TITLE

Streamlining pathways for minor injuries in emergency departments through radiographer-led discharge

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Abstract

Diagnostic imaging services are essential to the diagnosis pathway for many patients arriving at hospital emergency departments with a suspected fracture. Commonly, these patients need to be seen again by a doctor or emergency nurse practitioner after an X-Ray image has been taken in order finalise the diagnosis and determine the next stage in the patients' pathway. Here, significant waiting times can accrue for these follow-up consultations after radiographic imaging although the vast majority of patients are discharged. Research evidence from pilot studies suggests that patients with minor appendicular injuries could be safely discharged by a suitably qualified radiographer directly after imaging thereby avoiding queues for repeated consultation. In this study, we model patient pathways through an emergency department (ED) at a hospital in the South West of England using process mapping, interviews with ED staff and discrete event simulation (DES). The DES model allowed us to compare the current practice at the hospital with scenarios using radiographer-led discharge of patients directly after imaging and assess the reduction in patients' length of stay in ED. We also quantified trade-offs between the provision of radiographer-led discharge and its effects, i.e. reduction in waiting times and ED workload. Finally, we discuss how this decision support tool can be used to support understanding for patients and members of staff.

Keywords	Emergency department; early discharge; discrete event simulation; case study
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Submission Files Included in this PDF

File Name [File Type]

ORHC_2017_50_Rachuba et al_Response to reviewers.pdf [Response to Reviewers]

2017_rachuba_rld_v4.0.pdf [Manuscript File]

Submission Files Not Included in this PDF

File Name [File Type]

LaTeX source files.zip [LaTeX Source File]

We are grateful for the reviewer's constructive and focused feedback on our paper. This has helped to increase the flow of the paper and we believe that the content of the paper is now readily accessible for its readers. We have revised the paper accordingly and addressed all comments separately in the table below.

On behalf of the authors
Sebastian Rachuba

Reviewer 1

The authors are focused on evaluating the diagnosis pathway for patients with minor injuries in emergency departments (ED). In particular, the aim is to evaluate the impact of radiographer-led discharge under such circumstances and its impact in lengths of stay in ED, waiting times and ED workload. For this analysis, the authors propose to model patient pathways through an ED at a hospital in the South West of England using process mapping, interviews with ED staff and discrete event simulation.

Overall, the article presents an interesting and relevant topic, and is well written. Also, the proposed tool shows clear potential for use in real practice. Nevertheless, I have several comments that should be addressed by the authors before publication.

Section	**Comment**	**Response**
Comment 1, section 2.4	More details are required on each stage of the proposed methodology in Section 2.4. For instance, which was the key information gathered in semi-structured interviews? How did the authors select the stakeholders to be involved in the study?	*Thanks for this comment. In line with the second reviewer's comment, we have extended the information given in the methodology section. Since we also restructured the sections in order to do better justice to the overall modelling approach, this is now part of chapter 3, section 3.2.*
Comment 2, section 2.4	Regarding the last issue referred in Comment #1 (selection of stakeholders), this turns to be a critical point for the study, since different stakeholders with different concerns can be identified, and so a wide variety of KPIs may arise depending on the stakeholders involved. Within problem structuring methods, CATWOE analysis may be a good option to identify different groups of stakeholders, so as to justify which ones were included in the study, and finally, why specific KPIs were considered as the most relevant for the analysis.	*Thanks for this remark. We did not use specific techniques such as CATWOE in our study. In fact, the stakeholders to be involved and the resulting KPIs were made clear by hospital staff (clinicians and managers) and hence the focus was predetermined.*

Chapter 3	Chapter 3 could be improved if organized according to the three methodological steps identified in Section 2.4.	*This is very helpful indeed, thanks. We have restructured the entire modelling process by reorganising the previous sections 3 and 4. We believe that this improves the flow of the paper and makes it easier to follow.*
Page 6, lines 211-212	Is this true at a national level? Otherwise, how can one argue that this study and the proposed tool can be applied to other hospitals at a national level?	*The sentence has been reworded and now reads "In this study, very few patients received ultrasound, CT or MRI scans as part of their diagnosis. This is standard for minor injury pathways because the majority of injuries presenting within this stream of patients are readily diagnosed using radiographs alone. A minority of patients may have other imaging if their presenting symptoms are complex or they deteriorate during their time in the hospital."*
Figure 3, page 9	Identifying pathways A and B in Figure 3 would greatly improve its interpretation.	*We have adapted the formatting for the arrows according to figure 2 and this makes figure 3 easier to follow.*
Section 3.5	A paragraph in Section 3.5 showing how to read Figure 4 would be useful to better understand all the flows and information shown in the figure.	*As part of the new section 3, we have included a paragraph explaining the graphical interface of the DES model.*
Section 3.5 / 4	How did the authors model the impact of highly skilled radiographers? According to Section 3.5, historical data was used to model 'regular' discharges, but nothing is said regarding discharges by highly skilled radiographers (with this being expected to have impact on the number of discharges used as KPI). What did the authors assume for this particular situation?	*The assumptions for the pathway redesign were added. The idea was to have a short 'consultation' following image acquisition. We assumed durations to be around 5 to 10 minutes. This is now part of the section 'Pathway redesign' in section 3.*
Section 4	Differences between genders are referred in Chapter 4. Did the authors consider using probability distributions from historical data to capture the differences between male and female? Did the authors test it to verify if no significant differences arise in final results?	*We have added a sentence indicating that we did not test for differences, but the model could easily incorporate this for further analysis.*

Reviewer 2

This is an application paper of simulation modelling in health and it is contributing to the literature on emergency departments (A&E in UK). I like the focus of the paper on simulating the impact of upskilling radiographers to undertake duties that are traditionally associated with other ED professionals. The engagement with real healthcare professionals and the use of good quality data in good supply is a strength. However I feel that the paper is not well enough structured and this is not doing justice to the worked undertaken. The information for the most part is there but it needs reorganising. In addition you are not using the available literature particularly in DES enough in sections such as the description of the methodology and the discussion section.

We appreciate this feedback and in particular the suggested ideas for restructuring the paper. We have carefully revised our first version of this study and specifically paid attention to strong logical connections in the case study section. We believe that the revised version does more justice to our work and that is is easier to follow. However, as these suggestions imposed quite substantial changes to the work we presented, we paid careful attention to the fact that this is an interdisciplinary work and as such should contain sufficient amount of background on the medical application of interest. We think that this revision incorporates both, i.e. provides a clearer structure of the overall study and still focuses strongly on the medical application and exemplifies the use of this research.

Section	**Comment**	**Response**
1. Introduction	The introduction is missing the contribution which is found on page 5 (first paragraph only). The research questions are not needed here.	*Thanks, we have brought the contributions forward to the Introduction. At the same time, the research questions have been integrated in the modelling objectives where we believe, they fit best.*
The general structure I would suggest is: 2. Background	I would start with the literature on ED and upskilling medical staff to cope with increasing demand (think beyond radiographers to nurses), then simulation of ED and lastly literature specific to simulating radiology within ED if any. It will then be clear to the reader how your work is positioned and the novelty of your focus within the ED simulation literature.	*Thanks for this comment. We have moved the contribution to the front (see above). We do believe that our literature section follows a structure which is very similar to the one you suggested. However, we do not think that including the literature on upskilling staff in ED in general would add much but would rather distract from the studies focus, i.e. upskilling radiographers. Even with the current structure, we believe that the novelty of this approach becomes clear.*
3 Case study	This section could be divided into:	*We appreciate the suggested structure and have revised this section of the paper accordingly. Where necessary, we have*

		made minor amendments in some places which will be highlighted explicitly.
3.1 Description of the ED	Explain your involvement, motivation, project partners, contributors from hospital, timeline, problem in that setting etc	*We have expanded this part and named collaborators and highlighted the project motivation.*
3.2 Methodology	Explain the choice of DES, DES software, and outline process followed (Consider Conceptual modelling, model coding and V&V, experimentation and implementation.	*The section 'Methodology' has been revised. It now features the suggested aspects and we feel that it links well with the following subsections.*
3.3 CM	Understanding the problem, simulation objectives, inputs, outputs, model content and data requirements	*We have included all the major topics you mentioned. In addition, we have included the data analysis as a separate subsection following 3.3 because we believe the quality of the data is so good that it should have a prominent place in the modelling process.*
3.4 Model coding	How you represented the data in the model, KPIs/parameters, calibration of the model (justify run time and warm up) and V&V	*We have explained the DES model in a lot more detail. Given the additionally introduced subsection on data analysis, we have add KPIs and key parameters to that section. Given the applied nature of this work, it appeared quite natural to link the data with the KPIs.*
3.5 Experimentation	Outline the scenarios and how these were determined or if necessary the design of the experiments	*Thanks, we have revised accordingly. In particular, we have brought forward the description of the scenarios, which were initially part of the results section. After consolidating these descriptions, we believe it now reads clearer and is easy to follow.*
4. Results	explain the findings of the scenarios outlined	*We kept most of this part, but excluded the scenario descriptions (see previous comment).*

5. Discussion / conclusion	discuss implementation, contribution and reflect on the literature given your findings, propose subsequent work	In addition to the critical reflection on challenges when implementing radiographer-led discharge, we have expanded the last paragraph linking our findings with the literature and proposed next steps.

I hope this does not discourage you but a better structure will help the reader fully appreciate what you are putting forward.

Streamlining pathways for minor injuries in Emergency Departments through radiographer-led discharge

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Abstract

Diagnostic imaging services are essential to the diagnosis pathway for many patients arriving at hospital emergency departments with a suspected fracture. Commonly, these patients need to be seen again by a doctor or emergency nurse practitioner after an X-Ray image has been taken in order finalise the diagnosis and determine the next stage in the patients' pathway. Here, significant waiting times can accrue for these follow-up consultations after radiographic imaging although the vast majority of patients are discharged. Research evidence from pilot studies suggests that patients with minor appendicular injuries could be safely discharged by a suitably qualified radiographer directly after imaging thereby avoiding queues for repeated consultation. In this study, we model patient pathways through an emergency department (ED) at a hospital in the South West of England using process mapping, interviews with ED staff and discrete event simulation (DES). The DES model allowed us to compare the current practice at the hospital with scenarios using radiographer-led discharge of patients directly after imaging and assess the reduction in patients' length of stay in ED. We also quantified trade-offs between the provision of radiographer-led discharge and its effects, i.e. reduction in waiting times and ED workload. Finally, we discuss how this decision support tool can be used to support understanding for patients and members of staff.

Keywords: Emergency department, early discharge, discrete event simulation, case study

1. Introduction

The increasing demands on emergency departments (ED) in the United Kingdom (UK) are putting pressure on acute trusts and their staff, with some reports describing the pressures placed on staff and hospitals as being unsustainable [1]. Waiting times in EDs have increased and patients are being encouraged to use these services mindfully to try to reduce the pressure, with staff and resources frequently being stretched beyond capacity [2]. However, hospitals also need to assess the most appropriate methods for utilising staff effectively and streamlining the patient pathways to improve productivity. The current minor injuries (MI) pathway in ED is generally led by emergency-nurse practitioners (ENP), with additional medical support as necessary. Usually, around 60% of ED attendances require medical imaging, which is usually projection radiography (X-Ray). These images are most commonly interpreted within the ED by either junior doctors or

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ENPs who decide on and perform treatment or discharge based on the image. A formal report is later issued by a reporting radiographer or radiologist and The National Institute for Health and Care Excellence (NICE) guidelines for fracture recommend that this is now completed prior to the patient leaving ED [3]. However, the vast majority of patients requiring medical imaging will subsequently be discharged from ED. Those discharges sometimes include a referral to a patient's General Practitioner (GP) or other services such as Fracture Clinic or physiotherapy. Patients who are discharged following imaging can spend up to 50% of their time in ED waiting for a decision to be made after an image has been taken.

This paper combines evidence-based research looking at the benefits of radiographer-led discharge with operational research techniques and Discrete Event Simulation (DES) in particular. We build on existing studies but focus specifically on patients with minor injuries and suspected fractures. Most of these patients are likely to be discharged from ED and do not require any further treatment in the hospital. Secondly, we explicitly assess the trade-off between quality improvements (i.e. time savings) and the related cost for which we use staffing time as a proxy. The DES model we develop provides a decision support tool to help quantify the impact of redesigning the minor injuries pathway in ED. It enables clinicians and hospital managers to identify benefits and drawbacks of such a pathway redesign. As the pathway we investigate is very generic, there are clear opportunities to transfer these findings to other care providers such as large academic hospitals, smaller district general hospitals, or MIUs. To summarise, our paper addresses the following three key aspects:

1. *Model evidence-based changes to an existing ED pathway*
   The DES model serves as a safe environment and allows clinicians and managers to explore the impact of pathway changes and identify required changes to resource availabilities.
2. *Provide a DES model as a decision support tool*
   Although driven from a single trust's point of view, the model captures the common overall structure of a minor injuries pathway in ED. The DES model is designed to be possibly adapted by other hospitals. This allows the use of other trust's historic or expert data to perform similar analyses to the ones conducted in this paper.
3. *Provide insights about the role of conceptual and mathematical modelling* as part of interdisciplinary projects in healthcare operational research.

In order to address these questions, we examined related literature looking firstly at the evidence of the benefit of a radiographer-led discharge service, and then at how pathway analysis and modelling in ED has been applied using operational research techniques. A description of the Minor Injuries pathway in ED is subsequently presented in section 3 as a result of mapping and discussion sessions with ED staff. Building on this, we develop a discrete event simulation (DES) model as a suitable representation of the generic pathway which we present together with the extensive data sample we used for our study. In section 4, we present findings from a series of what-if simulation studies aiming to quantify the effects of introducing radiographer-led discharge. In particular, we analyse the trade-off between costs of providing such a streamlining concept and the resulting benefits, i.e. time savings. Finally, we outline how this study could inform practice at EDs in general and discuss benefits and drawbacks from this work.

2. Background

The study presented in this paper brings together radiographic research looking at the potential for earlier patient discharge and staff training, with systems modelling using operational research techniques to support health service redesign. Hence both we will initially provide background on the medical application before addressing the role of operational research in this context.

2.1. Medical background

Typically, diagnostic images acquired for patients on a minor injuries pathway in ED are interpreted in the first instance by nurses or junior doctors and the patients are treated or discharged based on these results. Radiologists or reporting radiographers then review the images either as soon as possible following imaging (*hot reporting*) or during the next available reporting session (*delayed* or *cold reporting*). Image acquisition is at the core of every radiographer's role, who unlike radiologists are not doctors, but the exact specification of the job role, level of autonomy and responsibilities vary across the world. The educational pathways are also very distinct. In the UK, which is the origin of our study, a radiographer is required to have completed an undergraduate degree programme which entails both academic and clinical training. Once qualified they are then able to progress their career through participation in postgraduate education in order to achieve Advanced or even Consultant Practitioner status (this would include reporting duties, i.e. providing a definitive diagnosis from an image). Undergraduate and postgraduate programmes of study must be recognised and accredited by the governing body of the profession, the Society and College of Radiographers (SCoR). Radiographer reporting has become widely accepted in recent years and a cross sectional survey in 2015 demonstrated that radiographer reporting was occurring in 55.1% of the respondent sites [4]. The SCoR recommend a minimum of a postgraduate certificate (PGC) taught at Masters level in the area of reporting for radiographers expanding in to this area of practice [5].

The responsibilities of radiographers in the UK include the acquisition of images, but preliminary clinical evaluation (PCE) is also recommended in the ED setting. This is a comment provided by the radiographer with regard to any normal or abnormal findings present on the image they have acquired. It should be noted that a PCE is not considered to be a conclusive report but is intended to alert the referrer of any potential abnormality assisting in the image interpretation undertaken by the ED doctors and ENPs, which underpin their decisions on further management of the patient, i.e. choosing the correct pathway for treatment or discharge. However, in a small minority of hospitals, radiographer discharge is undertaken at the point of imaging, but despite the reported benefits, this has yet to be adopted by other hospitals. Finally, radiographer reporting of projection radiography has become a standard aspect of advanced practice within the UK over the last 20 years and radiographers, with appropriate training, have consistently demonstrated the ability to accurately report radiographs at a standard comparable to Radiologists [6]. This portfolio might exceed the requirements of comparable jobs in other countries, but it marks the reference skill set for this study.

In general, nurses undertaking image interpretation roles have considerably less image interpretation education than their reporting radiographer counterparts [7]. A number of authors have reported a reasonable accuracy of nurse-led image interpretation in the ED setting [8, 9, 10]. However, radiographers with additional education in image interpretation were able to demonstrate greater accuracy in this area of practice [6]. Discrepancies between the initial diagnosis in the ED and the subsequent radiology report support the argument for RLD [11, 12, 13, 14]. Missed or delayed fracture diagnosis constitutes a substantially large financial burden to the UK's National Health Service (NHS) arising from litigation [15, 16, 17], so reducing missed or delayed diagnosis is key in any service development.

A pilot study from a hospital in the UK explored the potential of radiographer-led immediate reporting and discharge or referral for treatment direct from the radiology department for patients who had care plans detailed by ED [18]. This showed that the mean journey time for patients discharged directly by radiographers was reduced by more than 50% compared to the time prior to the study (i.e. 52 versus 134 minutes). Also for patients being referred on by a radiographer time in ED could be reduced by more than 60 minutes. From a randomised controlled trial of immediate or delayed reporting, Snaith et al. [19] reported that the reporting did not increase the patient journey time. Besides the effects on time, a significant reduction of errors in image interpretation was also observed. A study by [20] explored the cost effectiveness and quality of life outcome measures. There was a potential cost-saving of GBP 23.40 per patient for immediate reporting, while there were no differences reported in patient quality of life as measured by the EQ-5D at 8 weeks following their ED visit between the two arms.

Despite the clear benefits achievable by employing reporting radiographers within the ED and Minor Injury Unit (MIU) setting, there are currently insufficient numbers of radiographers in the UK to sustain an immediate reporting service. In fact, following a recent survey, just over half of hospitals responding (179 hospital sites in the UK and on the British Isles) have reporting radiographers [4]. Despite the benefits of the concept, smaller or medium-sized hospitals are unable to introduce radiographer-led discharge with immediate reporting because there are insufficient reporting radiographers available. Furthermore, most importantly, the evidence currently available is not strong enough to demonstrate the benefits reported in the literature would apply to individual service providers due to differences in patient pathways and hospital sizes. Finally, with an increasing demand for nursing staff in the South West of the UK and nationally NHS providers are struggling to recruit. The strategic vision to develop the radiographers' role in order to provide radiographer-led discharge from the ED is a potential resolution to ease the burden on ED services both locally, nationally, and potentially worldwide.

2.2. Discrete Event Simulation in Emergency Departments

EDs are among the most intensively studied areas within a hospital and numerous reviews support the choice of DES models to explore patient flows while taking into account various routing policies and stochasticity of both arrivals and activities along the process (e.g. Günal and Pidd [21] or Gul and Guneri [22] for comprehensive reviews). Crowded departments and excessive waiting times for patients are frequently cited as the main reasons why researchers aim to improve efficiency of service delivery [23, 24, 25, 26, 27]. DES has specifically been used to support streamlining efforts in EDs and has been widely applied for more than 20 years [24, 27, 28]. Besides DES studies, a large variety of techniques is applied ranging from Monte-Carlo-Simulation [29] to approaches using Queueing Networks [30] and hybrid approaches (e.g. combining agent-based simulation and DES) which are among the recently emerging trends in simulation in healthcare [31]. The vast majority of studies which support planning in ED originate from real world applications and address actual problems. However, most of the studies published do not to lead to implementation of findings as stated in Brailsford et al. [32].

Over the last decades, DES has remained a popular tool to support decision problems in healthcare and particularly in EDs (e.g. [33, 34, 35, 36]). Recently, studies have focused on patient pathway changes in ED due to either newly issued medical guidelines or in light of newly available medical evidence. Rachuba et al. [37] focus on pathways for patients presenting at ED with chest pain, whereas pathways related to stroke treatment are at the centre in the study by Komenda et al. [38]. Both papers employ DES models in order to assess the impact of the changes. Another study by Yang et al. [39] investigates how different triaging policies in ED affect the time patients spent in ED. In their DES study, greater time savings in ED can be observed with improved triaging when the workload for physicians is high. In relation, an empirical study by Kuntz and Sülz [40] found that higher or better qualified ED staff can treat patients faster when attendance level is elevated. On the opposite, slower durations for treatment were found with lower utilisation in ED. In contrast to the available literature, our paper is unique as the concept of radiographer-led discharge has only been addressed in medical pilot studies as outlined above. A pathway modelling and simulation study of this concept has not been published yet.

3. Case Study

3.1. Description of ED

Our paper evolves from a study that investigated the benefits of a streamlining concept *Radiographer-led Discharge* (RLD) for patients on a Minor Injuries pathway in ED. The work was funded by Health Education England (South West, HESW) and carried out in collaboration with acute trusts in the South West of England. The wider project looked at image interpretation competence among radiographers and the impact of pathway redesign on the patient journey. The first part featured a training needs analysis to assess the current level of competency in regard to diagnostic image interpretation (i.e. X-Rays) among radiographers and other members of ED staff. The second part of the study – presented in this paper – aimed to model current practice in ED and subsequently quantify potential time savings for patients being suitable for early discharge from ED. This part of the project was carried out in collaboration with managers, clinicians, analysts, and administrators at two hospitals in the South West of England. The main project team consisted of two operational researchers and two radiographers based at the University of Exeter's Medical School. It was intended to demonstrate how the concept of RLD could be beneficial at any hospital. Hence, we aimed to provide a sound modelling framework which could be applied to any hospital setting. The framework was aimed at medium-sized hospitals in the UK (district general hospital) in order to investigate the beneficial effects of RLD on the hospital's practice – if any. This work was carried out over 9 months – independent of the training needs analysis which featured the major part of the overall study.

3.2. Methodology

We employed a phased approach which benefited from good links to clinicians. This helped to maximise the utility of our work, in particular of the DES model and its results. The following components – briefly highlight hereafter – serve as a framework for the remainder of the paper:

1. Problem structuring approaches and assessing complexity
2. Conceptual modelling and identification of key focus
3. Data sourcing and analysis
4. DES model building, coding, and verification & validation
5. What-if experimentation and ways to implementation

The *problem structuring* took place in multiple sessions at a medium-size hospital in the South West of England and focused on the minor injuries pathway in ED. Together with consultants, nurses and information analysts, we captured the current practice at ED and visualised the flow of patients from admission to a final decision about discharge or admission. Methods employed were process mapping and semi-structured interviews with clinicians. The semi-structured interviews were intended to acquire a sound understanding of processes along the minor injuries pathway in ED i.e. sequencing, staff responsibilities, routing, etc. It was considered important to have both doctors, nurses, radiographers, radiologists, and analysts involved in this study as it would allow to capture many different views on challenges, opportunities, and potential limitations of this study. With respect to the specific individuals, some of the clinicians working at the hospital had existing links to the university and those clinicians suggested further links to administrators and data analysts. During the second phase, we simplified the underlying pathway to develop a *conceptual model* capturing key aspects of the pathway. This was done in close collaboration with clinicians and particularly information analysts in order to assess data availability. Clinicians then outlined the intended pathway redesign which was again captured in a conceptual flow chart diagram. One of the collaborating hospitals provided a well-documented historic data set which we used to populate the simulation model. We present a separate descriptive analysis in order to document the importance of good quality data in our study. Next, the conceptual models shaped the development of a *discrete event simulation model* which captured the current system pathways and allowed us to explore pathway redesign options, e.g. the introduction of radiographer-led discharge options. The model was verified and validated using both hospital experts and large historic data sets of good quality. Clinicians and managers specified the necessary changes to the minor injuries pathway and defined a series of what-if scenarios for analyses. Finally, during the *experimentation* phase we populated the DES model using historic data and quantified the effects of proposed pathway changes following the introduction of radiographer-led discharge. These experiments also highlight potential issues on the way to a wider implementation of the concept.

The project lend itself very naturally to the use of DES as a visual interface using distinct software, capturing uncertainty in process durations and arrivals, and incorporating stochastic routing options were key requirements for the pathway modelling. As the concept of radiographer-led discharge is a novel approach in comparison to common ED practice, it was desirable to have a visual interface, in particular with the aim to potentially roll-out this concept to other hospitals. The visual interface was considered to be supportive to achieve the required buy-in at other hospitals. The potential to use the developed tool elsewhere was a major goal from the start. Hence, we decided to use Simul8 (Simul8 Corporation, [41]) which is widely used for DES modelling and in particular for healthcare applications. Its graphical interface allows to provide live output of performance measures which was considered helpful in this case. This feature would allow the users to track individual patients and also see impact of pathway changes developing over time.

Engaging with information analysts alongside all phases was key to identify data availability and to confirm which key performance indicators could be quantified. Likewise, important stakeholders (i.e. clinical staff working in ED, but also analysts and managers at the hospital) confirmed the most important performance metrics which were then included in the DES model. These links were highly significant to the model development and the analysis of outputs. Since the focus of this study was very narrow from the outset, we did not include additional problem structuring techniques such as CATWOE analysis (the reader is referred to the work of Smyth and Checkland, e.g. [42]). It became clear during early stages of the project work that the metrics used herein and the stakeholders involved were of particular interest and no deeper analysis was deemed necessary.

3.3. Conceptual model building

According to the widely used concepts proposed by Robinson [43, 44], we distinguish four aspects of the conceptual model development, i.e. objectives, inputs, outputs, model content. The project's *objectives* were specified as follows:

1. What changes to an existing minor injuries pathways are necessary to incorporate RLD? The main task is to capture the current practice at the hospital's emergency department. This includes analysing the current pathway and available historic data records. Both is needed to inform the decision about reconfiguration of the current system.
2. What is the impact of RLD for a minor injuries pathway on patients' length of stay in ED? Based on the identified options to change the current system, i.e. what-if scenarios, a simulation model will be used to quantify the impact in terms of patients' length of stay.
3. What is the trade-off between the required staffing supply and desired effects when introducing RLD? Explore, how different availabilities of RLD would affect the length of stay in department, e.g. limiting the availability to certain weekdays or days on the weekend.

For this study, historic data sets from a hospital in the South West of the UK particularly looking at patient arrivals, process times (i.e. time of individual and between consecutive activities) and resource availabilities, were key *input* factors. Besides, the processes and patient pathways in ED were important for developing a useful model. The output of this modelling project is in fact a *proof of concept*, quantifying the effects of radiographic discharge in comparison to traditional discharge. This study wants to provide a generic model which can answer this question at a variety of hospitals.

The structure of the underlying minor injuries pathway in ED is of crucial importance for the pathway simulation model. We captured the current practice at a hospital in the South West of England and held an inter-disciplinary mapping session together with an Emergency Nurse Practitioner, an ED administrator, and other key members of ED staff. This session enabled us to assess the complexity and variety of the pathways in the minor injuries unit. Most commonly, minor injuries include diagnosis such as appendicular fractures, bruises or sprains (i.e. hand, foot, wrist, ankles) or soft tissue injuries. Minor injuries regularly account for more than 55% of the overall ED attendance and are mostly cared for in a separate area of the department, but in close proximity to the Majors area. About half the patients presenting with minor injuries require medical imaging to assist with the diagnosis. The vast majority of those images (in our study more than 95%) are diagnostic X-Ray images. In this study, very few patients receive ultrasound, CT or MRI scans as part of their diagnosis. This is standard for minor injury pathways because the majority of injuries presenting within this stream of patients are readily diagnosed using radiographs alone. A minority may have other imaging if their presenting symptoms are complex or they deteriorate during their time in the hospital. The mapping session's outcome is visualised in Figure 1. One might expect the pathway to be fairly linear with a few routing options but, in fact, it is complex incorporating a number of loops, such as repeated imaging or gathering expert advice. The hospital supports up to ten different discharge options for this pathway, which include various follow-up options such as plastering, physiotherapy or referral to the GP.

Typically, patients register their attendance in ED at a dedicated desk before joining the waiting room. An ENP or another qualified nurse then assesses the severity of patient's illness or injury during triage and diagnostic imaging might be requested at this point subject to certain conditions.

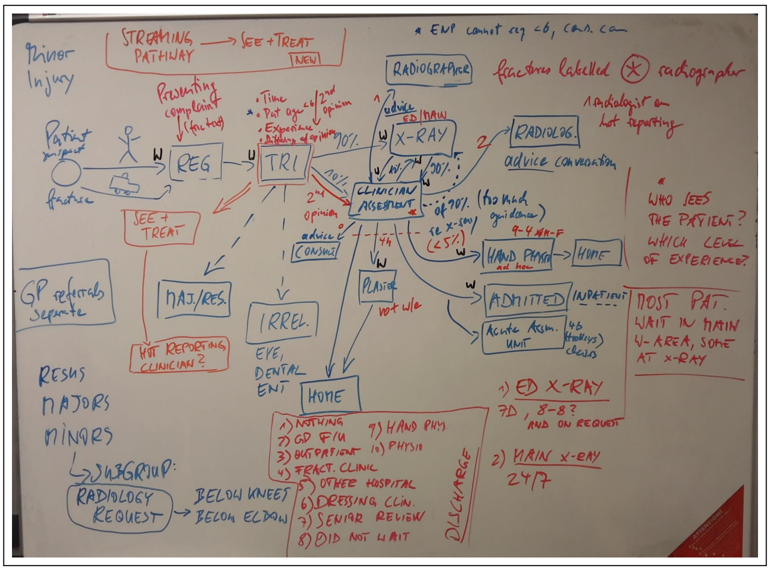

Figure 1: Outcome of an inter-disciplinary mapping session at an acute trust with ED staff.

For example, imaging for younger children cannot be requested at triage, but needs to be requested by a doctor during a medical assessment. Generally, the ordering of diagnostic imaging varies with medical experience and might also vary throughout the day or the week depending on the practitioner's own scope of practice. However, the vast majority of images are requested at triage and subsequently interpreted during a clinical assessment led by a doctor or ENP. During triage, patients may also be streamlined to other specialised departments of the hospital (e.g. outpatient clinics such as Ear-Nose-Throat, Ophthalmology, or a Dental Unit) or to the Majors area in ED when necessary. Following triage, during a medical assessment, additional advice might be acquired from radiographers, radiologists, or consultants. Further imaging might be required to finalise a decision on further management of the patient. Once the diagnosis has been established and the appropriate treatment given (plaster, pain relief, dressing etc.), the patient can then be discharged to the care of the physiotherapy team, orthopaedics or other specialist service or their own GP as necessary. Admissions become necessary for only approximately 5% of all patients. An abnormal image indicating a fracture does not usually lead to an admission, unless surgical intervention is required. However, a normal image regularly leads to a discharge unless other reasons require an admission into hospital, such as other or multiple conditions. Most EDs are based close to Radiology, where patients are sent for imaging, while others will have one or more X-Ray rooms within the emergency department. Alongside the flow of patients (as described), data requirements and their availabilities were linked to process activities or resource requirements as part of the mapping sessions.

The *simplified pathway* in Figure 2 focuses on the key activities which are performed on a minor injuries pathway. As part of our discussions with ED staff, three distinct routes were identified and we will refer to those as Pathway Options A, B, and C. The major differentiation being whether imaging is required (A, B) or not (C) and subsequently when X-Ray imaging is performed during the minor injuries attendance. The first and most common option is that imaging is taken after triage where it was requested (solid line, Option A). Secondly, imaging may be requested as part of the medical assessment by a doctor (dotted line, Option B). Finally, for some patients

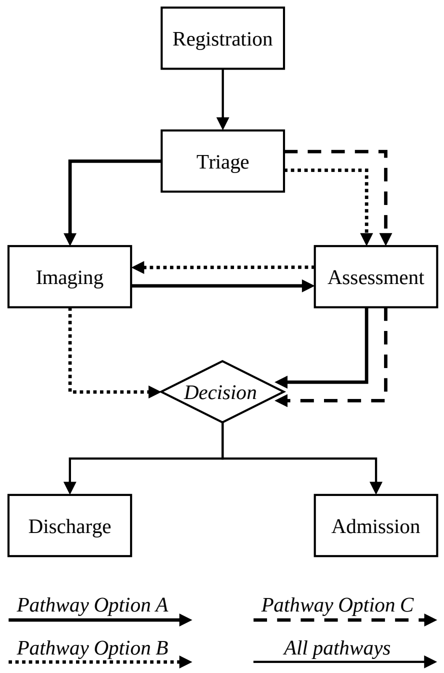

Figure 2: Generic pathway for minor injuries in ED.

imaging is not required and only a consultation is held during which a decision is made whether to admit or to discharge (dashed line, Option C). In general, approximately 50% - 60% of all minor injuries attendances require medical imaging and the vast majority of those sees the Triage nurse requesting the X-Ray imaging. Only 5% - 20% of all images are requested during the clinical assessment. Exact figures might slightly differ for hospitals across England and internationally, yet the general classification in options A, B, and C holds as well as the proportions of patients being a key parameter for the routing in ED. The conceptual model excludes activities which follow the attendance at ED, i.e. plastering or physiotherapy since those processes do not affect the changes of interest to this study or impact the potential service redesign options.

3.4. Descriptive data analysis

The collaborating hospital provided 23 months-worth of data covering all ED attendances from April 2014 to February 2016 on the minor injuries pathway. In total, 2810 individual patient episodes were considered with slightly more male (55%) than female (45%) patients. The average age of patients was 31.8 yrs with a median of 26 (male: 29.2 average and 24 median, female: 35.0 average and 29 median). For 56% of all attendances imaging was not required. In the remainder of this work we do not differentiate either process durations or routing probabilities by gender or age. This was beyond the scope of this study but could be included in the DES model for further experiments. Here, clinicians confirmed there were no notable differences across those categories – statistical testing was omitted to verify this. A monthly average of 120 patients attended ED with minor injuries, with a maximum of 213 patients during a busy period in autumn 2015 and a minimum of 64 patients in early 2015. A slight positive trend over the observed period of time was present which is in line with the general increase of ED attendances in England over the last years

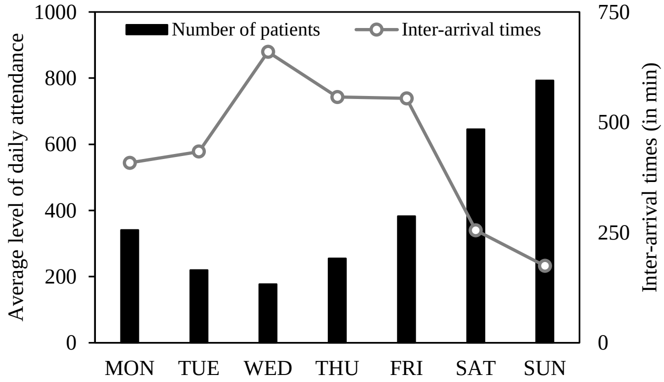

Figure 3: Attendance levels and inter-arrivals per day of week.

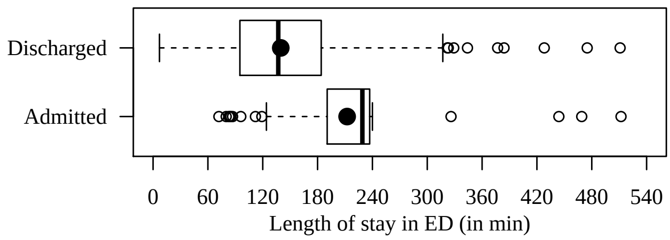

Figure 4: Boxplots representing LOS in ED for patients being admitted or discharged. Dots inside the boxes indicate the respective mean values.

(NHS England 2017 [45]). Arrivals varied significantly according to different weekdays and also during days. Figure 3 shows in graph (a) that more than 50% of arrivals were on a weekend and Wednesday had the lowest average daily attendance rate. Average inter-arrival rates as depicted in the same graph varied similarly to the arrivals and were shortest on weekends. Furthermore, the hourly inter-arrival times vary throughout the day with different effect sizes on weekdays and weekends. Approximately 5% of patients have to be admitted to inpatient wards, either to receive specialised care or in order to be monitored over a certain period. Admitting a patient commonly leads to longer stays in ED because admissions require more organisational tasks to be carried out before a patient can actually be transferred from the emergency department to an inpatient ward or to a clinic.

The average LOS on the investigated minor injuries pathway was 139min (184min, 95th percentile) for discharged patients and 212min (237min, 95th percentile) for admissions (Figure 4). The overall length of stay - as the weighted average across both categories - was 143.5min for all patients (199min, 95th percentile). Discharged patients had on average a shorter LOS with almost no 4 hour target breaches, whereas admitted patients - even though they stayed longer - had a similarly low probability of breaching the aforementioned 4 hour target. For the given data set, the target of 95% of patients not breaching 4 hours is met and thus we neglect the number of those actually breaching this target in further analyses. A more detailed analysis of the LOS in ED indicated variation with respect to the previously mentioned Pathway Options A, B, and C (Table 1). Patients spend on average significantly less time in ED when no imaging is required (140min versus 148min). Also, the LOS is significantly longer when imaging is requested at triage

	# patients	%	Length of stay (in min) Avg	Median	0.25	0.75	> 4h
Overall	2810		143.5	141	97	189.8	32
Imaging	1303	46.4	148	146	102	191	10
Triage – Imaging – Seen (A)	748	26.6	153	153	111	193	3
Triage – Seen – Imaging (B)	555	19.8	141.3	131	94	189	7
No imaging							
Triage – Seen (C)	1507	53.6	139.7	138	90	187	22

Table 1: Key performance indicators of the data provided by the collaborating hospital. Columns Q1 and Q3 report the 25th and the 75th percentile respectively of the LOS and the rightmost column shows the number of 4 hour breaches.

and thus takes place before the assessment (141min versus 153min).

Similar effects could be observed across the sub groups regarding patients being admitted and those being discharged. As only a small proportion of around 5% of all patients are admitted, the impact of their LOS on the overall LOS can be neglected and no further analysis is needed. Since RLD will only affect pathway options A and B, these require a more detailed analysis. Pathway option C, however, is included in the simulation study later on, as a significant amount of patients attending ED affect the queues, e.g. at the consultation, and therefore we still include it in this more detailed analysis of the process times. Figure 5 allows the identification of potential savings which could result from introducing RLD. If imaging is requested during triage (Pathway Option A) there is a delay of approximately 90 minutes on average from imaging being performed until the patient finally leaves ED. When imaging is requested during the consultation, there is still a wait of on average of 50 minutes between imaging and discharging the patient, which could be reduced. Additionally, earlier discharge would free ENPs' and doctors time and could have beneficial effects on other patients on the minor injuries pathway as doctors' availability would be increased. The previously mentioned durations for process steps, e.g. Triage to Imaging, include the durations of the actual process activities, i.e. triaging or imaging. The hospital information system only provides a single time stamp for each of the steps along the pathway. It is therefore necessary to make the assumption that those time intervals capture start-to-start relations of activities.

Key performance metrics and system parameters

Building upon the available data records we identified three key metric to indicate changes in performance which will be highlighted subsequently. Moreover, we link this to a key parameter, i.e. the availability of RLD and propose to investigate to what extent the changes in performance depend on the availability of the streamlining concept.

Length of stay in ED: RLD aims to reduce delays prior to discharge from ED, in particular for patients without a fracture and no other complicating diagnosis. Therefore, the length of stay (LOS) in ED is a key performance metric to assess the effects of radiographer-led discharge after imaging. EDs in England have to deal with the 4 hour target which intends to limit the time patients spend in ED in order to reduce the number of unnecessarily long stays. Introduced by the Department of Health in 2004, this standard requires that 95% of all ED attendances should be no longer than four hours for any hospital in the England. Generally, the LOS on a minor injuries pathway is likely to be shorter compared to the overall ED figures. Thus, an analysis on historical data later on will help quantify the impact on the number of 4 hour breaches.

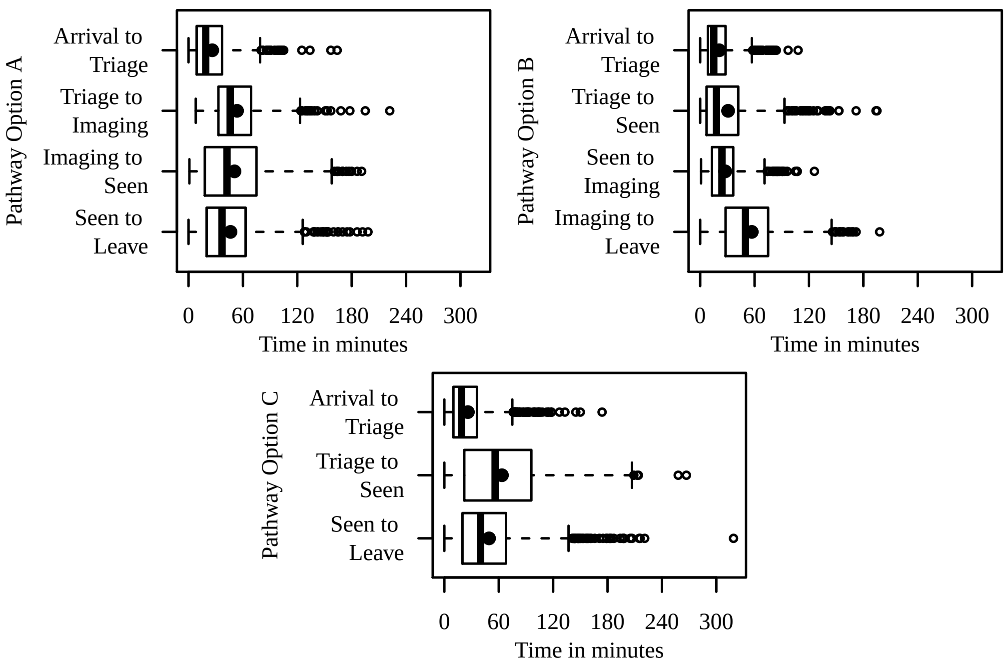

Figure 5: Boxplots explaining process times for pathway options. Dots inside the boxes show respective means.

Number of discharges: Another important criterion is the amount of radiographer discharges that can actually be offered by the hospital. A greater availability of highly skilled radiographers (e.g. reporting radiographers) will support a higher level of RLD where no fracture is detected. Increasing the number of reporting radiographers, however, also increases staffing costs as those are a highly qualified staff and more expensive than lower grade radiographers. Also, as previous studies revealed, there is a significant training need to upskill radiographers in order to facilitate direct discharge, and thus the hospital needs to decide to which volume of patients radiographer-led discharge should be made available.

Number of clinical assessments: The introduction of RLD intends to free time for doctors and ENPs which could be used for other patients with potentially more complex needs. Thus, the number of clinical assessments is considered a proxy for clinical workload occurring on a minor injuries pathway.

Availability of RLD: The beneficial effects of introducing RLD will likely be limited by either (1) a hospital's financial situation (higher costs for trained radiographers) or (2) the limited availability of accurately trained radiographers available to be scheduled. Thus, a hospital is interested in what time it should choose in order to allow suitably trained radiographers to discharge patients.

Anticipated trade-offs: Finally, the configurations of the system (i.e. availability of resources) will affect the mentioned performance indicators, i.e. higher (lower) availability will lead to stronger (less strong) effects on the LOS, the number of patients actually being discharged, and fewer consultations in ED

3.5. DES model development

We used Simul8 (Simul8 Corporation, [41]) to develop a generic DES model for minor injuries pathways which can be adapted to different hospital settings. It is intended as an interactive tool

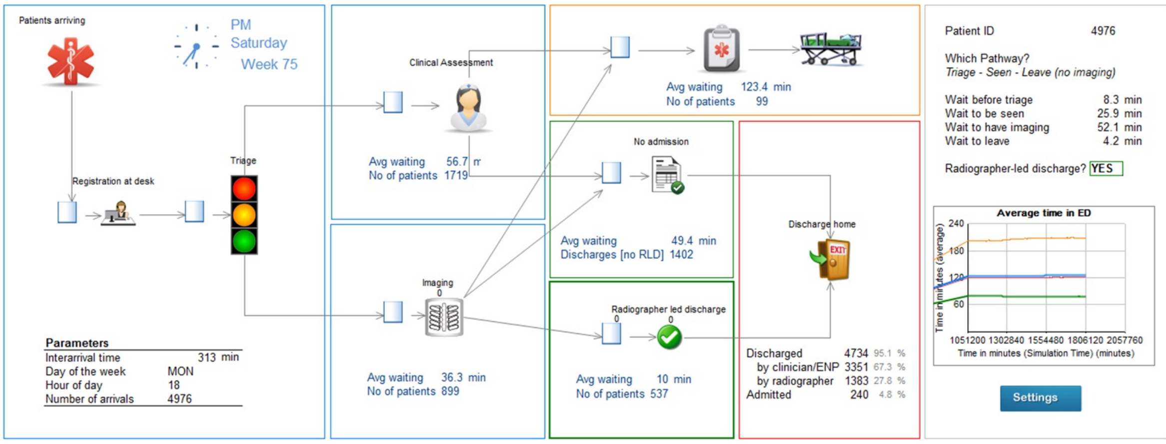

Figure 6: User interface of discrete event simulation model developed in Simul8.

for both decision-makers and the other stakeholders affected by potential pathway changes. The two main parts of this decision support tool are the DES model at the front-end and the data set required to populate the simulation model at the back-end. As shown in Figure 6, the model supports decision-making through visualising the pathway, highlighting volume data and performance information of ED such as length of stay, and information focused on a single patient, e.g. waits before seen by a clinician. Our discussions with practitioners demonstrated that an interactive interface facilitates engagement and supports working towards implementing successfully evaluated changes.

The simulation model's graphical user interface (GUI), as shown in figure 6, visualises the patient's way through ED (left to right) and builds upon the conceptual models introduced earlier (figures 2 and 7). All steps of the patient journey from arrival, via registration, triage, imaging, assessment, and finally admission or discharge are captured visually as individual entities. The GUI provides live outputs on model parameters (bottom left corner, e.g. mean of inter-arrival time distribution, day of week etc.) or waiting times before an activity starts (below individual activities). Furthermore, information on key performance indicators such as average time spent in ED (box on the right) is captured as well as aggregated patient numbers/attendance (with the activities, and also in table at bottom left corner). Finally, individual patient data (i.e. process times) and their pathway option are captured in the top right corner of the GUI.

The model captures time-dependent inter-arrival times and also varying process times along the pathway through ED. Upon arrival the pathway option for patients (being either A, B, or C as shown in figure 2) is sampled from a distribution based on the historic data set and routing along the pathway is based on labels assigned to patients. In the model, we considered queues and their associated activities as a single step of process. This is because the recorded timestamps for process activities is not coherently reported. Thus, for example, we modelled the time from triage to imaging as a delay in the queue and do not consider durations for the activities themselves. The user is enabled to specify the extent to which RLD is to be carried out, e.g. only on one day per week, during the weekend or 24/7. After patients have completed their pathway through ED they are either admitted or discharged which is sampled from a distribution based on the historic data set. According to the decision-makers preferred level of detail, both inter-day and intra-day variation can be captured. Various members of ED staff pointed out that another key feature would be to have real-time output of information on waits and the level of attendance. In response to these ED staff requests we incorporated information on patient waits, the average length of stay in department and patient counts for the various pathway options in order to make the DES model more useful. The developed model also features a dedicated section to analyse the pathway from a single patient's perspective which allows quantification of individual savings from the status quo setting to the radiographer-led discharge.

Our model is intended to inform how radiographer-led discharge affects the length of stay of various patient subgroups as previously outlined. This means that the routing of patients, e.g. at triage, is based on historic facts, i.e. we assume that for a particular patient the pathway option (such as A, B, or C) is known before triaging takes place. Discussions with ED practitioners pointed out that an analysis of different pathway proportions could be informative as it would capture different attitudes towards ordering imaging at Triage or Assessment respectively. Also, we assume that no repeated imaging during one visit takes place as this would again have to take into account doctor's decision making process which cannot be quantified satisfactory using only the available data set. In contrast to what the outcome of the mapping session suggested follow-up treatments at the hospital, such as plastering or physiotherapy, are not included in the pathway. The effects on the number of patients requiring those treatments within hospital should not be affected from a change to radiographer-led discharge as radiographers will mainly discharge patients. Assessing the impact on the overall LOS including those additional services is therefore out of the scope for this study.

Verification & validation of DES model

Verifying the model was in, fact, done in constant feedback discussions with clinicians, in particular with radiographers involved in this study. Clinicians at the hospital confirmed that time stamps are commonly recorded while the activity takes place but not necessarily to mark either the beginning or the end of an activity. With a sufficiently large number of patients going through this system, we assume that biases towards either start or end of activities are levelled out. We validated the DES model against the historic data to assess how it represents the status quo. Data was captured over a period of 699 days after a warm-up period of 2 years, we ran a trial with five individual simulation runs. The run time was chosen in order to be able to compare model outputs directly to the provided data set covering an uninterrupted series of the most recent patient records. The warm-up period of two years was chosen experimentally capturing the variation in the LOS as the major LOS. For the this study it was important to calibrate the model towards the historic data in order to be able to demonstrate effects in relation to most recent patient attendance. A comparison against 1 or 3 years of warm-up led to model results (i.e. KPIs) which had greater deviation from the historic values. Figure 2 shows that both the LOS in ED and also the number of patients attending ED on either of the three pathway options form a good representation of the historic data set.

3.6. Study design and experimentation

3.6.1. Pathway redesign

The introduction of radiographer-led discharge adds a new routing option to the studied pathway. Figure 7 represents how this affects Pathway Options A and B, i.e. those where acquiring X-Ray images would be needed. Initially, the hospital aims to select a subgroup of all those patients receiving diagnostic imaging, who will then benefit from the proposed changes, e.g. all those with minor appendicular injuries or those with injured lower limbs. If, under clearly defined conditions,

	Historic Data	DES Model		
Model parameter	Average	Average	95% Confidence Interval	Relative deviation
Length of stay in ED				
Overall	143.5	143.4528	[142.5, 144.4]	0.03%
Option A	153.03	152.5655	[151.3, 153.9]	0.30%
Option B	141.26	141.3876	[138.0, 144.8]	0.09%
Option C	139.67	139.8262	[138.0, 141.7]	0.11%
Discharges	139.7	140.043	[139.1, 141.0]	0.25%
Admissions	212.3	209.3986	[207.3, 211.4]	1.37%
Attendance				
Overall	2810	2826	[2730.3, 2922.1]	0.57%
Discharges	2655	2684.8	[2602.7, 2767.3]	1.12%
Admissions	150	141.2	[127.6, 154.8]	5.87%

Table 2: Validation of model output against the status quo setting based on historic data

a radiographer decides to discharge a patient this can then be done immediately after the image has been taken and interpreted. In this case, no further assessment would be required and patients could be sent to physiotherapy, the plaster room, or home with further advice on pain management, e.g. using specific information leaflets etc. Radiographer-led discharge would require doctors' pre-authorisation for discharge on the basis of normal images and no other conditions being present which would require specialised help. In addition, a high level of confidence would be necessary for radiographic discharge to proceed on the basis of an X-Ray image. Given those conditions and acknowledging that the vast majority of patients are discharged from ED, the proposed changes could significantly affect a large number of patients on the minor injuries pathway. In addition, the positive effect to be expected on the use of doctors' time can be considered equally important. During discussions with clinicians it was suggested that the required time for a radiographer-led discharge activity should take on average ten minutes, allowing for some variability. We therefore suggest to model this using a log-normal distribution with mean 10 and standard deviation of 5. In contrast to the common way of discharge, this additional option using highly skilled radiographers shortens the patient journey significantly and helps sending patients home much quicker. Basically, clinicians suggested that the radiographer-led discharge would be a brief consultation following image acquisition and interpretation.

3.6.2. What-If-Scenarios

In order to investigate whether and to what extent RLD is beneficial we analysed a number of what-if-scenarios alongside the current situation (i.e. Status Quo). These scenarios represent the extent to which RLD would be rolled out, i.e. on one or two days of the weekends, or all day long every day of the week. This could, in fact, also reflect the number of effectively trained radiographers who are authorised to discharge. We compare these scenarios to the Status Quo and identify the likely savings in terms of LOS. We are interested to find out how and to what extend the overall cohort of patients is affected by this streamlining option, and specifically we want to quantify savings along the pathway options A and B. We simulated the same period as was covered through the historic data set, i.e. 699 days. This was expected by collaborators to make the comparison easier. We performed trial runs with five simulation runs, each with independent pseudo-random number seeds. Every single run included a warm-up phase of two years which then

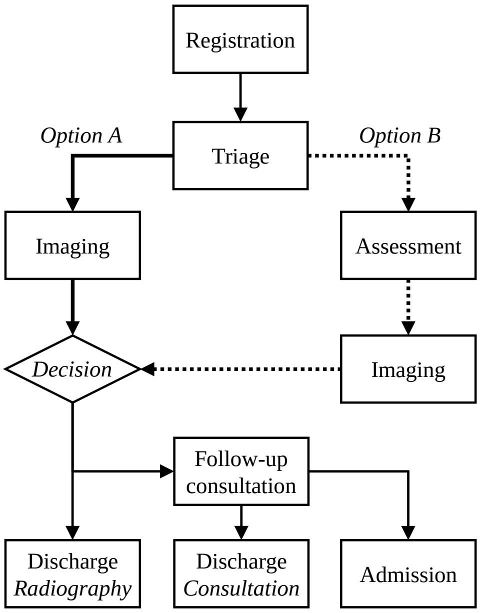

Figure 7: Redesigned pathway including potential radiographer-led discharging option. Formatting for pathway options A (imaging ordered during triage) and B (imaging ordered during assessment) according to figure 2.

ensured that the confidence intervals for performance indicators are close to the simulated mean. The obtained results for the key performance indicators are compared across the different what-if-scenarios and the Status Quo with a primary focus on savings in average LOS. We conducted a series of experiments with different levels of detail for the time-dependency of process durations. The model allows for hour-of-arrival-dependent process durations which we have aggregated into groups of four hours length. This was sufficiently accurate and led to good results during the validation of the model as reported above and is also in line with recent simulation studies in ED [37]. However, for inter-arrival times we chose detailed blocks of one hour length in order to ensure that ED attendance was sufficiently close to the historic data.

3.6.3. Trade-off analysis

The beneficial effects of radiographer-led discharge, however, might be restricted due to limited availability of qualified staff to take over the roles of discharging radiographers. As radiographers need to be upskilled and trained to be able to discharge patients immediately after imaging, we are interested in the trade-off between the improvement of the LOS and the associated costs to achieve this. We propose to use the time during which radiographer-led discharge is available as a proxy for the costs involved and link this to (1) LOS in ED, (2) the number of patients discharged by a radiographer, and (3) the number of assessments carried out by clinicians. Hence, this section extends the previously shown analysis and explores on which days of the week the effects of introducing this concept would be largest. We compare each weekday as on/off shifts and allow two shifts on weekends (morning and afternoon) as on/off which leads to a total number of 512 scenarios. For all these scenarios we compare results from simulated trials as specified above.

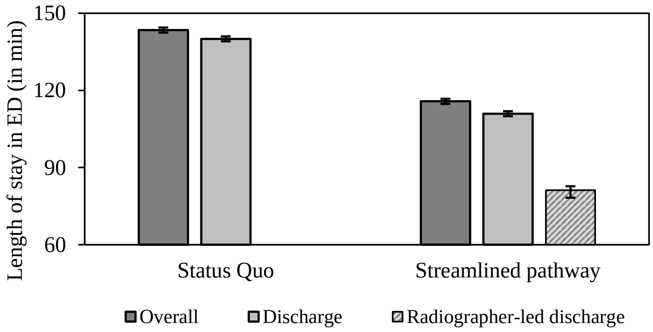

Figure 8: Length of stay for all patients and only those being discharged with respect to different intensity of radiographer-led discharge. Error bars report the confidence intervals at a 95% level.

4. Results

We present the computational results in two consecutive steps. Firstly, we highlight the effects on the LOS in ED when RLD is introduced. This is further analysed by looking at effects on the different pathway options. We also analyse the reduction in assessments and the actual number of radiographer discharges. Secondly, all these effects are linked to staffing requirements in order to be able to streamline patient pathways.

4.1. General findings

Figure 8 clearly demonstrates the beneficial effects of implementing an early discharge strategy on a minor injuries pathway. The sections Status Quo and Streamlined pathway in the graph compare the current setting at the hospital with a setting where RLD is fully implemented. The length of stay for all patients (LOS overall) could be reduced by more than 20min on average, which is particularly achieved by the shortened process between imaging and discharging patients. On average, all discharged patients spent 25min less in the department. This reduction is mainly driven through beneficial effects of RLD which allows to shorten the delay until discharge by 50min (on overall average) - with individual savings being a lot higher. Since approximately 55% of all patients received imaging this limits savings in this particular setting. However, reductions are significantly higher than 50min when imaging was requested at triage. The potential savings for the overall attendance in ED obviously vary according to the proportion of patients for which imaging is required and thus the effects might be either less or more prominent with other hospital settings. Another effect might be the seniority of staff triaging patients: more junior nurses or doctors could tend to request imaging more freely than more experienced members of staff. However, this was beyond the scope of our study and is therefore not included in this analysis.

The following analyses add further detail to the findings above. Firstly, gradually increasing the intensity of RLD shortens the length of stay for discharged patients, which then also reduces the overall LOS in ED. Figure 9 shows how the average LOS decreases when RLD is provided more frequently. The latter one is a key performance criterion for hospitals and RLD helps to reduce the risk of breaching the four hour target. With only 5% of all patients on the minors pathway requiring an admission the effect of RLD on the overall LOS in ED is very positive. For the two pathway options for patients who require imaging, it becomes apparent that especially for patients without a medical consultation, but a radiographer-led discharge consultation instead, RLD will significantly shorten their time in ED (Table 3). Patients whose imaging is requested during a

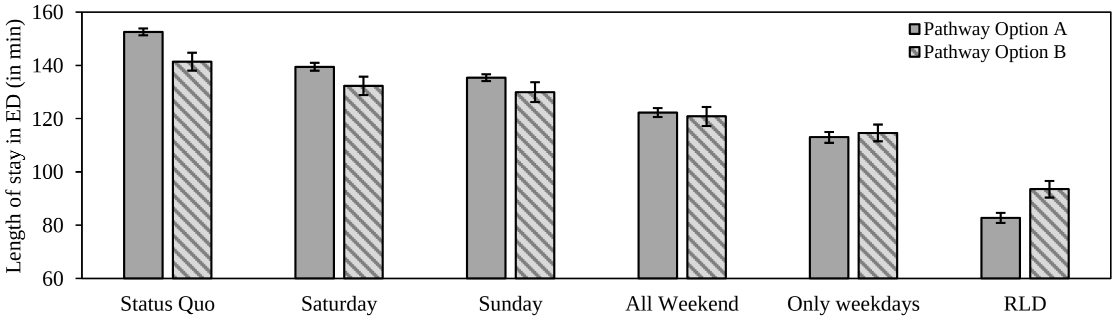

Figure 9: Effects of RLD on average LOS for all patients and those being discharged. Error bars report the resulting confidence intervals at 95% level.

	Length of stay in ED (in min)					
	Status Quo		Streamlined		Relative savings	
	Overall	Discharged	Overall	Discharged	Overall	Discharged
With imaging						
Triage - Imaging (A)	152.9	149	87.8	80.5	42.6%	46.0%
Triage - Seen - Imaging (B)	142.3	139.5	108.2	103.5	35.0%	37.6%
No imaging						
Triage - Seen (C)	139.5	135.6	139.5	133.6	–	–

Table 3: Average length of stay Status Quo and streamlined pathway (RLD) setting comparing overall and discharge only benefits.

medical consultation could potentially leave the department more than half an hour earlier. In both cases (Pathway Options A and B), the main benefit results from time savings while patients wait for the final assessment and the actual discharge procedure itself. The reduction in waiting times could become more prominent when a different case-mix is considered. In this study, a large number of patients do not receive imaging. For those patients, the length of stay is not directly affected through the suggested pathway changes. It is likely however that those patients will benefit from higher doctor availability, yet time-wise benefits are potentially not significant.

4.2. Trade-off analysis

In the following, the time-wise availability of radiographer-led discharge serves as a proxy for the likely costs. We analyse in particular effects on the LOS in ED, the number of discharges by a radiographer, and the number of assessments carried out by clinicians.

Overall effects: Firstly, the overall effect is in line with the generally positive results presented in the previous section. Allowing radiographers to discharge patients on selected days of the week only, however, allows a specific focus on the most impactful time periods such as weekends. This is particularly interesting when limited budgets or resource availabilities need to be taken into account, e.g. only few radiographers are trained to discharge patients. Figure 10 demonstrates that already very limited availability of RLD (i.e. one day per week) can reduced the average length of stay in ED (note that this includes all three previously mentioned pathway options). Separating out the two options, which actually involve image acquisition, we find similar effects that are stronger for patients whose imaging was requested at triage (option A). Although those

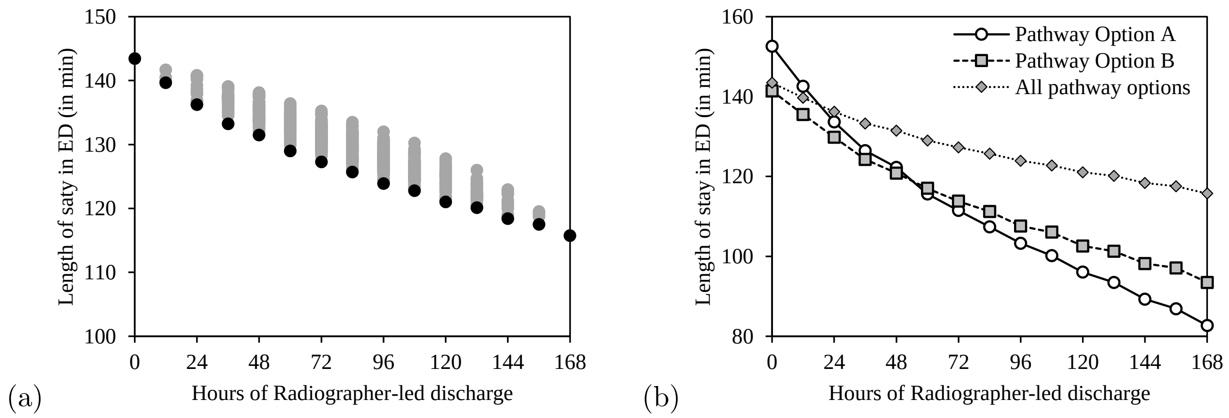

Figure 10: Trade-off between LOS in ED and the availability of RLD. (a) Scenario solutions represented as dots, and efficient solutions highlighted in black. (b) Efficient solutions visualising the trade-off between LOS in ED and the availability of radiographer-led discharge for two pathway options involving imaging (diamonds correspond with non-dominated solutions in (a)).

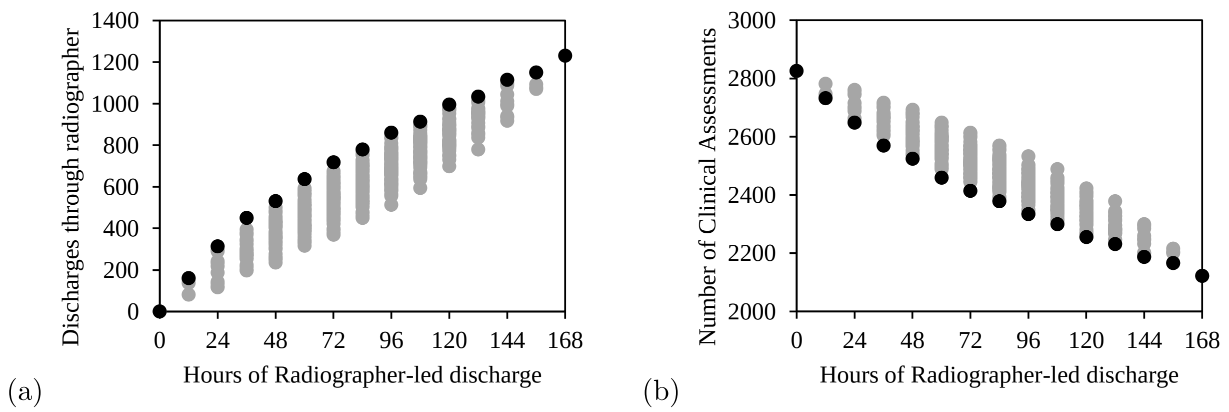

Figure 11: Trade-off between (a) radiographer-led discharge and (b) clinical assessments against resource requirements. Scenario solutions represented as dots, and efficient solutions highlighted in black.

patients spend more time in ED in the current setting without RLD, with 48 hours of radiographers working per week (i.e. on Saturdays and Sundays) the length of stay in the department can be reduced by roughly 10%. Any further rolling-out of RLD should always include an attendance level which is at least as high as the weekend attendance which accounts for more than 50% of the attendance. Figure 14 focuses only on the non-dominated solutions for the two pathway options including imaging. The steeper descent for Option A shows stronger effects with additional hours of RLD.

Discharges versus assessments: We now focus on the patient volume – i.e. those that would be discharged by a radiographer – rather than on LOS reductions. Figure 11 reiterates the beneficial effects of introducing RLD on weekends and Saturdays in particular, as those days regularly see very high attendance. This comparison nicely outlines the diminishing returns of scale, i.e. the effects decrease with an additional day of RLD because the share of patients per remaining day decreases as well. These findings can be immediately linked to the reduction in assessments as shown in graph (b). However, this effect is less strong, mainly because the subset of patients whose

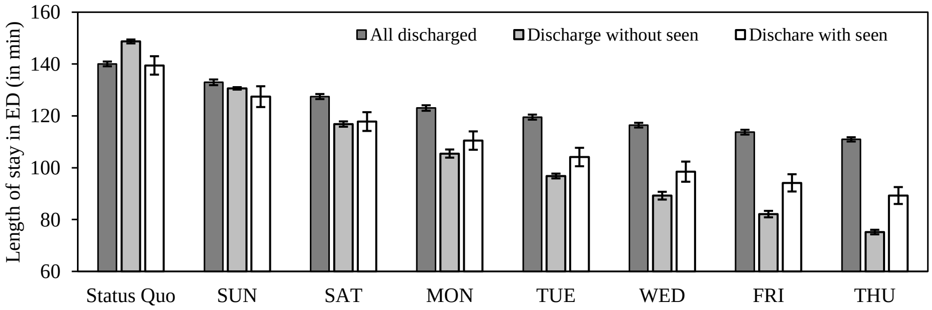

Figure 12: Maxium effects when introducing radiographer-led discharge step-wise, i.e. add only one day. Error bars report the 95% confidence level.

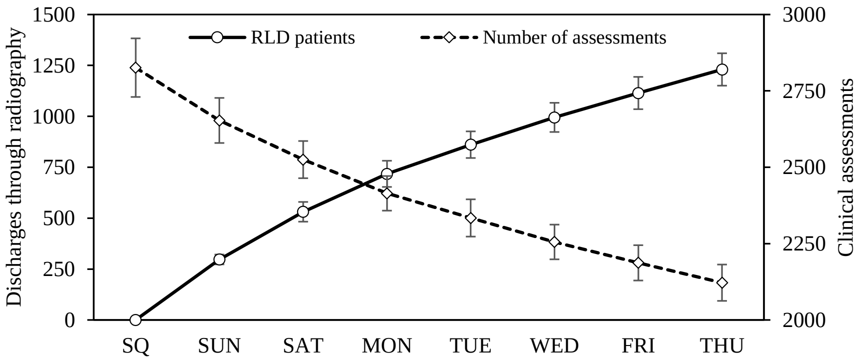

Figure 13: Comparison of increase in discharges and reduction in clinical assessments. The error bars indicate confidence intervals at 95%.

image is not requested at triage (requiring pre-imaging assessment) is still a substantially large proportion of the overall attendance. Hence, the above effect is mainly driven by the population of pathway option A. As introducing RLD requires upskilling of radiographers and/or financial resources to employ sufficient reporting radiographers; hospitals would aim to assess the impact of a step-wise introduction of RLD. Overall, we were interested to find out which sequence of days of RLD provision would lead to biggest effects on the total LOS in ED. We were interested which additional day would yields the minimum LOS given only one extra day can be chosen. This optimal sequence is

$$(\text{Sunday, Saturday, Monday, Tuesday, Wednesday, Friday, Thursday})$$

and was obtained using a greedy search strategy for all scenarios results. Figure 12 reports the resulting LOS changes when following this sequence. Finally, taking the above sequence into account, Figure 13 demonstrates how the introduction of RLD reduces the number of clinical assessments. Again, diminishing effects can be observed and a lot of clinical time could be set free on weekends only which would account for roughly 300 clinical assessments. At the same time, over 500 discharges could be initiated by radiographers, i.e. this also impacts other, e.g. ENP-led, discharge routes.

5. Discussion and outlook

This paper presents a generic modelling approach which both enables users to evaluate potential pathway changes to ED and facilitates engagement and communication about such system changes to management, staff, and patients. Process mapping the current pathways through ED, in particular, helped both operational researchers and clinicians to identify key bottlenecks and informed the subsequent development of the DES model. The process of capturing the ED as a system was supported by an extensive data analysis which generated additional insights and helped to identify the level of detail needed for the DES model. We found that an iterative process of modelling, analysis, and inter-disciplinary meetings with clinicians and operational researchers helped to develop a comprehensive and collaborative decision support context to assess the likely impact of pathway redesign options. The study demonstrates that even a relatively small predefined subset of patients made suitable for radiographer-led discharge can impact on time spent in ED particularly for those patients discharged earlier than usually. While patients being discharged benefit most, the restructuring of the pathway also impacts more generally on the time patients wait to be seen by a doctor because these events are less frequent with RLD. The strategic view of the minor injuries pathway provided by the model can also inform decisions about the frequency at which radiographer-led discharge should be offered. During meetings with clinicians, the DES model was able to assess the impact of other potential pathway changes that were raised during the discussion. Finally, as a generic model, the DES can be adapted to support similar restructuring of pathways at other Emergency Departments. Hence local variations can be accommodated which is likely to enhance credibility of the model among clinical staff and management at specific locations. For all mentioned stakeholders a clear and compelling visualisation of the model and its outputs is key to achieve a sufficient level of engagement.

Although the simulation study and the Training Needs Analysis (see section 1) were carried out independently during the overall project, findings from the pathway mapping and the simulation study have informed the training of future radiographers, i.e. students will work with pathway models that were derived from this study. Also, the pathway mapping and potentially the modelling will assist junior radiographers (and others) to visualise the benefits of this approach and provide a decision support tool. Importantly, we believe the use of process mapping and DES pathway modelling can critically assist in the decision making processes in health service delivery. Our study demonstrates how this can be achieved in the context of RLD in ED and shows how these approaches can provide clarity and a stronger evidence-informed basis for policy. Many other strategic issues however are fundamental to system changes in healthcare. In the context of our study, for instance, there are many issues relating to workforce and accountability which would bear on the application of radiographic discharge in ED. The currently availability, status, and salary of skilled radiographers able and willing to implement RD across the UK NHS is a key issue set against the current context of nursing shortages, shortage of radiologists and increasing ED attendances. Alternative strategies to balance workload in the department as well as proactive training programmes need to be investigated. In this sense, our work has quantified benefits in terms of workload reductions for doctors in ED, in particular at a senior level, who would interpret images. The necessary discussion around accountability and control, i.e. whether a system is acceptable to ED consultants, can be supported by a modelling approach as presented in this paper. Recently issued national guidelines have also highlighted the need for immediate reporting when diagnostic imaging is performed. The actual implementation and the transformation of processes into daily practice demands confident decision makers (and potentially pilot phases of the new intervention). The confidence aspect has transferred to the University side and led to the development of an MSc Programme Medical Imaging: Skeletal Reporting.

This study has shown that the application of RLD can potentially provide substantial reductions in patient journey times through ED as well as reduce load on nurses and consultants. However, as with all models, applying RLD in any particular hospital context demands that many other factors (such as patients and/or staff behaviour) are taken in to account. In general therefore, operational research methods can provide indicative outputs which guide decision making but they do not give hard and fast definitive solutions. Despite ongoing discussions about the potentials of DES [46, 47], this paper has given a profound demonstration of the effectiveness of this method for streamlining patient pathways in ED. In addition to a published case study by Snaith [18], our work shows how this concept can be rolled out to various hospitals in general. Hence, we address the often neglected way to implementation [32]. From a methodological point of view, the inclusion of staff scheduling within an iterative scheduling and optimisation approach but also the integration of longer term development in terms of a hybrid combination of System Dynamics and Discrete Event Simulation appear to be promising avenues for future research.

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