Applied Ergonomics 102 (2022) 103759

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

A socio-technical systems analysis of the application of RFID-enabled technology to the transport of precious laboratory samples in a large acute teaching hospital

Una Geary [a], Marie E. Ward [a,b,*], Vincent Callan [c], Nick McDonald [b], Siobhán Corrigan [b]

[a] Quality and Safety Improvement Directorate, St James's Hospital, Dublin 8, D08 NHY1, Ireland
[b] Centre for Innovative Human Systems, Trinity College Dublin, Dublin 2, D02 PN40, Ireland
[c] Facilities Management, St James's Hospital, Dublin 8, D08 NHY1, Ireland

ARTICLE INFO

Keywords:
Socio-technical systems analysis
RFID
Acute hospital

ABSTRACT

The scale and pace of improvement in patient safety in healthcare has been unacceptably slow. A paucity of research into the application of systems-thinking concepts and a failure to appreciate health systems complexity are cited as barriers to sustainable health systems improvement. This study reports on a socio-technical systems analysis, called the CUBE, of the characteristics of a large acute teaching hospital's system for the transport of precious specimens, a system enabled by radio-frequency identification tracking technology. The CUBE proved itself to be an effective analytic tool. The analysis provided a constructive framework to link diverse data and documentation; explicitly inviting consideration of the roles and understandings of different stakeholders; as well as broader cultural factors that could influence current or future activity. The analysis also supported recommendations to improve and extend operations. This study supports the argument for systems understanding and systems thinking being at the core of new approaches to patient safety.

1. Introduction

1.1. Background

The scale and pace of improvement in patient safety has been unacceptably slow (National Patient Safety Foundation, 2015). A paucity of research into the application of systems-thinking concepts (Braithwaite et al., 2018; Nesse et al., 2010; Greenhalgh and Papoutsi, 2018) and a failure to appreciate health systems complexity are cited as barriers to sustainable health systems improvement (Braithwaite et al., 2017; Amalberti, 2013; Hollnagel, 2014, 2018). Hollnagel (2018) challenges the concept of complexity from a safety management perspective. He contends that complexity is a "euphemism that we use to beautify our ignorance and cognitive limitations" in understanding and describing the conditions in which we live and act and the consequences of the changes we make (p.10). He argues instead for systems-thinking being at the core of new approaches to patient safety (Amalberti, 2013; Hollnagel, 2014, 2018).

The application of systems thinking approaches in response to this need in healthcare is becoming more evident. Hollnagel's Functional Resonance Analysis Method (FRAM) has been applied to understand transitions of care (O'Hara et al., 2020) and to study the response to the deteriorating patient following emergency abdominal surgery (Sujan et al., 2022). The Systems Theoretic Accident Model and Processes/Systems Theoretic Process Analysis (STAMP/STPA) (Leveson, 2012) have been applied across a diverse range of healthcare settings and patient safety problems (e.g. Carman et al., 2021; Kaya, 2021). The Systems Engineering Initiative for Patient Safety (SEIPS) has also been applied to understand aspects of the healthcare system (Carayon et al., 2020). The Royal Academy of Engineering (RAEngineering) joined forces with the Royal College of Physicians (RCP) to advocate for a robust understanding and consideration of four key and complementary perspectives in order to support the design and improvement of healthcare; people, systems, design and risk (Clarkson et al., 2017). These principles were informed from work on improving the safety of patients using oral methotrexate for the treatment of rheumatoid arthritis (Ward, Buckle et al., 2010). The Integrated Resilience Attribute Framework was developed by Anderson et al., 2020 to guide researchers in researching resilience, especially the linkages between resilience at

* Corresponding author. Quality and Safety Improvement Directorate, St James's Hospital, Dublin 8, D08 NHY1, Ireland.
E-mail addresses: ugeary@stjames.ie (U. Geary), maward@stjames.ie (M.E. Ward), vcallan@stjames.ie (V. Callan), nick.mcdonald@tcd.ie (N. McDonald), siobhan.corrigan@tcd.ie (S. Corrigan).

https://doi.org/10.1016/j.apergo.2022.103759
Received 1 December 2021; Received in revised form 23 February 2022; Accepted 29 March 2022
Available online 9 April 2022

Abbreviations

ASD	Aerospace Software Developments
EPR	Electronic Patient Record
FM	Facilities Management
ICT	Information Communication Technology
PPPGs	Policies, Procedures, Protocols and Guidelines
PSTS	Precious Specimen Transport System
RFID	Radio-Frequency identification
SEIPS	Systems Engineering Initiative for Patient Safety
STS	Socio-Technical System
STSA	Socio-Technical System Analysis

different scales of time and space across the whole healthcare system.

The term socio-technical system (STS) recognizes the interaction between people and technology in systems and was derived from work conducted with workers in the coalmining industry by Trist, Bamforth and Emery in the Tavistock Institute, London in the mid-1900s (Trist, 1981). Socio-technical systems analysis (STSA) involves studying the dynamic interconnectedness of elements of the system at different levels: e.g. social relations, information and knowledge, processes.

1.2. Socio-technical systems analysis using the CUBE

The method of STSA employed here is called the CUBE. The CUBE framework has been developed over several years across numerous programs of research in aviation and healthcare safety (e.g. McDonald et al., 2021; Corrigan et al., 2018; McDonald et al., 2018; McDonald, 2015; Ward, McDonald et al., 2010).

The CUBE allows for a rich understanding of an STS to be built around four domains: the system, the culture, the action and the sense-making.

- Culture: representing the pattern of shared basic assumptions and (what is often) partially shared understanding of the STS and incorporates Schein's (1984, 2010) and Pidgeon and O'Leary (1994) work on culture
- Sense-making: incorporating Weick's (1995) work on how individuals operating within the system make sense of it, often through practical action
- System functioning: incorporating Perrow's functional focus on complexity and coupling (1984) and representing how the system actually works and incorporates both formal (work-as-imagined) i.e. Policies, Procedures, Protocols, and Guidelines (PPPGs) as well as the informal elements (work-as-done or the sequence of activities that normally takes place) (Ward, McDonald et al., 2010)
- Action: representing how we act within the system, incorporates Turner and Pidgeon's (1997) work on the flows of information, knowledge and understanding and anything that happens in the system that is recordable or measurable; this can be analyzed at different levels such as individual actions, team performance against a standard, activity sequences, or key outcome, process and balancing measures in relation to system performance (McDonald, 2017)

These may seem to be alternative approaches but are in fact fundamentally mutually compatible and complementary theoretical frameworks for a whole-system approach (McDonald et al., 2021). Each in its own right has weaknesses with respect to a whole-system approach:

- Cognitive science has a local focus, which is not systemic (in the socio-technical sense)
- Organisation theory does not, in general, address functional aspects of processes or the achievement of value
- Process theory (which does address the value stream) does not effectively address the role of people
- Knowledge Management theory lacks the analysis of the content of knowledge that is held and partially shared by agents in the system

The use of the STSA CUBE attempts to synthesize understanding from these different approaches and bring together elements that may be overlooked if we adopt only one perspective. The four domains can each be explored in terms of four types of functional relationships: goals, process sequence, social relations and information and knowledge. Representing this in a CUBE diagram highlights the interrelationships between these elements, as illustrated in Fig. 1.

The CUBE framework as a whole is designed to lead the user through a sequence of implementation and verification of a proposed solution to an analyzed problem. At each stage the user is invited to consider the diverse STS aspects that may be relevant and to prioritise these through focusing on key aspects of the Context, Mechanism and Outcome of that phase.

In this study the CUBE framework will be applied to analyze the characteristics of a large acute teaching hospital's system for the transport of precious specimens - the Precious Specimen Transport System (PSTS) – which is currently enabled by Radio-Frequency identification (RFID) tracking technology. The CUBE will also be used to identify ways of improving the system. Its purpose is the safe and reliable transport of specimens from clinical areas in the hospital to the laboratory. Specimens are considered relatively "precious" because a patient would experience significant harm if the specimen were lost. Most precious specimens involved are destined for the Histopathology Department where they undergo microscopic examination.

1.3. Radio-frequency identification device tracking of precious samples

A system for transporting specimens has existed since histopathological examination of surgically excised tissue samples became standard hospital practice in the early 1950s (Underwood et al., 2006). The PSTS in this hospital setting was transformed by RFID tracking technology in 2016 (Callan 2017). The PSTS is used in the main Operating Theatre suite and the Day Surgery Centre. The use of RFID technology in this system was envisaged to improve the system's safety and represented a pilot project for a broader deployment of this technology in the hospital.

RFID is not new technology but was developed during World War II

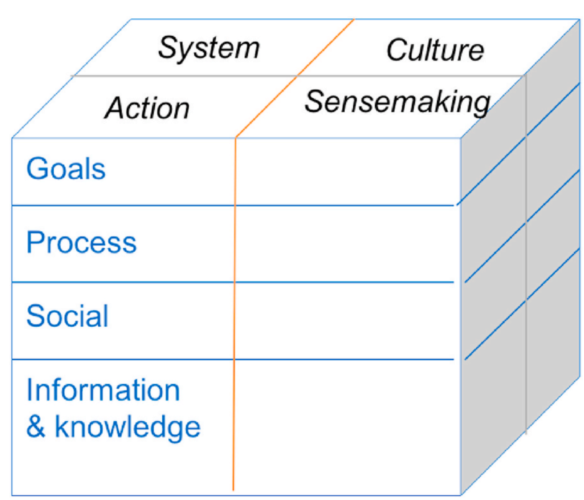

Fig. 1. The socio-technical systems analysis CUBE (from McDonald et al., 2021).

to identify aircraft to prevent friendly-fire incidents (Roberti, 2005). Its commercial use began in the 1980s (Wicks et al., 2006) based on patents developed in the early 1970s. Early adoption of RFID in healthcare commenced around 2002 (Mehrjerdi, 2015). An analysis of five hospital-based case studies of RFID systems in Taiwan by Tzeng et al. (2008) highlighted that RFID adoption resulted in varying degrees of success to reduce operating costs, improve patient safety, and to improve quality of medical service.

RFID has been used across many aspects of healthcare e.g. to track physician and nurse time spent on ward rounds (Sang et al., 2019); for monitoring blood tubes (El Khamlichi et al., 2019); to trace and monitor high value surgical products (del Carmen León-Araujo et al., 2019); to support contract tracing during COVID-19 (Ho et al., 2020); to give feedback on compliance to hand hygiene guidelines (Fish, Bopp et al., 2021); for detecting retained sponges post-surgery (Weprin et al., 2021). The benefits of RFID in healthcare were described by Yao et al. (2012), using an innovation-decision framework. They learned that early adopters found RFID to be functional and useful for tracking equipment and other assets; patients; staff; for patient identification; medication management and for preventing safety events such as the retention of surgical materials. They identified the benefits as including improved patient safety and reduced medical errors, real-time data access, time-saving, cost-saving, improved medical process and improved patient satisfaction. The barriers to RFID adoption they described in the literature included technological limitations, electric/electromagnetic interference concerns, prohibitive costs, a lack of global standards and privacy and legal concerns. They noted that multiple dimensions including economic, social, legal and organizational factors were neglected or not fully explored in the literature.

The social dimensions of RFID systems in healthcare were examined by Fisher and Monahan (2008, p180), who drew on more general ICT implementation literature and used interviews with healthcare providers to identify socio-technical needs for implementing or evaluating RFID systems highlighting the need for customizable systems, a need to establish clear policies and organizational relations and to manage workforce relations around issues such as surveillance.

There is less evidence available describing research on RFID in the specific healthcare context of laboratory specimen management and transport. The use of RFID for managing specimens at pre-analytical workstations to reduce laboratory errors has been described (Da Rin, 2010). Francis, Prabhakar and Sanderson (2009) reported that labeling errors on tissue specimens generated in a high-volume endoscopy center were reduced following the introduction of a combination of RFID technology, a paperless requisition process and the practice of confirmation of the correct site and patient by two staff members. Shim et al. (2011) designed and proposed a theoretical approach for the implementation of an RFID-enabled system for the management, including transport, of a range of laboratory specimens, but did not provide case-studies or other evidence to validate their model.

This research sought to apply the CUBE as a framework to analyze the STS of a RFID enabled PSTS in a large acute teaching hospital and to suggest improvements to the system. To the best of our knowledge this is the first time such a systems level analysis has been undertaken in relation to the use of RFID to enable specimen transport.

2. Material and methods

2.1. Setting and participants

The hospital is a large urban teaching hospital, comprising of 52 separate buildings on a 60-acre campus. It has 1000 in-patient beds and employs 4800 healthcare workers. Approximately 10,000 people pass through the site each day. The current laboratory building has been operational since 1981 and is in a separate building on the campus to the Operating Theatres and Day Surgery Centre from where specimens originate.

Specimen transport processes involve medical, nursing and other clinical staff in the Operating Theatre and Day Surgery Centre (130 people approximately), porters who transport the specimens (8 people), managers who oversee the RFID Track monitoring system (5 people). The management of specimens in the Laboratory also involves medical laboratory scientists and assistants, a laboratory manager and quality assurance personnel (22 people). These teams are aligned for governance and operational purposes within the Directorates for Surgery, Anesthesia and Critical Care; Facilities Management and Laboratory Medicine.

The RFID-enabled process at the core of the PSTS involves a nurse scanning an RFID tag and scanning a patient identity label generated by the Hospital's electronic patient healthcare record (EPR) system (Cerner Powerchart®) and putting the tag and specimen into a plastic bag (Fig. 2) which is then collected by a porter and brought to the laboratory.

The porter wears an RFID tag in a card similar to a credit-card that is held in the same wearable container as their hospital identity card and they and the sample are sensed by antennae placed at key locations across the hospital e.g. at the doors of the Operating Theatre, main hospital building and the Laboratory specimen reception areas.

Data from the sensors are monitored using a computer software system (RFIDTracker, Aerospace Software Developments [ASD] Ireland) such that a real-time electronic alert is issued by email and SMS text message if a tagged bag does not reach the laboratory within the designated transport time of 45 min - the "Delayed sample" alert. A second alert - "Sample Missing" - is generated after 90 min. Alerts are communicated to three managers – the Portering Services Manager, the Project Manager for the RFID Project and the Operations Manager of the Facilities Management Directorate. The Portering Services Manager is responsible in the first instance for responding to these alerts and immediately contacts relevant staff according to where in the system the specimen has been delayed, as indicated in the RFIDTracker records. A weekly report of all specimen transport episodes is generated and sent automatically by email to the three managers above, and the Laboratory Manager, the Operating Theatre Manager and the Director of Facilities Management. Reports can be downloaded as needed from the

Fig. 2. RFID tag in a specimen bag.

RFIDTracker software system.

Study participants were members of hospital staff who were directly involved in the management and delivery of the PSTS. The staff involved included a team of eight porters who undertook the task of transporting specimens, the Assistant Director of Nursing (Nurse Manager) for the Operating Theatre, the Portering Services and Concourse Manager, the Director of Facilities Management, the Operations Manager for the Facilities Management Directorate, the Laboratory Manager and the Project Manager for RFID Implementation.

2.2. Research team, ethics and governance

This research was carried out as part of the main authors (UG) Master's program. UG worked within the organization as the Director of Quality and Safety Improvement, but not directly with the PSTS, and collaborated closely with a second author (VC). VC worked within the organization as the Director of Facilities Management and had established the RFID process to support the PSTS. Both could be considered insiders to the organization but were also independent of the system under study. The other authors (MEW, NMcD and SC) were supervisors and lecturers on the Master's program, all with backgrounds in Psychology Human Factors Ergonomics and STSA and provided support, guidance and questioning for the research design, iterative analysis of the findings and write up. Participation by all hospital staff in the research was voluntary and sought through independent gatekeepers. Written consent was obtained for all interviews. Consent was given verbally by members of the focus group, at which attendance was voluntary. All study participants were informed of their right to withdraw from the study at any stage up to four weeks before finalization of the data analysis. To reduce the effects of social desirability bias in responses, a staff member from the Quality and Safety Improvement Directorate (not the Director) facilitated the project's focus group and workshop. Ethics approval for this research was granted by the Ethics Committee of the School of Psychology, Trinity College Dublin, Ireland (Ref: TCD 31.01.18).

2.3. Socio-technical systems analysis

The analysis of the RFID enabled PSTS was an iterative process, whereby the findings and learnings from each phase were shared with the research team, further refined and fed into the next stage (Fig. 3). The nature of the data that informed the STSA and the analysis performed on the data is outlined here.

2.3.1. Initial STSA CUBE informed by: interviews

Interviews were carried out (UG) with the following staff:

- Director of Facilities Management (FM)
- Assistant Director of Nursing for the Operating Theatre and Day Surgery Centre
- Laboratory Manager
- Portering Services Manager
- Project Manager for the RFID project
- External provider of RFID technology

The interview protocol was based on populating the CUBE framework and can be found in Appendix 1. Over 70 questions were asked of participants across the four domains of the CUBE with some additional questions asked on the individual's background and the system background. The information gathered here was used to identify areas to visit and see RFID in action; identify key documents and artifacts to analyze; create the first iterations of the process maps of the PSTS in the operating theatre and the laboratory, and create the first iteration of the social relations and communication map.

2.3.2. Deeper STSA CUBE of RFID enabled PSTS informed by

2.3.2.1. Site visits. Informal visits were carried out (UG, VC) with the relevant managers to the following areas to see the RFID technology in use: Histopathology Laboratory, Day Surgery Centre, Main Laboratory and Portering and Concourse Services Manager's Office, where the RFIDTracker data system could be observed in use.

2.3.2.2. Review of documents and other artifacts. Documents that would be relevant to the research were identified by interviewees during the conduct of interviews. A list of these can be found in Appendix 2. A video about the RFID project that is available in the public domain was also viewed (Appendix 2, document 3). A de-identified summary report of Adverse Incident Reports concerning the PSTS system for the period June 3, 2016 to June 2, 2018 was provided by the Hospital's Safety and Risk Manager and was reviewed, subsequent to the managers' workshop.

2.3.2.3. RFID activity data. Activity data for the system were available in the RFIDTracker database from the records of all tags tracked since the system was first piloted. A two-year sample from June 3, 2016 to June 2, 2018 was selected for analysis. These data were downloaded into a Microsoft Excel® spread sheet and analyzed using simple descriptive statistics as outlined in the results section.

2.3.2.4. Focus group. A focus group was held to gather the perspectives of the porters who collect and deliver specimens using the RFID-enabled system. The research team felt that by facilitating and encouraging group discussion among the porters a rich view of the PSTS could be obtained within a short timeframe. Voluntary participation in the focus group was sought from all portering staff by verbal invitation extended by the Portering Services Manager, who noted that they would not be in attendance at the focus group. There were eight focus group participants; comprising all the portering staff directly involved in the PSTS. To avoid social desirability bias the focus group was facilitated by a manager from the Quality and Safety Directorate (not the Director). The focus group format can be found in Appendix 3. Thematic analysis of the transcript of the focus group was undertaken using the six-phase approach outlined by Braun and Clarke (2006). The output from these activities was to further inform the STSA of the RFID enabled PSTS and the process maps.

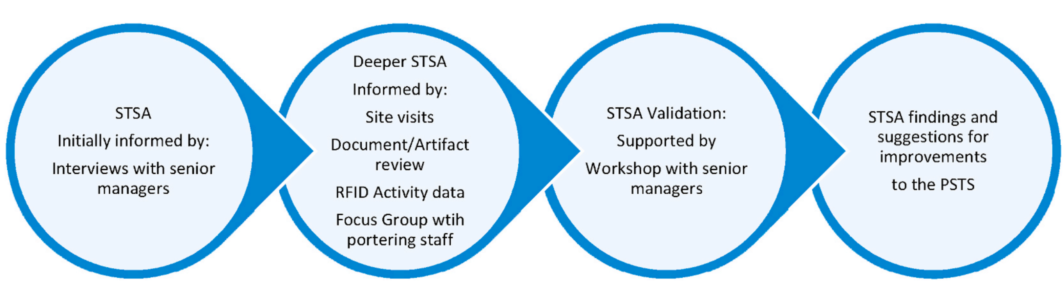

Fig. 3. Overview of the iterative phases of the STSA.

2.3.2.5. Validation of STSA CUBE carried out through: workshop. A workshop was conducted with the six people who had been interviewed: to invite and enable their validation and co-evaluation of the STSA CUBE of the RFID enabled PSTS. A 90-min duration was proposed for the workshop. The attendees were invited to the workshop through email. Information previously gathered was synthesized using the STSA prior to the workshop and presented at the workshop. The workshop was conducted on the July 16, 2018 and was 108 min in duration.

3. Results

3.1. Developing STSA of RFID enabled PSTS

The following data fed into the development of the STSA of the RFID enabled precious specimen transport system.

3.1.1. Interview data

The output of the interviews was the identification of areas to visit and see RFID in action; key documents and artifacts to analyze; and the creation of the first iterations of the process maps of the PSTS in the operating theatre and the laboratory, and creation of the first iteration of the social relations and communication map. Qualitative data gathered through the interviews also confirmed the overall positive regard in which the RFID PSTS was held by the managers involved, as illustrated by the following comments made in response to being asked what advice they would give to another hospital considering the introduction of similar technology: “Absolutely. I'd still support and recommend doing a small network”; “What we have is very good …. Want to roll out further”; “Absolutely - just do it”; “Absolutely”. There was unanimity among managers that the system was working well.

3.1.2. Findings of review of documents and other artifacts

An analysis on a set of documents and artifacts provided by the Director of Facilities Management, the Operations Manager for the Laboratory Medicine Directorate, the RFID Project Manager and the Assistant Director of Nursing for the Operating Theatres and Day Surgery Centre was carried out. Inaccuracies and discrepancies between process descriptions in the documents were identified.

A summary report of Adverse Incident Reports from June 3, 2016 to June 2, 2018 from the Hospital's Safety Management System was compiled by the Hospital's Safety and Risk Manager. This indicated that only one AIR had been received from an area using the PSTS but it related to non-adherence to the local protocol regarding the appropriate time for specimens to be collected. There were no reports indicating safety events in the course of the RFID-enabled processes within the PSTS. The hospital had a good reporting culture and an electronic platform for all staff to report adverse incidents had been introduced 10 years previous to this study.

3.1.3. RFID activity data

Activity data were obtained from the RFIDTracker ICT system, that was developed, implemented and is supported by ASD. Data were downloaded into a Microsoft Excel® spread sheet and analyzed using simple descriptive statistics. Each unit tracked consisted of a tagged bag that could include one or many samples, as was clarified in the workshop. Data were being continuously added to the system during the study period, so a sample of a two-year period of data from June 3, 2016 to June 2, 2018 was selected for the purpose of analysis. 16,733 ‘units’ (i.e. tagged bags) were transported over the two-year period commencing June 3, 2016. A mean of 24 tagged bags (median of 27) were transported each day and a median of 167 tagged bags were transported each week. The workload was relatively evenly distributed across weekdays (Fig. 4), ranging from 16% of specimens transported on a Tuesday, the least busy day, with Wednesdays and Thursdays being marginally busier with 21% transported each day.

Four per cent of samples were recorded as having been transported over the weekend, representing emergency work. Most samples were transported between 9am and 6pm but specimen transport activity extended into the late evening and night, representing emergency work (Fig. 5).

A run chart of the number of tagged bags transported each per week (Fig. 6) demonstrated that having been introduced in June 2016, the system reached steady state activity in mid-September 2016. This also illustrated the seasonal decrease in activity during Christmas and New Year holiday periods.

3.1.4. Focus group

The eight porters who were involved in the PSTS attended the focus group and represented 164 years of collective experience working in this role across a range 3–35 years of employment in the hospital. Thematic analysis of the focus group discussions was carried out and an overview of the themes derived is illustrated (Fig. 7).

Thematic analysis of the focus group identified themes in relation to positive impacts, the system's importance for patients, concerns, sharing of information and ideas for improvement. The theme of trust was very prominent in that it mattered greatly to the porters that they felt more trusted because RFID tracking provided visibility of the movement of specimens and they felt less likely to be blamed for losing samples since its introduction. They also appreciated that there were fewer telephone contacts made with them, both to collect samples and to investigate missing specimens, because of the RFID tracking technology.

The qualitative data provided by the porters when asked if the PSTS was successful included comments such as “Yes, fantastic, it works”; “Brilliant”; “Less stressful”. Their overall view of the system was positive.

Concerns were voiced regarding the work demands on the porter responsible for the transport of blood samples for testing in relation to transfusion and of blood products between the clinical areas, laboratory and transfusion service building. They were also concerned that the

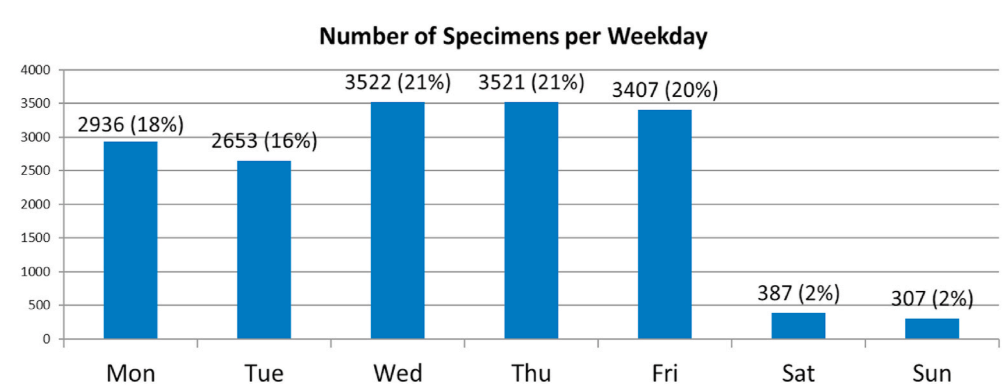

Fig. 4. Aggregate number of tags transported in the PSTS on each day of the week between June 3, 2016 and June 2, 2018.

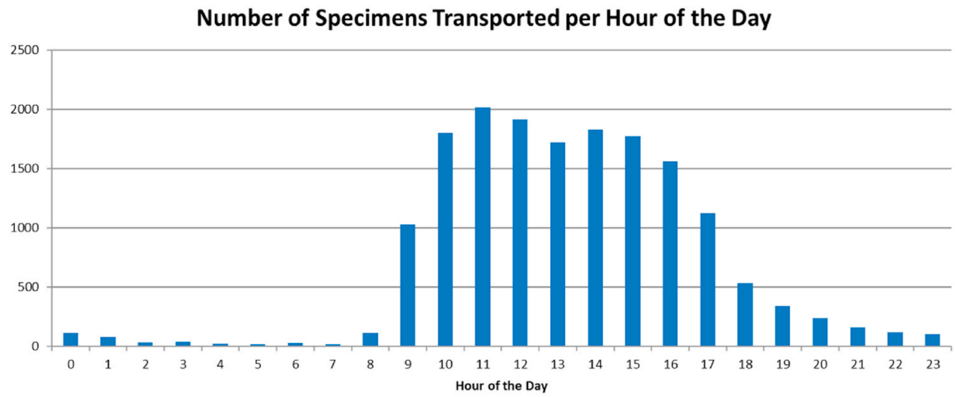

Fig. 5. Frequency distribution of the number of tagged bags transported through the PSTS per hour.

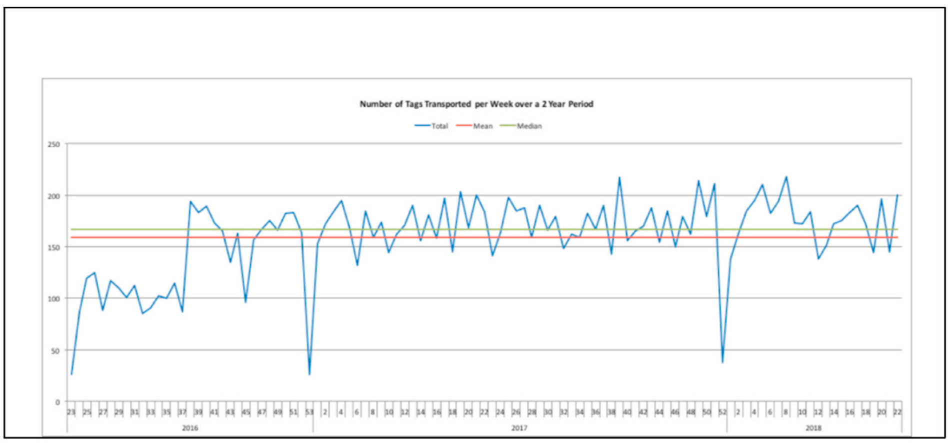

Fig. 6. Run chart of the number of tags transported per week between June 3, 2016 and June 2, 2018.

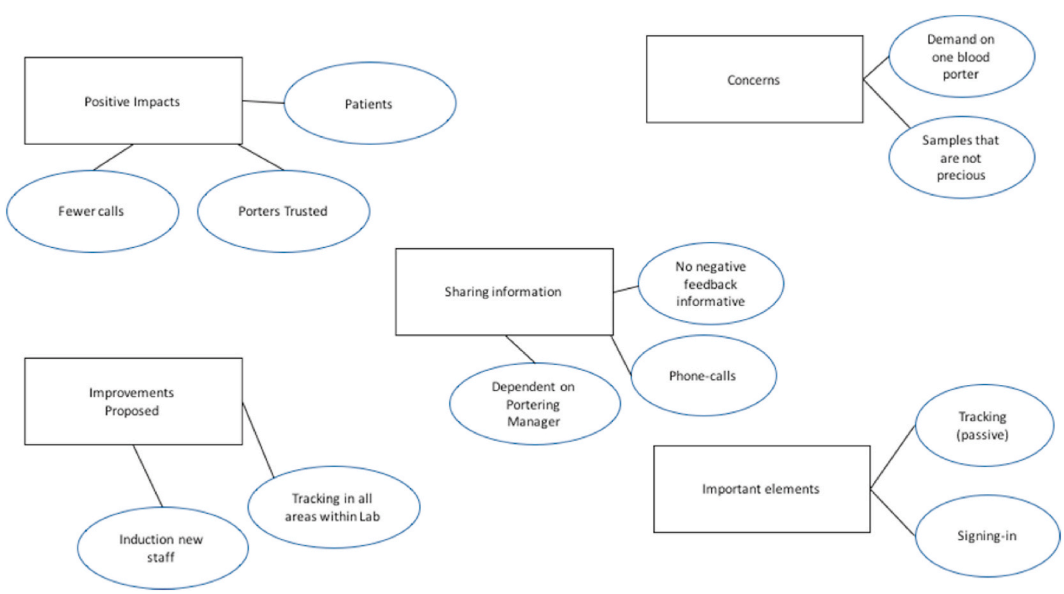

Fig. 7. Diagram of the results of thematic analysis of the porters focus group.

system was being misused in that specimens that were not precious were being sent by clinicians through the PSTS. They did not consider it likely that this behavior would change. They considered that having a paper record in which they 'signed-in' for the specimens was an important record when specimens were delayed or missing. They also appreciated that the system was passive in that it picked up the transport stages without the porter actively scanning the tags or having to "swipe" their cards through a reader.

How information is shared was also a significant theme. The porters perceived that there were no problems in the system because no negative information was shared with them. They were dependent on the Portering Manager for any information they received about the system and phone-calls were the only mode of communication they reported using.

The porters proposed improvements in the PSTS, firstly that all new staff involved in the system should receive induction and secondly, that the system should be expanded to include other areas in the laboratory because, at that time, only the Histopathology laboratory is included and samples that go to other areas such as Microbiology were not locatable within the tracking system at this end-point in their journey and were more difficult to trace if they were delayed.

3.2. Validation of the STSA

The analysis to date from the interviews, document analysis, activity data from the RFIDTracker and focus group was brought together in tabular form (Please see Appendix 4 Tables 1–4). A separate section in the table was constructed for each of the CUBE dimensions – the functional system, action, sense-making and culture and each dimension was explored under the mechanisms of goals, process, social and information. The granularity of information available for analysis reflected the detail of questioning in each of the areas covered in the structured interviews, information available in the documents and discussions in the focus group. The tabular format enabled cross-referencing of information and its validation across the various information sources. The information collated in the CUBE tables informed the workshop content but the tables were not distributed to the workshop participants as the level of detail was considered excessive for the purposes of group discussion.

The tables included a column where reflections on the issues raised were documented. These reflections were reviewed following the workshop and the perspectives that were coherent with those expressed by the team during the workshop were noted in bold type.

Six managers participated in the workshop, representing all the system's internal stakeholder groups and one external service provider. The construct of the workshop led the participants through an introduction to the concept of a STSA and through exercises focused on discussing key information that needed to be validated and gathering their perspectives on the dimensions of the CUBE. The outputs of the workshop included:

- Clarification of the interpretation of activity data that each unit counted was an RFID-tag and that each unit represented one or several specimens.
- Validation of operating theatre and lab collection process maps (Fig. 8 (a) & (b))
- Validation of Social Relations and Communication map (Fig. 9)
- Summary of STSA CUBE and clarification of Learning Points and Action Points from the workshop (Tables 1 and 2).

Copies of the revised materials were circulated by email to the workshop participants approximately four weeks after the interview.

4. Discussion

It was anticipated that the CUBE framework would provide a structure for organising and prioritising information about a complex STS such as the hospital PSTS, with the expectation that some of its emergent characteristics would be disclosed; enable the exploration of the relative roles and interactions of different system dimensions and provide insights as to how the whole system works together, while identifying and locating actual and potential functional anomalies that may point to systemic hazards and risk. While the CUBE framework covers the full cycle of implementation of change, in this study the focus was on setting the agenda for the interviews and focus groups and providing an analysis of the outcomes of these exercises. Through this it supported the productive engagement of different stakeholders in the research and facilitated a focus on how the system could change.

The CUBE enabled the exploration of the relative functions and interactions of different system dimensions and how the whole system

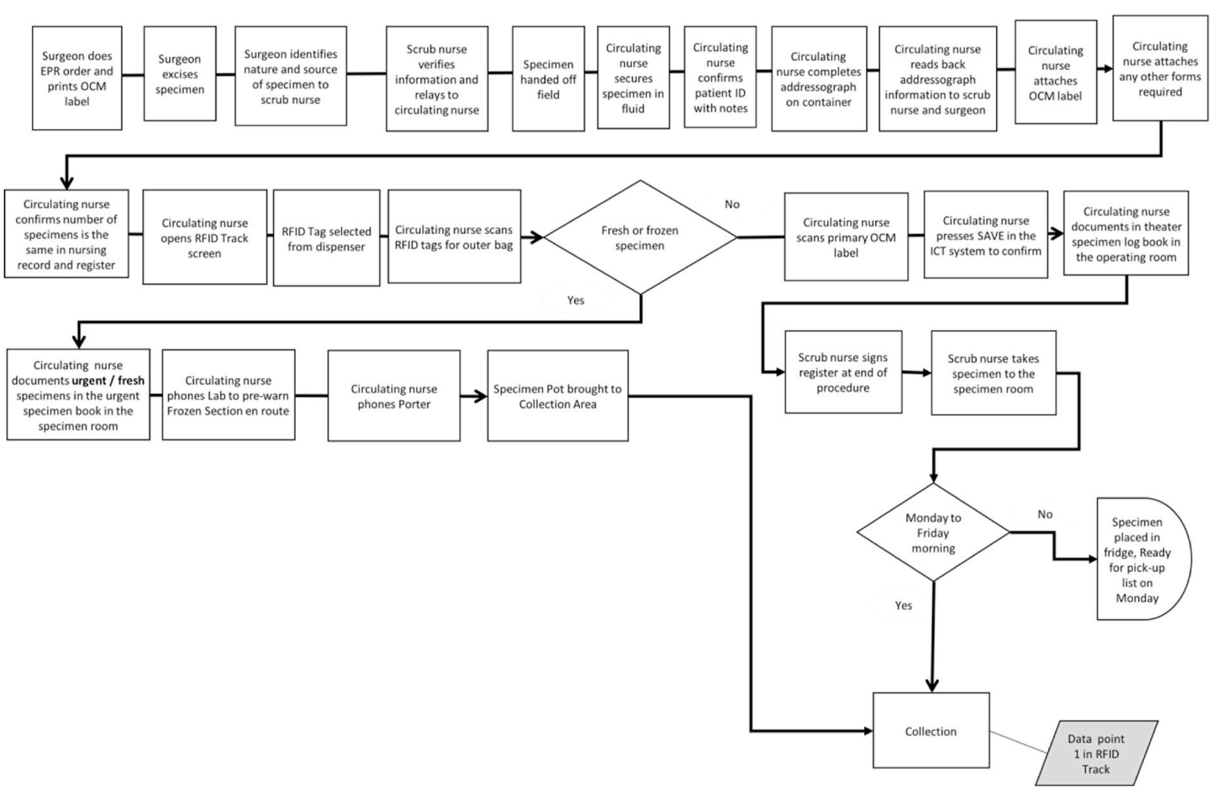

Fig. 8(a). Process map 1; operating theatre process (OCM=Order communications module).

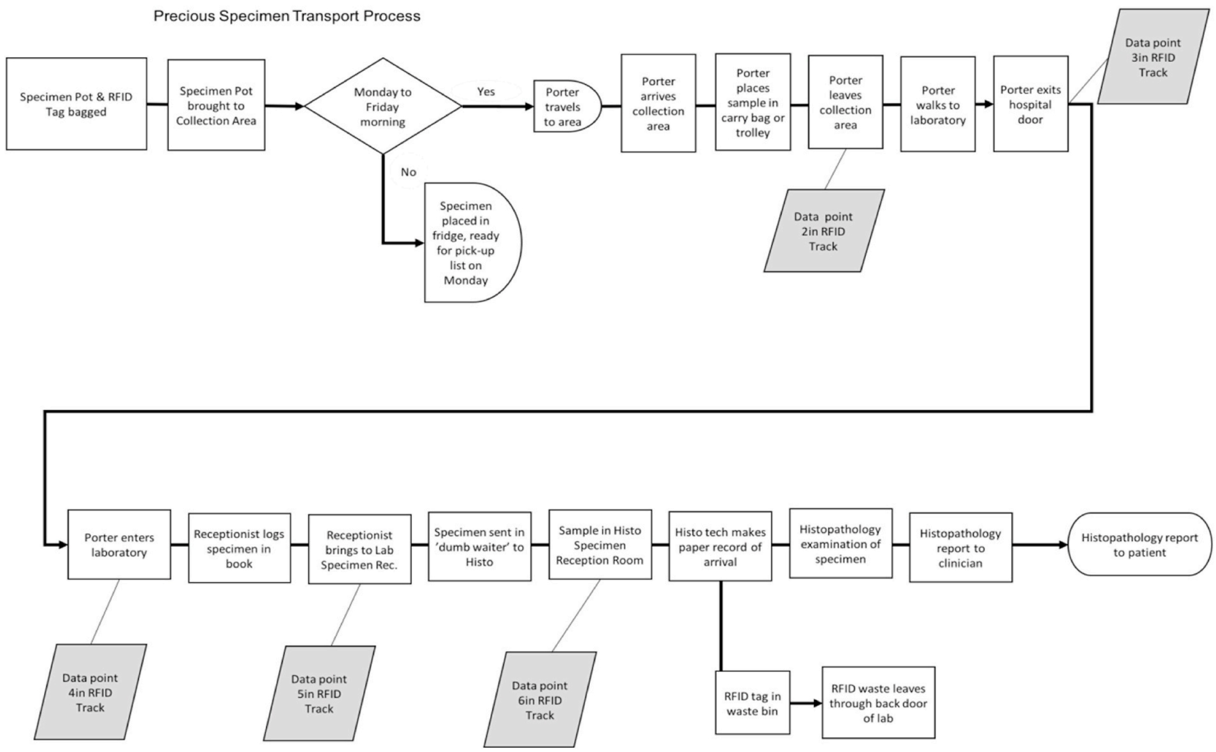

Fig. 8(b). Process map 2; collection point to laboratory.

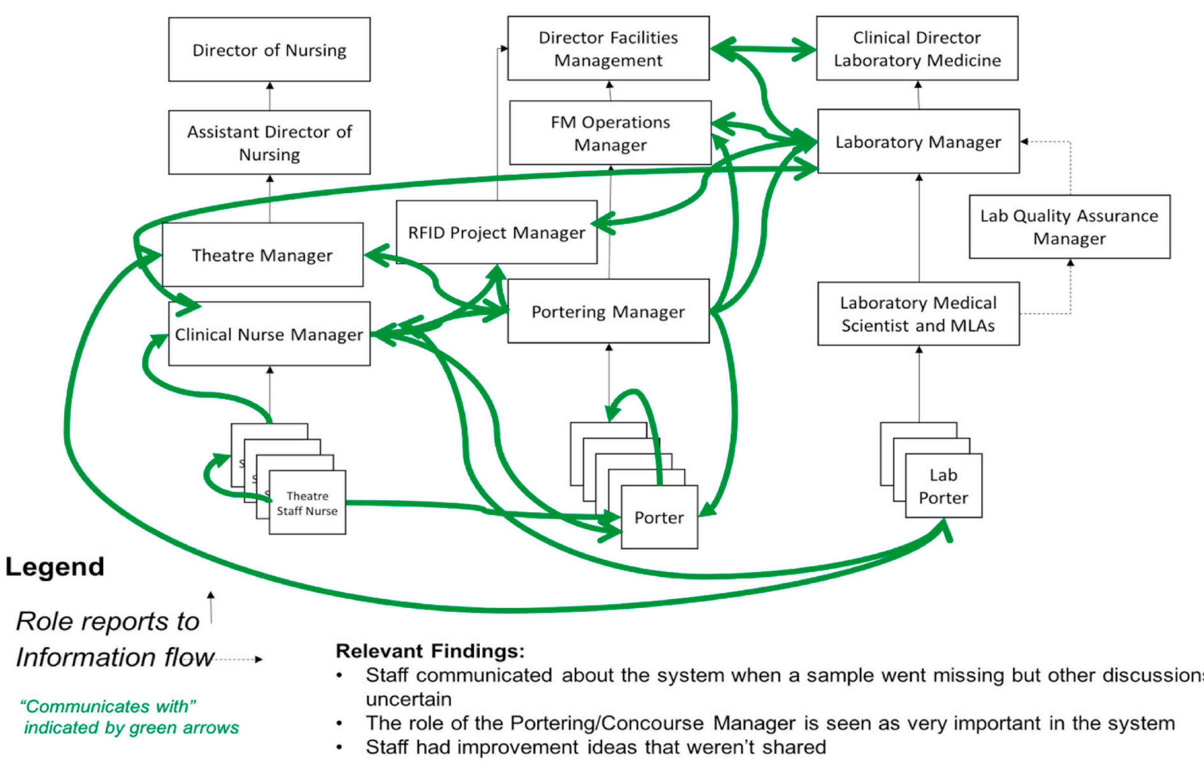

Fig. 9. Social relations and communication map (MLA = Medical Laboratory Assistants).

works together. While the CUBE supported analysis through interviews, document and other artefact review and quantitative analysis of activity data, it was through the focus group and workshop that most learning about the interactions of dimensions of the system emerged. It was also through the workshop that the systems complexity became most evident.

There was also learning in this study regarding the consideration of costs and value within the CUBE STSA and, with hindsight, the availability of cost data for the workshop process would have strengthened the analysis. Cost-savings were not a primary driver of this

Table 1
Summary of STSA CUBE analysis.

Goals	The system's paramount goal was clearly articulated through the STSA as being to improve patient safety. Cost containment and efficiency, identified in a number of published studies as being primary drivers of RFID-enabled systems implementation (e.g. Fosso Wamba, Anand and Carter, 2013), were not priority deliverables for this system. The focus on patient safety was clearly and consistently articulated by all staff members across the interviews, documents, the focus group and workshop.
Process	This study demonstrates that the application of the CUBE provided a useable framework for organising knowledge about this complex system of RFID enabled PSTS (Fig. 8). Prior to this project, documented information describing the system and its evolution, was distributed across various locations in the hospital, through this work it became readily accessible to all staff and will be stored in an electronic archive to which staff will have access. There was a wealth of tacit knowledge about the system among the staff delivering and managing the PSTS that had not been previously considered but some of which was drawn out through the interviews, focus groups and workshops of this research.
Social	The CUBE disclosed significant areas of new learning in relation to the social dimensions, and culture within the system. The project enabled positive feedback about staff experiences to be shared and this was identified as being important to their daily work and the future development of the system. It was noteworthy that there appeared to be a positive culture in this system and mutual respect was evident among the people involved in the PSTS. Front-line porters felt more trusted because of the information that the RFID technology provided. This was particularly interesting because the managers disclosed in the interviews and workshop that they had concerns early in the implementation that the porters' trust could have been undermined by their movements being tracked. The study findings indicated that the opposite effect occurred, with the porters appreciating having information about their movements and the location of specimens that countered any perceived suspicions that they had lost specimens. The STS analysis in this case identified a practical mechanism to improve safety awareness in the culture in this system in that it was disclosed that there was a belief that 'no news was good news' whereas the routine sharing of safety and risk data and other feedback information in the system, as the managers committed to in the workshop, would ensure that quality and safety were not assumed in the system but were monitored, measured, communicated and a source of learning.
Information and Knowledge	Information flows were also examined through the STSA across the functional system and other dimensions of the CUBE (Fig. 9). The RFIDTracker was central to data flows in the system and the research identified a number of areas for improvement in the capture and analysis of information in this system. Electronic alerts were the most obvious risk management intervention enabled by the RFID technology and the managers sought to build on the system's current capability by developing a real-time dashboard of specimen location to improve the timeliness of information and responsiveness and improving the auditing function in the system. The CUBE STSA also enabled information flows through formal reporting structures to be documented and for informal information flows across the system to be mapped. This provided an increased awareness of current information flows and how they could be used during future improvement of the system.

implementation though resource constraints limited the scope of the implementation, as discussed in the workshop. It was also stated in the workshop, that on a transactional level, the availability of data and information through the RFID-tracker and this analysis meant that future business-cases to support development and roll-out of RFID technology in the Hospital would be informed by data, rather than being based on

Table 2
Learning and improvement points from the Workshop.

Summary of Action- and Learning-Points from Workshop Discussions	
Systems Issues	
SI 1	Urgent (fresh or frozen) should be linked to a patient identification in addition to having an RFID tag so that they can be tracked if they go missing
SI 2	All the information in the system is retrospective – the implementation of a live dashboard was recommended.
SI 3	It would be beneficial, in future, to electronically track each sample from each patient
SI 4	Communication occurs when samples are missing, feedback to service users and communication across the hospital needs to be proactively managed
Considerations to Expand the Service	
E 1	Consider inclusion of RFID in other staff groups identification cards
E 2	Implement a pan-hospital RFID network
Learning Points	
LP 1	The leaders initial purpose to get assurance on movement of samples was achieved, but the system needs to be further developed to be expanded into other areas and fully include other types of specimens (e.g. frozen specimens).
LP 2	The Hospital should create a process to gather ongoing user feedback on all new ICT systems implemented to further improve them
LP 3	Implementation of the technology impacted the organizational culture. This needs to be taken into account in future ICT implementation.
LP 4	This is the first time that RFID was used for precious specimens and was framed as an investment in patient safety, not for cost-saving or better asset management. Patient safety is considered an important message for the hospital to promote in relation to change initiatives.

estimations of the value that could be achieved. This is also a recommendation from Fisher and Monahan's (2008) work. Fosso Wamba, Anand and Carter (2013) described the anticipated benefits of RFID-implementation to be related to efficiency gains, quality gains and management gains. In this system, improving patient safety was the primary goal, rather than efficiency. The CUBE STSA demonstrated quality and management gains (e.g. identifying risks and work-as-imagined vs work-as-done within the system) and also significant positive social and cultural impacts (e.g. the system functioning made explicit to all, positive perceptions of trust documented) achieved through the RFID-implementation. There was also a benefit to the managers involved of learning about systems, systems thinking and systems analysis through seeing how the CUBE STSA took place.

The CUBE is intended to help identify and locate potential functional anomalies that may point to systemic hazards. During the course of the study the CUBE analysis disclosed anomalies, for example, in the descriptions of systems processes in policy documents that were addressed through the review of draft process maps in the workshop. Exploration of the social dimension and teamwork in the focus group identified a system anomaly concerning unapproved practices that samples that were not precious were being notified to the porters as such, distracting them from their priority work, but, regrettably, the porters were not confident that these behaviours would be addressed. This pointed to issues concerning processes, governance, social relations and culture in the organisation and addressing this issue was subsequently included in the action plan. Systemic hazards were identified through other opportunities that emerged during the conduct of this research, specifically, the identification of room for improvement in terms of the management of identifiable patient data and the requirement to be able to audit the number of episodes in which samples were delayed in the RFIDTracker.

The process also allowed for the identification of risks by the managers including: inadequacies in the transport of urgent "fresh frozen' specimens (i.e. tissue samples that need to undergo histopathological examination prior to conclusion of the surgical procedure); the need for a real-time dashboard to enable real-time identification of sample location and thereby reduce time delays for specimen collection; and the need for more RFID-tag readers in the laboratory (also mentioned by porters) to enable the precise location of samples within different laboratory departments. The porters' focus group identified some anomalies that were different to those described by the managers (e.g. non-precious samples being included in the system) and this points to the need for truly multi-disciplinary meetings to discuss systems risks and potential improvements.

The technological challenges, that Yao et al. (2012) identified as barriers to RFID implementation, such as interference with tag reading, were documented through the CUBE STSA of this system, but had been overcome during the pre-implementation testing phase of RFID in this setting. Global standards were not a barrier in this implementation because of the adoption of GS1 standards.

In this study context, the EU General Data Protection Regulation 2016 was considered in the team workshop and the risk of tags being hacked was also recognized and is managed on an on-going basis.

Themes of ICT readiness, pre-investment in ICT, information system adaptability to accommodate RFID and technological knowledge were cited as key enablers of RFID system implementation and also featured in other studies (van der Togt et al., 2011; Adhiarna et al., 2013). In this study, integration with the hospital's EPR was critically important enabling the tag to be linked to a patient and an episode of care.

Researching the application of RFID-derived data, Zhou and Piramuthu (2010) proposed that RFID data could be used to inform real-time process management and staffing optimization across a range of healthcare settings and scenarios and expressed concern that the implementation of RFID tracking if not appropriately managed could have a negative impact on labor relations. In the system studied in this project RFID implementation did not adversely impact staff relations. Tracking staff movements was accepted in the setting and, in fact, increased staff perceptions of being trusted. There was an expressed view that implementation of the RFID tracking was valuable and justified because it enhanced patient safety.

The scope of the work was limited to one system in a single organization and the study findings may not be generalizable to other health system organizations and contexts. The exclusion of Medical Laboratory Assistants (MLAs) during the information gathering phases of the study could be considered a limitation, but their perspectives were not included because the specimens have reached their transport destination prior to the direct involvement of MLAs and the laboratory interface perspective was provided by the Laboratory Manager. Further important systems learning in relation to implementation challenges could have been obtained through interviews with staff in the endoscopy suite where deployment of the RFID-enabled PSTS was envisioned at the start of its implementation but did not come to fruition, though it is planned to introduce RFID in this area in the next phase expansion of the PSTS. There was only one interview with an external stakeholder. A more comprehensive analysis of the external organizational context in which the RFID-system exists was not explored in this work. It was not possible in the context of this study and its time constraints to apply the STSA CUBE iteratively along an extended multi-phase process and facilitate further adaptive learning, but the potential exists for the managers of this system to deploy the CUBE iteratively in the meetings they plan to conduct to further develop this system and resources gathered in this project will remain available to them to support this. The research completed provides base-line information and a foundation on which further iterative analysis and reflective learning can be built.

The CUBE is a general heuristic device designed to deconstruct a problem space into core elements that facilitates devising effective solutions. It is based on a synthesis of fundamental principles of STS functioning, spanning different theoretical frameworks. Thus, it aspires to be reasonably comprehensive in coverage but does not claim to be exhaustive; for example, the issue of costs and value were not built into the particular version of the CUBE current at the time of this study. There may be other components of STSA that the CUBE might not cover that other models noted in the introduction might. It challenges the user to consider the problem space from diverse angles and was successful in helping to make explicit much tacit knowledge that could be shared in the participative exercises, expressing different roles and points of view. Using the CUBE STSA contributed to enabling a richer and more valid consolidation and representation of the complexity of this healthcare system (Hollnagel, 2014). It provided a constructive framework to link diverse data and documentation (RFID data, process and role and communication maps). It explicitly invites consideration of the roles and understandings of different stakeholders as well as broader cultural factors that could influence current or future activity. The CUBE is a tool to be used by an analyst who has some knowledge and experience in STSA, to direct the enquiry and put a consistent and coherent structure on the interpretation of rich qualitative and quantitative data. This study has shown it to be particularly effective in combination with participative exercises with diverse groups of staff. Furthermore, this study led to improvements in the CUBE framework: it is now embedded in a software platform that links the CUBE to the analysis of risk and value and to a range of associated evidence (documentation, data, etc.), along an implementation of improvement pathway (McDonald et al., 2021).

5. Conclusion

This study demonstrated the benefits of using the CUBE STSA to understand the application of a specialized technology, RFID, to a novel operational situation - the transport of precious specimens in a hospital environment. This case study took what was already an apparently successful initiative to introduce RFID in the PSTS and demonstrated how to improve that intervention. This improvement could be seen at different levels: operational, social and cultural. There were recommendations to improve and extend operations and identification of some misuse of the system. The exercise radically improved mutual understanding between the different stakeholders in the process. It also increased reported transparency and trust in the PSTS itself.

Funding source

This research was part of a higher education program (Masters in Managing Risk and System Change, TCD) for which the main author (UG) received funding from St James's Hospital.

Financial disclosures

None declared.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to acknowledge the support of the following staff from St James's Hospital: Operations Manager, Facilities Management Directorate; Portering Manager, Facilities Management Directorate; Operations Manager, Laboratory Medicine Directorate; Portering Team staff members, Facilities Management Directorate; Assistant Director of Nursing, Surgery, Anesthesia and Critical Care Directorate; Quality Manager for Person-Centered Care, Quality and Safety Improvement Directorate, Data Analyst, Quality and Safety Improvement Directorate. The authors would also like to acknowledge the support of Ms. Siobhain Duggan, Director of Innovation and Healthcare at GS1 Ireland and Mr. Dave Browne, Aerospace Software Developments Limited.

Appendix 1

Interview protocol

General/Background Information

1) What is your current role/job title?
2) Have you worked in this role prior to and during implementation of the Track & Trace System?
3) How long have you worked in the Hospital?
4) What, if any was/is your involvement in the design, implementation and daily work of the PSTS?
5) What are your specific responsibilities in relation to specimen transport processes?

Goals

1) What is the expected outcome of the PSTS, from your perspective?
2) Are the goals of the PSTS defined? Are they documented?
3) Are they being met?
4) Are they shared between all staff members involved in PSTS?
5) Are there any barriers to achieving these goals?
6) Are there any key enablers of the goals?
7) What support was put in place for you to do this?
8) Has the system achieved any benefits that were not clear goals from the start?
9) How do you think this system influences patient safety?
    a) Staff safety?

Process Inputs and Controls

1) When did the system go live?
2) Where does the PSTS process start?
3) What inputs are there to the system e.g. people, samples etc.,
    a) How does an operator know they are there?
4) How is time a factor in the process?
    a) Earliest time it starts,
    b) Ends
    c) Duration
5) What geographical areas and distances are covered by this system?
6) What procedures are in place to ensure PSTS works?
7) Have there been any unexpected outcomes of the PSTS?
8) How do you know the process is working?
9) What checks, data or controls would alert you or other team members to times when it might not be working well?
10) Who is involved in these procedures/checks?
a) Who is responsible at each stage?
11) Is there any specific equipment used to monitor PSTS?
a) Who is responsible for accessing/maintaining this equipment?
12) What are the key challenges in ensuring the process is reliable?
13) What processes are in place for Staff training?
14) Are there any work logs or daily records of activity kept?
15) Are there any Standard Operating Procedures (SOPs) in place? Documented?
16) Have any changes been made to the process since it started?
    a) Have there been any upgrades to software or technology?
    a) What impact these changes had on current and future processes: Resources; Tasks; Coordination?

Social Relations

1) Do you work as part of a team?
2) Who do you work with on a daily basis in relation to the PSTS? Weekly if not daily?
3) Is there a clear way of working in PSTS understood by all?
4) Does everyone have the same goals in relation to PSTS? Or what different goals may be at play?
5) If culture is the attitudes and beliefs underpinning how we work together, do you think that the PSTS has impacted the culture in your directorate in any way? Please explain.
6) Has the system impacted teamwork? If yes, how
7) Is there a handover, shift change, briefing or other structured co-ordination?
8) Was or is trust an issue in the implementation or provision of the PSTS?
a) Were any staff members not in favour of, suspicious of, or opposed to its implementation and if so how was this managed?
b) Do you think that staff could be afraid to report a problem with the PSTS?
9) Do all the different stakeholders or interest groups involved to be able to contribute to delivering and improving PSTS?

a) Do they meet or communicate in any other way about the system?
b) Are there any groups/personnel not involved who should be?
10) Have you ever had doubts about the function or value of PSTS?

Information and Knowledge

1) What information systems support the PSTS?
2) How well do they work?
3) Do you have all the information you need to manage, support or engage in this system?
4) What testing occurred prior to system 'go live'?
5) Since implementation has there been any formal documented ….
   a) Safety audits;
   b) Risk assessment
   c) Hazard analysis
   d) Examination of the constraints on or barriers to systems safety?
6) Safety reporting:
a) Is it possible for you to report unsafe practice or events?
b) Have you ever submitted an Adverse Incident Report (AIR)?
c) How is it possible to make sure that reports are "followed up" and that action is taken to reduce likelihood of incidents happening again?
d) Are you aware of any reports that resulted in a change in the system?

Any other comments about how information flows in and around the PSTS?

1) Has your overall knowledge of PSTS changed over time and if so how?
2) How much information about this system and how it works is, in your opinion, documented? Accessible to the staff using the system? Tacit i.e. implied, understood rather than written down?
3) Are there ways of capturing, validating and sharing that tacit knowledge?
4) Do the staff using the PSTS have a way of feeding back knowledge or ideas about improving the system?
a) Within the transport team
b) From services that use the system or other interfacing departments or companies?
5) If we don't have these systems for sharing knowledge what do you think they might look like?

System

1) Are there any external regulatory requirements or safety standards with which this system must comply?
   a) If so, are there any inspections or assurance processes required?
2) How many other processes, departments and systems in the Hospital does the PSTS interface with?
   a) Are there external companies involved in this system?
   b) How are these relationships managed?
   c) Do any factors outside the control of the PSTS team or function contribute variability to the system?
3) What resources does the PSTS consume?
   a) Have personnel been allocated appropriate time, resources and support to do their job in PSTS?
   b) How are these monitored & managed?
4) Are there other alternative or competing transport systems in place?
5) What recommendations would you make for any other service implementing a system like this?
6) What are the current processes for reviewing and updating the system?
   a) Process improvement?
   b) Reviewing PPPGs etc.?
7) Is there sufficient authority or power to change the PSTS if it wasn't working?

Appendix 2

Documents analyzed

1. Text of a Q&A document prepared for submission to the RFID Journal Awards February 2018
2. Laboratory Medicine Directorate SOP 016; Specimens (Precious) transport SOP, July 27, 2017
3. SJH Project Path Video, Dillon Productions, 2017. Available at https://vimeo.com/233497698/d41c528d5c
4. RFID Technology in Healthcare. PowerPoint® presentation by PATH Project Manager, September 1, 2016
5. Microsoft PowerPoint® presentation by PATH Project Manager,June 17, 2016
6. Facilities Management Directorate PowerPoint® presentation by PATH Project Manager for RFID Precious Samples Go-Live Project, July 2015.
7. Business Case Precious Samples Tracking Using MedRFID, March 10, 2015
8. Crib Card (A3 Poster) Tracking Precious Samples from Theatre to CPL using RFID Tags (no date)
9. Main Operating Theatre, Specimens Care and Handling Protocol, (PPPG) February 2016

   In addition, the GS1 Ireland representative who partnered in the RFID implementation project offered the following documents for review:
   - Draft notes prepared from a preparatory discussion January 31, 2013, including:

– Proposal for a proof of concept to track precious samples from the collection area in the hospital to the lab using Electronic Product Code RFID based on GS1 Global Standards and
– Notes of site visit of December 18, 2012

Appendix 3

Focus Group Format

Please share any other thoughts or ideas regarding your experience of the PSTS that you think are relevant to this research.

General/Background Info

- Establish that all present are involved in the PSTS?
- Gather range of duration of employment in hospital

Goals

- How would you describe the GOALS (purpose) of the PSTS?
- Have you seen this written down anywhere?
- Did anyone talk to you about the goals or purpose?
- Is it doing what it is supposed to do?
- Describe anything that makes it difficult (barriers) for the system to work?
- Anything that makes it easier for it to work (enablers)?
- Did you see any benefits that were not expected at the start?
- Have you ever had doubts about the function or value of PSTS?
- How do you think this system influences patient safety?

Operational Process

- How do you know the system is working?
- Have you received any training?
- Have you seen any documented PPPGs?
- Have any changes been made to the system since it started?

Knowledge & Information Cycles

- Has what you know about the PSTS changed in any way over time?
- Do you have a way of feeding back ideas about improving the system?
- Is there any information about the PSTS that you need or would like but don't have?
- Have you been involved in an Adverse Incident/Patient Safety incident, its reporting or review? Any comments on this?
- Are you aware of any safety incidents that resulted in a change in the system?
- Do you think that staff could be afraid to report a problem with the PSTS?

Systems & Management

- Have you had any contact with people from the companies who provide the tags or the readers?
- Do you think you have enough time and support to do your job in the PSTS?

Teamwork/Social Relations/Culture/Trust

- Is there a clear way of working in PSTS understood by all?
- Does everyone have the same goals for PSTS? Or what different goals may be at play?
- Has the system impacted teamwork in any way? If yes, how
- Was or is trust an issue in the PSTS?
- Are there any meetings about the PSTS or when, if ever, do porters talk about the system?
- Have you seen the video about RFID in the hospital?
  o Would you like to? Link Available at https://vimeo.com/233497698/d41c528d5c

Summary

Please share any other thoughts or ideas regarding your experience of the PSTS that you think are relevant to this research:
Thank-you to all; provide post-focus group information sheet.

Appendix 4

Table 1
STSA Cube Framework - Socio-technical Mechanisms for the Functional System Dimension, what is known about system goals.

Functional System – Mechanism and Dimensions					
Issues, questions, maps	Data from Managers' Interviews	Focus Group Data	Document Review Data	Quantitative Data	Gaps identified/Improvement potential
Define goals. What value is delivered? What challenges need to be overcome to achieve goals? The rows below explore the data available in relation to goals, value and challenges.					
1. What is the expected outcome of the PSTS?	• "Patient safety" • "Assurance" samples not lost • 'Can't go wrong' • 'None lost'	• "sample gets to the lab'	• See documentation of goals and objectives below	Not Applicable (N/A)	• **Congruent views verbalized** in interviews but no single source defines outcome
2. Are the goals of the PSTS defined? Are they documented?	• Documented in Lab PPPG • Did see written when developing • "Goals not defined and documented"	• No documents seen	• General objectives in documents 3, 4,5, • PSTS-specific goals document 10	Not Applicable (N/A)	• Single set of goals • **No agreed location where documented** • Staff awareness of set and access • Who decides
3. Are goals being met?	• Yes - unanimous	• "Works"	• Nil documented	• There is a record of each transport event • There is no audit of interventions	• **Endoscopy** not fully implemented • **Data audit capability needs improvement**
4. Are they shared between all staff members involved in PSTS?	• Porters aware, according to manager • Goals shared with nurses • Nurses aware about patient safety • In Lab PPPG	• Evident in discussions	• N/A	• N/A	
5. Are there any barriers to achieving these goals?	• Theatre staff- none • Technical problems with dispensers in Theatre and technical problems with tags addressed • New badges for porters developed and tested • Laboratory – none	• Workload on one porter • Samples being misclassified as precious	• Nil referenced	• N/A	• What documentation exists describing technical problems that were addressed?
6. Are there any key enablers of the goals?	• Reducing nurse work reported by FM: Removal of paper records; know when sample in tray no further work to be done • None in lab • Was a "patient safety initiative, so well-received" • "Communication" • Porters understanding tracking protects them if samples lost	• Porter manager – dependency noted	• Document 1 Technology (hardware & software) worked well from first day • Document 4: staff 'buy-in'	• N/A	
7. What support was put in place for you to do this?	• Theatre – none extra • FM/Porters: done 'on a shoe string' • Lab – FM provided all	• Briefed at outset	• Cost areas described in Doc 10 but not quantified	• No analytics in system	• No further training or information sharing for porters • **Need for analytics** • Resource management - Who manages the budget for the system? Who monitors value?
8. Has the system achieved any benefits that were not clear goals from the start?	• Samples left in one specific place • Productivity monitoring not intended but distribution of work within porter team became evident • Enables laboratory audit and assurance	• Porters not being blamed • No disputes regarding where sample is	• Not specified in any of the documents	• N/A	• **Trust for porters is significant.** • **Positive impact on culture is interesting.** • **Pride in the system** • **Clear awareness of patient safety perspective**
9. How do you think this system influences patient safety?	• Patients not at risk of lost sample • Make sure goes from A to B for diagnostic purposes	• "could be life or death"	• Document 10	• N/A	
ACTIONS The key activity of the operation	• Use of the RFIDTracker explained in interviews	• Described their work – get to sample within 15 min	• Described in PPPGs documents 2 & 9	• N/A	• Would a document explaining monitoring of system shared with all add value?

(*continued on next page*)

Table 1 (*continued*)

Functional System – Mechanism and Dimensions					
Issues, questions, maps	Data from Managers' Interviews	Focus Group Data	Document Review Data	Quantitative Data	Gaps identified/Improvement potential
Tasks transform inputs to outputs with sequential links		usually, most delivered on time			
SOCIAL People have roles & collaborate with others Who works with whom? Who reports to whom?	• Draft reporting map developed from interview data	• Team work within portering group and contact with portering manager	• Described in PPPGs documents 2 & 9	N/A	• **Would documentation of reporting relationships add value? (Yes – requested and circulated after workshop)**
INFORMATION Data is transmitted & transformed into information and knowledge. Knowledge is acquired & shared. Tacit knowledge is converted to explicit and back.	• Tacit knowledge gathered through interviews, not represented in documents	• Only pathway for porters to share knowledge is through Portering Manager	• Knowledge in all documents; • PPPG/Doc 2 on intranet; PPPG/Doc 9 within craft group • Documents not consistently shared	N/A	• **Benefits of single document reposito**ry to be discussed. • **Entire team and stakeholders doesn't meet, communicate only around missing samples**

Table 2

STSA cube framework - socio-technical mechanisms for the action dimension.

Actions– Mechanism and Dimensions					
Issues, questions, maps	Data from Managers Interview s	Focus Group	Document Review Data	Quantitative Data	Gaps identified/Improvement potential
GOALS Are there key outcomes that are recorded? Is it possible to put a value on these outcomes? Is there an assessment of risk?	• No structured assessment of value • No risk assessments	• Nil	• Nil	• No outcome measures tracked	• **No documentation of progress on goals** • No analysis of long-term performance or resilience • Costing data sought
PROCESS Do any performance indicators relate to task performance? Is performance assessed? Describe the activity.	• Draft process map to be generated for the workshop	• Time targets for transport but not communicated as KPIs	• Documents 1,2, 3, 4,5,6,7, 8,9, 10 (all) Elements of the process e.g. OT and transport. • Crib card poster (Document 8) describes poster	• Simple statistics demonstrating activity by day, hour, week to be discussed at the workshop.	• **Multiple partial descriptions of process but no maps – would a single source may be helpful** • No KPIs – would these add value?
SOCIAL What actual co-ordination happens? Is there a handover, shift change, briefing or other structured co-ordination?	• Ad hoc, in response to missing sample	• Meetings with portering manager only • Induction	• Difficult to seek how documents have been aligned	• N/A	• Document alignment • Gaps in processes
INFORMATION What operational data is routinely recorded? What documents or messages are inputted to the operation? What reports are generated?	• RFIDTracker weekly report.	• Nil shared	• No documented process	• RFIDTracker technology; analysis conducted for research project	• **No overview reports in the RFIDTracker system** • **Would have to look at emails to check what had been searched for if delayed** • **No scheduled meetings to discuss trends**

Table 3

STSA Cube Framework – Sense-making Mechanism and Dimensions

Sense-making – Mechanism and Dimensions					
Issues, questions, maps	Interview Data	Focus Group	Document Review Data	Quantitative Data	Gaps identified/ Improvement potential
Goals Are the interests/goals of each role clear, related to overall goals and understood by all?	• Participants spoke clearly about their own roles and other managers	• Porters articulated their roles	• Roles and tasks clearly described for theatre staff in Document 9. • Roles described in Document	• N/A	• No assurance in theatre that staff have read the protocol documents.

(*continued on next page*)

Table 3 (*continued*)

Sense-making – Mechanism and Dimensions					
Issues, questions, maps	Interview Data	Focus Group	Document Review Data	Quantitative Data	Gaps identified/ Improvement potential
Process What are the requirements for task performance (competence)? Do they match the capability of each person (fatigue, workload)? How are tasks vulnerable to error?	• No competencies defined • Managers seemed comfortable in their roles	• Not formally assessed • Information at induction but no in-service reviews • Concerns re workload of blood porter	• Nil	• N/A	
Social What collaboration and co-operation is involved? (include informal as well as formal collaboration). How structured and supported are work or operational teams? Are the conditions right for trust?	• Managers collaborate when a sample is delayed or missing	• Portering manager links with porters • Trust enhanced by the technology	• Collaboration expectations not formally documented	• N/A	• **Area for potential improvement**
Information What know-how is needed to do the tasks and job? What information is provided to support situation awareness, decision etc.? *Do you have all the information you need?* What information is collected or exchanged?	• Have the tracking report weekly but no dashboard	• No oversight information provided to porters	• Policies contain much of the information	• Data in the RFIDTracker not previously analyzed	• **Review of "Sunday report" by PM, Porter and Lab manager – is there any discussion of issues or improvements**? • Workshop to discuss
External relationships – how are these managed?	• FM manages • Informal request for change in tracker at time of routine work	• No contact	• Not described in PPPGs	• N/A	• Is there a documented Memorandum of Understanding?
Knowledge changed over time?	• 4/5 no change	• No updates	• Updated as per policy	• N/A	• Director FM knowledge changed as had history – not others
Improvements made over time based on knowledge of the system, safety reports?	• Nil reported	• Nil noted	• Nil noted	• N/A	• **Missed opportunities?**
Testing prior to go live?	• Reported by FM and Theatre		• Evidenced in one slide presentation	• N/A	• Incomplete documentation
Safety audits now	• Audits in lab • No other safety audits	• Nil noted	• Nil	• N/A	• No routine cumulative safety reports
Reporting safety events	• Yes	• No	• N/A	• N/A	
External regulatory context	• Lab and Theatre guidelines reported	• N/A	• No archive of results	• N/A	• **Share awareness of regulators involved**
How has it impacted teamwork	• Initial mistrust reported re. potential monitoring porters' work	• Improved it • Trusted	• Not documented	• N/A	
What recommendations would you make for any other service implementing a system like this?	• All positive	• Recommendations around induction			

Table 4
STSA Cube Framework - Culture Mechanisms and Dimension

Culture - Mechanism and Dimensions					
Issues, questions, maps	Interview Data	Focus Group	Document Review Data	Quantitative Data	Gaps identified/ Improvement potential
Goals What general values are expressed & at least partially shared?	• Patient focus in all • Reliability of tracing	• Patient the main priority • Reliability of tracing	• Similar language in PPPGs. • Slides reflected patient focus	• N/A	• **No goals about data analysis**
Process Norms of behavior & everyday practice.	• Routine of weekly report but nil else	• Issues regarding samples that are not precious – not addressed	• N/A	• Information about processes in Tracker data could be shared with staff	

(*continued on next page*)

Table 4 (*continued*)

Culture - Mechanism and Dimensions					
Issues, questions, maps	Interview Data	Focus Group	Document Review Data	Quantitative Data	Gaps identified/ Improvement potential
Relevant organizational routines					
Social How is the organization divided into subcultures? (Professional, organizational, regional etc.) How coherent or fragmented is it?	• Teamwork improved as system used	• Perception of hierarchy • Not seen video • Ideas for improvement not shared • Would like repeat focus group	• Document 3 – Video is powerful social tool	• N/A	• How many staff have seen the video?
Information What knowledge & assumptions are shared (generally & in subcultures) about the system & how it works? Who is 'in-the-loop' for what information? Who is left out of shared information/knowledge?	• Director FM had history of the project	• Porters don't get PPGs, no feedback received	• No feedback loops described		• No systematic sharing of qualitative data • Who decides who gets what data

References

Adhiarna, N., Hwang, Y.M., Park, M.J., Rho, J.J., 2013. An integrated framework for RFID adoption and diffusion with a stage-scale-scope cubicle model: a case of Indonesia. Int. J. Inf. Manag. 33 (2), 378–389. https://doi.org/10.1016/j.ijinfomgt.2012.10.001.

Amalberti, R., 2013. Navigating Safety Necessary Compromises and Trade-Offs–Theory and Practice. Springer, London.

Braithwaite, J., Churruca, K., Long, J.C., Ellis, L.A., Herkes, J., 2018. When complexity science meets implementation science: a theoretical and empirical analysis of systems change. BMC Med. 16 (1), 63. https://doi.org/10.1186/s12916-018-1057-z.

Anderson, J.E., Ross, A.J., Macrae, C., Wiig, S., 2020. Defining adaptive capacity in healthcare: a new framework for researching resilient performance. Appl. Ergon. 87, 103111. https://doi.org/10.1016/j.apergo.2020.103111. ISSN 0003-6870.

Braithwaite, J., Churruca, K., Ellis, L.A., Long, J., Clay-Williams, R., Damen, N., Herkes, J., Pomare, C., Ludlow, K., 2017. Complexity Science in Healthcare – Aspirations, Approaches, Applications and Accomplishments: A White Paper. Australian Institute of Health Innovation, Macquarie University, Sydney, Australia. Retrieved 23/11/21 from. https://www.mq.edu.au/research/research-centres-groups-and-facilities/healthy-people/centres/australian-institute-of-health-innovation/publications-and-resources/complexity-science-in-healthcare-a-white-paper.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3 (2), 77–101. https://doi.org/10.1191/1478088706qp063oa.

Callan, V., 2017. A hospital wide approach to adopting GS1 standards. Accessed 23/11/21. https://www.gs1.org/industries/healthcare/news/hospital-wide-approach-adopting-gs1-standards.

Carayon, P., Wooldridge, A., Hoonakker, P., Hundt, A.S., Kelly, M.M., 2020. Seips 3.0: Human-centered design of the patient journey for patient safety. Appl. Ergon. 84, 103033. https://doi.org/10.1016/j.apergo.2019.103033.

Carman, E.M., Fray, M., Waterson, P., 2021. Facilitators and barriers of care transitions - comparing the perspectives of hospital and community healthcare staff. Appl. Ergon. 93, 103339, 2021.

Clarkson, J., Bogl, D., Dean, J., Tooley, M., Trewby, J., Vaughan, L., Adams, E., Dudgeon, P., Platt, N., Shelton, P., 2017. Engineering better care a systems approach to health and care design and continuous improvement. Royal Acad. Eng. 978-1-1909327-35-1 Available at: https://www.raeng.org.uk/publications/reports/engineering-better-care Last accessed 07/02/22.

Corrigan, S., Kay, A., O'Byrne, K., Slattery, D., Sheehan, S., McDonald, N., Smyth, D., Mealy, K., Cromie, S., 2018. A socio-technical exploration for reducing & mitigating the risk of retained foreign objects. Int. J. Environ. Res. 15 (4), 714. https://doi.org/10.3390/ijerph15040714.

Da Rin, G., 2010. Pre-analytical workstations as a tool for reducing laboratory errors. J. Med. Biochem. 29 (4), 315–324. https://doi.org/10.1016/j.cca.2009.03.024.

del Carmen León-Araujo, M., Gómez-Inhiesto, E., Acaiturri-Ayesta, M.T., 2019. Implementation and evaluation of a RFID smart cabinet to improve traceability and the efficient consumption of high cost medical supplies in a large hospital. J. Med. Syst. 43, 178. https://doi.org/10.1007/s10916-019-1269-6.

El Khamlichi, M., Alvarez Melcon, A., El Mrabet, O., Ennasar, M.A., Hinojosa, J., 2019. Flexible UHF RFID tag for blood tubes monitoring. Sensors 19 (22), 4903. https://doi.org/10.3390/s19224903.

Fish, L., Bopp, D., Gregory, D., Kerley, D.K., Gakhar, S., Lavigne, M.C., Boyd, F., 2021. Hand hygiene feedback impacts compliance. Am. J. Infect. Control 49 (Issue 7), 907–911. https://doi.org/10.1016/j.ajic.2020.12.010. ISSN 0196-6553.

Fisher, J.A., Monahan, T., 2008. Tracking the social dimensions of RFID systems in hospitals. Int. J. Med. Inf. 77 (3), 176–183. https://doi.org/10.1016/j.ijmedinf.2007.04.010.

Fosso Wamba, S., Anand, A., Carter, L., 2013. A literature review of RFID-enabled healthcare applications and issues. Int. J. Inf. Manag. 33 (5), 875–891. https://doi.org/10.1016/j.ijinfomgt.2013.07.005.

Francis, D.L., Prabhakar, S., Sanderson, S.O., 2009. A quality initiative to decrease pathology specimen-labeling errors using radiofrequency identification in a high-volume endoscopy center. Am. J. Gastroenterol. 104 (4), 972–975. https://doi.org/10.1038/ajg.2008.170.

Greenhalgh, T., Papoutsi, C., 2018. Studying complexity in health services research: desperately seeking an overdue paradigm shift. BMC Med. 16 (1), 95. https://doi.org/10.1186/s12916-018-1089-4.

Ho, H.J., Zhang, Z.X., Huang, Z., Aung, A.H., Lim, W.Y., Chow, A., 2020 May 26. Use of a real-time locating system for contact tracing of health care workers during the COVID-19 pandemic at an infectious disease center in Singapore: validation study. J. Med. Internet Res. 22 (5), e19437 https://doi.org/10.2196/19437.

Hollnagel, E., 2014. Safety-I and safety-II. In: The Past and Future of Safety Management. Ashgate, Surrey.

Hollnagel, E., 2018. In: Safety-II in Practice Developing therResilience Potentials. Routledge, Abingdon, Oxon, UK.

Kaya, G.K., 2021. A system safety approach to assessing risks in the sepsis treatment process. Appl. Ergon. 94, 103408.

Leveson, N., 2012. Engineering a Safer World. Mit Press, Cambridge, Ma.

McDonald, N., McKenna, L., Vining, R., Doyle, B., Liang, J., Ward, M.E., Ulfvengren, P., Geary, U., Guilfoyle, J., Shuhaiber, A., Hernandez, J., Fogarty, M., Healy, U., Tallon, C., Brennan, R., 2021. Evaluation of an access-risk-knowledge (ARK) platform for governance of risk and change in complex socio-technical systems. Int. J. Environ. Res. Publ. Health 18, 12572. https://doi.org/10.3390/ijerph182312572.

McDonald, N., Callari, T.C., Baranzini, D., Mattei, F., Citino, S.A., Sroeve, S., Woltjer, R., Johansson, B.J.E., Oskarsson, P.A., 2018. Operational mindfulness manager. Future sky safety. Eur. Commis. Accessed 23/11/21 https://www.futuresky-safety.eu/wp-content/uploads/2018/03/FSS_P5_TCD_D5.12_v.2.0.pdf.

McDonald, N., 2017. (Trinity College Dublin, Ireland). Using the CUBE for STSA. Course Module, M.Sc. In: Managing Risk and System Change.

McDonald, N., 2015. The evaluation of change. Cognit. Technol. Work 17 (2), 193–206. https://doi.org/10.1007/s10111-014-0296-9.

Mehrjerdi, Y.Z., 2015. RFID role in efficient management of healthcare systems: a system thinking perspective. Int. J. Industr. Eng. 26 (1), 45–61. http://ijiepr.iust.ac.ir/article-1-389-en.pdf.

National Patient Safety Foundation, 2015. Free from Harm: Accelerating Patient Safety Improvement Fifteen Years after to Err Is Human. National Patient Safety Foundation, Boston, MA. Accessed 23/11/21 from. http://www.ihi.org/resources/Pages/Publications/Free-from-Harm-Accelerating-Patient-Safety-Improvement.aspx.

Nesse, R.E., Kutcher, G., Wood, D., Rummans, T., 2010. Framing change for high-value healthcare systems. J. Healthc. Qual. 32 (1), 23–28. https://doi.org/10.1111/j.1945-1474.2009.00060.x.

O'Hara, J.K., Baxter, R., Hardicre, N., 2020. Handing over to the patient: a FRAM analysis of transitional care combining multiple stakeholder perspectives. Appl. Ergon. 86, 103060.

Perrow, Charles, 1984. Normal Accidents: Living with High-Risk Technologies. Basic Books, New York, NY, USA.

Pidgeon, N., O'Leary, M., 1994. Organisational safety culture: implications for aviation. In: Johnston, N., McDonald, N., Fuller, R. (Eds.), Applications of Psychology to the Aviation 1488 System. Avebury Aviation, Tonbridge, UK.

Sang, A.X., Tisdale, R.L., Nielsen, D., Loica-Mersa, S., Miller, T., Chong, I., Shieh, L., 2019 Aug 1. How much time are physicians and nurses spending together at the patient bedside? J. Hosp. Med. 14 (8), 468–473. https://doi.org/10.12788/jhm.3204. Epub 2019 May 12. PMID: 31112496.
Schein, E.H., 2010. Organisational Culture and Leadership, fourth ed. Jossey-Bass Professional Learning, San Francisco, CA, USA.
Schein, E.H., 1984. Culture as an environmental context for careers. J. Organ. Behav. 5 (1), 71–81.
Shim, H., Uh, Y., Lee, S.H., Yoon, Y.R., 2011. A new specimen management system using RFID technology. J. Med. Syst. 35 (6), 1403–1412. https://doi.org/10.1007/s10916-009-9417-z.
Sujan, M., Bilbro, N., Ross, A., Earl, L., Ibrahim, M., Bond-Smith, G., Ghaferi, A., Pickup, L., McCulloch, P., 2022 Jan. Failure to rescue following emergency surgery: a FRAM analysis of the management of the deteriorating patient. Appl. Ergon. 98, 103608. https://doi.org/10.1016/j.apergo.2021.103608. Epub 2021 Oct 14. PMID: 34655965.
Roberti, M., 2005. The history of RFID Technology. RFID J.
Trist, E., 1981. The evolution of socio-technical systems. Occas. Pap. 2. Accessed 23/11/21, 1981. http://www.lmmiller.com/blog/wp-content/uploads/2013/06/The-Evolution-of-Socio-Technical-Systems-Trist.pdf.
Turner, B.A., Pidgeon, N.F., 1997. Man-made Disasters. Butterworth-Heinemann Books, Boston, MA.
Tzeng, S.-F., Chen, W.-H., Pai, F.-Y., 2008. Evaluating the business value of RFID: evidence from five case studies. Int. J. Prod. Econ. 112 (2), 601–613. https://doi.org/10.1016/j.ijpe.2007.05.009.
Underwood Hall, J.P.A., Wright, N.A. (Eds.), 2006. Understanding Disease: A Centenary Celebration of the Pathological Society. John Wiley and Sons, Chichester.
van der Togt, R., Bakker, P.J.M., Jaspers, M.W.M., 2011. A framework for performance and data quality assessment of Radio Frequency IDentification (RFID) systems in health care settings. J. Biomed. Inf. 44 (2), 372–383. https://doi.org/10.1016/j.jbi.2010.12.004.
Ward, M., McDonald, N., Morrison, R., Gaynor, D., Nugent, T., 2010. A performance improvement case study in aircraft maintenance and its implications for hazard identification. Ergonomics 53 (2), 247–267. https://doi.org/10.1080/00140130903194138.
Ward, J.R., Buckle, P., Clarkson, P.J., 2010. Designing packaging to support the safe use of medicines at home. Appl. Ergon. 41 (5), 682–694.
Weick, K.E., 1995. Sensemaking in Organisations. SAGE Publications, London, UK.
Weprin, S., Crocerossa, F., Meyer, D., Maddra, K., Valancy, D., Osardu, R., Kang, H.S., Moore, R.H., Carbonara, U.J., Kim, F., Autorino, R., 2021 Jul 12. Risk factors and preventive strategies for unintentionally retained surgical sharps: a systematic review. Patient Saf. Surg. 15 (1), 24. https://doi.org/10.1186/s13037-021-00297-3.
Wicks, A.M., Visich, J.K., Li, S., 2006. Radio frequency identification applications in healthcare. Int. J. Healthc. Technol. Manag. 7 (6), 522–540. https://doi.org/10.3200/HTPS.84.3.3-9.
Yao, W., Chu, C.-H., Li, Z., 2012. The adoption and implementation of RFID technologies in healthcare: a literature review. J. Med. Syst. 36 (6), 3507–3525. https://doi.org/10.1007/s10916-011-9789-8.
Zhou, W., Piramuthu, S., 2010. Framework, strategy and evaluation of health care processes with RFID. Decis. Support Syst. 50 (1), 222–233. https://doi.org/10.1016/j.dss.2010.08.003.