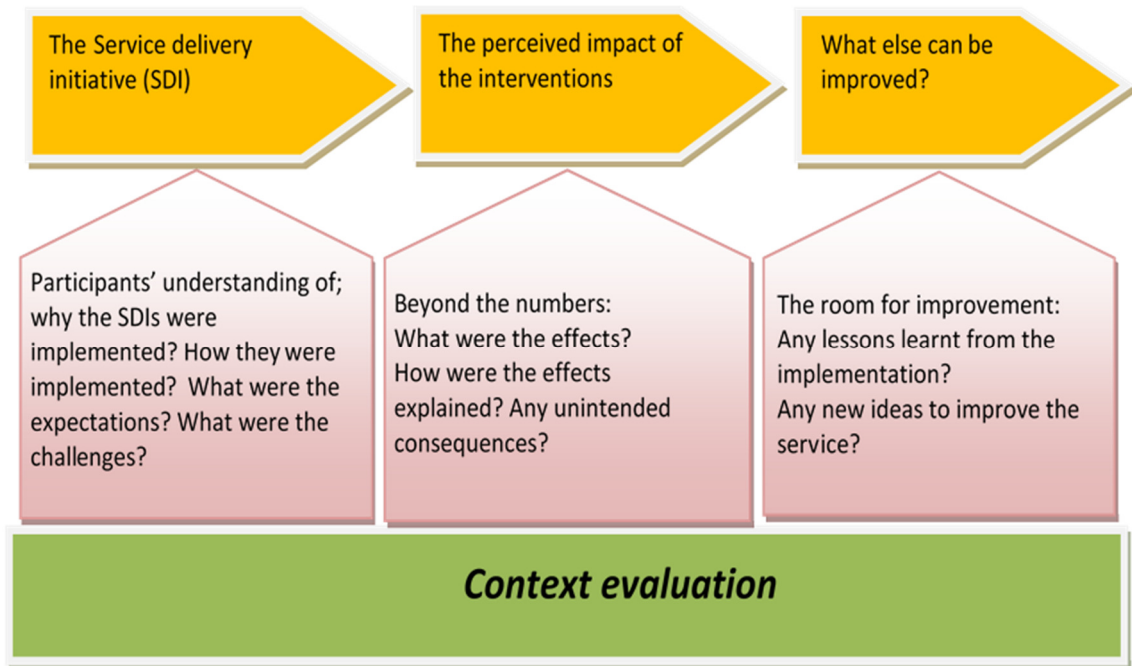
## **5.2 Methods**

### **5.2.1 Study design: the qualitative case study**

The study used the qualitative case study design. A qualitative study provides an avenue for researchers to understand how participants make meaning of a phenomenon (Pope and Mays, 2006; Seidman, 2013) such as the implementation of SDIs within a radiology department. The qualitative case study design is adopted for this study because it allows researchers to explore in detail a phenomenon demarcated by time and activity, through the collection of detailed information using a variety of data collection instruments and procedures (Yin, 2009). The case study method allows data to be collected, analysed and interpreted with a view to understanding participants' perceptions of a particular case in detail. In other words, the qualitative case study method allows for the examination of the wider context of an intervention (Yin, 2009) including the unexpected impact of the interventions and according to Glesne (1999), seek alternative explanations for the perceived outcomes. Figure 5.1 summarises the conceptual framework for this qualitative study.



**Figure 5.1 The conceptual framework (logic model) for the qualitative study**



## 5.2.2 Study setting

The study was performed in the radiology department of the Birmingham Heartlands Hospital site of the Heart of England NHS Foundation Trust (HEFT). The study setting was described in detail in chapter 1 section 1.3.

## 5.2.3 Study participants

The participants were healthcare professionals (staff of the radiology department and referring clinicians within Birmingham Heartlands Hospital) who used radiology services between 2008 and 2015. The participants were chosen from those who had experienced the SDIs and agreed to share their experiences. Participants

were selected using purposive sampling (Gray, 2009) to represent the referring clinicians and key staff groups within the radiology department.

A general email which included a brief description of the study was sent to 395 potential participants (appendix 16). Two separate emails were sent: (a) to referring clinicians using the hospital consultants' mailing list and (b) to the radiology staff using the radiology staff mailing list. This is an accepted method for inviting members of an organisation to take part in a research study (Gray, 2009). Potential participants were advised to contact the researcher (BO) for more information if they were interested in sharing their experiences. The study information sheet (appendix 17) was sent to the potential participants who made enquiries, by email.

### **5.2.3.1 Inclusion criteria**

To be included in this study, the participants must be using radiology services as a healthcare professional, and is either a;

- a. Hospital based consultant who refers patients to the radiology department,
- b. Consultant radiologists,
- c. Radiographers/sonographers or
- d. Secretary (transcriptionist) within the radiology department.

There might be an argument for including patients and GPs in the qualitative interviews. However, they were excluded (a) due to time and financial constraints; this being an unfunded student research project that needed completion within a tight time frame and (b) this researcher believes that the views of the hospital-based referring clinicians will closely approximate those of GPs as referrals from the outpatient and GP clinical pathways are classified as 'routine examinations' and generally have similar waiting times.

### **5.2.3.2 Exclusion criteria**

The following persons were excluded from participating in the study;

- a. Locum /agency staff,
- b. Any member of staff who did not fit the criteria listed in the inclusion criteria.

### **5.2.4 Data collection and transcription**

Data was collected using the qualitative interview instrument. Interviews are an important source of information in a case study (Yin, 2009) and they allow for detailed exploration of participants' experiences (Von Wagner et al., 2009). Qualitative interviews allow researchers to learn about what they cannot see and explore alternative explanations for what they can see (Glesne, 1999; Seidman, 2013). This is especially important because people experience the same phenomenon in different ways. The topics explored in the interviews included participants' understanding of

why the interventions were implemented, the perceived impact of the interventions, alternative explanations for the perceived impact of the interventions and suggestions for further improvement of the radiology service (appendix 18 Topic guide for the semi-structured qualitative interviews).

Face-to-face semi-structured interview was used for this study. A semi-structured interview is an appropriate method to explore these issues as it allows the accounts of participants to be elicited while giving the researcher the flexibility to accommodate the perspective of each participant and to probe deeper into areas of interest (Boyce and Neale, 2006; Von Wagner et al., 2009). Semi-structured interviews allow the researchers to be guided by the research questions as well as allowing the participants to expose on areas of interest to them (Von Wagner et al., 2009). The questions were framed in an open ended format to allow participants freedom to answer as they wished which gives the researcher the opportunity to tap into their experiences.

Preliminary analysis was done alongside the interviews. Recruitment into the study was stopped when no new themes were emerging from the interviews. This is termed saturation of the themes (Mason, 2010; Baker and Edwards, 2012). However, for the purposes of data triangulation, the interviews were not stopped until at least, two participants had been interviewed from each of the four staff groups to be purposively sampled (referring clinicians, consultant radiologists, radiographers/sonographers and transcriptionists).

Data triangulation is the process of collecting data from different individuals, collecting diverse forms of data or using different data collection instruments (Carter et al., 2014). Data triangulation was ensured by interviewing referring clinicians from different clinical departments, different staff groups within the radiology department and no less than two participants from each of the four groups to ensure that diverse perceptions and experiences were explored.

The interviews were conducted by the researcher (BO), between 20<sup>th</sup> February and 16<sup>th</sup> July 2015. All interviews were conducted in the participants' offices except two which were conducted in a radiology consultation room. All interviews were initially scheduled for 20 minutes. The interviews were conducted, recorded, and transcribed by the researcher (BO). Features of spoken (oral) language such as "um", "eh", stutters, pauses, non-verbal and involuntary vocalisations etc. were removed to make the transcript easy to read. Some researchers refer to this method of transcription as denaturalised transcription (Oliver et al., 2005).

### **5.2.5 Data analysis**

Data analysis is the process of making sense of qualitative data by reducing, consolidating and interpreting the data (Walcott, 1994; Braun and Clarke, 2006). The transcripts were read several times and recurrent expressions of the participants' perceptions of their experiences were coded. The descriptive coding method (Walcott, 1994; Saldana, 2013) was adopted. Descriptive coding summarises the basic topic of a chunk/passage of qualitative data; what the participant is talking

about, using a short phrase (Saldana, 2013). The descriptive coding method allows for thematic analysis of the coded data (Auerbach and Silverstein, 2003; Smith and Osborne, 2008).

According to Braun and Clarke (2006), thematic analysis is a technique for recognising, analysing and presenting patterns (themes) within qualitative data. Thematic analysis was done in line with the six steps outlined in Braun and Clarke (2006): (a) familiarity with and transcribing the data (b) generating the initial codes and analytic ideas (c) searching for themes (d) reviewing the themes (e) defining the themes and (f) writing up the report. The codes generated above (step b) were subsequently grouped into more general sub-themes which bring together participants' experiences into a broad 'descriptive group' (step c) which can then be interpreted (Braun and Clarke, 2006). The broad 'descriptive groups' were further coalesced into broader groups (themes) which are linked to and addressed the research questions (steps d and e).

A theme is the fundamental concept that links the expressions found in a text, to the research question (Ryan and Bernard, 2003). A theme has also been defined as a level of pattern response or meaning that captures something important about the data in relation to the research question (Braun and Clarke, 2006). The themes generated in this analysis were independently verified by a medical sociologist (one of the supervisors of this thesis). Data storage and management was done with Nvivo10™ (QRS international Ltd, Melbourne, Australia).

## **5.2.6 Ethical considerations**

As previously stated in Chapter one, this study received favourable ethical opinion from the Science, Technology, Engineering and Mathematics Ethical Review Committee, University of Birmingham (ref: ERN\_12-1537 dated 20<sup>th</sup> February 2013, updated 8<sup>th</sup> September 2014) (Appendix 1). Local NHS organisation' permission was also obtained from the Heart of England NHS (appendix 2). All participants were provided with the study information sheet (appendix 17) which explained the purpose of the study, the type of information to be gathered and its intended purpose.

The participants were informed that they could withdraw from the study at any point in time should they wish to do so. During the interviews the participants were given the opportunity to address any concerns that they might have had. The individual participants and their responses were not revealed to anybody outside the research team. All participants were adult (NHS staff). The participants signed a consent form for the interview which also provided permission to use direct quotations in publications provided that anonymity is preserved (appendix 19).

## **5.3 Results**

Invitation to participate in this study was sent to 395 people, 63 (16%) of which agreed to participate. Fourteen of those who agreed to participate were interviewed. Table 5.1 shows the distribution of the participants by professional group. The referring clinicians were from the departments of oncology, respiratory medicine,

general surgery, accident and emergency and infectious diseases. In presenting the results, two identifiers will be used to mark extracts from the participants' responses: the study recruitment number, and the professional group identifier. For example, "thank you for interviewing me" (001, clinician), refers to an extract from participant number one who is also a referring clinician.

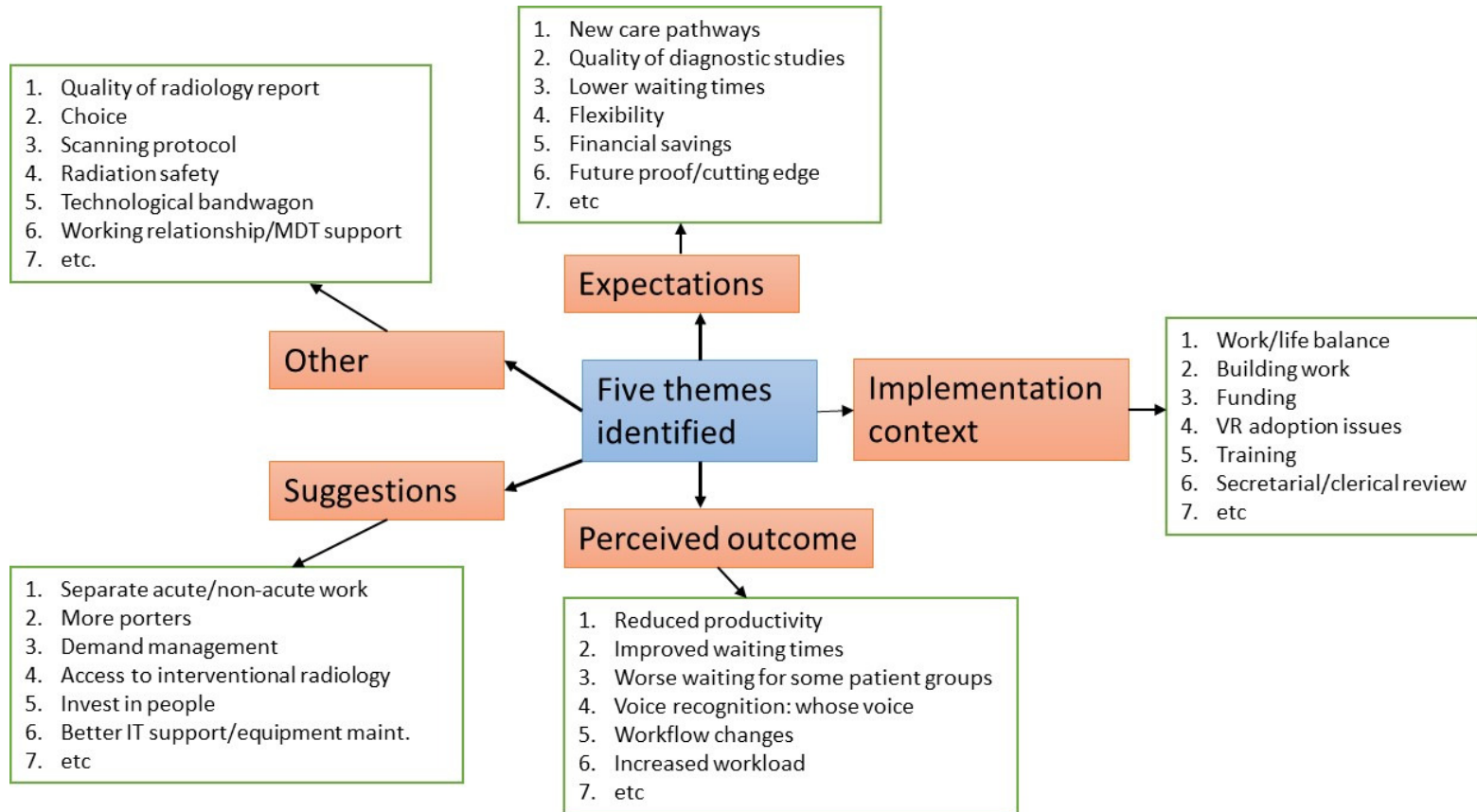
**Table 5.1 Study participants by professional group**

<i>Interviewed group</i>	<i>Professional group identifier</i>	<i>Number interviewed</i>
<i>Referring clinician</i>	Clinician	7
<i>Consultant radiologists</i>	Radiologist	3
<i>Radiographers</i>	Radiographer	2
<i>Medical secretaries / transcriptionists</i>	Secretary	2

Thematic analysis of the data identified five themes (Figure 5.2): (a) expectations, this theme captures the participants' understanding of the reasons for implementing the SDIs and what the SDIs were expected to achieve; (b) the implementation context, captures the wider context within which the SDIs were implemented and what challenges were encountered; (c) perceived outcomes and alternative explanations, captures the perceived effectiveness of the interventions and explanations of why they might have worked or not; (d) suggestions, captures the participants' suggestions for how the radiology service could be further improved and e) other, captures any other important issues raised by the participants.



**Figure 5.2 The themes identified from analysis of the qualitative interview data**



The theme other is not discussed further as it does not directly address the research questions. The results are presented by themes in the following sub-sections.

### **5.3.1 Expectations**

This theme captures the participants' understanding of the reasons for implementing the SDIs and what the SDIs were expected to achieve. The expectations for the three interventions are presented below.

#### **5.3.1.1 The CT intervention**

Most of the participants, especially referring clinicians expected pre-examination waiting times to improve following the CT intervention. However, other participants including radiologists, and radiographers expected very minimal if any improvement in pre-examination waiting times. This was expressed with phrases like

*I was expecting waiting times to drop following the new scanner (006, clinician).*

*I didn't think the waiting time would greatly be affected. Because I think in terms of CT the throughput is quite high anyway (008, radiologist).*

*But we didn't expect that to change the waiting time a great deal (012, radiographer).*

The scanner was also expected to bring the possibility of introducing new care pathways for patients with chest pain. A radiologist and an A&E consultant while

explaining their expectations from the new CT-Scanner talked about the acute cardiac care pathways and how the affected patient population presented a real re-admission challenge to the hospital.

*... well originally, the whole reason we got, or part of the reasons we were able to get it, was that A&E will go and have this pathway for acute cardiac care where they did that triple rule out for PE, dissection and coronary arterial diseases (009, radiologist).*

*There are patients who are high risk, you take one look at the patient and you think this is a walking time-bomb, do an angiogram. And there are patients who are intermediate risk in which you are unsure if they have cardiac sounding chest pains ... being labelled as having angina by their GP. They keep re-presenting. And unless we have, you know, absolutely clear imaging ... to tell them you have normal coronary arteries, they become re-admitted. These are the highest rate of re-admissions which we think could be avoided (004, clinician).*

The 320-slice CT-Scanner was not only expected to improve the diagnostic quality of some complex examinations and provide opportunities for clinical research, it was also expected to remain relevant for a number of years to come (future proofing).

*The expectation was that we would be able to do cardiac imaging of the top order. And it was probably the second scanner going into the NHS. So we were at the leading edge ... peripheral angiograms are quicker and they are better quality studies ... the virtual colonoscopy, I think they are better on the 320-slice because there is less peristaltic activity (008, radiologist).*

*... and yes, with the 320-slice, I'm sure you know, we can start looking at subarachnoid pathway and all sorts of things ... I mean we do scan subarachnoid now, but I think to a greater degree of accuracy will be good (007, clinician).*

*So currently any research that I am doing involving research scans happens over at xxx [names hospital] ... But the addition of this scanner will potentially mean that I could scan some of my patients here (002, clinician).*

*But anything that we introduce clinically now, you know is likely to be here for a number of years, so we needed to think about future proofing (010, radiologist).*

### **5.3.1.2 The speech recognition reporting (SRR) intervention**

Participants' expectations from the SRR system were quite varied. Many of the participants felt that SRR might lead to reduced report turnaround times, some expected that this might be at the expense of productivity and a few participants expected waiting times to increase for some clinical pathways.

*Well I think obviously the expectation must be from our point of view that we get much quicker turnaround of reporting which is important to us in emergency medicine (007, clinician).*

*... there's got to be a reduction in the length of the time from dictating the report to verifying it, because it is verified there and then (010, radiologist).*

*Well, there is basically, there is a gain to be obtained by using voice recognition which is the immediacy of the report. And which is clear, which is definitely a gain ... but there is a trade-off against that gain ... I completely expected to be less productive with it, as a sort of predictable side-effect (009, radiologist).*

*The expectation was that, my expectations were limited actually, in the sense that I was not too keen (008, radiologist).*

*I would have thought that it would have produced a faster report but only in that small subset of patients where it is done sort of outside the hours or maybe close to the end of the day where you would often wait for the secretaries to type them up (010, radiologist).*

*We all expected that it will reduce the report turnaround time, because you were expecting that you will be able to report smoothly without any hassle, without any problem ... (011, radiographer).*

*I thought it will increase the waiting time for reports, especially with outpatients, and oncology clinics, GP referrals as well (014, secretary).*

Other participants felt that SRR reporting was implemented as a cost-cutting measure; not particularly to reduce report turnaround times.

*... we initially invested money in voice recognition thinking that we could save money ... when we went from magnetic tape to digital, I think that was what we needed. And I think we should have stopped there (008, radiologists).*

*... it might save on secretarial time; save money, even if it doesn't save time (002, clinician).*

### **5.3.1.3 The extended working-hour (EWH) intervention**

Many of the participants expected the EWH intervention to improve access to service and reduce waiting times. Some of the participant thought that EWH was not necessarily implemented to reduce waiting times though, but to stop pre-examination waiting times from spiralling out of control.

*I thought it would bring it down (002, clinician).*

*I expected it to almost stay the same. Again, you would have an initial may be improvement when you first implemented it (010, radiologist).*

*... And then all the outpatients that would have been done during the day, have been pushed to the 5 to 8. If we didn't do that extended day, they would be waiting even longer (008, radiologist).*

*Simply because the workload, the caseload, the demand for the services just exceeded what potentially we will be able to do. So when you extend the working hour it is just to stand still. ... We are just managing at the national waiting limits 6 to 8 weeks or something like that (012, radiographer).*

*I mean, well, I suppose, because I'm a cynical sort of person and I know we are drowning under the demand, I probably realised that we weren't going to actually make a dent on the waiting times (009, radiologist).*

Other reasons given by the participants for implementing the EWH intervention included increased flexibility for working families, to improve attendance rate and to improve patient flow by facilitating timely discharge of patients from the hospital.

*It will just give some increased flexibility when they can come, because some people are at work and they like coming after hours. So it will make things quicker (006, clinician).*

*... to start with, it was to provide a little bit more wide range of time because sometimes working families will sometimes struggle to make it during the day. So giving them evening hours ... will hopefully improve the attendance rate (012, radiographer).*

*... you can't expect patients to wait on the hospital ward longer than they should. Not that we scanning might make it better, but we want less excuse for clinicians not to send patients home (008, radiologist).*

## **5.3.2 The context of implementation**

This theme captures the wider context within which the SDIs were implemented; including how the interventions were implemented and the challenges encountered during the implementation.

### **5.3.2.1 The CT intervention**

There was an initial challenge of building work which was done to accommodate all CT-scanning activities in one location. This allowed the scanners to

be sited back-to-back, sharing a single control room and support staff. Training of radiographers to operate the scanner was also highlighted as an initial challenge. Participants also noted that following its installation, the CT-scanner could not be used to its full potential because of funding constraints.

*When we replaced the Aquillion one, we actually did some building work and made it into a dual scanner on the back of the old scanner. Now before, prior to that, we had a CT-Scanner within the main department and a CT-Scanner peripheral to, by A&E (010, radiologist).*

*...but we did have a problem because we had a number of radiographers rotating through CT and all needed to know how to work the new scanner, but not only work the new scanner but also be able to use the new technique of volume smart scanning and cardiac scanning (010, radiologists).*

*What did not happen, is that there was not enough funding to do all the patients we would have liked to do ... So there was a rationing of what we could do for the patients (008, radiologists).*

The participants felt that the new scanner created fresh demand especially for complex and time-consuming imaging procedures, which the department did not have the capacity to cope with. Each of the complex procedures done, displaced about three routine procedures.

*... but we were also by obtaining a 320-slice Aquillion scanner, we were also taking on a new set of patients because we couldn't previous to that perform CT cardiac exams. So we were adding extra*



*patients to our list ..., a burst of patient coming from lots of different areas which we couldn't really cope with after a bit, because lots of clinicians were asking for the tests and we couldn't really, we didn't have the staff or the capacity input to match that in terms of resources to try and combat it really (010, radiologist).*

*So if you just did standard scans, you could have done three scans in the same time it takes to do a cardiac scan. The scan itself takes a third of a second, but the preparation delays things, so I suppose it swings around (008, radiologist).*

### **5.3.2.2 The speech recognition reporting (SRR) intervention**

A major challenge with the implementation of the SRR system was getting clinicians to use it. Some of the clinicians were not particularly keen on the SRR system. Some participants also noted that the initial training on the software could have been better.

*... not all the consultants were using it. Majority of them didn't use it (013, secretary).*

*I would think that about half of the consultants didn't use voice recognition reporting because they didn't like it (014, secretary).*

*I was one of the less pro- voice recognition people. In the sense that why would I want to do secretarial work, why would I want to be paid xxx [quotes radiologists' hourly pay] when somebody who was paid xxx [quotes medical secretaries' hourly pay] could do it better (008, radiologist).*

*there were some reporting radiographers during that time who didn't even attempt using SRR. They just carried on using the normal dictation because they can't just, can't use it. It was not working for them (011, radiographer).*

*... it was placed on the computer and you have to use it. I think I had half an hour training on voice recognition and I did have that (012, radiographer).*

Those who adopted the SRR system were selective about the type of work they did with it. When asked, what proportion of their reporting was done with SRR, one participant replied

*Probably 20 to 30%, in the end they would have been all the inpatient work. So I would have done all the inpatient work to make sure it is done and dusted and anything that is outpatient I would rather do it in my own time in my own style (008, radiologist).*

Another participant was asked if they selectively chose when to use SRR, and the participant replied

*Yes, I used to do that, I used to do that. So A&E for example, I will always use voice recognition for A&E because they needed it instantly (009, radiologist).*

There was a general perception that the SRR software was not as good as it could be, that it slowed down the reporting process and that errors were slipping into the reports.

*... and also the fact that voice recognition when we initially started in 2009 was totally rubbish (008, radiologist).*

*But it just doesn't get it, kind of that last 20%, if you know what I mean, it is kind of like, it seems to get stuck at about 80% good. And that last little bit you always have to struggle with ... I was always frustrated by that business of the lack of it being slightly good enough, you know, it will not just learn certain things and so that last 20% always used to be an annoyance and slows you down (009, radiologist).*

*The problem was that the ability of the voice recognition was a bit poor and it often misspelled words, misheard you and you often had to re-type what you were dictating. The quality of the software certainly isn't good (010, radiologist).*

*... I wasn't happy with it at all ... it was rubbish. It wasn't good at all (011, radiographer).*

*I guess one of the unpredictable thing was the fact that we are sending out more reports verified with errors in them now (009, radiologist).*

*We thought it was not timely, it was not effective enough and errors were slipping into the reports (008, radiologist).*

*... you quite often get mistakes in it because of the voice recognition not understanding and then that not being picked up by the radiologist (001, clinician).*

In response to a question regarding why errors are not picked up by radiologists during the report dictation, editing and verification process, a radiologist replied

*One of the sort of psychological features of the thing is that when you read what you've just dictated you don't see the errors in it (009, radiologist).*

As a result, some clinicians dictated the report, saved it and came back after a while to check and sign off the report.

*I know some of the consultants will VR the report and save it, then go back to it later and read it and verify it. Apparently they are not supposed to be doing that. But I know some do. And I can understand why (014, secretary).*

Referring clinicians felt that the errors in the report do not generally affect patients' management and many of them appear to be happy with the SRR system. When asked if the errors in the radiology reports impacted on patient management, participants responded as follows;

*... not usually and usually it is clear that it is a voice recognition issue you know, because it makes no sense at all, you know, it is not that it is, they are missing out, you know, there is no abnormality or something like. It is that it doesn't make any sense at all you know, talking about tomatoes or something ... (001, clinician),*

*I have noticed a few mistakes in reports but there are mistakes in everything if you look closely enough (002, clinician).*

*I mean there is bound to be, I mean there is bound to be, even when you haven't done voice recognition. Even years when it is done with a tape, I mean there is always mistakes (003, clinician).*

However, referring clinicians noted that they occasionally have to contact the radiology department to clarify the contents of some report.

*So quite often you get, get something that doesn't quite make sense and you can usually interpret what it means ... occasionally you have to go back and just double check exactly what they meant, but usually you can work it out (005, clinician).*

*... well sometimes what they require us to do is to go and follow up. So I might go and speak to the radiologists, say what did you mean there (007, clinician).*

Frequent contact with clinicians wanting to clarify errors in radiology reports; which constitutes an interruption of the routine workflow was reported by some participants and they felt that this has detracted from the efficiency of the whole system.

*... so that impacts negatively on your efficiency when you are trying to, well everyone's efficiency, which is obviously what it is supposed to be boosting (007, clinician).*

*We've got GPs phoning in, and writing in to say can you check this report for me? Is this correct? ... Some are glaringly obvious, like in the wrong side of the body, but some are not so obvious (013, secretary).*

*I heard a few of them complain that the system gets it wrong. That errors were creeping into the reports. And I can understand that because I receive letters and phone calls from GPs and even consultants querying the content of reports, for clarification (014, secretary).*

Participants felt that the SRR intervention was poorly implemented particularly with regards to medical secretaries whose jobs were directly affected. A secretarial review was supposed to have taken place before the implementation of the SRR intervention but this never happened.

*... secretarial and clerical review was planned sort of in advance of the implementation of the voice recognition but it didn't happen (010, radiologist).*

There appeared to be confusion regarding what to do with the secretarial staff following the SRR intervention. Some participants suggested that the secretaries were going to be made redundant.

*... and we were intent on getting rid of staff who are in essence paid pittance. You've lost the goodwill of those people ... That was a totally confidence shattering experience for the people involved (008, radiologist).*

Apparently there was a change of plan to keep the secretaries and find some other work for them to do.

*So what they decided to do was to look for other jobs for us to do. And it was like almost in a panic; they can do this, they can do that. So we've now got so much to do, which is not really medical secretary-type work (013, secretary).*

According to some participants, many of the secretaries were unhappy and left.

Therefore, some radiologists do not have a named secretary.

*... and people are leaving because they are not happy. So we have lost about 50% of our staff (014, secretary).*

*... and now we've got more consultants than ever, less secretaries, which means that a lot of the consultants don't have a named secretary (013, secretary).*

The participants' noted that radiologists are having to do more secretarial-type duties such as MDT referrals and clinical letters, as a result of losing many secretaries.

*And for me personally I do a lot of clinical letters to patients. ... And also I do not have a safe way of recording clinical letters. I would have a tape in the past, I will put on it and say this is for patient X and here you go. The tape might have gone missing, but at least the secretary will do all that is necessary, to format it, do whatever and put it on. Now I am becoming the typist, I need to fight with the voice recognition to do an English letter which is not medical English (008, radiologist).*

The participants also explained that following the CT and SRR intervention, many more scans were done than could be reported on a single radiologist's session.

Therefore, the department adopted a workflow process, which meant that all CT-scans that could not be reported on a given session go into reserve (reporting pot). The scans on the 'reporting pots' are reported using 'initiative lists', whereby radiologists are paid to report a certain number of scans outside of their normal contractual hours. But they (radiologists) chose what scans to report based on their sub-specialty and probably time waited on the list.

*... In terms of scans as well they changed the reporting mechanism. Whereas they [radiologists] all used to have allocated scans, now they have pots ... now, the pot allows radiologists to cherry pick ... (012, radiographer).*

### **5.3.2.3 The extended-working-hour (EWH) intervention**

The EWH did not apply to the whole department; the EWH intervention mostly applied to radiographers. In terms of clinical units, the EWH intervention applied to CT, interventional radiology and MRI, in addition to plain film imaging within the A&E setting which always had a 24/7 service. The rest of the Department; management, secretarial and clerical staff did not work extended-hours.

*... not the whole Department, certainly key areas like CT, MRI. MRI currently does, but doesn't really offer a full A&E service (010, radiologist).*

*I think it hasn't really impacted very much on radiologists. It has affected people who have evening lists, who need to be available to cover the contrast examinations, I am one of them (008, radiologist).*



There was a considerable staff opposition to the EWH intervention and finding enough staff to cover the EWH rota was initially a problem. Also it became more difficult to cover emergency shifts which might result from sickness etc.

*The satisfaction of the extended working day, initially was bad. Because initially it wasn't wanted by staff, because the staff didn't want to work more of weekends and staff didn't want to work more evening shifts (010, radiologist).*

*Now there is no point stretching the day without having enough bodies on the ground which I know created so much troubles in getting the rotas and everything sorted for the extended day. I think that is crucial (008, radiologist).*

Some participants thought that staff were not too happy about EWH because they did not want to work unsocial hours or lose their overtime pay.

*... They were paid more with the old working arrangement because they get overtime payments whenever they did out-of-hours shifts ... So now if there is any shift that needs covering, people just say no, unless they make it a bank shifts. Then they get paid on bank (011, radiographer).*

Some participants felt that the EWH intervention was poorly implemented especially with regards to radiographers who wanted to work different shift patterns: there were radiographers who wanted to compress their contractual hours into few days of work but were not accommodated. Some radiographers left as a result.

*... there were radiographers who wanted to work only long hours and others wanted to work weekends. We did not exploit those opportunities. Instead, we wanted everybody to work the same shift pattern. And we lost a lot of our good radiographers as a result. We could have been more flexible (008, radiologist).*

*I mean depending on where you were, for the staff who have families, some had to leave because it was impossible to do (012, radiographer).*

The challenge of reporting the extra scans that were done during the EWH was pointed out by the participants, as EWH did not generally apply to radiologists.

*So scanning 8 to 8 has meant we scan more patients but it hasn't addressed the problem of reporting (009, radiologist).*

Another unintended consequence of the EWH intervention is that there is no buffer to accommodate evening catch up lists in the event that a scanner breaks down within the day.

*... but at the moment you lose that buffer of sort of catch up ... And if this scanner goes down unexpectedly, you don't lose just three hours of scanning time. You lose eight hours of scanning time (009, radiologist).*

An important workflow change was also introduced as part of the EWH intervention: Radiographers on routine EWH shifts were gradually trained to perform urgent but non-complex CT-examinations for the A&E and inpatient clinical pathways.

These would have ordinarily required the attendance of the on-call cross-sectional radiographer who has to come from home.

*During the extended-working-day, we also gradually trained the on-site radiographers to do routine CT-examinations for the A&E instead of having to call the on-call radiographer which meant that these examinations are done a little bit quicker too (010, radiologist).*

### **5.3.3 Perceived effectiveness and alternative explanations for the impact of the SDIs**

This theme captures the perceived effectiveness of the interventions and explanations for why the interventions might have worked or not.

#### **5.3.3.1 The CT intervention**

Some participants thought that waiting times have improved considerably over a long period of time but could not attribute this to the new CT-Scanner.

*Over the period of ten years that I have been in the Trust, there has been a significant improvement in radiology services especially the CT-Scanner. How much of that is contributed to by the new scanner is difficult to say (004, clinician).*

*Yes, I think, I mean it depends, over a reasonably long period of time the improvement is completely dramatic. I mean this used to be a truly awful department ten years or so ago. And the waits were months and months and months for everything and nobody wanted*

*to do anything and that's completely changed ... Your waiting times, I don't know when, the waiting time is miles better than it used to be (003, clinician).*

However, there were participants who felt that there was little or no improvement in waiting times, particularly for the outpatient clinical pathway.

*It is probably slightly better than it was but it was always pretty good to be honest, so I wouldn't say there is a massive improvement (001, clinician).*

*I didn't really notice a lot of difference to be honest (002, clinician).*

*I mean I suppose some patient who don't need scan urgently and are getting it after a certain amount of time, just because there is a new scanner, the amount of time would stay the same, like for instance a routine scan I don't think it has to be any faster (006, clinician).*

There is a perception that waiting times for the inpatient and A&E clinical pathways have improved considerably. When a clinician was asked how the new CT has impacted on waiting times, the clinician replied “... *I mean Inpatients scans are incredibly fast (006, clinician).* In response to the same question, an A&E consultant replied ... *imaging is rarely our problem (007, clinician).* This view is supported by participants from the radiology department.

*Patients in A&E, their waiting time for CT-scan is not a problem of radiology ... Anybody who is deemed to require a CT from A&E,*

*literally the scanner is available from that minute (012, radiographer).*

The participants explained that the perceived improvements in waiting times are the results of efficiencies gained from the building work which allowed the two scanners to be sited back-to-back, sharing a single control room and support staff, rather than the speed of the scanner.

*... the reason for the improvement was, when we replaced the Aquillion one, we actually did some building work and made it into a dual scanner on the back of the old scanner. Now before, prior to that, we had a CT-Scanner within the main department and a CT-Scanner peripheral to, by A&E which were working separate from each other; which didn't utilise the capacity of both scanners. When a scanner became free for instance in the main department or in A&E there wasn't necessarily the communication to the other scanner. But now because they are next to each other with the dual control room, you could almost work continuously (010, radiologist).*

*... and I think we probably gained a little bit in the fact that the scanners are now back-to-back with a shared control room and a shared waiting area. Whereas before they were in remote locations ... And so the porters and the assistants who are cannulating the patients and preparing the patients are all in one place. The radiographers can swap patients from one scanner to the other when they know there is a gap. So we've gained those little bit of efficiencies like that (009, radiologist).*

*... if you can reduce your scanning time by a few seconds over 30 patients in a day; 30×20 seconds is nothing in the grand scheme of things [laughs]. The time it takes is in getting patients on and off the scanner and do the other things which has not changed (012, radiographer).*

The participants appear to suggest that the new CT has had a differential impact on the four clinical pathways: improved waiting times for A&E and inpatients, and deteriorated waiting times for the GP and outpatient clinical pathways. The explanations given for the perceived pattern of impact included the fact that HEFT has focused its limited resources on facilitating the flow of patient through the acute pathways (A&E and inpatients), by necessity. On top of that, is the clinical priority system operated within the hospital which ensures that A&E and inpatients are given priority because their conditions are more acute.

*... So the whole organisation has concentrated for the last five years, I would say, on the front door of the hospital and patient throughput. So all the resources and pressure and targets and everything is about getting patients seen promptly in A&E, triaged, scanned if necessary and then slotted into wherever they have got to go; get them out of A&E into an inpatient bed. And then the next thing is to get the inpatient scanned and sorted, quickly moved through the system. So all the focus has been on that, by necessity, so that is what's happened (009, radiologists).*

*... so whether you buy five scanners, what you are trying to do is to scan those who are in hospital first before we scan the outpatients (012, radiographer).*

Limited hospital resources and a necessary focus on the inpatient and A&E clinical pathways is further compounded by increasing inpatient population and a changed case mix.

*I would expect that we have got a higher turnover of inpatients and the inpatients are sicker, so they take priority. And, but that is appropriate you know, so I mean an outpatient is an outpatient because they don't need to be in, because their condition is thought to be less urgent ... (002, clinician).*

*... when I started in 2005, my standard CT list would contain, consists of maybe 1/3 or ¼ inpatient work, and 2/3 will be outpatient work. And in the last 2 to 3 years, my work seems to be 90% inpatient work and 10% outpatient work. So the mix has changed, meaning that every patient that hits the hospital seems to be getting a scan. And then all the outpatients that would have been done during the day, have been pushed to ... (008, radiologist).*

Some participants felt that the CT intervention has not had the expected impact of reducing patients waiting time because of increased workload, including extra workload of complex and time-intensive examinations generated by the new scanner itself.

*... but we were also by obtaining a 320-slice Aquillion scanner, we were also taking on a new set of patients because we couldn't previous to that perform CT cardiac exams. So we were adding extra patients to our list ..., a burst of patient coming from lots of different areas which we couldn't really cope with after a bit, because lots of*

*clinicians were asking for the tests and we couldn't really, we didn't have the staff or the capacity input to match that in terms of resources to try and combat it really (010, radiologist).*

*... however because of increasing demand, you might find that the waiting time is stable (006, clinician).*

*... we've got more patient coming through now, so again the number of patients we are seeing is more, the scanner is quicker, so probably your waiting time is much the same (002, clinician).*

*When you are getting increases each year of 10 to 15%, you need a third scanner to make an impact, you know not a super-fast second scanner (009, radiologist).*

*Year on year we are seeing increasing demands for cross-sectional imaging, both inpatient and outpatients, so we are never going to be able to catch up, unless we are constantly expanding our services (008, radiologist).*

Each of the more complex and time-consuming examinations which were done on the new scanner displaces about three routine scans.

*So if you just did standard scans, you could have done three scans in the same time it takes to do a cardiac scan. The scan itself takes a third of a second, but the preparation delays things, so I suppose it swings around (008, radiologist).*

The new scanner was not always used in its ultrafast 320-slice mode: outside the complex examinations such as coronary angiogram, peripheral angiogram, virtual



colonoscopy etc. the scanner is used as 64-slice scanner, *just another scanner* (009, radiologist).

*In terms of actual speed, as explained technically, the benefit of having a 320-slice scanner is purely on limited applications. It is never used in that 320 mode for everything else* (012, radiographer).

*In terms of general scanning of which we did a lot of body scanning, we effectively use it the same as a 64-slice Scanner* (010, radiologist).

*... for most of the other stuff that I do, like staging oncology scan and stuff like that, it is just another scanner ..., so that was, the main interest for me was just getting another scanner* (009, radiologists).

In summary, a combination of the necessary organisational focus on the acute clinical pathway, the clinical priority system operated within the hospital, increased workload, especially increased workload of time-consuming scans generated by the new scanner, changed case mix, and the fact that the scanner is not always used in its ultrafast 320-slice mode has meant that any improvement made possible by the efficiency gains which resulted from workflow changes have benefited the acute clinical pathways at the expense of the non-acute clinical pathways.

### **5.3.3.2 The speech recognition reporting (SRR) intervention**

There was a general perception that following the SRR intervention, the report turnaround times deteriorated considerably for the outpatient and GP clinical pathways, and improved for the inpatients and A&E clinical pathways.

*... for inpatient scan you are almost guaranteed report within a couple of hours if not sooner. For urgent scans, reports are sometimes dictated and appears on the system before the patient comes back from the scan which is very good (004, clinician).*

*Outpatients, I have noticed a deterioration. So again it used to be relatively quick but I think for outpatient reporting of radiology, that definitely takes longer now than it used to. So it could easily take several weeks for a report to come out now on a scan, whereas they used to be quicker (001, clinician).*

*... some of the routine scans sometimes take a bit of time to come back, a couple of weeks or something (002, clinician).*

A radiologist summarised the perceived impact of SRR on the report turnaround times as follows:

*A&E gets an amazing service, all the inpatients get an amazing service, and all the cancer staging patients and the outpatients have been pushed to the bottom of the pile ... And that's what has happened (009, radiologist).*

Some participants felt that part of the reason why the SRR system might have not had the expected impact is because the delays in radiology reporting is not caused by high transcription times, but by a shortage of radiologists.

*Somebody has to do the voice, somebody has to do the report, I mean the reporting is sometimes quite slow, I think your problem is the number of radiologists (003, clinician).*

*... and then you got reporting issues. You got consultant capacity issues as well (005, clinician).*

*I was led to believe that it will be quicker because they will be reported more or less as they are done. But that is when they find someone to report the examinations. I honestly think it would increase the turnaround times for some patients (013, secretary).*

*... Well I guess that the block, the barrier to the system might not be the speed of the transcription... because if the rate limiting step is not the speed of the time it takes the secretary to type ... then that would probably explain it (002, clinician).*

The few radiologists and reporting radiographers that were available concentrated on reporting the examinations for the acute clinical pathways, which meant that the acute clinical pathways experienced some improvement in turnaround times.

*So they are doing the urgent reports first, as they should. So the outpatient reporting completely takes the backseat and sometimes isn't getting touched much (013, secretary).*

As noted by participants, a critical factor in the ineffectiveness/differential impact of the SRR system is that it was implemented in a piecemeal approach which is partly attributable to the poor quality of the SRR software. There wasn't a 100% switchover from the old reporting framework to the SRR system: not all the consultants and reporting radiographers used the SRR system.

*... not all the consultants were using it. Majority of them didn't use it. We didn't notice much difference in our work then (013, secretary).*

*I would think that about half of the consultants didn't use voice recognition reporting because they didn't like it (014, secretary).*

Those consultants who switched over to SRR, might have experienced a learning curve, but more importantly were also selective on how they used SRR: they used it for about 20 to 30% of their reporting workload and mostly on reporting examinations for the acute clinical pathways.

*... so yeah, I think it's just, I think it's a bit of a learning curve, isn't there (005, clinician).*

*Probably 20 to 30%, in the end they would have been all the inpatient work. So I would have done all the inpatient work to make sure it is done and dusted and anything that is outpatient I would rather do it in my own time in my own style (008, radiologist).*

*there is a sense then, a consultant thinking well, it is an outpatient report, the patient is not coming back to clinic for two weeks, why do I need to go through the hassle to do voice recognition which is harder work for me? Why can't I just bang it onto a tape and give it to the secretary? (005, clinician).*

*... I used to do that, I used to do that. So A&E for example I will always use SRR for A&E because they needed it instantly (009, radiologist).*

Other participants felt that radiologists' productivity would have suffered as a result of the SRR intervention due to (a) poor quality of the SRR software and (b) radiologists having to spend more time doing secretarial duties instead of radiology reporting (c) because of having smaller number of secretaries within the department.

*We sort of expected the system to be slightly better than it turned out to be, voice recognition. If it was a bit better, then that will be nice because we wouldn't have to make so much editorial changes to it (009, radiologist).*

*... But there is a trade-off in the amount of our productivity, the number of scans we are able to get through has gone down because we are spending more time on the secretarial side of things (009, radiologist).*

*And for me personally I do a lot of clinical letters to patients. ... I would have a tape in the past, I will put on it and say this is for patient X and here you go. ... Now I am becoming the typist, ... (008, radiologist).*

*... it took a lot longer time to report therefore you report less (010, radiologist).*

Some participants explained that the report turnaround times for the GP and outpatient clinical pathways have not only increased but have also become increasingly variable partly due to the adoption of counter-productive workflow processes following the SRR intervention: (a) due to a high error rates in the dictated reports, many radiologist are saving the reports and coming back after a while to check

and sign them off because “... when you read what you’ve just dictated you don’t see the errors in it” (009 radiologist) and (b) another counter-productive workflow allowed radiologists to choose what they report from “reporting pots” instead of being allocated a reporting workload.

*... In terms of scans as well they changed the reporting mechanism. Whereas they [radiologists] all used to have allocated scans, now they have pots. ... now, the “pot” allows radiologists to cherry pick. Not that they would do such things, but they do. Therefore, reporting times are very haphazard, very haphazard (012, radiographer).*

### **5.3.3.3 The extended working-hours (EWH) intervention**

Many of the participants from the radiology department felt that the EWH intervention has not improved patients waiting times.

*I think everyone was expecting that there will be a massive reduction in the waiting time. But looking at it now I don’t think there has been any difference. I can’t see any difference (011, radiographer).*

*Because I’m a cynical sort of person and I know we are drowning under the demand, I probably realised that we weren’t going to actually make an indentation into the waiting times (009, radiologist).*

However, many referring clinicians felt that the EWH intervention has helped them in early decision-making and to discharge patients sooner.

*... it allows us to make decision making a lot sooner. Often we can discharge patients early so that's really important. Especially with things to do with headache and things like that you know ... And I think it is allowing us to make, actually discharge patient a lot sooner as well ... (007, clinician).*

The participants explained that the EWH intervention was not meant to reduce patients' waiting times but to keep it from spiralling out of control.

*... Extended day while it does provide more access to radiology over a longer period of time which is good, it also is there just to cope with the workload, so it doesn't necessarily mean that you're going to have a decrease in waiting times. It's because the waiting times were so bad that the extended-working-day had to happen, not as an intervention to make waiting times less than they were (012, radiographer).*

*... then all the outpatients that would have been done during the day, have been pushed to the 5 to 8. If we didn't do that extended day, they would be waiting even longer (008, radiologist).*

The perception that waiting time did not deteriorate following the EWH intervention was seen as a sign of effectiveness, as captured by one of the participants.

*But then, you know in a sort of funny sort of way, not letting the waiting times slip in the NHS radiology, is as good as, if you see what I mean, as good as shortening it. I mean being able to stand still is an achievement, because we are so overwhelmed with demand (009, radiologist).*

There were also suggestions that staffing issues and poor initial uptake contributed to the pattern of impact associated with the EWH intervention; the lack of improvement in waiting times.

*... firstly, I would want to know how well the late slots were being used, how willing patients are, particularly outpatient are to coming out in the evening on a winter evening for instance, so whether you are able to fully utilize the additional slot, either early in the morning or late in the evening (005, clinician).*

*... there is no point stretching the day without having enough bodies on the ground which I know created so much troubles in getting the rotas and everything sorted for the extended day. I think that is crucial (008, radiologist).*

When asked why the A&E clinical pathway had experienced reduced pre-examination waiting times in the longer term following the EWH intervention, a participant explained that the gradual training of on-site radiographers to perform urgent but non-complex CT-scans for the acute clinical pathways might be a contributory factor.

*... we also gradually trained the on-site radiographers to do routine CT-examinations for the A&E instead of having to call the on-call radiographer which meant that these examinations are done a little bit quicker (010, radiologist).*



### 5.3.4 Suggestions for service improvements

One of the objectives of this study was to elicit suggestions from participants on how the radiology services at Birmingham Heartlands Hospital might be further improved. This theme captures all such suggestions. One of the most frequently suggested improvement strategies is the separation of the acute (A&E and inpatient) from non-acute (outpatient and GP) activities. According to the participants such separation will have workflow, training, aesthetic and psychological benefits.

*There are clearly issues with inpatients getting onto the scanner, so I think that is where our problem is. Our problem should be a dedicated outpatient scanner and dedicated inpatient scanners. Which should then make it easier to regulate the flow of all patients and you might get more patients in (008, radiologist).*

*... And this will be away from the acute thing ... and it will be a good teaching type place ..., I mean when you are sitting on a CT-Scanner here, I mean, all hell break loose, doesn't it? (003, clinician).*

*I mean when I am trying to report a complicated outpatient scan and people are knocking on my door asking for where is the, you know CT brain or CTPA that I have just done. It gets very inefficient. ... some people can be just reporting inpatients and other people can hide away somewhere and be very productive with outpatients, it is a good thing to do. And in terms of acquiring the images, I think that probably works as well (009, radiologist).*

*When you segment, like I told you on CT-scans, segment services to say this scanner deals with acute medical cases, this scanner deals*

*with only inpatients, the scanners deal with outpatients, to run the whole services within the same bunch does make the whole thing very inefficient (012, radiographer).*

*... wires, drips, bleeps and it's not happy. So the patient thinks oh my God that could be me (008, radiologist).*

There is a general perception that too many scans are being done, probably because it is too easy to get a scan. An A&E consultant said *"it is one of the Trusts in which getting CT-scan organised is fairly easy and the response is very good (004, clinician)*. Another referring clinician summarised it as follows:

*I think we also do scan more people than maybe we did before. And I don't know to what extent that is because we can get things done more easily, so maybe in the past we might have waited a little bit, thought about it for a while because we knew we wouldn't have got the scan straight away. Now we do it straight away. So maybe we scan more people down than we did (002, clinician).*

The fact that the demand for radiology services, especially cross-sectional imaging, is increasing was a recurring theme throughout the interviews. One referring clinician felt that there is a need to manage the number of scans being done.

*I think too many scans are done. So I think radiologists are probably very busy doing the scans and reporting the scans and doing interventions. I sometimes think that radiologists could spent some time sort of querying the clinicians. Like I am surprised how little I get challenged. Like someone saying, you know, I just booked a CT and I wouldn't mind if every now and then someone is on the phone*

*to me and say this is, why are you doing this? you should do an x-ray or is this really indicated? Because I think too many scans are being done and I am as guilty as everyone else. It is so easy to book a scan. It is easy to get the patient out of your room by saying we do a CT-scan. And I think there should be a bit of gate keeping, but that takes, I think a higher level input. So the radiologist has got to have time to look at the request (006, clinician).*

Does the radiology department do enough demand management? This question was put to another participant who responded as follows:

*the clinicians don't provide sufficient information, detailed information, background information to make you able to make an informed decision yourself, so you have to ask them for more information. So, and getting hold of them, is very very difficult and is very time-consuming. So if I have like 20 scans to vet, to protocol, it could take you, you know, most of the morning [laughs] sometimes to deal with all of those cases. By the time you have located the people who are in theatre ... in different hospital ... not answering their phones or whatever. In many ways, I am not advocating that we do this, but in many ways we should just dispatch with all of that and just scan whoever comes through the door (009, radiologist).*

Some participants felt that extending working hours to 8 PM is not sufficient, they would rather see a 24-7 working.

*If we have to work a seven-day week as clinicians in acute medicine for the hospital, inevitably I think radiology would have to do that too (002, clinician).*

*I think, I mean it is good, I mean it needs to be seven days a week, and it needs to be more than that, and that is the way we are all going (003, clinician).*

Closely related to the 24-7 working is a suggestion to improve access to interventional radiology. Participants thought that access to interventional radiology is a problem, and that possibly less interventional work is being requested as a result.

*I sometimes suspect that we do less interventional radiology than maybe we could or should ... because we haven't got such easy access to it (007, clinician).*

Participants also suggested employing more porters because often times expensive equipment and staff are kept idle and unproductive because of inefficient patient transport system.

*We are a high capital ..., with million pounds machine that is sitting idle for 40 minutes because we haven't got a porter to bring patients down, it is just ludicrous (009, radiologist).*

Participants felt that better IT support system, better equipment maintenance for optimal performance of the PACS, network systems and efficient image delivery will improve productivity across the board: *I don't want to see egg timers (009, radiologist)*. They felt that if possible equipment should be maintained on weekends rather than weekdays.

*So the answer to that problem is to make sure that your service level agreement with your maintenance people are all tiptop. You have got good IT support and all the rest of it so that it doesn't go down. When it does, you got 26 radiologists and 60 radiographers twiddling their thumbs. And the aftermath of patching it all up afterwards takes most of the following week (009, radiologist).*

Staff shortages was identified as a major problem that can be improved. The need to invest in people was a recurring theme as well; employ more staff and train them properly.

*We just need more people, we seem to always be, you know, we seem to be always few people short of what we need all the time. So a bit more staff will be good as well (009, radiologist).*

*... So I think the capital has to be spent on people ... Now there is no point stretching the day without having enough bodies on the ground ... If you can have enough money to get enough people to come into the place, then you can open out services, you can provide more kits (008, radiologist).*

Participants from the radiology department suggested that more scanners are needed not a second superfast scanner.

*One thing that you have to do is to increase the number of machines that you have. For the population that we serve, if you are looking at this Trust for example say MRI and CT-Scanners, we only have four CT-Scanners ... In terms of access to these services, United Kingdom still lags way way behind anybody else in Europe, it is a fact (012, radiographer).*

*The key thing is more capacity. And matching of the gap between demand and capacity. So we would need another CT-Scanner, another MRI scanner, no question (009, radiologist).*

*When you are getting increases each year of 10 to 15%, you need a third scanner to make an impact, you know, not a superfast second scanner (009, radiologist).*

*... well with this number of increasing workload, increasing number of referrals, we just have to think of other options like having new, installation of new machines, more machines are needed (011, radiographer).*

Other suggestions included a re-implementation of the cardiac care pathway which has been hindered by a lack of funding.

*There are two things I would suggest, the first thing is we need seriously to look at re-implementing the pathways for doing CT coronary angiograms in patients because that will definitely reduce the duration patients with chest pain stay in hospital and also reduce the re-admission of those patient which is one of the highest numbers of re-admitted that we have (004, clinician).*

The next sub- section is a reflection on how the researcher has maintained a balanced view throughout this qualitative research project.

### 5.3.5 Reflexivity

Reflexivity in qualitative research has been defined as being sensitive to the ways in which the researcher (including his roles, expertise, experience and prior assumptions) and the entire research process shape the data collection and analytical process (Mays and Pope, 2000). The advantages and disadvantages of interviewing colleagues (peers) for research purposes are well discussed in the literature (McConnell-Henry et al., 2009; Burns et al., 2012; Blythe et al., 2013; McDermid et al., 2014; Berger, 2015; Elaine Byrne et al., 2015a).

According to Berger (2015), as a researcher conducting qualitative interviews within a radiology department in which I work, my position can potentially affect the research process in three major ways: (a) access, (b) researcher-researched relationship and the type of information the participants are willing to share (c) my background and worldview, which might shape how questions are posed and the lens through which the data is filtered.

Access covers the willingness of the participants to share their experiences with a researcher whom they felt might be more understanding of their settings (Berger, 2015). Working within the radiology department makes me an 'insider' which might have facilitated recruitment of participants and made organising the interview appointments a bit easier. Also being an 'insider' helped with a quick establishment of rapport and trust based on pre-existing relationships. This meant that the participants were more likely to engage in an in-depth discussion of the questions with greater openness. For example, one of the participants while making a suggestion for radiology

to separate acute from non-acute activities recounted a detailed personal experience to me.

*... the last time I was having a cardiac one here, I come in and then, you have to have your heart rate below 65 or 60, so you are getting all calmed and ... somebody rushed in from A&E with somebody with multiple trauma with tubes and lines and I get bundled out onto the corridor again. It was a hell of very sick patient with multiple trauma and he gets done and comes out again and I get wheeled in again and I tried to get my pulse rate down to under 65 again you know, to try and be all calm again. ... Somebody who doesn't know what is going on, I would have been completely destroyed by all that you know (003 clinician).*

The researcher-researched relationship addresses the negative effect of power and ensures that the relationship is ethical and non-exploitative (Pillow, 2003). All the people interviewed in this study apart from the two medical secretaries, are peers.

The association between reflexivity, the researcher and the investigated phenomenon is under developed (Berger, 2015). My professional background has meant that I understand radiology processes, the interventions investigated, the terminologies and jargons used by the participants within this context. This often means that a relatively large amount of data can be collected in a short time (Warr et al., 2011). As argued by Hockey (1993) my familiarity with the systems and processes of the department meant that I can approach the study with some knowledge and can



easily gauge the accuracy of the responses and follow up with clarifying questions as required. Peer interviews do have some disadvantages.

The disadvantages of peer interviews as listed by Unluer (2012) and Berger (2015) include (a) dual identity (b) making assumptions about participants' responses without seeking clarifications, (c) participants making the assumption that the researcher already knows what they know and (d) familiarity with the investigated phenomenon might 'colour' the researcher's view of the data. I share with the participants, experiences of the investigated interventions. The participants can potentially assume that I already know what they know and probably withhold some information. On the other hand, my background could potentially mean that I make assumptions about what a participant was trying to say and fail to seek clarification. Again, participants may also feel inhibited about making their true views known to a colleague, especially if those views are different from the ones they have openly identified with. Crucially, there is the potential that my view and interpretation of the data is filtered through the lens of my professional background, experiences and assumptions.

I have a favourable disposition to the interventions discussed in this thesis (super-fast CT-Scanner, SRR and EWH interventions). I use speech recognition software at home and have partly used it in writing up this thesis report. But I feel that I have maintained objectivity and distanced my personal disposition and experiences from the data collection and analysis.

## 5.4 Discussion

Thematic Analysis of the interview data revealed several sub-themes (broad descriptive groups) such as workload, workflow changes, productivity, demand management etc. The sub-themes were amalgamated into four (plus one) themes which are linked to and addressed the research questions: expectations, context of implementation, perceived effectiveness and alternative explanations, suggestions for further improvement and other (Figure 5.2). Many participants felt that waiting times especially for inpatients improved dramatically following the CT intervention. It was perceived that the improvement was driven by workflow changes which included siting the CT-Scanners back-to-back, sharing the same control room and support services such as cannulation and patient preparation, rather the scanning speed. Sharing of personnel across both scanners was felt to increase the effectiveness of the staff. This is consistent with the finding of previous studies that highlighted the importance of workflow changes in the productivity of a CT-Scanner, by reducing scanner idle time (Katz et al., 2006; Boland, 2008). Workflow issues such as reducing the distance travelled by staff (Aloisio et al., 2009), and good quality computer network (Wang et al., 2012) have been reported to increase the productivity of a CT-scanning unit. The participants emphasised their perceptions that scanning speed may not have contributed meaningfully to the observed improvement by arguing that (a) the scanning speed is critically important only for limited applications such as cardiac CT, peripheral angiogram, virtual colonoscopy etc.; outside these applications, the scanner is used just like any other scanner and (b) high scanning speed could possibly gain a

few seconds of table time per patient, other scanning activities like patient preparation have not changed. This view is supported by Roos et al. (2002), who argued that workflow rather than the speed of multi-slice CT-Scanner is the main driver of productivity in a CT unit.

The business case for the scanner was partly based on its ability to support new care pathways, according to the participants. Some participants felt that implementation of the cardiac care pathway has a potential to improve acute bed utilisation, as patients suspected of having cardiac sounding chest pains presented one of the highest risks of re-admission. HEFT is suffering from acute-bed shortages (HEFT, 2013a) and is focusing most of its resources on patient flow through A&E and inpatient wards, it should therefore benefit from cutting down re-admission rates. However, this expectation was not fully realised due to funding constraints. It is therefore very important for any radiology department purchasing such expensive equipment to carefully consider the impact of clinical pathways funding on its operations.

In the past, radiology was perceived as constituting a bottleneck in patients' journeys through the healthcare system (Audit Commission, 2002). The findings of this study suggest that while that might be the case for the outpatients and GP clinical pathways, CT imaging is not perceived as a problem for the A&E and inpatient clinical pathways, in this particular Trust. This is probably because a high priority is given to the flow of acute patients through the hospital.

There is a general dissatisfaction and frustration with the SRR system. Radiologists perceive the SRR system as being prone to errors and having a negative

impact on productivity. The findings from this study support previous research which identified the challenges of SRR within radiology to include low productivity (Strahan and Schneider-Kolsky, 2010), poor quality of software/errors (Basma et al., 2011; Najran et al., 2015) and high rates of dissatisfaction and frustration due to increased editing time (du Toit et al., 2015). Participants felt that the errors did not generally affect patient management. However, some clinicians noted that they spend valuable time clarifying the errors in radiology reports which they believe is due to the use of SRR. Time spent on clarifying errors in the radiology report is seen as a drag on productivity for the entire system. Error rates and hopefully, productivity should improve as the SRR software matures (Najran et al., 2015).

There is no question that the SRR system has the potential to reduce the delay between dictation and transcription of radiology report. There is a general perception that report turnaround times improved for the A&E and inpatient clinical pathways at the expense of the outpatient and GP clinical pathways following the SRR intervention. The reasons given by the respondent for this pattern of effect included

- a. Shortage of radiologists; implementers must be aware that SRR systems only address the delay between dictation and transcription of reports, but cannot address the problem of a shortage in reporting capacity - *“somebody has to do the voice” (003, clinician)*.
- b. The hospital concentrated on facilitating the flow of patients through A&E and inpatient wards, prioritising reports for these pathways is part of the facilitation process.

- c. A piecemeal SRR implementation; many of the clinicians did not use the SRR software due to dissatisfaction and frustration with the poor quality of the software; those who did, mostly used it to report A&E and inpatients examinations.
- d. Increased workload, specifically an explosion of inpatient scans.
- e. Adoption of counter-productive workflow practices such as the 'reporting pot' which probably allowed radiologists to select whatever they wished to report, might have added to the increased variability in report turnaround times for the non-acute clinical pathways.
- f. Adoption of personal workflow practices which negated the whole essence of SRR: some radiologists used SRR to dictate reports, saved the reports and came back to verify them much latter.

These findings are consistent with the result a previous study which concluded that benefits obtainable from SRR correlated more with work habits of clinicians and workflow processes than with workload, suggesting that human behaviour is a critical factor (Krishnaraj et al., 2010).

The EWH intervention applied to all radiographers and a few radiologists. Although the general expectation was that EWH might lead to reduced pre-examination waiting times, some of the participants thought that the EWH intervention was implemented just to cope with increasing demand and stop waiting times from spiralling out of control. As a result, even if pre-examination waiting times

did not reduce; but did not deteriorate either, the intervention was perceived as effective, according to some participants. These findings are consistent with the results of a previous survey study of radiotherapy departments in UK (White et al., 2007) which found that EWH mostly applied to radiographers and that the main reason for extending the working hours was a response to check increased waiting times arising from increasing demands.

Most of the referring clinicians felt that the EWH intervention was very successful as it helped them to make clinical decisions earlier and discharge patients sooner, thereby reducing the length of hospital stay. This is also consistent with the long held view that improved access to diagnostic imaging services has a wider implication for the overall effectiveness of the hospital (O'Kane, 1981). Possible ways for EWH to reduce the length of hospital stay include; (a) reduced waiting times for imaging and (b) referring clinician acting more quickly on the results of imaging or both. This finding is consistent with the results of a report commissioned by NHS England on Seven-Day working (Knowles et al., 2013) which found that weekend working (not radiology in particular) was associated with a savings of about 5000 bed days by the Salford Royal NHS in the 2012/13 activity year.

Respondents pointed out that the challenges of implementing the EWH intervention included the problem of finding enough staff to cover the shifts, lack of buffer time to implement evening scanning sessions should the scanner fail during daytime. During the EWH intervention, on site radiographers were gradually trained to perform urgent but non-complex CT-scans for the inpatient and A&E clinical pathways,

instead of calling the on-call specialist CT radiographer. The participants explained that, this workflow change meant that those CT-scans were done a little bit quicker. This finding particularly highlights the importance of qualitative data on interventions, as will be discussed later in chapter six (a synthesis of the quantitative and qualitative studies).

One objective of the current study was to elicit suggestions from participants on how radiology services at the Birmingham Heartlands Hospital can be further improved. Eliciting suggestions from service users has been highlighted as a very astute way to improve radiology services (McMenamy et al., 2015). The suggestions given by the participants included a separation of the acute from non-acute activities; better maintenance, performance and support for the PACS and IT systems; employing more porters; re-implementation of the cardiac care pathway and better CT-scan demand management. Participants felt that it is probably too easy to have a CT done within the hospital. This in itself is not a bad thing, but it does mean that the threshold for requesting CT-scan becomes reduced, thereby increasing the demand. Better demand management will hopefully cut down on the number of scans being done and ensure that those who require urgent scans get it sooner. The participants felt that separation of acute from non-acute CT-scan activities will not only increase efficiency and throughput but will also enhance patients' experiences and teaching.

## **5.5 Summary and conclusion**

### **5.5.1 Strengths and weaknesses of the study**

A major strength of this study is that it used semi-structured peer (insider) interviews. According to Byrne et al. (2015a) peer interviews are a valuable means of improving understanding by generating information which will be difficult to obtain if the interviews were conducted by 'outsiders'. As previously mentioned, semi-structured interview allowed the accounts of participants to be elicited while giving the researcher the flexibility to accommodate the perspective of each participant and to probe deeper into areas of interest (Boyce and Neale, 2006). Another important aspect of this study is that participants were drawn from diverse professional groups, specialities and clinical departments, thereby ensuring data triangulation.

A possible limitation of this study is that the interviews were conducted several years after the interventions. There is a distinct possibility that participants' memory of the interventions might have faded over time. This can be considered a weakness for the study. Although the interviews were conducted two to five years after the interventions, the participants recalled the interventions in great detail as illustrated by the personal experiences shared by a participant while supporting a suggestion to separate acute from non-acute services (see section 5.3.5 Reflexivity).

Again, due to limited resources, interviews, transcription and analysis were performed by one researcher (BO). This could be seen as a limitation. However, data collection by one person could be seen to ensure consistency in the data collection



process. With regards to the analysis, the themes generated from the data were independently verified by a medical sociologist (one of the supervisors of this thesis) using a few transcripts.

## **5.5.2 Cross-cutting contextual issues**

Of particular interest in the thematic analysis of the interview data is the 'cross-cutting' of contextual issues across the interventions. The sub-theme workflow changes (and many others) re-occurs in the explanations of the impact of the CT, SRR and EWH interventions on patients' waiting times. For example, for the CT intervention, siting the scanners back-to-back allowed important workflow changes, which meant that the scanners worked almost continuously with less idle time.

For the SRR intervention, some radiologists adopted 'negative' personal workflow changes that involved dictating the reports and instead of signing it off immediately, saved and came back to it latter. Participants felt that errors were slipping into radiology reports due to poor quality of the software, and as one participant explained it, if you read what you have just dictated, you are unlikely to detect any errors it.

For the EWH intervention, the workflow changes involved training the on-site radiographer to perform urgent routine scans for the A&E and inpatient clinical pathways instead of waiting for the on-call radiographer who has to come from home. Such cross-cutting of the contextual issues explains why the results were presented by themes, sub-stratified by the interventions.

### 5.5.3 Summary

This study has investigated the context within which the CT, SRR and EWH interventions were implemented and their perceived effectiveness. Thematic analysis of the semi-structured interviews data identified four major themes: expectations, the implementation context, perceived outcomes and alternative explanations and suggestions for further improvement. Broadly, the interventions were implemented within the following context: (a) there was no separation between acute (A&E and inpatients) and non-acute (outpatient and GP) activities, (b) acute activities were prioritised over non-acute activities, (c) increasing workload and (d) staff shortages.

For the CT intervention, the participants felt that pre-examination waiting times improved for the acute clinical pathways and deteriorated for the non-acute clinical pathways. For the SRR intervention, there is a general perception that the report turnaround times deteriorated considerably for the outpatient and GP clinical pathways, and improved for the inpatients and A&E clinical pathways.

For the CT intervention, workflow changes (siting the scanners back-to-back) was identified as the most likely factor responsible for improved waiting times rather than the speed of the scanner. For the CT and SRR interventions, the combination of a necessary organisational focus on the acute clinical pathways, the clinical priority system operated within the hospital, increased workload, especially an increase in the volume of complex time-consuming scans generated by the new scanner, changed case mix, a piecemeal implementation and poor quality of the SRR

system and the adoption of counter-productive workflow changes were identified as some of the reasons for the pattern of effects.

Some participants felt that the EWH intervention was implemented mainly to cope with the increasing demand, not necessarily to reduce waiting times. The EWH intervention was perceived as effective because it has kept waiting times from further deterioration. More importantly referring clinicians felt that EWH allowed them to make clinical decisions earlier and discharge patients sooner.

#### **5.5.4 Conclusions**

The qualitative study found that the three interventions were implemented in a radiology department where; (a) there is no separation between acute (A&E and inpatients) and non-acute (outpatient and GP) activities, (b) acute activities are (rightly) prioritised over non-acute activities, (c) demand for services is increasing (d) there is an acute staff shortage (e) the SRR and EWH interventions were poorly implemented and (f) staff have a high level of discretion. The above contextual issues have shaped the interventions in such a way that improvement in waiting times for the acute clinical pathways was gained at the expense of deteriorated waiting times for the non-acute clinical pathways.

# **CHAPTER 6. A SYNTHESIS OF THE QUATITATIVE AND QUALITATIVE EVALUATIONS OF THE THREE SDIs IMPLEMENTED WITHIN BIRMINGHAM HEARTLANDS HOSPITAL**

## **6.1 Background**

As previously noted in chapter one, section 1.2.1, the mixed methods research design is a powerful tool for investigating the effectiveness of healthcare interventions as it leverages on the strengths of the quantitative and qualitative research methods (Creswell and Clark, 2011). The mixed methods design, comprising interrupted time series (ITS) analysis and semi-structured interviews, has been used to evaluate the impact of three interventions to improve patients' waiting times in Birmingham Heartlands Hospital. The findings of the quantitative study were reported in chapter four, and the qualitative study in chapter five. The quantitative study found a differential impact of the interventions on waiting times for the four clinical pathways: improved waiting times for the inpatient and A&E clinical pathways and deteriorated waiting times for the outpatient and GP clinical pathways. The qualitative study investigated the contextual issues which might have shaped the interventions.

The results of the quantitative study are better explained and understood when synthesised with the qualitative study.

This chapter presents a narrative synthesis of the quantitative and qualitative studies; using the qualitative data to explain the findings of the quantitative study. Section 6.2 provides an overview of the general method adopted for the synthesis. Section 6.3 is a brief summary of the quantitative and qualitative results. Section 6.4 synthesises the quantitative and qualitative study. Discussion and conclusions are presented in sections 6.4 and 6.5 respectively

## **6.2 Methods**

The methods for this chapter draw extensively from the recommendations of Feters et al. (2013) and Creswell Creswell and Clark (2011) for integrating a mixed methods study at the reporting level. As previously discussed in chapter 1 section 1.2.1, Feters et al. (2013) identified three ways of integrating a mixed methods study at the reporting level: the narrative, data transformation and joint display approaches. The narrative approach is further subdivided into the weaving, contiguous and staged approaches. The weaving approach to narrative synthesis is used within this chapter and involves writing both qualitative and quantitative findings together on a “theme-by-theme or concept-by-concept basis” (Feters et al., 2013); on intervention-by-intervention basis in this case.

## 6.3 Results

Many of the participants cited increased workload as a major reason for increased waiting times. Although the quantitative study controlled for the effect of workload on waiting times, it does not account for the change in the proportion of the weekly workload that is attributable to the various clinical pathways (case mix). The proportion of the weekly workload attributable to the various clinical pathways did change. And although the participants believed that there was an “explosion” of inpatient scans, the quantitative study found that the proportion of the weekly workload attributable to inpatients only increased marginally from 33% to 36% within the study period while the proportion attributable to the outpatient clinical pathway decreased from 47% to 41% (Table 4.2). This might have given the impression of an “explosion” of inpatient scans.

Five main contextual issues whose effects cut across all three SDIs were identified in the qualitative study: (a) organisational focus on the inpatient and A&E (acute) clinical pathways, (b) radiology resources are limited and shared amongst the four clinical pathways: there is no separation of acute and non-acute activities, (c) adoption of productive and counter-productive workflow changes, (d) acute staff shortages and (e) increased workload. The impact of all three interventions was shaped by the contextual issues mentioned above, however there were some other issues that are peculiar to each intervention. In the following sub-sections, a weaving narrative synthesis is presented on an intervention-by-intervention basis.

### **6.3.1 The CT intervention.**

The quantitative study found that the CT intervention was associated with an immediate and sustained improvement in pre-examination waiting times for A&E; an immediate and continued improvement in pre-examination waiting times for inpatient and an immediate deterioration followed by a longer term improvement of pre-examination waiting times for outpatient and GP.

The results of the quantitative study are largely in line with findings of the qualitative study. Most of the participants felt that there was a general improvement in the waiting times for inpatients and A&E. The participants felt that the waiting times for routine CT-scans (outpatient and GP) deteriorated following the CT intervention. Although the quantitative study found that pre-examination waiting times for outpatient and GP improved in the longer term, this was not perceived by the participants.

There was a perception that waiting times for CT within the hospital have been improving gradually over a long period of time. This is probably the only discordance between the results of the qualitative and quantitative studies: the quantitative study found no significant underlying trends of pre-examination waiting times before the CT intervention.

## **6.3.2 The speech recognition reporting (SRR) intervention**

The quantitative study found no significant underlying trend of report turnaround times for the outpatient and GP clinical pathways. Whereas the underlying trend of report turnaround times for the inpatient and A&E clinical pathways were improving before the SRR intervention. Following the SRR intervention, there was an immediate and sustained deterioration in the level and variability of report turnaround times for outpatient and GP. On the other hand, there was an immediate and sustained improvement in report turnaround times for A&E. There was no change in the level and trend of report turnaround times for inpatient. The variability of report turnaround times for inpatient and A&E reduced following the SRR intervention.

Again, the findings of the qualitative study are largely in line with the results of the quantitative study. Participants felt that report turnaround times have greatly improved, (*'incredibly fast'*) for the A&E and inpatients clinical pathways; and deteriorated considerably for the outpatient and GP clinical pathways following the SRR intervention.

## **6.3.3 The extended-working-hour (EWH) intervention.**

### **6.3.3.1 Pre-examination waiting times**

The quantitative study found that the underlying trend of pre-examination waiting times were increasing for all four clinical pathways before the EWH intervention, but this was not significant for the GP clinical pathway. The EWH



intervention was associated with immediate and sustained improvement in the pre-examination waiting times for inpatient. The impact of the EWH intervention on the outpatient, GP and A&E clinical pathways was a gradual rather than an immediate improvement.

There is a slight discord between the findings of the quantitative and qualitative studies on the impact of the EWH intervention on pre-examination waiting times. Participants from the radiology department felt that the EWH intervention has not reduced the pre-examination waiting times at all. However, referring clinicians (participants from outside of radiology) felt that the EWH intervention has helped them in early decision-making and timely patient discharge as a result of reduced waiting times following the EWH intervention.

### **6.3.3.2 Report turnaround times**

The quantitative study found that the underlying trend of report turnaround times were increasing for the outpatient and GP clinical pathways before the EWH intervention. The EWH intervention was associated with an immediate and sustained deterioration in report turnaround times for inpatient, but no significant immediate or longer term impact on the report turnaround times for the other three clinical pathways.

There was little disagreement between the findings of the qualitative and quantitative studies on the impact of EWH on report turnaround times. The participants felt that the EWH intervention was associated with increased report

turnaround times for the outpatient and GP (non-acute) clinical pathways. However, the quantitative study found no significant immediate or longer term changes in the report turnaround times for the GP and outpatient clinical pathways.

## **6.4 Discussion**

When combined with a comprehensive qualitative data on the intervention, the ITS design is probably more useful and cheaper than a randomised trial intended to answer a comparable question (Penfold and Zhang, 2013). To the best of the researcher's knowledge, this is the first implementation of a mixed ITS and semi-structured interviews in the evaluation of the effectiveness of interventions to improve patients waiting times within clinical radiology. The qualitative data adds contextual information that allows for a proper understanding and interpretation of the quantitative results.

The quantitative study found that the interventions had differential impact on waiting times for the four clinical pathways. The results are best interpreted by looking at the general context within which the interventions were implemented: that of overwhelming demand for shared limited resources in a system (waiting list) that operated like a priority queue. Within the study periods, the hospital focused most of its resources (including radiology resources), by necessity, on maintaining the flow of acute patients through the hospital.

The interpretation / synthesis of the quantitative and qualitative studies draws extensively from the discipline of service operational research, especially the recent work of Jaeker et al. (2014), on the impact of improved ordering system for ultrasound on performance parameters within an A&E department. The study highlighted with empirical evidence that process improvement (making ordering of ultrasound tests easier) in a system with shared limited resources can result in a negative impact for some other users of the A&E unit, including those who did not necessarily require ultrasound examination. Operations management research has shown that in an interconnected system, where resources are limited and service providers have a high level of discretion, increased resource consumption by one type of user (acute clinical pathways in this case) can lead to congestion for all other type of users (non-acute clinical pathways in this case) (Jaeker and Tucker, 2013). The discretion in this case is the (interpretation of the) priority status accorded the various clinical pathways and to patients within the same clinical pathway, which allowed patients on the higher priority clinical pathways to consume more resources. The next sub-sections discuss participants' explanation of the impact of each intervention in view of the above theoretical propositions.

### **6.4.1 The CT intervention**

Participants felt that the impact of the CT intervention is mainly due to efficiencies gained from positive workflow changes: pre-installation building work allowed the two scanners to be sited back-to-back. This workflow changes allowed the

scanners to operate more efficiently and be less idle. Participants felt that the speed of the scanner might not have contributed much to improved waiting times because (a) scanning time accounts for a very tiny proportion of the scanning process, (b) the scanner is used in its ultrafast 320-slice mode in limited applications.

Previous studies have demonstrated the impact of positive workflow changes on productivity within a CT-scanning unit. For example, Aloisio et al. (2009) demonstrated with empirical evidence that simply reducing the distances that staff had to walk between workstations is associated with increased productivity. The impact of daily efficiency gains is most likely to benefit inpatients because they are within the hospital and can be easily called upon when spaces become available.

In addition, many complex examinations such as cardiac CT and peripheral angiograms were done on the new scanner. These complex and time-intensive examinations were mostly done on the very sick: the acute pathway. Increased consumption of resources by the complex procedures has meant that some routine scans were displaced: thus causing 'congestion' for the routine scans. Routine scans happen to be the priority status of the outpatient and GP clinical pathways. This might explain the deterioration in waiting times for GP and outpatient following the CT intervention. However, the quantitative study found that pre-examination waiting times for GP and outpatient improved in the longer term. It is believed that (a) the cutback in the number of complex procedures due to a lack of funding would have meant that more routine scans could be accommodated, (b) continued training of radiographers which was a challenge at the beginning did improve with time. These

might have contributed to the longer term improvement in waiting times for GP and outpatient.

There was a small immediate and sustained improvement in pre-examination waiting times for A&E. This is not totally unexpected because A&E usually have very low waiting times. The new scanner not having a longer term impact on pre-examination waiting times for A&E might be partly due to (a) there is limited room for improvements in the waiting times and (b) the waiting times for A&E patients are not totally dependent on radiology because as a participant said, *“anybody who is deemed to require a CT from A&E, literally the scanner is available from that minute”* (012 radiographer). Another participant corroborated this fact with an account how, the participant’s scan was abruptly interrupted to accommodate an A&E patient who needed to be scanned:

*.... somebody rushed in from A&E with somebody with multiple trauma with tubes and lines and I get bundled out onto the corridor again... (003, clinician).*

#### **6.4.2 The speech recognition reporting (SRR) intervention**

The SRR intervention was implemented in a piecemeal approach. Not all the consultants and reporting radiographers used SRR. Those who switched to the SRR system were frustrated by the poor accuracy of SRR software; they found that it required a high level of editing and errors were creeping into the reports. A similar finding was reported in du Toit et al. (2015). A high level of frustration meant that they

only used it for 20 to 30% of their reporting workload; mostly using it to report the higher priority cases (A&E and inpatient). Due to the high error rates, some of the users adopted a workflow practice that negated the whole concept of SRR; they dictated the report and verified it much later because if they checked it immediately, they might not see the errors in the reports. A piecemeal implementation coupled with counter-productive workflow gave rise to a two speed system and a high variability in the reporting times for the non-acute clinical pathways. Whereas variability reduced for the A&E and inpatients (Figure 4.6).

Human behaviour has been identified by Krishnaraj et al. (2010) as one of the reasons for not reaping the full benefits of the SRR system in radiology. Krishnaraj et al. (2010) found that two of 30 radiologists in their study did not experience improved report turnaround times because of their individual work habits. The study further states that only those who *“reviewed, revised, and finalized reports at the time of image review”* had improved report turnaround times.

The participants identified another reason for the increase in level and variability of report turnaround times for the outpatient and GP clinical pathways to include a change in the departmental reporting workflow. It used to be that radiologists were assigned to cover and report all examinations done in a scanning session. But now, more scans are done in a scanning sessions than could be reported by the attending radiologist. Therefore, only inpatients and A&E scans are reported on the day and all outpatient and GP examinations go into a reserve (‘reporting pot’) from which radiologists pick and choose what to report based on their sub- specialties (e.g.

musculoskeletal, gastrointestinal, cardiac, etc.) and time waited in the 'pot', using a high level of discretion. In addition, there was also a change in the case mix of radiology workload. Participants felt that they were reporting a lot more of inpatient scans than previously done.

With reference to the previously highlighted work of Jaeker et al. (2014), there are a limited number of radiologists, many more scans to be reported and the radiologists now have a higher level of discretion. The exercise of that discretion is usually in favour of the acute clinical pathways, which introduces congestion into the reporting times for the routine cases (the non-acute clinical pathways). The participants acknowledged that routine cases have been '*... pushed to the bottom of the pile*' (009, radiologist) and '*... sometimes isn't 'getting touched'*' (013, secretary).

A comparison of the current study with a similar study of the impact of SRR on report turnaround time (Hart et al., 2010) reveals two key differences in (a) the quantitative research methods and (b) the context within which the interventions were implemented. Hart et al. (2010) evaluated the impact of a 100% switch over to SRR in an NHS hospital with a stable workload and found sustained improvement in report turnaround times for all four clinical pathways (inpatient, A&E, GP and outpatients). Whereas Hart et al. (2010) used the simple pre- and post-intervention design without control, the current study adopted a more methodologically robust ITS 'segmented spline' regression. In terms of the context of implementation, the previous study adopted a 100% switch over to SRR and reported a stable workload within the study period whereas the current study was a piecemeal implementation of SRR in a

department that is not only experiencing increased workload but also a changed case mix. Workload increased by about 40% within the period of the current study.

### **6.4.3 Extended-working-hour (EWH) intervention**

The EWH intervention had an immediate impact only on the inpatient clinical pathway (immediate and sustained improvement of pre-examination waiting times). The EWH intervention was not associated with immediate improvement of pre-examination waiting times for the outpatient, GP and A&E clinical pathways. The participants thought that the lack of immediate impact of the EWH intervention on the outpatient and GP pathways might be related to low initial uptake of the service and the difficulties with staffing. The quantitative study found that in the longer term, the A&E, outpatient and GP clinical pathways experienced improved pre-examination waiting times following the EWH intervention. The participants felt that this is possibly due to an improved uptake of the EWH service and a resolution of the staffing issues with time. But for A&E, another explanation was found in the qualitative study. Following the EWH intervention, radiographers on the EWH shifts were gradually trained to perform urgent but non-complex CT-scans for the A&E clinical pathway. This meant that the on-call cross-sectional radiographer was not called from home for these scans. This meant that they were done a bit quicker.

Although some participants were sceptical about the effect of the EWH intervention on waiting times, referring clinicians were very positive about its impact. Referring clinicians did not notice any change in waiting times for the outpatient



clinical pathway. This is probably in line with what participants expected of the EWH intervention anyway. Participants believed that the EWH intervention was implemented to stop waiting times from spiralling out of control rather than reduce it.

Investigations of the impact of EWH within clinical radiology is limited to its impact on clinical performance of the individuals working extended-hours (Krupinski et al., 2010; Krupinski and Reiner, 2012) and the training of resident radiologists (Ruutinen et al., 2013). This is first study looking at the impact of EWH on waiting times in radiology.

## **6.5 Conclusions**

Seen through the lens of operational research, the results of this study suggest that in an interconnected system with limited resources, where such resources are shared amongst clinical pathways of varying clinical priority statuses, increased resource consumption by the acute (A&E and inpatient) clinical pathways, limits the resources available / and introduces congestion to the non-acute (outpatient and GP) clinical pathways. This might explain why improvement in waiting times for the acute clinical pathways comes with deteriorated waiting times for the non-acute clinical pathways following the SDIs.

# CHAPTER 7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Introduction

Chapter seven summarises the key findings of this thesis. The overarching aim of this thesis has been to evaluate the effectiveness at reducing patients' waiting times of SDIs implemented within radiology departments. The research questions were:

- a. How effective at reducing patients' waiting times are SDIs implemented within diagnostic radiology departments? and
- b. How have the SDIs recently implemented within the radiology department, Birmingham Heartlands Hospital impacted on patients' waiting times for CT-scan?

This thesis used systematic review to survey the literature for the type of interventions implemented to reduce waiting times within radiology departments and the methods used in evaluating their effectiveness. The ITS design was combined with semi-structured interviews in a mixed methods case study to assess the effectiveness at reducing patients' waiting times of three SDIs implemented within the radiology

department, Birmingham Heartlands Hospital. Section 7.2 summarises the findings of the systematic review and section 7.3 summarises the findings of the case study, respectively, in relation to the research questions. The overall conclusions of the thesis and recommendations for further research are presented in sections 7.4 and 7.5, respectively.

## **7.2 How effective at reducing patients' waiting times are SDIs implemented within radiology departments?**

Chapter two presented the results of the systematic review. The type of SDIs implemented to improve waiting times in clinical radiology includes extended scope practice, quality management, outsourcing, pay-for-performance, productivity-enhancing technologies and multiple interventions. Most of the studies used either the pre- and post-intervention without control or the post-intervention only designs. The majority of the included studies reported improved patients' waiting times. This is not surprising because the pre- and post-intervention study designs are prone to overestimating effect size.

The results of the studies could not be pooled in a meta-analysis due to a high level of heterogeneity. The studies were heterogeneous in terms of varied research design, the breadth / combination of SDIs, variation in the population and settings of the studies. More importantly, there is a large inconsistency in the definition of patients' waiting times within the published literature.

The reporting quality was generally poor. For example, many of the studies that reported improved outcomes did not test and / or report the statistical significance of their findings. Virtually all the included studies failed to give any information on the technical features of the implemented systems or the information technology (IT) infrastructure and the levels of integration within the study settings.

The review concluded that the evidence base of the effectiveness of interventions to improve patients' waiting times in clinical radiology departments is poor. The use of higher quality designs and mapping of the definitions of patients' waiting times in radiology to generic timelines, which should make it easier and less restrictive to pool the results of future studies in a meta-analysis is suggested.

Higher quality studies might consist of interrupted time series or, randomised designs. As there is obviously a need for pragmatism, one possible appealing randomised design might be the stepped-wedge design. The stepped-wedge is a cluster study design, and so would involve multiple sites or modalities, which would (be randomised to) sequentially receive an SDI.

### **7.3 How have the SDIs recently implemented in Birmingham Heartlands Hospital impacted on waiting times for CT-scan?**

Chapter four presented the results of the ITS study performed to evaluate the effects of a 302-slice CT-scanner, speech recognition reporting (SRR) and extended-working-hour (EWH) interventions on patients' waiting times for CT-scan. The ITS study

found that the CT intervention was associated with: an immediate improvement in the median pre-examination waiting times for the inpatient (22%/7.5 hours) and A&E (3%/0.5 hours) clinical pathways; and an immediate deterioration in the pre-examination waiting times for the outpatient (14%/3.5 days) and GP (15%/3.8 days) clinical pathways. A continued (longer term) improvement in pre-examination waiting times was noted for three of the four clinical pathways: inpatients 1% (0.33 hours) per-week; outpatient 0.4% (0.30 days) per-week and GP 0.3% (0.1 days) per-week following the CT intervention. The initial improvement in the pre-examination waiting times for A&E was sustained but there was no additional improvement over the longer term.

Before the SRR intervention the trend of report turnaround times for the inpatient and A&E clinical pathways were improving at the rate of 0.21% per week respectively. The SRR intervention was associated with an immediate deterioration of report turnaround times for the outpatient (20%/0.5 days) and GP (21%/0.5 days) clinical pathways and an immediate improvement of report turnaround times for the A&E (26%/0.7 hours) clinical pathway. The initial improvement in report turnaround times for the A&E clinical pathway was sustained but there was no additional improvement over the longer term. There were no immediate or long-term impact on the report turnaround times for the inpatient clinical pathway following the SRR intervention.

For the EWH intervention, there was an immediate and sustained improvement of pre-examination waiting times for the inpatient clinical pathway

(17%/1.7 hours). There was no significant immediate impact on pre-examination waiting times for the A&E, outpatient and GP clinical pathways. However, the A&E, outpatient and GP clinical pathways experienced improved pre-examination waiting times in the longer term. The EWH intervention was associated with a marginal immediate but sustained deterioration in the report turnaround times for inpatient. There was no immediate or longer term impact on the report turnaround times for the outpatient, GP and A&E clinical pathways following the EWH intervention.

Chapter five presented the findings of the context evaluation of the SDIs. Six main contextual issues that might have shaped the interventions were identified: (a) organisational focus on the inpatient and A&E clinical pathways, (b) radiology resources were shared amongst the four clinical pathways: there is no separate scanner or reporting framework for the acute and non-acute pathways, (c) adoption of productive and counter-productive workflow changes (d) limited resources; acute staff shortages and insufficient number of scanners, (e) increasing workload and (f) challenges with training.

For the CT intervention additional contextual issues included building work, the fact that many complex and time-consuming procedures were done on the new scanner. A lack of funding to continue with the newly developed cardiac care pathway led to rationing/cut-back of the complex procedures. For the SRR intervention, there was a piece-meal implementation; most consultants and reporting radiographers did not use SRR due to its poor accuracy. Those who used SRR adopted a counter-productive workflow process of not signing off the report at the time of image review.

For the EWH intervention, there was poor initial up-take of the service, initial difficulties with staffing the shifts and training of radiographers on the EWH shift to perform urgent but non-complex CT-scans for the A&E clinical pathway instead of having to wait for the on-call radiographer who has to come from home.

The participants suggested the following as possible ways to further improve radiology services at the Birmingham Heartlands hospital: separation of acute from non-acute activities, implementation of active demand management programme to reduce the number of scans being done, improved access to interventional radiology, improved patient transport systems, improved IT systems and better equipment maintenance for optimal performance of the PACS systems with efficient image delivery and improved staff recruitment and retention.

## **7.4 Conclusions**

This thesis concludes that the evidence base for the effectiveness of SDIs to improve patients' waiting times in clinical radiology departments is poor. The studies included in the systematic review of the effectiveness of interventions to improve waiting times in diagnostic radiology are highly heterogeneous and the results could not be pooled. Therefore, organisations wishing to implement any of the reviewed SDIs, should critically appraise the studies for their designs, results, and explanation of the mechanism of impact of the evaluated interventions; especially the components of

the interventions that they think are critical to achieving their (interested parties') objectives.

The three SDIs implemented to reduce patients' waiting times in the radiology department, Birmingham Heartlands Hospital, have had differential impact on patients' waiting times: improved waiting times for the inpatient and A&E (acute) clinical pathways and deteriorated waiting times for the outpatient and GP (non-acute) clinical pathways. This pattern of impact could be explained from the perspective of service operations research. In an interdependent system, like a radiology department; where limited resources are shared amongst clinical pathways of varying priority levels, where there is an acute shortage of staff, demand for service is increasing and service providers have a high level of discretion, an improvement in waiting times for one clinical pathway can be gained at the expense of deteriorated waiting times for the other clinical pathways following a service delivery initiative. This type of interaction should be taken into consideration by service managers, when designing and implementing service delivery initiatives in a system as complex as a clinical radiology department. Recommendations for further studies are provided in the next sub-section.

## **7.5 Recommendations for further research**

This thesis has examined the effect of SDIs on patients' waiting times but has not looked at the cost effectiveness of the SDIs. Therefore, future studies might



examine the cost effectiveness of the interventions. The Birmingham Heartlands Hospital adopted a 100% transition to SRR reporting in April 2015. It will be useful to compare the impact of a full transition with a piecemeal implementation of SRR within the same setting.

This thesis evaluated the SDIs base on a single outcome measure, patient waiting times. The SDIs might have impacted on other quality indicators within the radiology department e.g. patient safety and quality of care, imaging utilisation, aggregate costs, education, research and probably hospital-level quality indicators e.g. length of hospital stay. For example, some participants in the qualitative study felt that the extended-working-hours intervention might have impacted on early patient discharge and that the new super-fast 320-slice CT scanner might have created opportunity for some type clinical research activities within the Trust. Again, due to time and financial constraints, patients and GPs were excluded from the qualitative study.

Future studies might examine the impact of the SDIs on the above mentioned quality indicators, especially imaging utilisation, patients' safety and quality of care, aggregate costs and length of hospital stay. Future studies might also broaden their scope to include GPs and patients to get their perspectives and assess if there are variations from those of the hospital-based referring clinicians and patients referred from the outpatient clinical pathway.

Evidence of effectiveness is clearly paramount in the implementation of appropriate SDIs in radiology departments as a means to improve patients'

experiences. Future studies need to be of higher quality. As previously mentioned, higher quality studies might consist of interrupted time series, stepped-wedge or mixed methods designs.

# Appendices

## Appendix 1: Ethical approval



Appendix: 2 Local NHS organisation' permission to perform study



## Appendix 3: The search strategy implemented on MEDLINE

### Population terms

- #1 \*diagnostic imaging/
- #2 \*radiology department, hospital/ or \*radiology/ or \*radiology, interventional/ or \*radiology information systems/
- #3 \*radiography, interventional/ or \*radiography, dental/ or \*radiography, panoramic/ or \*radiography, bitewing/ or \*radiography, thoracic/ or \*radiography, dental, digital/ or \*radiography, abdominal/ or \*radiography/ or \*radiography, dual-energy scanned projection/
- #4 medical imaging.mp.
- #5 or / 1 – 4

### Intervention terms

- #6 \*"appointments and schedules"/
- #7 health care rationing.mp. or \*health care rationing/
- #8 quality improvement.mp. or \*"quality of health care"/ or \*total quality management/ or \*quality improvement/ or \*practice guidelines as topic/ or \*health services research/ or \*quality assurance, health care/
- #9 \*quality indicators, health care/
- #10 \*efficiency, organizational/ or six sigma.mp.
- #11 (speech or voice recognition).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
- #12 reminder systems.mp. or \*patient compliance/ or \*reminder systems/
- #13 (organization and innovation).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
- #14 \*workload/ or \*"personnel staffing and scheduling"/ or staffing level.mp. or \*personnel management/
- #15 \*"health services needs and demand"/ or \*decision support techniques/ or capacity planning.mp. or \*"utilization review"/
- #16 extend\* work\* hour\*.mp.
- #17 24 hour service.mp.
- #18 \*after-hours care/ or after hour care.mp.
- #19 \*organizational innovation/ or radiology planning.mp.
- #20 \*medical order entry systems/ or \*data collection/ or computerized order entry system.mp. or \*hospital information systems/
- #21 exp \*teleradiology/ or exp \*outsourced services/ or outsource radiology.mp.
- #22 \*delegation, professional/
- #23 (radiographer\* and radiologist\*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
- #24 radiographer\* role\*.mp. or exp \*inservice training/ or exp \*staff development/
- #25 (radiographer\* and report\*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]

### Outcome terms

- #26 \*health services accessibility/ or \*waiting lists/ or wait\* list\*.mp.
- #27 (wait\* and time\*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]
- #28 \*time factors/ or turnaround time.mp. or \*"time and motion studies"/
- #29 exp \*patient satisfaction/ or exp \*consumer satisfaction/ or customer satisfaction.mp. or exp \*"marketing of health services"/
- #30 \*patient compliance/
- #31 or / 6 – 30
- #32 5 and 31
- #33 limit 32 to (humans and yr="1995 -Current")

The numbers '#’ show the progression of the search (sequences), the search strings shown as '\*.../' are MeSH, those strings shown as '....mp' are free text s. As there are a wide variety of service delivery interventions which may not be well indexed in the database, we

adopted a more 'sensitive' (rather than 'specific') strategy by combining general terms related to radiology (lines 1-4) with any terms related to either service delivery interventions or outcomes of interest (lines 6-30), as shown in line 32 of the search strategy. Similar strategies were implemented on the other databases.

## Appendix 4: Characteristics of the included studies

<i>Study ID</i>	<i>Type of Intervention</i>	<i>Study design</i>	<i>Risk of bias: # of low risk domains</i>	<i>Outcome measure &amp; definition.</i>	<i>Main findings</i>
<i>Brealey and Scuffham (2005)</i>	Extended scope practice (ESP)	Time series regression model	5/7	RTAT: Not defined.	The study used monthly data collected from Feb 1993 to June 1998 comprising 2 and 3 years pre- and post-intervention data segments, respectively. The RTAT was averaged yearly and presented in a pre- and post-intervention format as well. The impact of ESP radiographers' reporting was assessed using 3 separate time series regression models. 1) Proportions of examinations reported, 2) RTAT for A&E examinations and 3) RTAT for GP examinations. The mean RTATs for A&E plain film examinations during the baseline periods were 94.6 and 115.1 hours for 1993 and 1994 respectively. The post intervention RTATs were 112.3, 155.6 and 100.8 hours for 1995, 1996 and 1997 respectively. Regression analysis suggests that: increased proportion of A&E examinations reported by ESP radiographers reduced the RTAT by 36.8%, $p < 0.001$ ; ESP radiographers' reporting was associated with 12% (per month) increase in the proportion of reported A&E examinations after controlling for increased workload, $p = 0.05$ .

<i>Kennedy et al. (2009)</i>	Tele-radiology	Controlled Pre- and post-intervention (intervention and control were on one site)	6/9	RTAT: time from the completion of examination to the time of finalised report.	This study evaluated the impact of tele-radiology on the RTAT for CT pulmonary angiograms performed between 6 PM and 12 AM on weekdays and 2 - 7 PM on weekends. The control group comprises CT brain done within the same time brackets. The proportion of reports completed within 40 minutes in the intervention group were 34% (163/485; CI 29, 38) and 43% (268/617; CI 39, 47) pre- and post-intervention respectively, p<0.01. Stratified analysis of individual shifts did not reveal uniform improvement. No significant changes were noted in the control group.
<i>Laurila et al. (2001)</i>	Continuous quality improvement (CQI)	Controlled Pre- and post-intervention (one intervention and one control site)	4/9	TRWT: Time elapsed from when the patient leaves and returns to the outpatient department with the finalised radiology report and film.	CQI was implemented in the intervention site while a "traditional" management method that consisted of calling for assistance when the queue of waiting patients is elongated was used in the control site. CQI was associated with a drop in the percentage of chest x-ray examinations with TRWTs over 2 hours: from 34 to 16% pre-and-post CQI intervention respectively. However, a follow up measurement at 8 months post intervention showed that the improvement was not sustained. The proportion of examinations with TRWTs over 2 hours remained unchanged at the control site.
<i>Akhtar et al. (2011)</i>	SRR	Uncontrolled Pre- and post-intervention	NA	RTAT: time elapsed from the completion of the examination to the availability of the	Data was collected on 6 radiology sub-specialties (CT, MRI, NM, FLUO, US and IR) from July 2007 to July 2008 (dicta phone period) and June 2009 to May 2010 (SRR period). The percentage of radiology reports completed within 24 hours improved across all imaging modalities following SRR



				finalised radiology report.	implementation. For example, the proportions were 63.9 and 71 % for CT pre-and-post SRR respectively, $p < 0.001$ .
<i>Aloisio et al. (2009)</i>	The Six Sigma methodology	Uncontrolled Pre- and post-intervention	NA	TRWT: time elapsed from "examination order to end of procedure".	This was a process improvement project in an academic radiology department that performs about 68, 000 inpatient CTs annually. The mean inpatient TRWTs were 20.7 (SD, 23.03) and 11.6 (SD, 15.2) hours pre- and post-intervention respectively. The improvement was sustained over the subsequent 18 months.
<i>Aloisio and Winterfeldt (2010)</i>	Quality management	Uncontrolled Pre- and post-intervention	NA	TRWT: time elapsed from "examination order to end of procedure".	The study was performed in a radiology department that performs about 6000 CTs / month using 4 static and one portable CT-Scanners. The study reports on a process re-design involving bringing staff schedule in line with variations in CT demand. The average TRWT dropped from 8.2 to 6.5 hours (weekdays) and 13 to 8 hours (weekends). An improvement of 20 and 38% for weekdays and weekend examinations respectively.
<i>Andriole et al. (2001b); a)</i>	Pager notification system (PNS)	Uncontrolled Pre- and post-intervention	NA	RTAT: the difference between the actual times imaging was completed and when radiology report was faxed to ED.	The study was performed in an academic radiology department with PACS installed. The mean RTATs for A&E examinations were 90.05 (SD 77.47; range 9 - 299) and 40.05 (SD 20.86; range 15 - 78) minutes pre-and-post PNS respectively. However, the gains were not sustained beyond 1 week post PNS as the radiologists either lost the pager or stopped responding.

<i>Ayal and Seidmann (2008); (2009)</i>	RIS / PACS	Uncontrolled Pre- and post- intervention	NA	RTAT: time interval between the completion of examination and the finalised radiology report.	The study assessed the value of implementing large scale information systems in a radiology department by examining a range of outcome measures including revenue, waiting times and satisfaction levels. The average RTATs were 115.6 and 23.81 hours pre- and post-intervention respectively.
<i>Blakeley et al. (2008)</i>	ESP	Uncontrolled Pre- and post- intervention	NA	RTAT: Not defined	The study combined quantitative and qualitative methods to assess the impact on RTAT of ESP radiographers' reported images of appendicular skeleton on the accident and Emergency department of an NHS hospital. The mean RTATs were 10.23 (SD 7.65) and 5.62 (SD 4.27) days pre-and-post ESP respectively. In addition, the proportion of appendicular images reported were 37.9% and 80.4% pre- and post-intervention respectively. The percentage of the entire A&E plain images that were reported increased from 38.4 to 54.4% pre- and post-intervention respectively.
<i>Giles W. L. Boland et al. (2010c)</i>	Pay-for- performance (PFP)	Uncontrolled Pre- and post- intervention	NA	RTAT: time interval between the completion of an examination and the finalised radiology report.	The PFP program comprises a \$5000 bonus payment annually to radiologists who met specified report approval target. The mean departmental RTATs were 42.7 (SD 99.3), 31.6 (SD 78.2) and 16.3 (SD 53.6) hours before, after intervention and 2-year follow up periods respectively, $p < 0.0001$ . The changes were significant for all sub-specialties evaluated, except nuclear and neurovascular radiology.

<i>Bucci and Musitano (2011)</i>	Lean Six Sigma	Uncontrolled Pre- and post-intervention	NA	PEWT: not defined.	PEWT dropped from 25 days to 1 - 2 days following the intervention. It was not specified whether 25 days was median, mean or IQR.
<i>Cavagna et al. (2003)</i>	The Six Sigma	Controlled Post-intervention	NA	RTAT: time from the end of examination to when the film and finalised report were available for delivery to the ward.	The study is set in a radiology department that performs about 90, 000 examinations annually and uses SRR and dicta phone systems in parallel. 78% of the reports were produced using SRR. The median departmental RTAT was 49 hours. The mean RTATs for reports generated with SRR and dicta phone were 45.75 and 95.97 hours respectively. Inpatient reports were generated 95% of the times with SRR. Almost all inpatients' reports were delivered with 36 hours. Authors concluded that radiologist should be encouraged to use SRR to reduce report delivery times.
<i>DeFlorio et al. (2008)</i>	SRR, interlinked with RIS and HISS, staffing, education and proposed sanctions	Uncontrolled Pre- and post-intervention	NA	RTAT: time interval between the completion of examination and availability of the finalised radiology report on the HIS.	Study was performed in the radiology department of a 641-bed level 1 trauma Centre. The department performs about 250, 000 examinations annually. The interventions included SRR, specified radiologist to report A&E CT and plain film images, integration of RIS with HIS, staff education and proposed sanction. The RTATs for periods 1 to 5 were 86.4 (SD 31), 2.3 (SD 2.2), 2.6 (SD 3.6), 1.7 (SD 1.9) and 2.4 (SD 14.2) hours respectively. The following factors improved RTAT: 1) provision of on-call radiologist), use of SRR. The following did not improve RTAT: 1) staff education on the need to

comply with RTAT requirements, and 2) proposed sanction on non-compliance with RTAT target.

<i>Halsted and Froehle (2008)</i>	Paperless workflow management system (WMS)	Uncontrolled Pre- and post-intervention	NA	RTAT: time interval between when images were available on PACS and when the finalised radiology report.	The study reports on the development and implementation of a WMS in a RIS, PACS and SRR environment. The WMS is an automated system for prioritizing cases on PACS for reporting. Results were presented for three patients groups: A&E, inpatient and Outpatient. The mean RTATs were 7.72 and 6.18 hours for A&E; 7.33 and 7.12 hours for inpatient and; 6.73 and 5.03 hours for outpatient pre- and post-intervention respectively, $p < 0.05$ .
<i>(Hangian dreou et al., 1997)</i>	PACS	Uncontrolled Pre- and post-intervention	NA	RTAT: time elapsed from when the examination was started to when images /report were returned to the requesting physician.	This study investigated the impact of PACS on RTAT for images done out-of-hours in a community practice. The images were reported by a radiologist in an academic radiology department some distance away. Before PACS, the images were sent by a pneumatic tube. The study found reduced average RTAT for urgent out-of-hours examinations from 128 to 32 and from 58 to 42 minutes for examinations done within regular clinic hours pre-and-post PACS respectively.
<i>(Harmelink, 2008)</i>	The Lean Methodology	Uncontrolled Pre- and post-intervention	NA	Waiting pre-examination and waiting post-examination: Not defined.	The Lean methodology was used to map and improve the workflow processes of a radiology department. The mean pre-examination waiting times were 4.1 and 1.2 while the post-examinations waiting times were 3.39 and 1.2 minutes pre- and post-intervention respectively. This represents 64

<i>Hart et al. (2010)</i>	SRR	Uncontrolled Pre- and post- intervention	NA	RTAT: the total time between image acquisition and finalised report.	and 69% improvements in the pre and post-examination waiting times respectively.
<i>Hawtin et al. (2010)</i>	Service re- design	Uncontrolled Pre- and post- intervention	NA	PEWT: The time elapsed between the date on request form and date of examination.	This study reports the implementation of SRR in a multi-site hospital that used different workflows before SRR implementation: site 1 used handheld dicta phone while site 2 used digital speech file. The study found statistically significant drop in RTAT for all 4 patient groups: Casualty, GP, outpatient and inpatients. The RTATs for site 1 were: casualty 6.29 (0.78) and 1.76 (0.32); GP 6.00 (0.70) and 1.84 (0.32); inpatient 9.10 (1.50) and 2.90 (1.39); outpatient 8.82 (1.29) and 2.75 (1.14) days pre- and post-intervention respectively. The RTATs for site 2 were Casualty 4.53 (0.74) and 1.60 (0.46); GP 3.44 (0.56) and 1.44 (0.45); Inpatient 5.84 (1.43) and 1.66 (0.76); outpatient 4.87 (0.74) and 1.92 (0.66) days pre- and post-intervention respectively, SD in parenthesis.  This study evaluates the impact on PEWT of providing same day ultrasound service (turn-up-wait-and-be-examined) in addition to the usual appointment system. Same day patient had to turn up 9 - 11 am or 2 - 4 pm to be examined in the morning or afternoon sessions respectively. The median PEWTs for GP patient who choose to book appointment were 10 (IQR, 7 - 20) and 6 (IQR, 4 - 10) days pre-and-post implementation respectively, p<0.0001, despite increased workload. While the median PEWTs for outpatient were 14 (IQR, 7 - 44) and 9 (IQR, 5 - 155) days pre-and-

<i>Hayt et al. (2001)</i>	PACS / 24-hour on site radiologist coverage / SRR	Uncontrolled Pre- and post-intervention	NA	RTAT: the percentage of reports completed within 12, 24 and 48 hours of examination.	post implementation respectively, $p < 0.0001$ . Both patient groups waited longer on the day of examination, however, the GP patients who did not book appointment waited longest.
<i>Hodler et al. (1999)</i>	Service re-design	Uncontrolled Pre- and post-intervention	NA	RTAT: the interval between the last radiograph and report printing time.	This was a process improvement project comprising the implementation of PACS, SRR and 24-hours radiologist coverage. The proportions of reports generated within 12 hour of examination were 7.4 - 9.6, 40 and 65 -66 % before, after implementation and follow-up periods respectively. The proportion of examinations reported between 24 - 48 hours dropped from 25 to 11% and those reported over 48 hour dropped from 47 to 27% pre-and-post implementation respectively.  The service was re-designed to reduce the total time delay for orthopaedic outpatients referred for x-rays examination. The changes involved the provision of an additional radiographer 15 minutes before the start of orthopaedic clinic, designating a duty radiologist to supervise the reporting room, an extra computer in the reporting room, and scheduling time intensive examination during off peak periods. The mean RTATs were 13 (range 0 - 71), 11 (range 0 – 93) and 11 (range 0 - 84) minutes before, after implementation and 12-months follow up periods respectively. However the percentage of patient spending more than 45 minutes in radiology dropped

<i>Horii et al. (2000)</i>	Service re-design, PACS and dedicated scheduler.	Uncontrolled Pre- and post-intervention	NA	PEWT: time from faxing request to the start of examination.	from 41 to 29% between the baseline to the follow up period, $p < 0.001$ . There were only marginal changes in volume of patients. Data collection was by a mixture of observation, interviews and RIS query. The number of examinations was counted rather than time intervals. Moving the film reading location from A&E to the main radiology department does not significantly affect the median PEWT: 0.07 and 0.08 hours pre- and post-intervention respectively. However implementing PACS and subsequently dedicated scheduler increased median PEWT from 0.12 and 0.27 hours respectively.
<i>Humphries et al. (2011)</i>	The Lean Methodology	Uncontrolled Pre- and post-intervention	NA	PEWT: the time interval between request and completion of CT-examination.	The study applied the Lean methodology to improve the PEWT for CT-examinations in an academic trauma Centre. The key changes included encouraging radiographers to facilitate workflow by "pulling" patients, changing CT protocol, aligning radiographers' rota with variations in CT demand, improved communication between radiology and A&E and performance feedback to radiographers. Following these changes, PEWT dropped from 55.8 (90% CI 54.1, 57.4) to 35.9 (90% CI 34.4, 37.5) minutes, in parenthesis. This represents a 36% improvement in PEWT.
<i>Hundt et al. (1998)</i>	Computerised reporting system	Post intervention	NA	RTAT: the time from the moment x-ray films had been	The study describes the development and implementation of a computerised / coded reporting system which was compared with two conventional reporting systems for impact on RTAT. The mean RTATs were

		(with control)		developed to when the finalised report had left the department.	5.9 (SD 2.3), 1.3 (SD 0.5) and 0.4 (SD 0.9) hours for tape, the coded and handwritten reporting systems respectively.
<i>Hurlen et al. (2010)</i>	PACS and process re-design in a RIS environment	Uncontrolled Pre- and post-intervention	NA	RTAT: time from image acquisition to the availability of the finalised report.	Activity data for CR, CT, US, MRI and interventional radiology were retrieved from the RIS. There was an initial improvement following implementation, this was not sustained over the post implementation periods. The median RTAT dropped from 22.78 to 12.78 hours post PACS, 44% reduction. Subsequent measurements were 13; 15, 19 and 21.65 at 8, 12, 16 and 20 months post PACS respectively. The impact at modality level varied.
<i>Inamura et al. (1997)</i>	RIS in a HIS environment	Uncontrolled Pre- and post-intervention	NA	TRWT: the time from radiology request to the time when the films/report returned to the ward/clinics.	This was a time and flow study. Data was collected using integrated circuits (IC) card, carried together with the imaging request card. The card is clocked at specified locations to track TRWT. The information is transferred to a central location. The mean TRWTs were 26.8 (SD 6.8) and 3.6 (SD 2.5) hours pre-and-post RIS respectively. The pre implementation distribution of system TRWTs was wide and bimodal while the post implementation distribution was keen and uni-modal, concentrated around 1 hour.
<i>Johal et al. (2003)</i>	Service re-design	Uncontrolled Pre- and post-intervention	NA	PEWT: Not defined.	This is one of the earliest radiology modernisation projects implemented within the UK in response to long patients' waiting times for imaging examinations. This study found that although capacity was in excess of demand, PEWT was 22 weeks for barium enema. Following service re-



<i>Kelley (2011)</i>	SRR	Uncontrolled Pre- and post- intervention	NA	RTAT: the time between completion of examination and the finalised radiology report.	design, PEWT dropped to 5 weeks for barium enema, and from 18 to 1 week for barium meal / swallow. These changes were sustained. On the other hand, demand for ultrasound exceeded capacity and extra capacity was provided.  There were 2 and 3 data points pre- and post-intervention respectively. The target RTAT of 30 minutes for A&E patients was achieved 3% of the times during the baseline periods. This changed to 73, 85 and 85% during the post-intervention periods. The proportions of reports that met the 90 minutes RTAT target for outpatient were 2 and 12% pre intervention and 79, 85 and 91% during the post intervention periods. Whereas the 120 minutes RTAT target for inpatient was met 4 & 18% during the pre-intervention periods, this increased to 83, 90 & 95% during the post-intervention periods.
<i>Koivikko et al. (2008)</i>	SRR	Uncontrolled Pre- and post- intervention	NA	RTAT: the time from completion of imaging to the availability of finalised report on the RIS/online.	The study compared the RTAT using SRR with cassette-based reporting system in an academic health Centre that has implemented HIS / PACS. Data from MRI, CT, US, special examination, interventional radiology and plain x-rays were included. The mean RTATs were 24.77 (SD 76.52), 5.39 (SD 27.7) and 4.67 (SD 12.72) hours before (cassette-based system), after (SRR system) and follow-up periods respectively, p<0.0001.
<i>Krishnaraj et al. (2010)</i>	SRR	Uncontrolled Pre- and	NA	RTAT: the interval between when the images were available	The study was performed in the radiology department of a 700-bed academic hospital. Data from 8 radiology sub-specialties were collected for 9 months (Jan – Sept. 2006) pre-and-post (April - Dec 2007) implementation.

		post-intervention		on PACS and the finalised radiology report.	The average departmental RTATs were 28 (range 4.6 - 65.9) and 12.7 (range 1.2 – 47.3) hours respectively. All the 8 sub-specialties experienced improved RTAT. Of 30 radiologists, 2 did not experience RTAT improvement. The extent of improvement varied with radiologists' work habit.
<i>Krupinski et al. (1999)</i>	Tele-radiology	Post intervention (with control)	NA	RTAT: the time from receiving a case to when the report is generated and faxed back to sending site.	This was a retrospective data analysis of a 2-year tele-radiology programme. Satellite site send images via dial-up link to an academic radiology department. The department logs all cases received. The average RTAT was 1.27 (SD 2.9) hours. 69.5 and 96% of the cases had RTATs under 1 and 6 hours respectively. The control group (cases sent by courier) has average RTAT of 6 hours. No statistical test was performed.
<i>Kuo et al. (2003)</i>	PACS	Post intervention	NA	RTAT: the interval between when the image was generated and when the written report was made available on PACS and HIS.	The study evaluated the impact on RTAT of implementing PACS in a HIS / RIS / fee-for-service environment. Data was collected between Oct 1999 and Sept 2000 by stratified random sampling (using a random number table) of patient episodes from angiography, CT and specialized examinations. The median RTATs during working hours were 98 (170,251), 105 (124,135) and 105 (134, 89) minutes for radiography, CT and special examination respectively, mean and SD in parenthesis. These times are within acceptable limits for the hospital. The mean RTATs for the out-of-hours period ranged from 306 to 1769 minutes in CT and radiography respectively.
<i>Lahiri and Seidmann (2009)</i>	RIS	Uncontrolled Pre- and	NA	RTAT: the time elapsed from the end	The study evaluated the impact of implementing a commercially available RIS on the RTAT in a network of 7 free-standing imaging Centres (4 included

		post-intervention		of examination to the finalised report	in this study). The network performs about 125, 000 examinations annually. The mean RTATs were 4.06 (2.34) and 2.17 (1.43) for mammography; 3.11 (1.87) and 3.20 (1.85) hours for MRI pre- and post-intervention respectively, SD in parenthesis. These results were statistically significant at 5%.
<i>Langer (2002a); b)</i>	Comparison of 4 workflow types: Films/ manual transcription Film/SRR, PACS/ manual transcription and PACS/ SRR	Uncontrolled Post intervention	NA	RTAT: the time interval between the completion of an examination and the finalised report.	This is a one off survey of 40 radiology practices in North America for RTAT and productivity. The average RTATs in hours / normalized productivity for the different workflows were 48.2 (50%)/ 16.2 for film & manual transcription; 15.5 (93%) / 2.27 for film and SRR; 13.3 (119%) / 21.8 for PACS & manual transcription; and 15.7 (98%) / 30.6 for PACS & SRR. The uncertainties for RTAT in parenthesis. Film / SRR have the best productivity and largest uncertainty. The high uncertainty is due to small number of respondents.
<i>Langlois et al. (1999)</i>	CR	Post intervention (with control)	NA	TRWT: the time from patient' arrival at the x-ray reception desk to the finalised radiology report.	This study compares the efficiency of digital and conventional systems. 220 examinations were included: 111 and 109 in the digital and conventional arms respectively. The examination process is the same for both arms except for the image acquisition technology. The mean TRWTs were 4.65 and 1.03 hours for A&E chest x-rays, 1.80 and 2.24 for A&E orthopaedic examinations, 9.83 and 21.11 for inpatient chest x-rays, 22.72 and 4.71 for

<i>Lemme and Morin (2000b); a)</i>	SRR	Uncontrolled Pre- and post- intervention	NA	RTAT: not defined.	inpatient orthopaedic examinations, 10.39 and 57.26 outpatients chest x-rays, 41.53 and 90.57 hours for outpatient orthopaedic examinations for digital and conventional systems respectively.  The study reports the design and implementation of SRR in a RIS environment. The department was using remote digital dictation system before this time. Activity data for CT, MRI, ultrasound and nuclear medicine were included in the study. The average RTATs were 120, 5 and 3.5 minutes before after SRR and follow-up periods respectively.
<i>Mackinnon et al. (2008)</i>	PACS /RIS	Uncontrolled Pre- and post- intervention	NA	RTAT: the time elapsed from examination completion to the issuing of finalised report.	This study evaluated the impact on RTAT of PACS /RIS implementation. 5 blocks of 3-month data (Feb - April, 2002 – 2006) for Plain radiographs and, specialist examinations (CT, MRI, US and nuclear medicine) were retrieved from the RIS. There results were mixed at the level of imaging modalities. The mean RTATs were 6.8 and 5 days for radiographs; 4.2 and 3.1 days for specialist examinations, p<0.001, pre- and post-intervention respectively. The mean RTAT for CT remained stable at 2 days. RTAT for MRI increased from 4.6 to 7.5 days, p<0.001. RTAT decreased at department level despite 30% increase in patient episodes.
<i>Marquez and Stewart (2005)</i>	RIS/ SRR /MS in a PACS environment	Uncontrolled Pre- and post- intervention	NA	RTAT: the time interval between the start of examination and final report.	There was 100% adoption of SRR. The average departmental RTATs were 9.38, 1.72 and 1.18 hours before, after RIS / SRR and WMS, respectively. Modality level data were also reported.

<i>Mattern et al. (1999a); Stamford et al. (1999)</i>	CR / PACS	Uncontrolled Pre- and post- intervention	NA	1) PEWT: Time from request to beginning of examination, 2) TRWT: Time interval between request and when film and final report reaches the physician.	This small study involving 215 patients was performed in the radiology department of a no-appointment ambulatory care hospital. The study examined the impact of switching from cassette / film based plan film examination to complete electronic imaging system. The mean PEWT increased from 0:15:54 (0:03:31) to 0:26:47 (0:03:37), $p=3.5^{-5}$ . The TRWT reduced from a mean 4:21:54 (1:17:15) to 0:55:09 (0:07:06) $p=8.98^{-7}$ , pre- and post-intervention respectively, 95% CI in parenthesis.
<i>A. Mehta et al. (2000b); a)</i>	PACS in a RIS / HIS / SRR environment	Uncontrolled Pre- and post- intervention	NA	RTAT: the time interval between the examination completion on the RIS and the availability of finalised report on the HIS.	RTAT data for CT (only abdomen/pelvis) were retrieved from the RIS for two 1-year periods (March 1 1997 - March 1 1998 and March 1 1998 - March 1 1999) representing the periods pre-and-post PACS implementation respectively. The mean RTATs were 5.49 (3.6, 0.04 - 28.6) and 5.97 (3.2, 0.005 - 65.5) days pre-and-post PACS respectively, representing 9% increase, median and range in parenthesis.
<i>Newman and Nightingale (2011)</i>	Extended scope practice	Uncontrolled Pre- and post- intervention	NA	PEWT: time elapsed between referral and completion of the examination. RTAT: not defined.	The impacts of ESP on PEWT and RTAT for video fluoroscopy were investigated. Data were retrieved from the RIS for April 2003 to Mar 2004 and April 2009 to March 2010 representing the pre-and-post implementation periods respectively. There was 75% decrease in the mean PEWT for inpatient from 8 (range 1 – 14) to 2 (range 0 – 6) days and 62.5% for outpatients from 32 (range 15 – 95) to 11 (range 0 – 26) days pre-and-

<i>Nitrosi et al. (2007)</i>	PACS in a RIS / HIS / SRR environment	Uncontrolled Pre- and post-intervention	NA	TRWT: the time elapsed between imaging request and finalised radiology report. PEWT: Not defined.	post implementation respectively. The combined average RTATs were 7 and 0 - 1 day pre-and-post implementation respectively.	The study was performed in a radiology department that performs about 180, 000 examinations yearly. Study data were retrieved from the RIS for 15/10/2002 to 15/4/2003 and 15/1 2003 to 15/4/2004 representing the pre-and-post implementation periods respectively. The mean inpatient TRWTs were 29.6 (SD 32.36) and 13.5 (SD 24.75) hours for CT, 33.9 (SD 56.25) and 9.62 (SD 26.09) for chest x-rays and 38.35 (SD 28.5) to 24.9 (SD 31.6) hours for MRI pre- and post-intervention respectively, p<0.001 for all three modalities. The average outpatient PEWT reduced from 90 to 40 days for nun-urgent CT and from 90 - 180 to 30 - 60 days for nun-urgent ultrasound examinations pre- and post-intervention respectively. But this was thought to reflect the impact of separate interventions: reminder system and improved scheduling.
<i>Oguz et al. (2002)</i>	Pager notification	Uncontrolled Pre- and post-intervention	NA	RTAT: the time interval between completion of the examination and the finalised radiology report.	This paper reports a pager notification system (PNS) project designed to inform radiologist when reports have been transcribed and ready for signature as means of reducing the RTAT. This study was designed to evaluate the signature times using same site controlled pre- and post-intervention. The intervention group comprised 26 voluntarily enrolled radiologists. The control group comprises 8 radiologists who did not enroll.	

<i>Pallan et al. (2005)</i>	Service re-design	Post intervention (with control)	NA	PEWT: the time interval between referral (community group) / receipt of request (NHS group) and the date of examination.	<p>Signature time was not an outcome of interest in this review. However, the study reported the departmental RTAT pre- and post-intervention. Therefore, the study is being used as a pre-and-post design for a not fully subscribed PNS intervention. The RTATs pre- and post-intervention were 46.56 and 36.3 hour respectively. A reduction of 14.91 hours (32%).</p> <p>This was a retrospective cross sectional study of the PEWT of patients attending for ultrasound scan in the community and a local NHS Trust. Sample size calculation was done. A random sample of 200 patient episodes was taken from the two patient populations. Data on PEWT were taken from computerised patient records management systems. The PEWTs were 17.44 (95% CI 15.86, 19.02) and 44.53 (95% CI 38.83, 50.23) days for the community and hospital services respectively. Monthly mean PEWTs were also reported.</p>
<i>Patel et al. (2012)</i>	Service re-design	Uncontrolled Pre- and post-intervention	NA	TRWT: The time interval between imaging request and finalised radiology report.	<p>This structured abstract reports clinical audit of CT head CT body. The target TRWTs were &lt;60 and &lt;90 minutes for CT head and body respectively. The following changes were made: second dedicated A&amp;E CT-Scanner, prompt CT-examination request by A&amp;E doctors, wireless telephone for radiology registrars, dedicated CT portering staff. The mean TRWTs were 51 and 69 minutes for CT head; 69 and 82 minutes for CT body pre- and post-intervention respectively.</p>

<i>Redfern et al. (2000)</i>	PACS	Uncontrolled Pre- and post- intervention	NA	PEWT: time elapsed from request to image dispatch.	This study assessed changes in radiology workflow and efficiency following PACS implementation. The study included 31, 000 examinations requested by A&E and Medical intensive care unit (MICU) over a 5-year period. Data were downloaded from the RIS. The PEWT increased from 20 to 25 minutes and 34 to 42 minutes for A&E and MICU respectively, $p < 0.0001$ .
<i>Rosenthal et al. (1998)</i>	SRR	Uncontrolled Pre- and post- intervention	NA	RTAT: the time elapsed between completion of examination and finalised radiology report.	This study evaluated the impact of SRR on RTAT in an academic radiology department. Two blocks of one-week data for musculoskeletal radiology activity were collected representing the pre- and post-intervention periods. RTAT dropped from 62 to 24 hours (61% improvement). Again, it is not certain if these represents mean, median e.t.c values.
<i>Seltzer et al. (1997)</i>	Multiple	Uncontrolled Pre- and post- intervention	NA	RTAT: time from completion of examination to the finalised report.	The study was set in a teaching hospital that performs 250, 000 radiology examinations annually. Different interventions were implemented within different radiology sub-specialties: home signing, buddy signing system, accelerated transcription, SRR, structured reporting etc. The mean RTAT decreased from 81.2 to 36.2 hours (55% change) following the interventions, $p = 0.001$ .
<i>Sferrella (2003)</i>	SRR in a RIS / electronic requesting environment	Uncontrolled Pre- and post- intervention	NA	RTAT: the time from examination completion to finalised report.	The study was performed in a multi-site hospital with annual procedure volume of 360, 000. SRR was implemented with 100% adoption by radiologists. 2-year pre implementation and one-week post implementation data were used. Although it was a multi-site intervention results were



<i>Steffen (2010)</i>	Service re-design	Uncontrolled Pre- and post-intervention	NA	PEWT: time elapsed from imaging request to completion of examination.	presented for only one site: The Lehigh Valley Hospital. The proportions of reports with RTATs less than 24 hours were 41 and 78% pre-and-post SRR respectively.  The process re-designs involved creating a centralised patient scheduling system for each imaging modality. The PEWT dropped from 12 hours to 33 minutes after implementation Again it was not specified if 12 hours represents mean or median value.
<i>Tavakol et al. (2011)</i>	Outsourcing	Post-intervention (with control)	NA	PEWT: time in days that patients had to wait for examination.	All MRI examinations requested by the oncology department within the first trimesters of 2005 and 2006 which were outsourced to an external MRI service provider were included in the study, n = 97. These were matched for organs with MRI examinations performed in-house within the same periods, n = 97. Preferred examination time frames were specified by the referrer in 59/93 and 65/93 for the in-house and outsourced groups respectively. The specified time frames were not met in 39 and 36% for the in-house and outsourced groups respectively. In these cases waiting exceeded the requested time by an average of 18.2 (SD 20) and 22.1 (SD 21) for the in-house and outsourced groups respectively, p=0.4. Referrers did not specify time in 34/93 and 28/93 for the in-house and outsourced groups. PEWTs for these were 55 (SD 23.3) and 36 (SD 21) days for the in-house and outsourced groups respectively, p<0.001.

<i>Van Lom (2009)</i>	SRR in a RIS / PACS environment	Uncontrolled Pre- and post-intervention	NA	RTAT: not explicitly defined, however, included the availability of final reports online.	This is a report about a not-for-profit stand-alone imaging Centre that performs 450, 000 cases per year. The practice had SRR and RIS that were not integrated with PACS. The intervention involved switching to a more functional SRR and PACS integration. Radiologists edited 70 - 80% of their reports. The average RTAT reduced from 24 to 6 hours.
<i>Whang et al. (2002)</i>	SRR	Post intervention (with control)	NA	RTAT: the time from image acquisition to finalised radiology report.	UCLA was expecting to install PACS and SRR. A baseline analysis was done comparing the current status with LAVA which already has functional SRR. UCLA outsources its report transcription service. Data for musculoskeletal (MSK) x-ray and chest x-ray were collected for three weeks period by observation. The mean RTAT for the MSK division at the UCLA (no SRR) and West LAVA (SRR) were 37.1 (2.1) and 10.6 (1.9) hours respectively; whereas the values for chest x-ray were 32.3 (3.2) and 6.3 (0.94) hours for UCLA and West LA VA respectively, standard error in parenthesis.
<i>Wheeler and Cassimus (1999)</i>	SRR in a RIS / PACS environment	Uncontrolled Pre- and post-intervention	NA	RTAT: not defined.	This is report was about the implementation of SRR in a facility with procedure volume of 85, 000. The SRR was implemented in 3 phases The RTAT averaged roughly 60 hours before SRR. Following SRR 50, 80 and 90% of reports have RTATs within 1, 3 and 5 hours respectively.
<i>Adam et al. (2005)</i>	CPOE	Uncontrolled Pre- and post-intervention	NA	TRWT: the time from order writing to results availability.	The study population consists of A&E patients with chest pain for which a chest x-ray was done. Data was collected for 3 months pre- and post-intervention on 150 randomly selected patients. Method of randomisation was not disclosed. Statistical analysis was based on t-test and chi-square

<i>Thompson et al. (2004)</i>	CPOE	Uncontrolled Pre- and post- intervention	PEWT: the time from order to completion of examination.	<p>test. The study found that examination turnaround times remained stable at 80 minutes despite an increase in the volume (18 to 135) of examinations <math>P = 0.49</math>. It was suggested that this increase might be the result of better documentation resulting from CPOE implementation.</p> <p>The study was base in an ITU of a 400-bed tertiary hospital. Only patient who had urgent / "stat" request for CT or plan film imaging were included in the study. Data was collected during two 1-month periods (10 months pre- and 2 months post- CPOE implementation. The pre intervention data were obtained from patients' charts. The study included 26 and 46 episodes within the pre- and post-intervention periods respectively. Statistical analysis was based on Kruskal -Wallis test.</p> <p>This study reported that CPOE was associated with a decrease in the median time interval from request to the completion of examination, 96.5 to 29.5 minutes <math>P &lt; 0.001</math>. There was less variation around the media value following CPOE implementation.</p>
<i>Mekhjian et al. (2002)</i>	CPOE	Uncontrolled Pre- and post- intervention	PEWT: the time from physician order (manual or electronic) to the completion of the procedure.	<p>This was hospital wide study including pharmacy radiology etc. However, we abstracted data for the radiology aspect only. Study population consists of patients referred from the transplant service. Data were included for the Chest and abdominal x-rays and abdominal ultrasound. Manual data collection was used in the pre-CPOE periods; 11 and 54 patient episodes in the pre-and-post CPOE periods respectively. Statistical analysis was based in</p>

<i>Cordero et al. (2004)</i>	CPOE	Uncontrolled Pre- and post- intervention		PEWT: the time from order to image display	<p>Students' t-test. The study reported a 43% reduction in the PEWT from 7 hour 37 minutes to 4 hours 21 minutes, pre-and-post CPOE implementation respectively <math>p &lt; 0.05</math>. It was not stated whether these are mean or median values.</p> <p>This study was performed in the Neonatal Intensive Care Unit (NICU) of an academic hospital. The hospital had already implemented PACS. The study population comprises very low birth weight (VLBW) infants born within two consecutive periods of 6-months pre-and-post implementation of CPOE: Only data from the first chest and abdominal x-ray taken following endo-tracheal intubation / umbilical catheter placement were included. The study measured time from order to arrival of radiology technician and to image display. Statistical analysis was based on unpaired t-tests. Data from 107 pre and 99 post CPOE VLBW infants were included. The baseline characteristics were similar. The time interval from order placement to arrival of radiology technician were 28 (SD 13) and 17 (SD 12) minutes pre-and-post CPOE respectively <math>p &lt; 0.001</math>. The order to image display times were 42 (SD 12) and 32 (SD 16) minutes. The times from technician arrival to completion of examination were similar 14 and 15 minutes pre-and-post CPOE respectively.</p>
<i>Steele et al. (2014)</i>	CQI	Uncontrolled Pre- and	NA	Time to next appointment (PEWT).	<p>This study was performed at a neuro-interventional ultrasonography clinic at the cancer centre that provides head and neck imaging and biopsy services.</p>

Alexander  
J. Towbin  
et al.  
(2013)

CQI

post-  
intervention

Uncontrolled NA  
Pre- and  
post-  
intervention

Time from request to  
the next available  
appointment slot

Report turnaround  
time (RTAT): Time  
from completion of  
examination on the  
RIS to the availability  
of the final radiology  
report.

Before implementation of CQI, mean wait time was 25 days. CQI team created an Ishiaka (cause and effect) diagramme which identified inefficient staff use, poor use of space and difficult procedure as the caused pf delay. Three-stage intervention including adjusting room and staff use, eliminating many steps involved in booking walk-in US, creating a rotating lead role sonographer and clerk roles were created. Study data was obtained from the scheduler (RIS). Implementation was completed by July 2011. Assessment was done 30 weeks post intervention. Total number of available booking slots increase 45% from 38 to 55. The mean weekly time to next appointment decreased from 25 to 1 day, 30 weeks following the interventions

The study was performed in the accident and emergency department of a large tertiary-care children's hospital in an urban centre. The intervention was the provision of turnaround time information to the on-call radiologist. Data was obtained by querying of the SRR system. Statistical process control chart was used to analyse the proportion of plan film reported within 35minutes. 80-days baseline data from July to sept 2011 and 89-days post intervention data from Oct 17 2011 to Jan 13 2012 was included in the analysis. The proportion of reports completed within 35mins increased from 82 to 93% p<0.01. The mean RTAT dropped from 24 (SD 23) to 15 (SD 13) mins; median from 15 to 10 mins

<i>S. Tiwari et al. (2014)</i>	Service re-design	Uncontrolled Pre- and post- intervention	NA	Pre-examination waiting time (PEWT): not defined.	This is a clinical audit of inpatients with fractured neck of femur for whom MRI was requested. Initial audit identified three main causes of delays in obtaining MRI imaging: failure to contact the duty radiologist for urgent scan, slow vetting of request, resistance the weekend scanning, and delays in completing MRI safety questionnaire. Strategies were developed to address these issues. Pre-intervention data were collected between April 2010 and March 2012; post intervention data between August 2012 July 2012 (12 months). Two sample t test was used to compare the result. There were 1552 patients with hip fracture in 24 months. Mean PEWT before intervention was 34 (range 15 – 216) hours. Only 56% of patient were scanned within 24 hours. Following the intervention, the mean PEWT dropped to 23 (range 30 – 163) hours; and 72% of patient were scanned within 24hours p=0.024
<i>Mahmoud et al. (2013)</i>	CQI	Uncontrolled Pre- and post- intervention	NA	On-time start; the proportion of examinations started within 10 minutes of the scheduled time	The study was conducted in a large urban paediatric medical centre. The Plan-do-study-act framework was used to improve the process for paediatric MRI patients requiring general anaesthesia. Baseline data was collected April to May 2010 from the electronic records. Post-intervention data was collated manually from August 2010 to December 2011 using data sheets. Statistical process control chart was used to measure the impact of intervention. The proportion of cases started within 10 minutes of scheduled time increased from 36% to 84% following the intervention.

<i>Clarke et al. (2013)</i>	Multiple	Uncontrolled Pre- and post- intervention	NA	Total radiology waiting time: TR WT, defined as time between the request and final reports	This was a clinical audit to assess the impact on patients waiting times of weekly A&E radiology group meetings, authorisation of a A&E CT head requests by radiographers, implementation of an escalation policy, immediate transfer of A&E patients to the CT unit, and the provision of radiology registrars reporting hub next to the CT-Scanners. The scanner is located within the A&E. Data was collected in October 2011 and December 2012. Following the interventions, the mean request report time (RRI) dropped from 65 and 77 in 2011 to 65 and 77 minutes in 2012 for CT head and CT body respectively despite a reported 48% increase in number of requests.
<i>Li et al. (2013)</i>	Other technologies	Uncontrolled Pre- and post- intervention	NA	Exam waiting time: the difference between the initial front desk registration and the moment a patient is called for examination.	An automated workflow management system was devised a assign patients to the appropriate ultrasound examination rooms depending on priority, exam type, and gender. Under this algorithm, critical patients were automatically identified and ranked highest in priority and given appointment as soon as possible. Baseline data were collected from March to September 2009. After the implementation of the workflow management system, post implementation data was collected from March to September 2010. Statistical analysis was by the independent sample t-test. Sonographers stress level was also measured on a visual analogue scale. The scale consisted of 10cm line drawn on paper to represent stress levels. The study was conducted in the veteran General Hospital Taiwan. The study

<i>Dang et al. (2015)</i>	Service re-design	Post-intervention only	NA	PEWT defined as time from when the request was received to the initiation of scan. RTAT, defined as the time from the initiation of scan to when the preliminary report became available.	included 18,939 and 19,656 patients during the pre- and post-intervention periods respectively. The exam waiting time decreased from 30.50 minutes (SD 20.40) during the pre-implementation period to 20.30 minutes (SD 16.17) during the post-implementation period. The study also reported a decreased stress level of sonographer from the pre-implementation to post-implementation period.  Study aims to assess whether a CT-Scanner within the A&E departments improves A&E workflow by comparing the workflow of an A&E unit with a dedicated CT inside it and an A&E unit without a dedicated CT. The study included 776 in the A&E with dedicated CT and 920 in the A&E without dedicated CT: Only abdominal CT-examinations were included. PEWT 16 minutes lower in the A&E with a dedicated CT-Scanner compared to A&E without a dedicated CT-Scanner $p < 0.0001$ , RTAT is 15 minutes lower in the A&E with a dedicated CT-Scanner compared to A&E without a dedicated CT-Scanner $< 0.0001$ . PEWT is in the order of 90 minutes with dedicated scanner and RTAT is in the order of 85 minutes without a dedicated scanner (graphically presented).
<i>Kao et al. (2015)</i>	Computer aided diagnosis	Uncontrolled pre- and post-intervention	NA	Dictation turnaround time, defined as the time interval between completion of	A computer aided diagnostic system was developed to flag up chest x-rays with abnormalities. The aim of this study was to assess the impact of the CAD system on the turnaround times for chest x-rays with abnormality in Kaohsiung Medical University Hospital Taiwan. Two radiologists were used



				examination and dictation of report	to evaluate the turnaround times of the proposed system; 60 days without the proposed system and 60 days with the proposed system. The study included a sample of 1711 examinations in all. The mean turnaround times for, chest x-rays were 1.36 days (SD 1.95) and 2.94 (SD 1.89) days for radiologist A with and without CAD respectively which is 50% improvement. And 1.29 (SD 1.66) days and 1.74 (SD 2.78) days for radiologist B with and without CAD respectively which 38% improvement
<i>Olteanu and Gaetano-Klosek (2013)</i>	Digital radiography	Uncontrolled pre- and post-intervention		Average turnaround time: not defined	This study assessed the impact of digital radiography on the average turnaround times for x-ray examinations in a long term care and rehabilitation setting within a 6-month period. The study involved 187 procedures with traditional films compared with 325 procedures done using mobile digital system. Study found that average turnaround times reduce from 3 days to 4 hours.
<i>Prevedello et al. (2014)</i>	SRR	Uncontrolled pre- and post-intervention	NA	Report turnaround time: time from end of image acquisition to final radiology report	SRR was implemented in the hundred and 50 bed community hospital between May 2011 and July 2011. Median radiology turnaround times were compared between the pre- and post-intervention periods. The study also measured radiology productivity within the study period. Media report turnaround times dropped from 24 hours to approximately one hour following the implementation of SRR ( $p < 0.0001$ )

<i>Tobey et al. (2014)</i>	CQI	Uncontrolled pre- and post-intervention	NA	Report turnaround time: Wet read; not defined	The study was performed in the North Shore Medical Centre, a 300-bed hospital processing about 225, 000 radiology examinations per year. The hospital implemented an automated system for faxing the outpatient report for wet films. The intervention was implemented following a plan-do-study-act (PDSA) cycle. The average wet reads (report turnaround time) dropped 66% from 44 to 15 minutes following the implementation PDSA and automated faxing system.
<i>B. P. Mehta et al. (2013)</i>	Service re-design	Uncontrolled pre- and post-intervention	NA	Door-to-suite time: not defined	A protocol for early alerts of neuro-interventional radiology team was implemented to allow early intervention within the treatment window in cases of acute ischaemic stroke in patients with large vessel occlusion. The impact of the early alert protocol on the door-to-angio-suite arrival time was evaluated. 71 patients were included in the studies 48 pre-and 23 posts intervention. The neuro interventional radiology team received early alert in 83% of the cases and the median door-to-suite time dropped from 124 to 76 minutes
<i>Rao et al. (2013)</i>	SRR	Uncontrolled pre- and post-intervention	NA	Dictation time: time from dictation to typed report. And report turnaround	This is an audit of the impact of SRR on report turnaround times for VQ scans in two UK hospitals. Data was collected from the radiology information system. Reporting time of 89 VQ scans were included in the audit. The mean dictation time dropped from 14 (SD 25) to 1 (SD 5) hours while the mean

<i>Schneider et al. (2013)</i>	CPOE	Uncontrolled	NA	time: time from scan to typed reports	report turnaround time increased from 12 (SD 18) to 21 (SD 82) hours following the implementation of SRR.
				Examination turnaround time: time from first order to final report	MRI safety questionnaire was embedded in the CPOE system and its impact on the effectiveness of the MRI scan unit was evaluated. The study included in patient MRI examinations performed in November 2010 (post-implementation period) and examinations performed in April to June 2011 (post-implementation period). The study included 442 and 1428 pre-and post-implementation inpatient requests respectively. The median time from request to completion of examination are 8.9 and 8.1 hours pre-and-post implementation respectively p = 0.92. The median time from request to radiology report dropped from 12.6 to 10.5 hours following the intervention; with a reported mean reduction of 1.1 (CI 1.0, 1.3) hours.

## Appendix 5: STATA codes for simulation the hypothetical waiting time data

The dataset used in demonstrating ITS analysis was simulated with the following equation

$$Y_t = a_0 + a_1 t + b_1 H(t - k) + b_2 (t - k) + \varepsilon_t$$

Where the residual term  $\varepsilon_t$  is generated by an AR(1) process,

$$\varepsilon_t = \phi_1 \varepsilon_{t-1} + u_t$$

in which the  $u_t$  constitute an uncorrelated sequence with mean '0' and constant variance. The  $\phi$  is the AR parameter is 0.9

$a_0$  is the initial waiting time,  $a_1$  is the initial slope,  $k$ , is the time of intervention,  $b_1$  is the change in level,  $b_2$  is the change in slope

The model parameters were substituted as follows:

$$Y_t = 30 + 0.07 * t + 10 * H(t - k) - 0.03 * (t - k) + 0.9 * \varepsilon_{t-2} + \mu_t$$

The parameters were arbitrarily chosen for the purposes of this illustration. The

STATA™ code for generating the data with the above equation is shown below.

```
set seed 1
set obs 500
gen t=_n
tsset t
gen e = rnormal(0, sqrt(2))
generate yt = 0.9*L.yt + e in 1
replace yt = 0.9*L.yt + e in 2/l // ar (1) error
gen y = 30 + yt
drop in 1/294 // drop 294 from 500 observations leaving 206 weeks = 4 years
```

```

gen time = _n
drop t
tsset time
*generate the intervention time
gen intervention = 1
replace intervention =0 if time<105

*generate increasing trend of 0.07 days per week (0.07 is arbitrary value, any value will do)
gen trend = 0.07*time

*generate a trend change variable
gen post_slope = (time - 104)* intervention

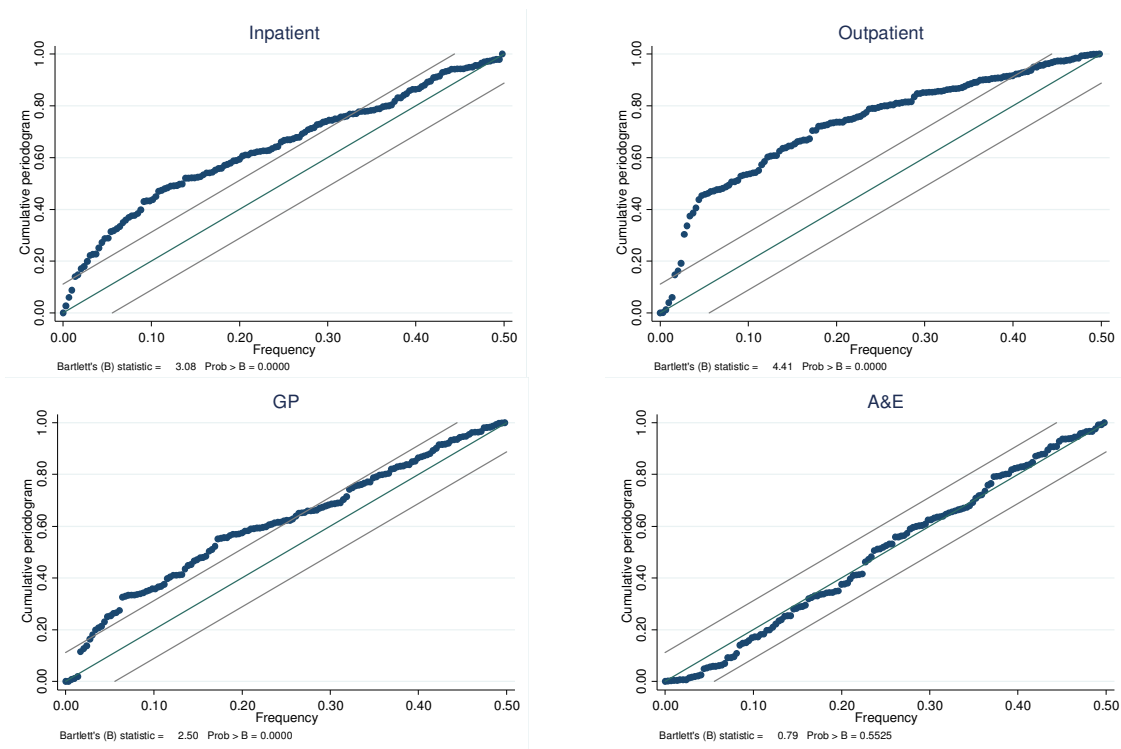
*generate a trend of 0.03 days per week (0.03 is arbitrary value, any value will do)
gen slope_change = -0.03*post_slope

*generate a reduction in y of 10day after the intervention (10 days is arbitrary value; any value will do)
gen intervention_effect = -10*intervention

*final series equation = initial waiting + trend + intervention + change in trend
gen waiting_time = y + trend + intervention_effect + slope_change

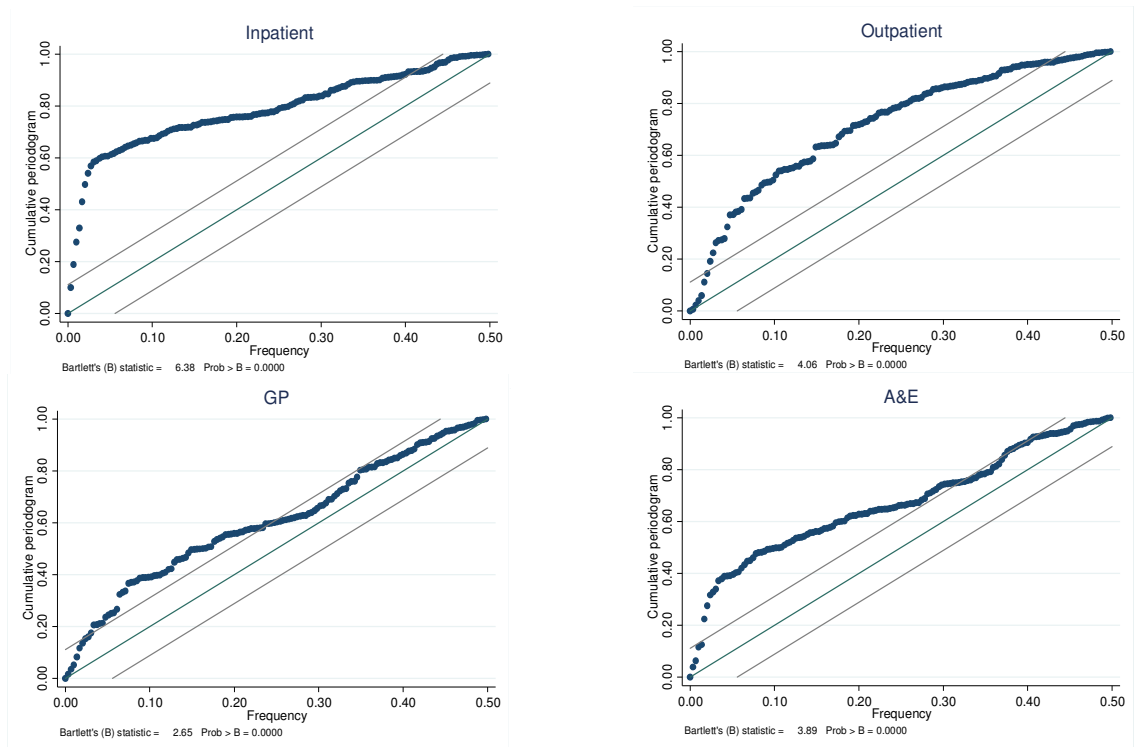
```

## Appendix 6: The cumulative periodogram test on the errors of the OLS model for pre-examination waiting times (PEWT)

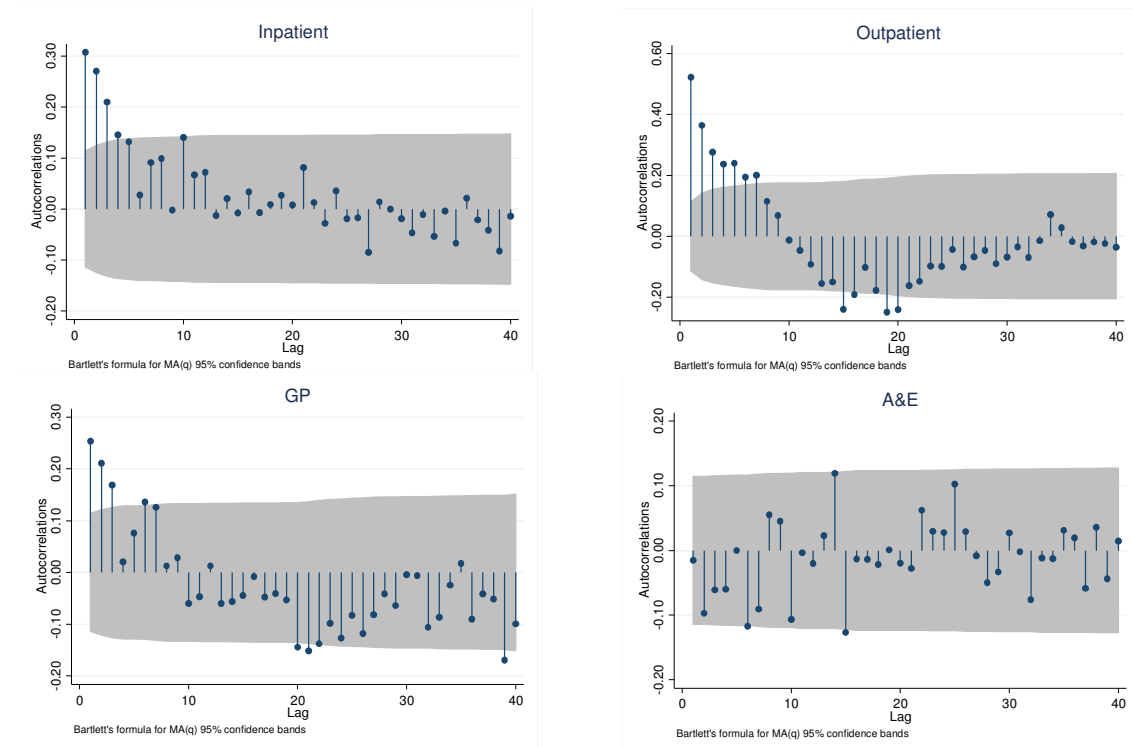


The errors of the OLS models for the A&E series showed no evidence of autocorrelation: cumulative periodogram (CP) does not go outside the bounds of the 95% confidence interval.

## Appendix 7: The cumulative periodogram test on the errors of the OLS model for report turnaround times (RTAT)



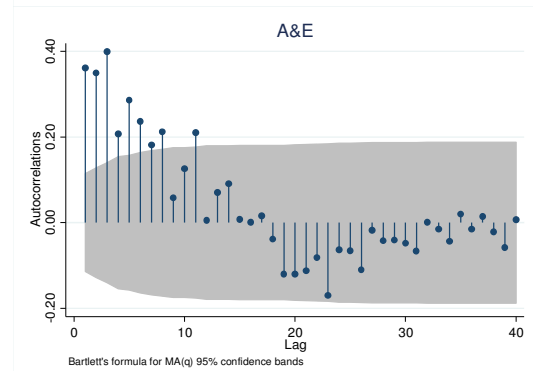
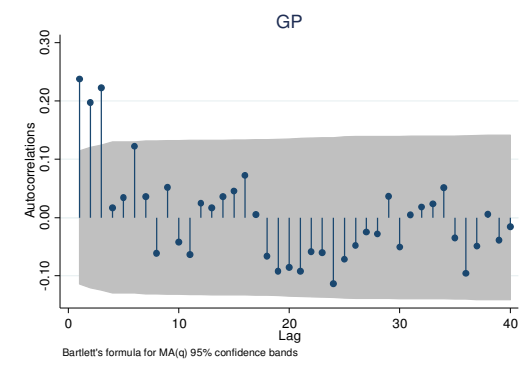
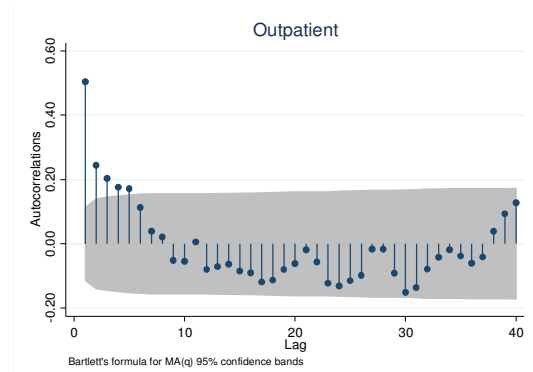
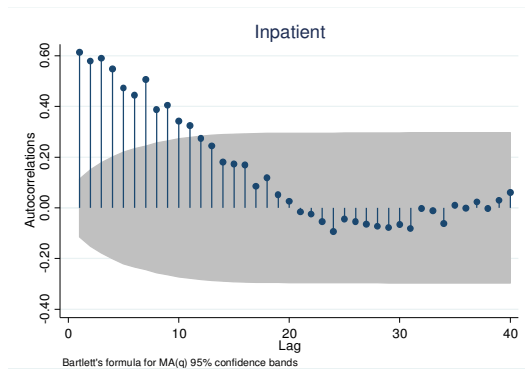
## Appendix 8: The ACF plots of the errors of the OLS models for pre-examination waiting times



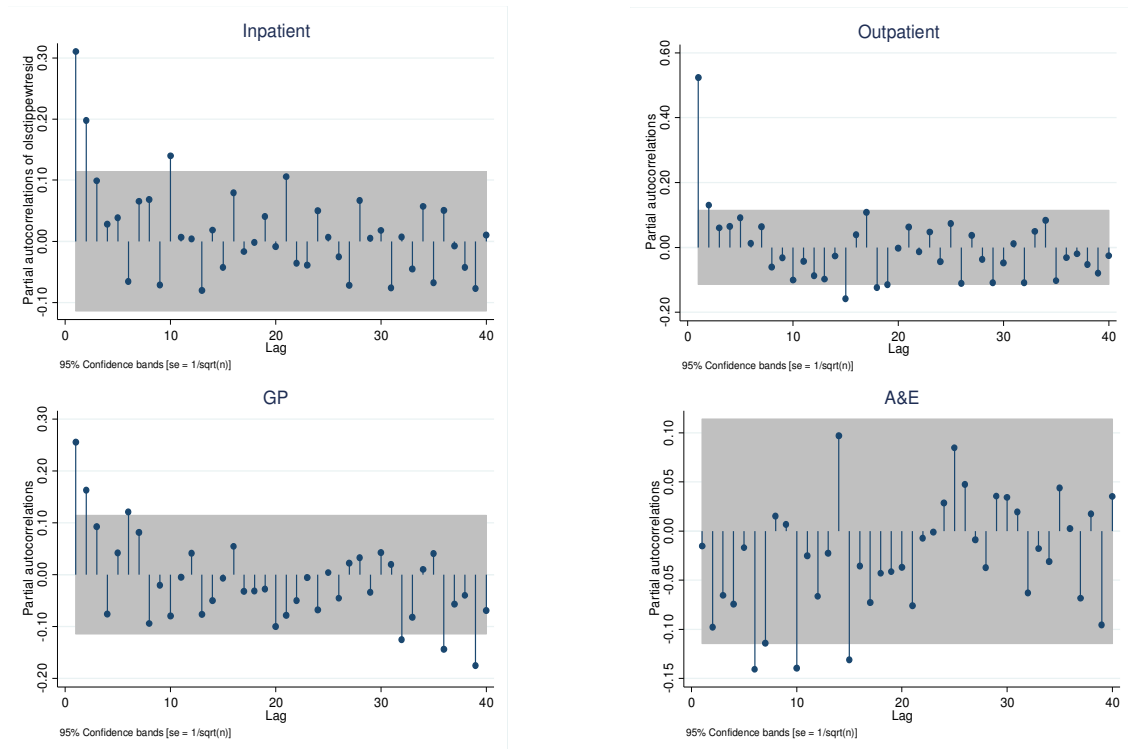
Again, the ACF of the A&E series does not show any evidence of autocorrelation: there is no significant spike outside the bounds of 95% confidence interval.



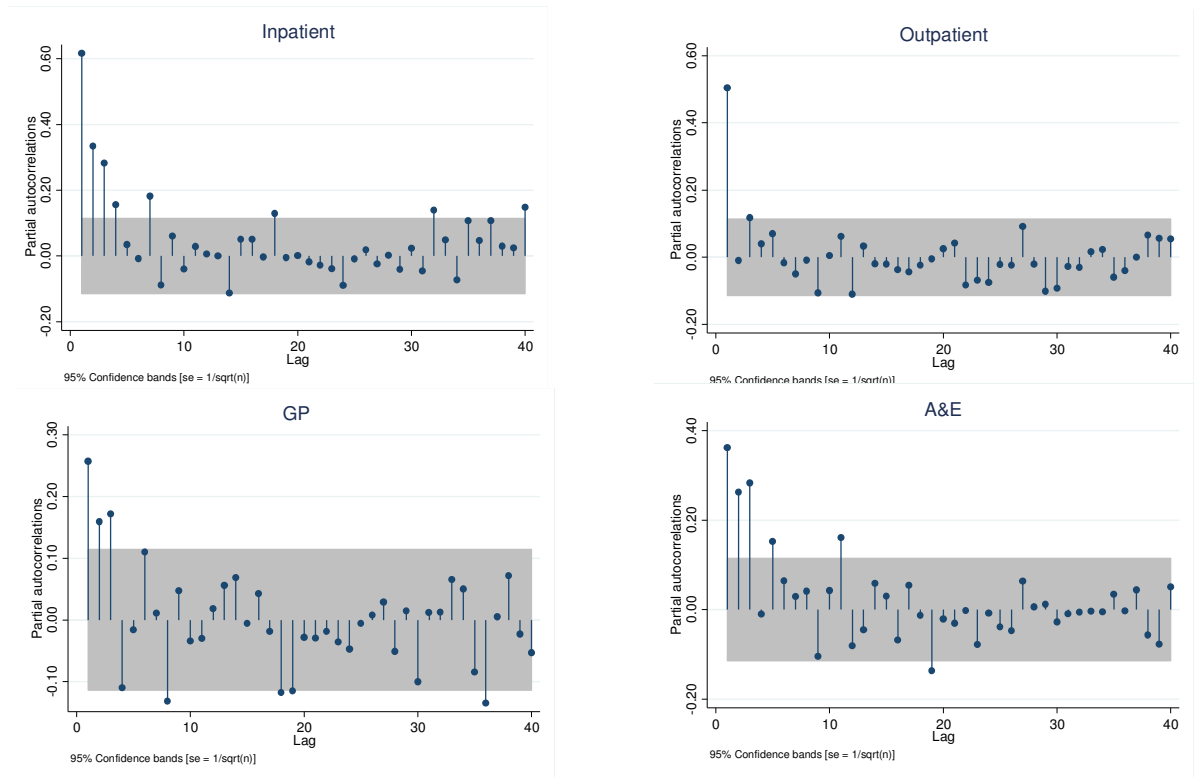
## Appendix 9: The ACF plots of the errors of the OLS model for report turnaround times



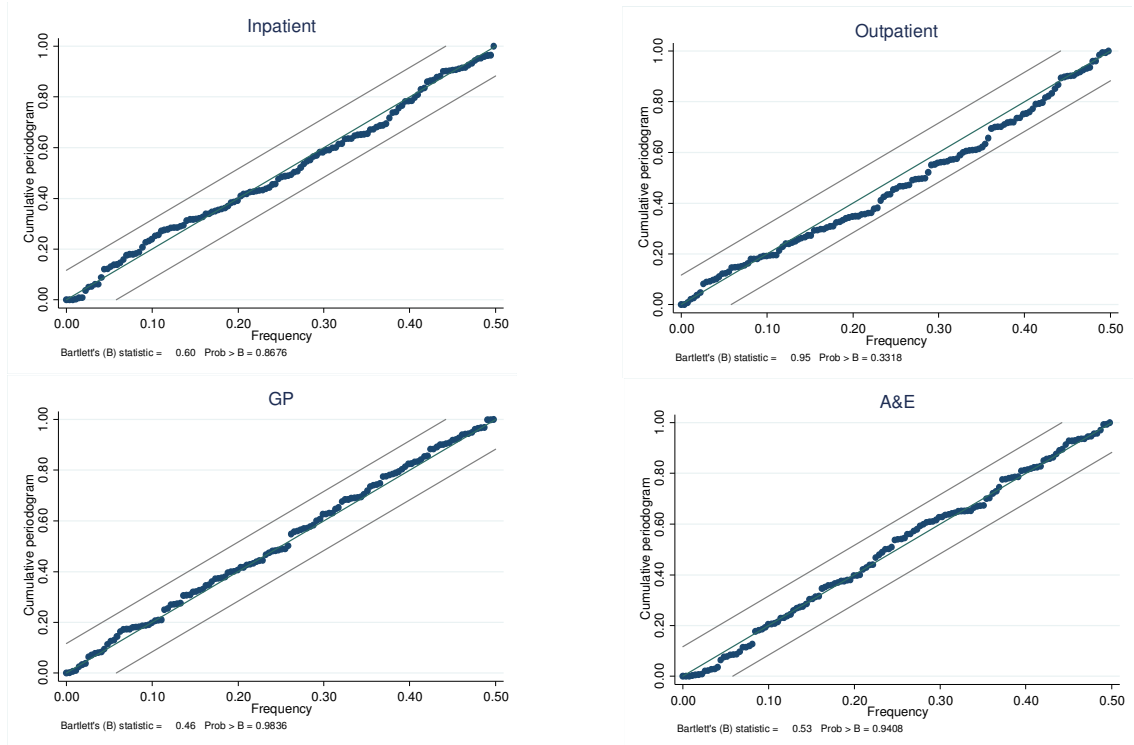
## Appendix 10: The PACF plots of the errors of the OLS model for pre-examination waiting times



## Appendix 11: The PACF plots of the errors of the OLS model for report turnaround times (RTAT)

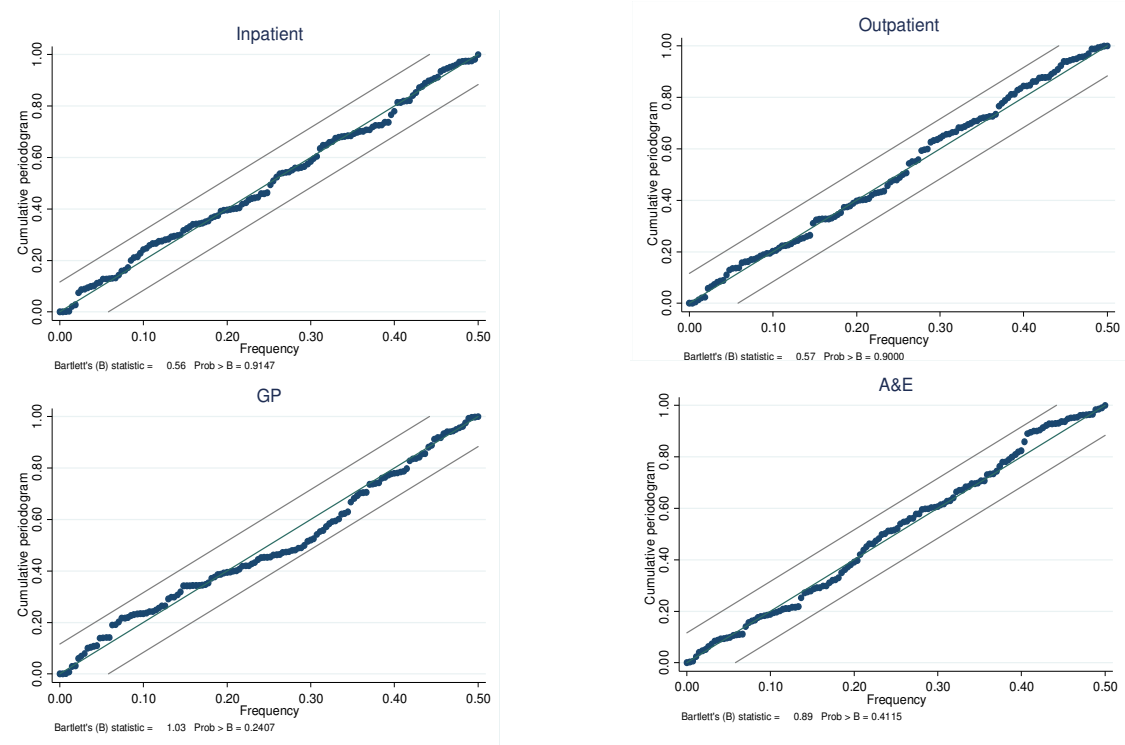


## Appendix 12: Bartlett cumulative periodogram test on the errors of the models with autocorrelated errors for the pre-examination waiting times (PEWT)



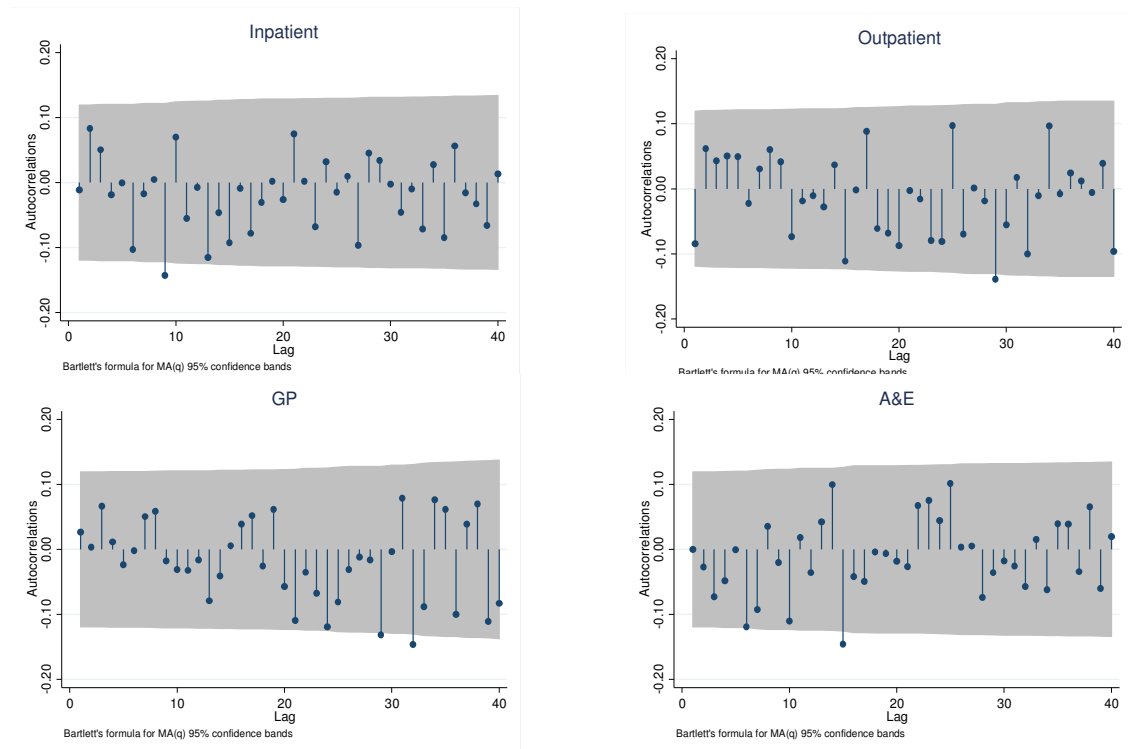
The cumulative periodogram test, appendix 5 show a very good alignment with the 45° line for all the series. Also there is no deviation outside the bounds of 95% confidence interval, indicating that all non-random periodicity including seasonality has been accounted for within the models.

## Appendix 13: Bartlett's cumulative periodogram test on the errors of the models with autocorrelated errors for report turnaround times (RTAT)



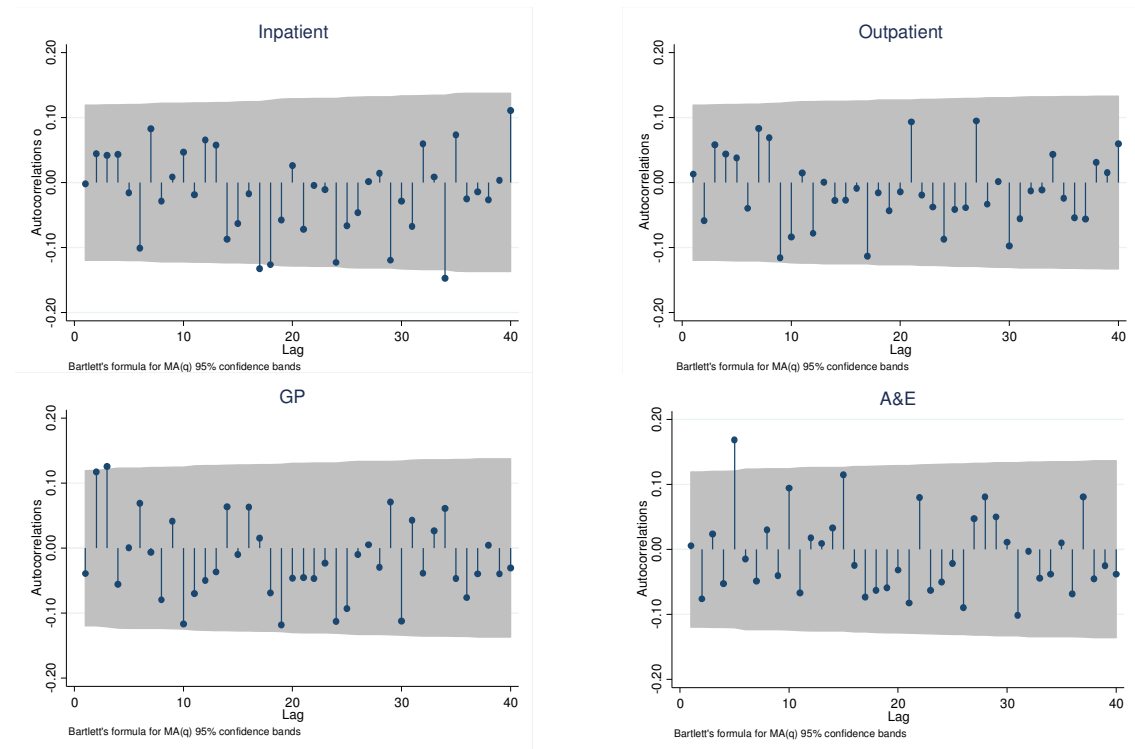
The cumulative periodogram test, appendix 5 show a very good alignment with the 45° line for all the series. Also there is no deviation outside the bounds of 95% confidence interval, indicating that all non-random periodicity including seasonality has been accounted for within the models

## Appendix 14: The ACF plots of the errors of the models with autocorrelated error for pre-examination waiting times (PEWT)



The ACF plots show no significant spike outside the shaded portion (95% confidence interval boundaries).

## Appendix 15: The ACF plots of the errors of the models with autocorrelated for report turnaround time (RTAT) by referral sources



The ACF plots show no significant spike outside the shaded portion (95% confidence interval boundaries).

## Appendix 16: Invitation to participate in a short interview for a research study titled: Evaluating the impact of service delivery initiatives on patients' waiting times within radiology departments: a qualitative assessment

I am writing to request your assistance with an important research project. This is part of a student PhD research project evaluating the impact of service delivery initiatives on patients' waiting times within radiology departments, we are conducting semi-structured interviews with referring clinicians and key radiology staff to assess their perceptions of the impact of service delivery initiatives on patients' waiting times. The initiatives include the implementation of 320-slice CT-scanner, voice recognition reporting and extended-working-hours in the radiology department, Birmingham Heartlands Hospital.

You were selected to be part of this project because you are either a referring clinician or a member of staff of the radiology department. We know that you have a very busy schedule, but hope that you will be able to participate in this short interview (20 – 30 minutes).

The results of this study will be reported as thematic summaries so that it is not possible for readers to link responses to individual respondents.

If you are happy to participate in the study or have any question about the interviews / study, please contact Bernard Olisemeke or Dr Madava Djearaman, radiology department for more information including a copy of the participants' information sheet.



Bernard Olisemeke

[Redacted]

Dr Madava Djearaman (Consultant Radiologist)

[Redacted]

Thank you in advance for your participation in this important research project.

Yours sincerely

Bernard Olisemeke  
R&D coordinator, radiology department

## Appendix 17: Participants' Information Sheet

### **Evaluating the impact of service delivery initiatives on the quality of service in radiology department, Birmingham Heartlands Hospital: a qualitative assessment**

We are a group of researchers from the University of Birmingham and Heart of England NHS FT (HEFT). We would like to invite you to take part in a short interview to gather information on your perceptions of the quality of the services delivered by the radiology department, Birmingham Heartlands Hospital. But first, please read through this information sheet to gain an understanding of what we propose to do and what your role would be. This study is being conducted as part of a PhD research project.

#### **What is the study about?**

Within the last few years the radiology department has implemented several service delivery initiatives (SDIs) to improve its quality of service. These include the installation of a new 320-slice CT-Scanner, adoption of speech recognition reporting and extended-working-hours. In order to assess the impact of these initiatives we are investigating the perceptions of radiology staff and referring clinicians within the Trust of the quality of radiology services. Our research aims to assess whether users and providers of radiology services perceive any improvement in the quality of service and how those perceptions are formed.

## **How many participants do you need to recruit?**

About 15 participants are required for this study.

## **Why am I being invited to take part?**

You have been invited to take part in this study because either you refer patients for radiology investigations and are well-placed to discuss your experiences of the radiology services and how it affects the management of your patients, or you are a member of staff of the radiology department and have experienced these initiatives in your daily routine, and are equally well-placed to discuss the impact of these interventions on your workflow.

## **What will I have to do?**

If you agree to participate, you will be one of the people taking part in a short interview to express your perceptions and attitude towards the quality of radiology services. The interview will only take 20-30 minutes to complete. We will require a signed consent form to proceed with the interview and for audio recording

## **Will I be identifiable in the transcription of the interview?**

No. Your participation in the study will be kept confidential. We will not be collecting any information about you that will allow others to identify you. You will not be personally identifiable in the typed transcription. The tapes will not be heard by anyone other than the transcriptionists and the researchers.

### **What are the risks of participating in the study?**

There are no risks associated with taking part in this study. Our study will run separate from your clinical work and there will be no impact on clinical outcomes or waiting times for your patients.

### **Do I have to take part in the study?**

No, this is completely up to you.

### **Can I withdraw after agreeing to participate?**

You can stop the interview anytime you wish. You can also withdraw after the interview has been completed by contacting the persons listed at the end of this information sheet and if you so request, your responses will not be included in the study. However, if you wish that we (researchers) do not use your responses, you will need to notify the study team within two weeks of completing the interview.

### **What happens to the data?**

The study data will be coded and stored in password-protected NHS / University of Birmingham computers. Only members of the research team will have access to the study data. The study data will be held securely for three years after the publication of the study results. Thereafter data will be completely deleted from the systems. All tapes will be stored securely in locked premises and electronic material

will be password protected in NHS and University of Birmingham computer.

Audiotapes will be destroyed three years following completion of the study.

### **What will happen to the result of the project?**

We intend to publish the results of this study in a peer reviewed academic journal. Neither your name nor any personal identifiable information will appear in any print. To ensure anonymity of participants, aggregate and / or thematic results will be presented. We will not be presenting results that will allow identification of individual participants. If you wish to find out the results of the study, you can use the contact details at the end of this information sheet.

### **Who has reviewed the research study?**

The study has been reviewed and given favourable opinion by the University of Birmingham's Science, Technology, Engineering and Mathematics Research Ethics Committee.

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If you have any question or need further clarification on any issue discussed above, please do not hesitate to contact

**Bernard Olisemeke** (Supt Radiographer)  
Radiology Department, HEFT  
Email: [Bernard.olisemeke@heartofengland.nhs.uk](mailto:Bernard.olisemeke@heartofengland.nhs.uk)  
Tel: 0121 424 0869

**Madava Djearaman** (Consultant Radiologist)  
Radiology Department (HEFT)  
Email: [Madava.djearaman@heartofengland.nhs.uk](mailto:Madava.djearaman@heartofengland.nhs.uk)  
Tel:

## Appendix 18: Topic guide for qualitative interview

### Opening the interview

Introduce myself, re-iterate the purpose of the study, confirm the clinical department of the participant, professional group and how long the participant has been with the Trust. Briefly go over the study information sheet and obtain signed consent form.

The interviewer will follow the topic guide while allowing the pace to be set by the participant. Follow-up all general statements made by the respondent with clarification question, particularly bearing in mind the purpose of the research.

Topic 1 320-slice CT-Scanner at BHH July 2009

**Q1.** What impacts did you expect the 320-slice CT-Scanner to have on radiology workflow?

- In particular, how did you expect the scanner to impact on (your) patients waiting time, why
- In reality, how did the scanner impact (your) workflow and (your) patient waiting times, why?
- Tell me about how this intervention was implemented / are you satisfied with this
- How would you explain the impact of the CT-Scanner on patients waiting times?
- Tell me about your satisfaction / dissatisfaction with the CT-Scanner
- What were the unexpected impacts of the new scanner if any?

**Q2.** What impact did you expect the speech recognition reporting (SSR) system to have on radiology workflow Sept 2009?

- In particular, how did you expect the SRR system to impact your workflow and your patients' waiting time, why?
- In reality, how did the SRR system impact your workflow your and patient waiting times, why?

- Tell me about how this intervention was implemented / how satisfied are you with the implementation
- How would you explain the impact of the SRR on patients waiting times?
- Tell me about your satisfaction / dissatisfaction with the SRR initiative
- What were the unexpected impacts of the SRR system if any?

**Q3.** What impact did you expect the extended hour working practice to have on radiology workflow Sept 2012?

- In particular, how did you expect the extended-working-hours practice to impact (your) workflow and (your) patients waiting time, why?
- In reality, how did the extended hour working practice impact your workflow and patient waiting times, why?
- Tell me about how this intervention was implemented / are you satisfied with this
- How would you explain the impact of the extended working day initiative on patients waiting times?
- Tell me about your satisfaction / dissatisfaction with the extended working day initiative
- What were the unexpected impacts of the SRR system if any?

**Q4.** What more changes to working practices within radiology department do you think is necessary to improve services?

**Closing the interview**

When the topic guide questions are completed, the interviewer will ask for any additional comments the participant would like to make and remind them that all the information given will be kept confidential.

Thank the participant and ask if he/she has any question about the interview and answer as appropriate. The interview is closed with the following statement:

*“That is all the questions I have for you. Thank you for your patience and co-operation; that is really appreciated. “We will be in touch should anything come up for which we might need your expert opinion, and we will be available should you need to contact us for any reason related to this interview. Many thanks for your time and have a good day.”*



## Appendix 19: Consent form for interview

**Participant Identification Number for this study:**

### **Study title: Evaluating the impact of service delivery initiatives on patients waiting times in radiology departments: a qualitative assessment**

1. I confirm that I have read and understood the information sheet (Version 3) dated 04/01/2014 for the above study. I have had the opportunity to consider the information, ask questions of a member of the research team and have had these answered satisfactorily.
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason.
3. I understand that relevant sections of my data collected during this interview, may be looked at by individuals from the research team, at the University of Birmingham, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.
4. I agree to take part in the above named study.
5. I agree to audio recording of the interview.
6. I agree to the use of direct quotations in publications provided that anonymity is preserved.

\_\_\_\_\_  
Participant's Name                      Date                      Signature

\_\_\_\_\_  
Interviewer                      Date                      Signature

When completed: 1 (original) to be kept with the study, 1 for participant;

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