Improving Patient Throughput by Streamlining the Surgical Care-Pathway Process

David Mc Mahon[1](✉), Joseph Walsh[2], Eilish Broderick[3], and Juncal Nogales[1]

[1] Tralee Institute of Technology Co., Kerry, Ireland
david.martin.mcmahon@research.ittralee.ie,
juncal.nogales@staff.ittralee.ie

[2] Head of School (STEM), Tralee Institute of Technology Co., Kerry, Ireland
joesph.walsh@staff.ittralee.ie

[3] Head of Department, Tralee Institute of Technology Co., Kerry, Ireland
eilish.broderick@research.ittralee.ie

Abstract. The delivery of a patient, to the operating theatre, in every hospital, consists of several heterogeneous departments working synchronously via communicating and sharing information, in relation to the current state of a patient's care, as they travel through the surgical care-path way. The surgical care-pathway typically starts at admissions and finishes as the patient is leaving recovery. The problem being, as a patient navigates the care-pathway, there are numerous risk factors in the forms of technical, environmental and human that can influence a delay in the delivery of care. This paper will discuss these risk factors and highlight different approaches taken by several authors to address such issues. Additionally, a software application will be discussed that has being developed by the author that uses portable mobile devices, to address similar issues, for a private health care provider in the south of Ireland. The results of implementing the new solution show a potential decrease in patient throughput time and an overall increase of task visibility, across the surgical care-pathway.

Keywords: Surgical care-pathway · Communication & information · Portable mobile devices

1 Introduction

Proper communication systems and methods are vital for hospitals to obtain maximum efficiency in the delivery of care [1]. When transferring a patient from one department in the hospital to another, workers depend heavily on accurate clinical information [2]. Clinical staff who make decisions about the current state of a patient's health depend on information from numerous departments inside a patients care-path-way [3]. This information needs to be non-ambiguous and accessible in order to reduce delays to a patient's care and to avoid clinical errors that place the patient's health at risk [4].

J. Nogales—Project Coordinator.

J. Ye et al. (Eds.): MobiHealth 2020, LNICST 362, pp. 186–207, 2021.
https://doi.org/10.1007/978-3-030-70569-5_12

In order to reduce the patient risk rate and improve the workflow and patient throughput, of the surgical care-pathway, key areas have been identified in literature that form both the problem and solution definition and can have a positive or negative influence on the patients surgical care-pathway and subsequently the hospitals throughput average. These being; communication structure [5, 6]; communication culture [7, 8]; communication quality [9, 10]; interdepartmental communication [1, 11–14]; and information sharing and collaborative systems [4, 15, 16].

In order to address the risk factors mentioned above, newer technologies such as portable communication applications have been introduced into hospitals [17–20]. These technologies offer a solution by enabling rich content of information to be shared between both individuals and departments. Additionally, these systems allow for asynchronous communication, accessibility of information at the point care and accessibility to clinical decision makers without disrupting their workflow [10]. In doing so these systems increase a patient's care by reducing delays in their care-pathway and promote interdepartmental communication, patient task visibility, task compliance and information security and distribution [21–23].

The main aims of this research paper is to; (1) identify and understand the potential negative impact of the five key risk factors mentioned above inside the patient surgical care-pathway; (2) highlight how assisitve and complementary technologies are been used to counteract these risk factors; (3) demonstrate through a case study in an elective surgery based hospital in Ireland how streamlining the surgical care-pathway using a bespoke software application can improve patient throughput.

The following sections of this paper will be formatted as follows. Section 2 will present an overview of the problems associated with communication and collaboration in the hospital environment. Section 3 will present implemented solutions taken from studies that highlight both technical and non-technical solutions to the problem space. Section 4 will present the case study and implement solution and finally Sect. 5 will highlight results of the case study with conclusions.

2 The Problem Domain

This section will now explore the problem domain of some of the key influencers to poor communication and information sharing inside the patient surgical care-path that have a negative impact on the delivery of care and patient throughput.

2.1 Interdepartmental Communication and Collaboration

Interdepartmental communication in hospitals is the process of several departments collaborating and communicating, patient care objectives, in relation to their current health status, care-pathway trajectory and assessments [16]. In doing so, clinicians can make best practice decisions, for a patient, based on their findings [1]. Issues arise, if there is no collaboration between departments which can lead to ambiguity of facts, around information shared, between departments [2]. This can delay care for a patient, or put the patient at risk, of being misdiagnosed.

Additionally, hospitals can be held liable, if it is deemed that inefficient communication methodologies are being implemented, that could potentially place a patient at risk [24]. Furthermore, inventory management is effected by poor interdepartmental communication practices. If the auditing of surgical instruments is not communicated, in a timely manner, the hospital may incur a delay, in the purchasing or ordering, of the instruments. This in turn, effects the theatre scheduling process and can cause a delay to surgery [25].

2.2 The Hierarchical Influence

Another barrier to effective communication and information sharing in the hospital environment is the hierarchical structure. This structure is unique, unlike most industries where there is one leader and all decisions and objectives filter down through, sub-teams and management groups, hospitals usually have a dual hierarchy, consisting of, the medical management group and the traditional management group [26]. These hierarchies tend to form work silos [27]. Work silos promote partitioning of services that are detrimental, to the collaborative effort, needed from all departments, to deliver the best possible care for a patient [28]. Similarly, the work culture is affected by this as staff should be represented at all levels should a strategic change happen in relation to the hospitals current business objectives [8].

2.3 Hospital Information Systems

Most hospitals use information systems to store and sort, patient information in the form of EMR (Electronic Medical Records), [15].The patient's data should be, easily accessible to the medical staff who are providing care for a patient. Information systems help to collaborate different departments who are providing care for a patient. The processing of information is vital, as it must be conducted across all departments, in order to keep all departments aligned, with the current state of the patient's care [4]. Complex systems that involve trawling through data, to obtain patient information, are counterproductive [29]. Furthermore the use of arcane legacy systems, due to the time taken to retrieve the relevant information, is not efficient [30]. This can lead, to costly software migration approaches being adopted, as the interoperability of the system, does not exist, in relation to the porting functionality, with newer systems [31]. Finally, poor logic implementation and the use of unintuitive interface design, has a negative impact on information sharing and data distribution [32].

2.4 Conventional Forms of Communication

Conventional forms of communication, involve the use of letters, wired phones, pagers, email and fax to distribute, or audit information that directly influence, a patients care. By law, hospitals must use conventional forms of communication, when signing clinical documentation in a paper format, however, the document has then to be distributed manually, to different departments, for other clinicians to read. This relaying of information is inefficient and time consuming [33]. During peak demand or capacity periods in the hospital a failure to communication the patient task status in real-time, can create a backlog of tasks to be completed, hence conventional methods of communication and human error, are one of the main causes of bottlenecks in a patients care pathway [34].

Peri-operative nurses, rely heavily on information gained, via telephone calls and written messages, to assist them in relaying important information, to the surgeon and also serve as a first phase assessment tool, for post-operative care. This is a long laborious process that can lead to ambiguity of facts, about the patients care needs and can delay surgery [35]. Communication methods such as face to face conversations, between clinical workers, are the most informative methods used, in the hospital environment. The problem with this method of communication is that department representatives, directly responsible for a specific patients care, that were not engaging in the primary conversation could now be missing vital information, about the patient. This method of conversation is not robust or transparent and can lead to ambiguity of facts and increased waiting time for patients [36].

2.5 Patient Handover and Transfers

A failure to communicate efficiently, during the clinical handover process, is recognized as the key factor that causes major incidents, in the care of patients and also contributes highly, to patient and staff dissatisfaction [10]. Additionally, a standard protocol in the transfer of care often involves, paper based check lists, consisting of patient information such as type of surgery, current allergies, medical history, frequency of medication and any immediate concerns, that the patient may have [11]. Notifications are then communicated to the workers, in the receiving department via telephone and computer email. The transfer is also logged in the unit admission transfer and discharge log sheet. This form of data capture and communication is not efficient and prone to be lost, or possibly discarded out of human error [12].

2.6 Patient Security

GDPR (General Data Protection Regulation) in hospitals, is now being implemented, as a form of patient security and patient confidentiality. Under GDPR, data is not to be made available, about patients, if it breaches, the principle of purpose limitation, guidelines. This simply means, that the amount data, should be condensed or limited, with regards to its necessity, in completing a patients-care path process [37]. For development of new applications in the health care sector under GDPR privacy by design is a new method of development whereby all data that is being collected must be anonymised.

Additionally, any algorithm's that are used in the sorting and processing of data must carry out a data protection impact statement (DPIA).This is a risk evaluation process that is mandatory to all types of data processing practices. In particular, evaluating the risk associated with the processing of sensitive patient data [38]. By adhering to the new GDPR guidelines developers need to take numerous precautions when designing applications in the healthcare sector and this can be a costly process that is difficult to police. Additionally, making existing applications GDPR compliant can cost a substantial amount of money due to the possible need to overhaul and test the entire system.

2.7 From an Irish Context

With regards to the key areas defined in Table 1 below, the National Service Plan, published in 2020, provides a strong correlation between the literature based problem domains mentioned above and the proposed priorities and actions outlined by the Office of the Chief Information Officer (OoCIO). The OoCIO are responsible for the delivery of ICT health services at a national level in Ireland. With regards to communication and collaboration, data distribution and security, the following actions have been scheduled for the implementation pillar titled Enabling Healthcare Delivery [39].

Table 1. A table representation of some of the priorities and actions under the national service plan 2020, X = not applicable to column value, 0 = applicable to column value, CC = communication & collaboration, DD = data distribution, S = security.

#	Action description	CC	DD	S
1	Design and develop the summary and shared care record	0	0	X
2	Implement digital patient records for all strands	0	0	X
3	Establish the ePharmacy and the ePrescribing programmes	X	0	X
4	Finalise the procurement of an acute floor information system	0	X	0
5	Implement the telehealth strategy	0	0	0
6	Establish an eHealth solution to support referral pathways	0	X	X
7	Deliver a single software architecture approach to promote better access and sustainability	0	0	0
8	Enhance the data dictionary to facilitate the adoption of common definitions and promote interoperability	0	0	X
8	Enhance the data dictionary to facilitate the adoption of common definitions and promote interoperability	0	0	X
9	Implement the cyber security strategy to protect sensitive patient data	X	0	X
10	Migrate older legacy systems to more sustainable software solutions	X	0	0
11	Establish a centre of excellence to support and promote the implementation of cloud based technologies	0	0	0
12	Establish the interRAI It based assessment system	0	0	0
13	Establish mobile data integration and distribution services	0	0	0

Table 1 outlines a strong correlation between the actions proposed at a national level and the findings from the literature with regards to the problem domain and how communication, collaboration information sharing and security are to be prioritized going forward into 2020.

Furthermore, it has being identified in the eHealth Strategy for Ireland 2020, that ICT sector spending needs to increase to the European rate of 2–3% from the current rate of 0.85%.This new investment will go towards the implementation and maintenance of the programs mentioned above in Table 1 and help fund key research into new approaches of improving health care via eHealth solutions [40].

2.8 From a European and American Context

Based on data obtained from the European Risk Observatory Report in relation to emerging issues and crisis in the healthcare sector, communication, collaboration and information sharing are key developments that need to be addressed. The uses of eHealth systems and mHealth frameworks are of high importance when advancing the efficiency of the collaborative effort needed to deliver positive clinical and administrative workflows [41].With regards to cyber-security the European commission for ICT has provided funding for several pilot projects such as Serums, Secure Hospitals and Sphinx. These are all aimed at safe guarding the patients data during the storage and distribution process [42]. In the US the trend in the problem space is similar with poor communication practices and the use of arcane communication technologies leading to escalating costs in the delivery of care [43] (Fig. 1, Tables 2 and 3).

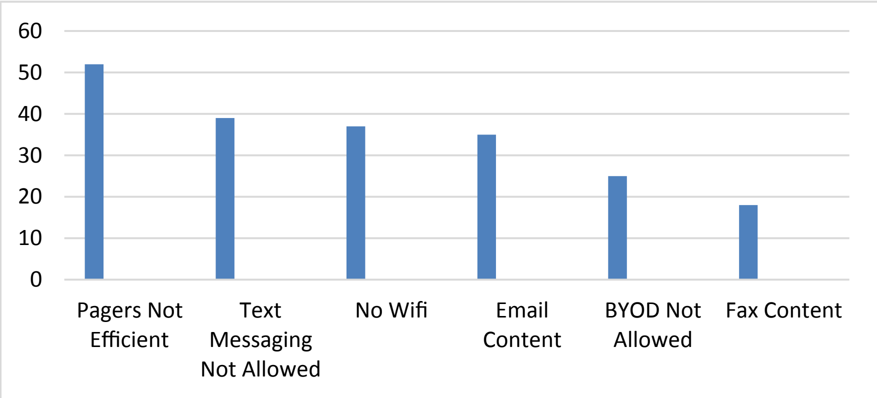

Fig. 1. The 2014 Imprivata report on the economic impact of inefficient communications in health [44]. Highlighted are the main reasons for time wasted when communicating with colleagues in US Hospitals.

Table 2. The 2014 imprivata report on the economic impact of inefficient communications in healthcare [44]. Highlighted are the cost saving estimates from adopting a mobile text messaging service to replace conventional forms of communication.

Output descriptor	Mins per patient	Mins per day	Hr per year	Annual labour cost
The collective total time spent per patient	51.2	5,223,2	31,774,5	$1,123,228
Time wasted because of communications efficiencies	33.2	3,365.1	20,592.8	$727,957
Estimated time savings using mobile text messaging	16.3	1,667.5	10,144.2	$358,596

Table 3. Continued findings from the imprivata report on the economic impact of inefficient communications in healthcare.

Workflow descriptor	Extrapolated Annual cost of Inefficient Time per hospital	Number of registered hospitals	Extrapolated annual impact for the industry (U.S. $ billions)
Patient admissions	$727,957	6.409	$4.67
Emergency response	$265,254	6.409	$1.70
Patient transfers	$753,755	6.409	$4.83
Total	$1,746,966	6.409	$11.20

3 Current Solutions

In order to improve the communication and workflow process inside the surgical care-pathway, varying types of devices applications and technologies have be introduced to the hospital environment. Some of these new approaches are mobile solutions [45–47]; the digital capture and intra distribution of medical records [48–50]; data visualization and availability [51, 52]; and patient identification and security [53, 54].The following section will now highlight some of these approaches and their impact in the delivery of patient care and patient throughput.

3.1 Mobile Based Approaches

Tran [55], identified the use of pagers, as a direct cause of bottlenecks in the patient care pathway. Not only were pagers disruptive to the workflow, they did not provide the capability, for sharing and distribution of rich content. To address this issue, Vocera communication badges were introduced. This enabled staff, to communicate on the go, without the disruptive polling of paging, and in doing so, it reduced the communication time, associated with specific tasks by 25%. O'Connor [18], also addressed the issue of team coordination and how pagers, due to their lack of functionality and their disruptive alert system, were not efficient, at coordinating team objectives. Instead a push email service was implemented, that allowing users to communicate asynchronously, without delay and provided rich content in their messaging.

Additionally, Wu [56], promoted the idea of using mobile phone applications, to address the issue of inadequate interdepartmental communication, between x-ray and oncology. The problem being that for specific x-rays, both parties needed to be present, to make clinical decisions. This would often cause bottlenecks, for patients waiting for x-ray. To address this issue, the use of mobile applications was introduced, whereby information and imagery could be shared between workers and in doing so, promote collaboration and reduce the waiting time for x-ray services.

3.2 Data Capture and Information Sharing

Abraham [14] highlighted the need to improve the hospital information systems capabilities, as the storing of patient data is essentially static and not distributed efficiently, throughout the care path-way. Additionally, these stationary systems, offer little communication capabilities, or task compliance functionality. Qiaoyu [20], re-iterated the same points and proposed the concept of, cross platform mobile technologies that are portable, and allow, for the collaboration of key decision makers to be available at all times. This reduces waiting times for patients and improves collaboration between departments and clinical workers Meijla [57].

Vezyridis [58], suggested that there is a lack of clarity in relation, to the patient data being stored. This data influences hospital workflow and if the data is inefficient or inaccurate, bottlenecks can happen in the care pathway. The use of digital whiteboards to assist nursing in their patient tasks enables nurses to view their workload in a structured manor. Additionally, the new system could be distributed throughout the care path-way, allowing a nurse to access information, view pending tasks and discuss prioritization of patients, without disrupting their workflow.

3.3 Data Visualisation

Traditionally white boards are used in hospitals, to organize staff in relation to their workload. Bossen [59], identified the use of white boards as inefficient in the scenario where, a workers tasks change, as this involves, a worker finding out what their next task is, where it is happening and with which patient. This can delay patient care and be disruptive, to the hospital workflow. To address this issue, a digital white board was implemented allowing workers to track, communicate and audit their tasks in real-time. The application could also be used to coordinate a group of workers, to specific tasks and in doing so promote, worker collaboration, compliance of tasks and improve communication. Vezyridis [58] also eluded to the same point by introducing, a digital display board to improve worker collaboration and information access.

Additionally, Kim [60], expanded the concept of digital white board to be more cognitive and interlink related information, about a patient from various departments, in the hospital. This in turn, reduced the workload and improved accessibility, to the patient's information, by efficiently tracking the patient's workflow, via event feeds and time line markers, on the display.

3.4 Patient Identification and Security

Troester [61], highlighted the need to improve interdepartmental communication and collaboration between workers. A key problem area was, the need to track medication and provide an audit trail, so the pharmacy department would know in advance, what medication was needed on a daily basis. The use of a barcode tracking and compliance application was introduced, improving the workflow and reducing waiting times for dispensing medication. In relation to QR code scanning, Wangwan [62] proposed QR codes, to track patients status in the hospital environment, improving operational efficiency. The main reason for this was, the patients chart was an inefficient medium of sharing and distributing, patient information. Furthermore, static workstations were not efficient at updating patient information, in real-time. To address the problem, RFID readers were used to provide updates via mobile device scanning.

Additionally, Anton [63], addressed the same point, by using QR codes and RFID to capture, patient data more securely via encryption and also improve the distribution of, patient data by moving away from, remote workstations and paper based patient documentation. Finally, Li-Chuan y[64] highlighted similar points in relation to QR code security and used a similar system, to track surgical equipment that needed repairing. This simplified the auditing and compliance process and helped to control inventory management in real-time.

4 Case Study – The Development of a Bespoke Software Application That Streamlines the Surgical Care-Pathway

Having explored the problem and solution domain from approaches found in the literature, this section will discuss the implementation of a new software solution to solve similar issues such as the patient throughput and delay paradigm discovered in a hospital in the south of Ireland.

4.1 Case Study Background

A hospital group in the south of Ireland wanted to improve their patient throughput by identifying and reducing the bottlenecks inside their surgical care pathway. The hospital has a capacity of 144 beds, with four theatres and typically uses an elective surgery framework. The hospital relies heavily on conventional forms of communication such as wired phones, pagers and face to face communication to receive updates about a patient's pre-post operation state, from different departments that provide a care service as the patient navigates their surgical care-pathway. The use of fixed workstations that involve complex ad-hoc querying is common through all the wards. These are typically located in corridors away from the patient's point of care.

With this information in mind, the hospital wanted to explore the concept of possibly introducing a new technology to cater for all the idiosyncrasies of each departments input into the patients surgical care pathway and in doing so, create a streamlined service that if implemented efficiently, would reduce the turnaround times for elective patients and improve the quality of care in the hospital. Additionally, the new system would serve to combine all departments under a uniformed communication system that is easy to use and relays information about a patient's state throughout the course of the patient's surgical care-pathway.

4.2 Solution Methodology Introduction

The bespoke software application was designed by implementing a hybrid of a spiral model SDLC and a water fall model. This was primarily due to the need to provide rapid prototypes to demonstrate to the stakeholders on a monthly basis. These were then critiqued and the best components were kept for the next iteration. Once enough components were finalised the waterfall model could be implemented for the final development process.

4.3 Requirements Gathering and Analysis

In order to capture and define the system user's requirements, observational research was carried out over a two-year period. This consisted of arranging to meet and interview all department staff and managers that have an influence on the patient as they navigate the surgical care-pathway. The process flow of the patients was captured by shadowing patients who were going for surgery. This shadowing proved to be a vital task, as some of the information obtained from the interview process did not correlate, with the findings from the shadowing process. By using the spiral SDLC model, these new findings could be addressed and the user requirements could be re-defined. Additionally, due to the variability of a patient's health on the day of surgery a patients workflow could alter its trajectory from the perceived norm. This had to be considered when designing the system and determining the system limitations and real-life process correlation, hence re-enforcing the importance of adopting a spiral SDLC methodology. Furthermore, meetings had to be arranged with the administrative staff with regards to the overheads required to get a software system up and running. The engagement with the hospital IT department had to start early in the project as hospital resources tend be at capacity. If a solution was to be piloted the IT department would have to dedicate resources outside of their current planned horizon and this process would need to be determined.

Finally, if the system was to use mobile technologies the Wi-Fi access points of the hospital would have to be mapped and all black-spots would have to be known. To map the hospitals coverage a mobile tracking application was used on a standard smart phone and the speed and access points along the surgical care-pathway were determined.

4.4 Application Design - Overview

Having obtained data from the iterative observational research phase, the second phase in the project was to use this data to pin-point the key areas for improvement and remove the risk of potential bottlenecks, in the surgical care-path workflow process. From the qualitative analysis of the data, it was determined, that there were five key communication points, inside the surgical care-pathway, that needed to be streamlined and at certain points the calling mechanism, needed to be automated. Additionally visibility in the surgical care-pathway needed to be improved as the patients state with regards to their admission status, current location, current and pending workflow process task status and patient transfer eligibility status was not available to all the departments connected to the patient inside their surgical care-pathway. Furthermore to identify the patients and to provide security, the system uses QR codes.

These QR codes will be added to the existing 2D barcode patient wristband and will provide unique content about the patient. Finally as access to patient data, inside the surgical care-pathway currently involves performing relatively complex ad-hoc queries, at fixed workstations, that are located away from the point of care, it is not feasible to assume, that this process is efficient, patient centric, or that the data capture, is accurate, to real-time. To address these issues, the use of mobile technologies, will allow users, to capture and distribute, patient data. This data is then securely filtered for the user, based on their role within the hospital work group (Fig. 2).

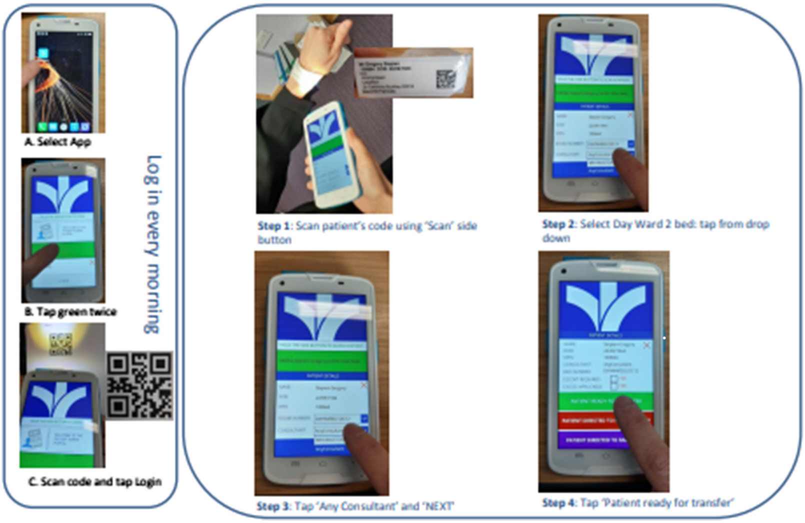

Fig. 2. The QR code scanning mobile application for the admissions process.

4.5 Application Design - Communicating Transfer Requests

The first communication process to be streamlined was a request for transfer from the theatre to the pre-op ward and porter service, for all patients, except the first patient. The second process was a patient transfer request being initiated from the anaesthetist in the ward to the theatre and the porter service. The third transfer request was from the theatre to the ward and the porter service, for the transfer of a patient to the holding bay. The fourth communication process was a request to transfer a patient from the recovery ward to their assigned returning ward. The final communication process was a request from the receiving ward to the porter service to collect the patient from the recovery ward. These transfer requests are currently all manually initiated by staff members, using conventional forms of communication such as wired phones. The proposed new system will champion the use of a push message service that alerts the application users when a transfer request has being initiated (Fig. 3). Additionally where applicable the push message service will be automated based on a task being completed. An example of this would be where a delay is initiated by the returning ward with regards to their capacity to initiate the transfer request. If the delayed time estimate is reached and the request has not being resolved the message will automatically be sent again without being initiated by the message source (Table 4).

4.6 Application Design – Task Visibility

Based on the observational research, it was concluded that task visibility, needed to be available throughout the entire surgical care-pathway, as a means to pseudo-interconnect, all the departments that interact with the patient, during their surgery process. Additionally, the format of the visibility would have to vary, per device, device component and user. For instance, visibility in the theatre, on a large touch screen computer,

Table 4. A communication process table to be streamlined by the new system.

Request origin	Receivers	Description
Theatre	Porters, Pre-op Ward	A request to deliver the patient to the operating theatre is broadcast to the porters and the pre-op ward. Additionally all assessments have being completed
Ward/Anaesthetist	Pre-op Ward, Porters	Based on the first patient selection process the anaesthetist broadcasts a message to the ward and the porters to deliver the patient to the operating theatre
Theatre	Pre-op, Porters	A request to deliver the patient to the operating theatre is broadcast to the porters and the pre-op ward. The anaesthetic assessment has not been completed
PACU	Returning Ward	The returning ward receives a request from the PACU ward to collect a patient from their recovery bay
Returning Ward	Porters, PACU	The returning ward broadcasts a reply to the porters to collect the patient and provides compliance for the PACU ward via a verification message

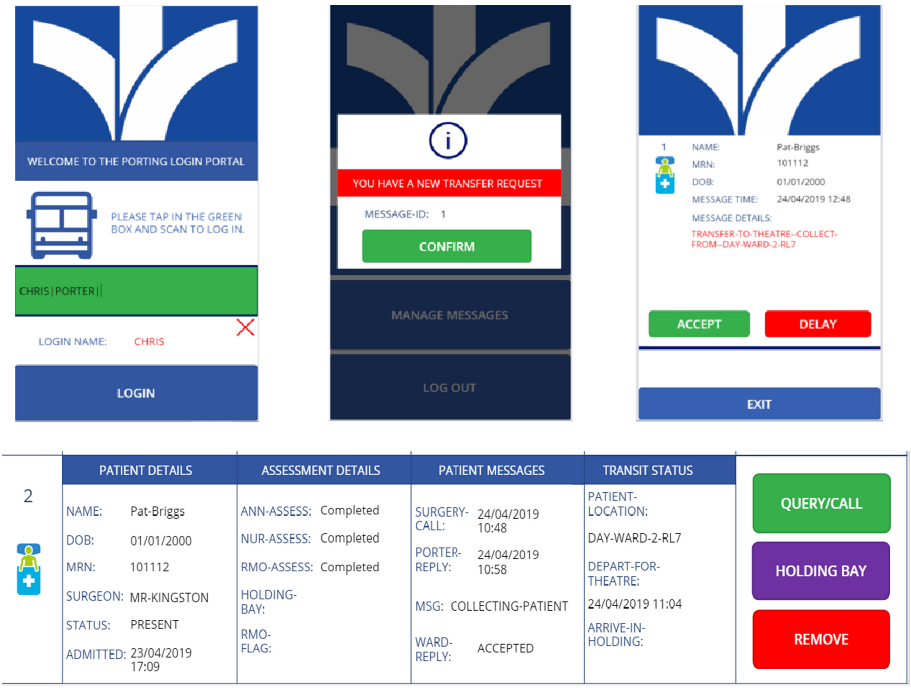

Fig. 3. An example of the porter application message acknowledge & distribution process as it relates to the theatre screen view.

of a patient who has being admitted, would be represented by, a dynamic animation in a process flow chain, that updates based on the next completed event (Fig. 4). Respectively, the same process, for the patient escort, on a mobile device, would be the dynamic addition of the patient values to a text based work-list (Figs. 5 and 6).

4.7 Application Implementation – Software and Architecture

Having finalised sections of the design and the project work break-down structure the next phase was to actually develop the application. This involved writing code for the controls

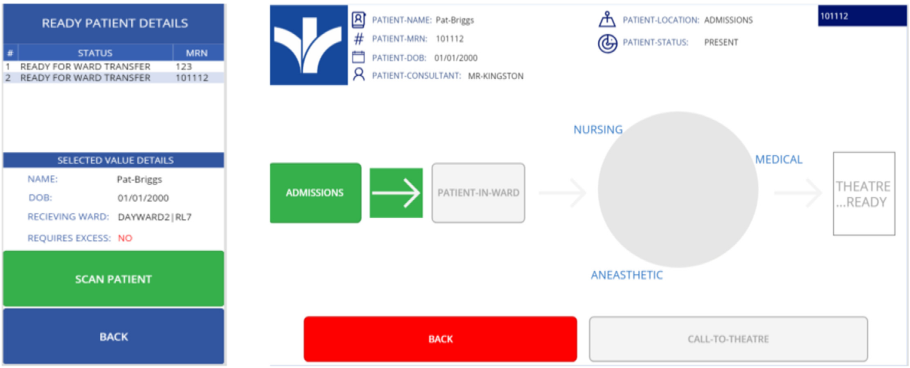

Fig. 4. A patient escort mobile device and a theatre touch-screen pc view of a patient's status as they have been admitted into the system.

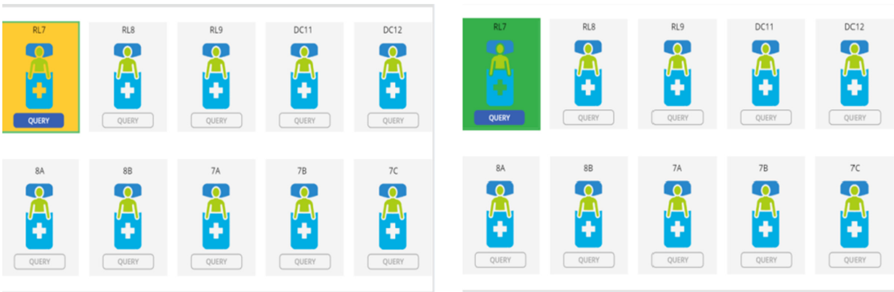

Fig. 5. A pre-op ward view depicting the traffic light system implemented by the new system. The amber status indicates that assessments for the patient are pending and the green status indicates that all assessments have being completed and the patient is ready to be called for surgery. (Color figure online)

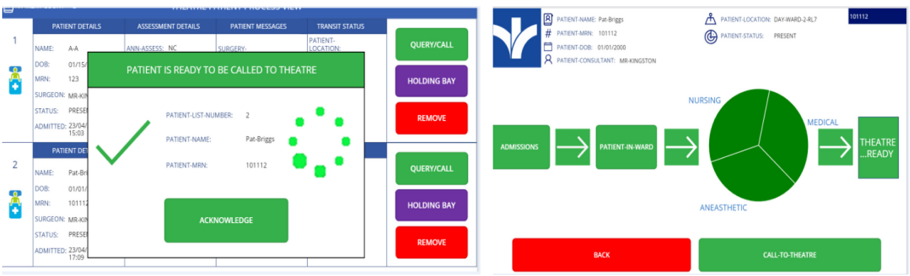

Fig. 6. A theatre view of the received popup-message that indicates that all assessments have being carried out on the patient and they are now ready to be called to surgery. (Color figure online)

for the front end components of the Microsoft Powerapps framework and connecting them to stored procedures in the back end. The stored procedures and tables associated with them were written in Microsoft SQL Server 2018. The physical devices were connected via an SQL connector API and the data XML transforms were carried out inside embedded Microsoft flow connections. To remove the load on the SQL connector the application was divided into seven different applications. This reduced the demand to poll the applications from the same source and improved efficiency. From a 'look and feel' perspective, the application design adopted a colour scheme similar to the hospital colour scheme. The application was designed to be user friendly with text prompts to inform users about the next process. The scanning process has a colour system whereby a patient would be scanned with a green theme in the application screen and the patient location would be scanned using an amber theme. This theme was further developed in the pre-op-ward screen and the PACU unit screen, where a traffic light system was used to signal, if the patient had, processes to be completed (Amber), was delayed (Red), was ready for the next phase of process (Green).These processes varied as the patient navigated the surgical care-pathway, however, the colour theme remained uniform. With regards to security, most of the stored procedures had input validation to prevent SQL injection, and there was additional client-side validation, on the QR code scanning component as well. Finally, every selection component is either a drop-down menu of controlled content or a checkbox. This further re-enforced the security of the application by not allowing the user to type bad input data into the system (Fig. 7).

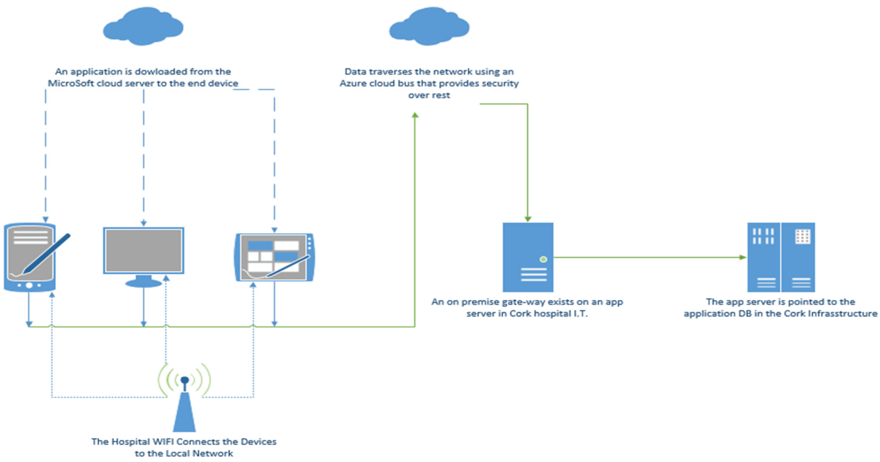

Fig. 7. The newly implemented systems architectural design.

4.8 Application Implementation - Hardware

The new system consists of two large medical grade touch screen computers that are used in a day ward and an operating theatre. Additionally based on the observational research eight medical grade handheld devices will be used by various personnel throughout the surgical care path-way. Furthermore, five tablets are dispersed throughout a recovery ward to provide alerts and compliance for messages from the PACU to collect patients.

These additional tablets were based on new features which form the basis of the second case study which is outside of the scope of this paper.

4.9 Application Testing

Once the local and remote testing phases were completed the system was now ready to be piloted in a hospital environment. The first phase of the pilot ran over four months, from September 2019, until December 2019. The pilot covered the care-pathway from admissions to recovery, for all paediatric patients, who were being operated on, by a particular consultant, in a set theatre. It was observed, that the paediatric patients, can have varying times of admission and the average time of surgery, due to the complexity, of the surgery type, is hard to define. This was a robust test for the new system, as most of the functionality, would be used, throughout the course of the pilot. Additionally, only patients that were admitted on the day of surgery were tested by the pilot. This was primarily due to the need to form comparative analysis, of admission times, versus patient surgery arrival times. The system was piloted three days a week, typically starting at 7:30 am and finishing at 8:00 pm.

5 Results

In order to compare the old process of data capture and workflow the comparison will be divided into two sections. The first analysis will compare the new and existing systems with regards to their ability to provide, visibility, verification, data distribution and communication of completed or pending tasks for a patient inside their care-pathway. The second will compare the task completion times, targeting two key processes of the patient care-pathway. These processes are, the admissions to surgery call process, and the surgery call to arrive in theatre holding process. These were selected, as there was comparative data available, in the current system for these processes. There was no valid visibility of the recovery transfer process, for this phase of the pilot.

5.1 Task Visibility, Communication, Verification and Data Distribution

With regards to task visibility the new system improves the visibility by 80%.With regards to the task verification process the new system improves this process by increasing the amount of verification points by 60%.With regards to the data distribution process, the new system increased the distribution of data by 60% throughout the patient surgical care-pathway. Finally the new communication process automates the entire patient calling process. This reduces the need to constantly poll wards for acknowledgement and verification and in doing so increases incidence of proactive communication by 80%. Table 5 is an example of how the new system when implemented in the admissions process generated an increase of over 50% more incidents of process capture, task visibility and data distribution across three separate scenarios'.

Table 5. A data capture comparison table of the old and new system for the pre-op patient transfer call process with pending anesthetic assessment 0 = yes X = no

Sceanario	Stake holders	Process capture	Old sys	Pilot sys
A theatre worker selects a patient to transfer to the holding bay for surgery	Current ward Theatre Porters	1. Call verification 2. Call time 3. Ward verification 4. Porter verification 5. Patient departure time 6. Patient arrival time	0 0 X X X 0	0 0 0 0 0 0
A theatre worker selects a patient to transfer to the holding bay for surgery pending an anaesthetic assessment	Current ward Theatre Porters	1. Call verification 2. Call time 3. Ward verification 4. Porter verification 5. Patient departure time 6. Patient arrival time 7. Patient pending assessment status	0 0 X X X 0 X	0 0 0 0 0 0 0
A porter receives a notification and collects the patient from the ward	Current ward Operating Porters PACU	Call verification Call time Patient location Patient name Delay patient transfer Patient arrival time Patient pending assessment status	X X X X X 0 X	0 0 0 0 0 0 X

5.2 A Time Comparison of the New and Old System from Admission to Surgery Transfer Request

The results of this process comparison suggest several assumptions about the new system. The first being, the new pilot system was more efficient in the numerical sense, however, it is still limited to the process flow of the current hospital workflow (Table 6). With more training and possible process change, the system should deliver higher turnaround times. Secondly, even though there was an increase of 80% in the visibility and verification of tasks, there remained a high correlation between the old system and the new system (Fig. 8). This would again re-iterate the influence of process change and additionally suggest the accuracy of the data being captured by the current system is prone to error. Finally, overall the new pilot system navigated a patient 9.3 min faster than the current system from admissions to the surgery transfer request phase of the surgical care-pathway. The impact that time alone, if repeated for all surgical cases, would mean significant increase in patient throughput, which in turn generates more revenue for the hospital and improve the patient care experience.

Table 6. A time capture comparison between the new and old system based on the time taken to admit the patient and the theatre calling the patient to surgery. The data here is based on patients who were admitted between 7:00 am and 7:45 am. All of the patients are from a specific surgeon who had booked a block of time in a specific operating theatre. All surgical procedures are of a similar type. The larger times found in patients 7–10 are based on patients who were admitted early even though they were scheduled to operate on in the afternoon.

Patient#	Manual time	Pilot time
1	68 min	44 min
2	73 min	90 min
3	118 min	61 min
4	111 min	118 min
5	107 min	84 min
6	74 min	48 min
7	78 min	97 min
8	174 min	180 min
9	334 min	334 min
10	139 min	127 min

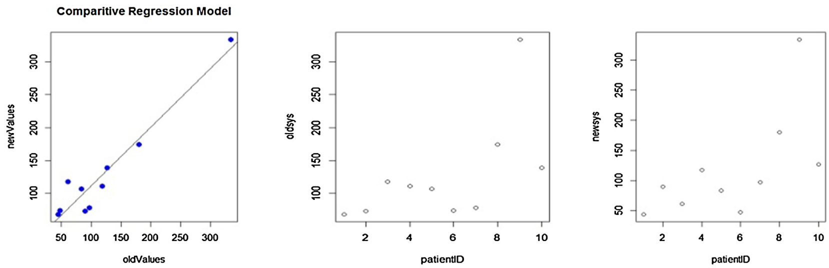

Fig. 8. A regression model built in R studio depicting a strong correlation between the old and new system times for the admissions to surgery request process.

5.3 A Time Comparison Between the New and Old System from Surgery Transfer Request to Theatre Arrival

Based on the results, it can be concluded than the communication system is far more efficient than the current system in the navigation of a patient from the pre-op ward to the surgery holding bay (Table 7). With an improvement of 80% more visibility and task verification this new communication system, once fully implemented, should create even more efficient task turnaround times. Due to the highly complex multitasking nature of the work inside the surgical care-pathway it extremely difficult to connect key decision makers and influencers at the same time. The new system streamlines the communication process by connecting the right people to the right process at the same time. The system additionally provides security via patient identification in the transfer process and also allows for the user to issue a delay in the transfer process. This delay is then broadcast to the appropriate departments and allows the user to handle this delay. In doing so, the repetitive and costly process of polling departments for service is eliminated. Finally, the impact of reducing the patients transfer time by 22 min is highly cost effective, taking into consideration the cost of overheads for a delay to surgery, and this also serves to improve the patients overall care experience inside their surgical care-pathway (Fig. 9).

Table 7. A time capture comparison between the new and old system based on the time taken to call the patient and deliver them the patient to surgery.

Patient #	Manual time	Pilot time
1	25 min	6 min
2	40 min	7 min
3	12 min	6 min
4	15 min	9 min
5	14 min	6 min
6	18 min	9 min
7	19 min	11 min
8	59 min	7 min
9	18 min	4 min
10	69 min	4 min

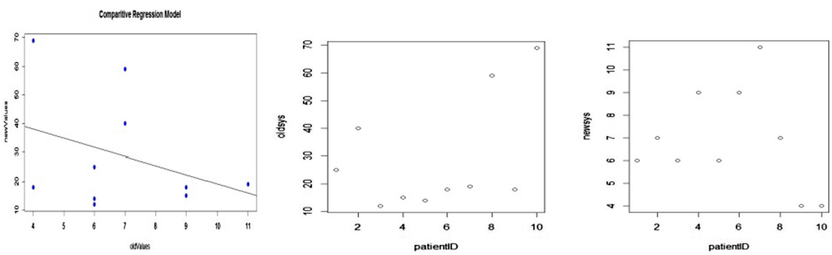

Fig. 9. A regression model built in R studio depicting a weak correlation between the old and new system times for the admissions to surgery request process.

6 Conclusion

This paper has examined how the streamlining of the surgical care-pathway can improve patient throughput by; enhancing task visibility and verification; promote interdepartmental communication and successional task compliance; securely identify and locate a patient for assessment processing and transfer; communicate with and integrate services autonomously based on adopting a task workflow completion messaging mechanism. This approach was devised from firstly exploring the varying problem domain that was identified in several studies and current government initiatives from an Irish, European and American context. Then, through several months of observational research and data analysis in a hospital in the south of Ireland, similar trends were discovered that correlated to problem domain. From here, a software solution was developed, tested and deployed and returned positive results in relation to improvements on the time taken to navigate the pre-op sections of the surgical care-pathway.

Finally, efficient patient calling in the surgical care-pathway can only be achieved by efficient interdepartmental communication at the point of patient transfers. The effect that technology has in relation to improving communication is difficult to measure. Once a technology has promoted and addressed the lack of communication and this issue has being addressed via process change, the technology may become obsolete again. Most of the technologies in the literature are aimed at improving the current state of communication. Additionally, as the surgical care-pathway is interconnected to a least 4 departments, the technical solution are not merely a messaging service to replace wired phones. This was evident in the pilot whereby every process that lead to making a wired phone request for transfer had to be, documented, digitized and re-engineered to match the existing workflow. Whether the pilot will prove to be efficient across the post-operative surgical care-pathway process remains to be seen, however the current results are very positive.

Acknowledgements. This work was supported with the financial support of the Science Foundation Ireland grant 13/RC/2094 and co-funded under the European Regional Development-Fund through the Southern & Eastern RegionalOperational Programme to Lero - the Irish SoftwareResearch Centre (www.lero.ie).

References

1. Junge, T.L.: Surgical Technology for the Surgical Technologist, p. 18. Taylor & Francis (2004)
2. Li, P.: A prospective observational study of physician handoff for intensive-care-unit-to-ward patient transfers. Am. J. Med. **124**(9), 860–867 (2011)
3. Fairbanks, R.J.T., Bisantz, A.M.: Interpersonal communication and public display tools in the emergency department. In: Proceedings of the 2005 Systems and Information Engineering Design Symposium, p. 1–4 (2005)
4. Haux, R.: Strategic Information Management in Hospitals: An Introduction to Hospital Information Systems, p. 14. Springer, Heidelberg (2013)
5. Sharma, D.K.: Hospital Administration and Human Resource Management. PHI Learning (2017)

6. Weimann, E.: High Performance in Hospital Management: A Guideline for Developing and Developed Countries, pp. 93–94. Springer, Heidelberg (2017). https://doi.org/10.1007/978-3-662-49660-2
7. Rosiek, A.: Organizational Culture and Ethics in Modern Medicine. IGI Global (2015)
8. Langabeer, J.R.: Competitive Business Strategy for Teaching Hospital, pp. 211–212. Creenwood Publishing Group (2000)
9. Sears, K.: Influencing the Quality, Risk and Safety Movement in Healthcare: In Conversation with International Leaders, pp. 171–172. Ashgate, Farnham (2015)
10. Suzanne, E.: Effective Communication in Clinical Handover: From Research to Practice, pp. 17–18. Walter de Gruyter GmbH & Co KG (2016)
11. Zaoutis, L.B.: Comprehensive Pediatric Hospital Medicine, p. 62. Elsevier Health Sciences, Amsterdam (2007)
12. Gillingham, E.A.: LaFleur Brooks' Health Unit Coordinating, pp. 355–356. Elsevier Health Sciences, Amsterdam (2013)
13. Edward, M.D.: Financial Management Strategies for Hospitals and Healthcare Organizations: Tools Techniques Checklists and Case Studies, pp. 59–60. CRC Press, Boca Raton (2013)
14. Abraham, J.: Challenges to inter-departmental coordination of patient transfers: a workflow perspective. Int. J. Med. Inform. **79**, 112–122 (2010)
15. Dudeck, K.: New Technologies in Hospital Information Systems. IOS Press (1997)
16. Association of Surgical Technologists: Surgical Technology for the Surgical Technologist, p. 100. Cengage Learning (2016)
17. Arisaka, N.: Trial of Real-Time Locating and Messaging, pp. 689–699. IOS Press (2016)
18. O'Connor, C.: The use of wireless e-mail to improve healthcare team communication. J. Am. Med. Inform. Assoc. **16**(5), 705–711 (2009)
19. Hanada, E.: Managing the availability of hospital wireless communication systems. In: URSI Asia-Pacific Radio Science Conference (URSI AP-RASC), pp. 737–739 (2016). From the viewpoint of the electromagnetic environment
20. Sun, Q.: Application of wireless local area network in hospital information system. In: 2017 IEEE 2nd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), pp. 263–266 (2017)
21. Johnston, M.: Requirements of a new communication technology for handover and the escalation of patient care: a multi-stakeholder analysis. J. Eval. Clin. Pract. **20**(4), 486–497 (2014)
22. Cavada, D.: A multi-functional mobile information system for hospital assistance, pp. 1–6. IEEE (2013)
23. Vinu, M.: The use of a digital structured format for nursing shift handover to improve communication. In: 2016 IEEE 29th International Symposium on Computer-Based Medical Systems (CBMS), pp. 71–74 (2016)
24. Giesen, D.: International Medical Malpractice Law: A Comparative Law Study of Civil Liability Arising from Medical Care, p. 65. BRILL Publishings (1988)
25. Marcinko, D.E.: Financial Management Strategies for Hospitals and Healthcare Organizations, Tools, Techniques, pp. 59–60. Checklists and Case Studies. CRC Press, Boca Raton (2013)
26. Greenwald, H.P.: Health Care in the United States, Organization, Management and Policy, p. 121. Wiley, San Francisco (2010)
27. Hall, R.: Patient Flow: Reducing Delay in Healthcare Delivery, pp. 102–103. Springer, Heidelberg (2006). https://doi.org/10.1007/978-0-387-33636-7
28. Rosenstein, M.: Professional communication and team collaboration. In: Patient Safety and Quality: An Evidence-Based Handbook for Nurses, Rockville, vol. 2, pp. 271–274 (2015)

29. Wen, D.: The challenges of emerging HISs in bridging the communication gaps among physicians and nurses in China: an interview study. BMC Med. Inform. Decis. Making **17**, 1–11 (2017)
30. Ward, D.M.: Issues in Cost Accounting for Health Care Organizations, p. 335. Jones & Bartlett Learning (1999)
31. Tsujii, H., Kamada, T., Shirai, T., Noda, K., Tsuji, H., Karasawa, K. (eds.): Carbon-Ion Radiotherapy. Springer, Tokyo (2014). https://doi.org/10.1007/978-4-431-54457-9
32. Graban, M.: Lean Hospitals: Improving Quality, Patient Safety, and Employee Engagement, 3rd edn., p. 97. CRC Press, Boca Raton (2016)
33. Fordney, M.T.: Administrative Medical Assisting, p. 211. Cengage Learning (2007)
34. Charles, P.: Leveraging Lean in Ancillary Hospital Services: Creating a Cost Effective, Standardized, High Quality, Patient-Focused Operation, p. 142. CRC Press, Boca Raton (2014)
35. Rothrock, J.C.: Alexander's Care of the Patient in Surgery, p. 7. Elsevier, Amsterdam (2010)
36. Ramlaul, A.: Patient Centered Care in Medical Imaging and Radiotherapy, p. 25. Elsevier Health Sciences, Amsterdam (2013)
37. Dixit, S.: Human Bond Communication: The Holy Grail of Holistic Communication and Immersive Experience, p. 192. Wiley, Hoboken (2017)
38. Yuan, B.: The policy effect of the general data protection. Int. J. Environ. Res. Public Health 1–15 (2019)
39. HSE: eHealth Strategy for Ireland. Department of Health an EU Commission On Helath (2020)
40. HSE. National Service Plan 2018. HSE (2018)
41. de Jong, T.: European Risk Observatory. Publications Office of the European Union, Luxemburg (2014)
42. Directorate-General for Communications Networks, Content and Technology: Research and Innovation in the Field of ICT for Health. Digital Society, Trust and Cybersecurity (2019)
43. Khosrow-Pour, M.: Advanced Methodologies and Technologies in Medicine and Healthcare, p. 289. IGI Global (2018)
44. Ponemon Institute: The Imprivata Report on the Economic Impact of. Ponemon Institute (2014)
45. Karahoca, A.: Advances and Applications in Mobile Computing, p. 162. BoD – Books on Demand (2012)
46. Househ, M.: Social Media and Mobile Technologies for Healthcare, pp. 48–55. IGI Global (2014)
47. Kornak, A.: Enterprise Guide to Gaining Business Value from Mobile Technologies, pp. 185–186. Wiley, Hoboken (2004)
48. Sinha, P.K.: Electronic Health Record Standards, Coding Systems, Frameworks, and Infrastructures. Wiley, Hoboken (2012)
49. Cruz-Cunha, M.M.: Handbook of Research on Developments in E-Health and Telemedicine: Technological and Social Perspectives: Technological and Social Perspectives, p. 414. IGI Global (2009)
50. Harrington, L.: Usability Evaluation Handbook for Electronic Health Records, p. 46. HIMSS (2014)
51. Patel, V.L., Kannampallil, T.G., Kaufman, D.R. (eds.): Cognitive Informatics for Biomedicine. HI, p. 225. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-17272-9
52. Ugon, A.: Building Continents of Knowledge in Oceans of Data: The Future of Co-Created eHealth, pp. 283–284. IOS Press (2018)
53. Patton, R.M., Zalon, M.L., Ludwick, R. (eds.): Nurses Making Policy: From Bedside to Boardroom, p. 348. Springer, New York (2014). https://doi.org/10.1891/9780826198921

54. Schreier, G.: Health Informatics Meets eHealth. In: Proceedings of the 12th eHealth Conference, p. 276. IOS Press (2018)
55. Tran, K.: Effects of clinical communication interventions in hospitals: a systematic review of information and communication technology adoptions for improved communication between clinicians. Int. J. Med. Inform. **81**(11), 723–730 (2012)
56. Wu, V.: Development of a prototype of the tele-localisation system in radiotherapy using personal digital assistant via wireless communication. J. Med. Imaging Radiat. Oncol. **57**(1), 113–118 (2013)
57. MejÍa, D.A.: Understanding and supporting lightweight communication in hospital work. IEEE Trans. Inf. Technol. Biomed. **14**(1), 140–146 (2009)
58. Vezyridis, P.: Going paperless at the emergency department: a socio-technical study of an information system for patient tracking. Int. J. Med. Inform. **80**(7), 455–459 (2011)
59. Bossen, C.: Implications of shared interactive displays for work at a surgery ward: coordination, articulation work and context-awareness, pp. 464–469. IEEE (2008)
60. Kim, T.: Assessing the usability of a prototype EMP centered EHR display. In: 2018 IEEE Conference on Healthcare Informatics, pp. 1–22. IEEE (2018)
61. Troester, S.: Drive nursing activities to the bedside with a closed-loop system. Nurs. Manag. **37**(12), 18–20 (2006)
62. Sangwan, R.: Using RFID tags for tracking patients, charts and medical equipment within an integrated health delivery network, pp. 1–13. IEEE (2005)
63. Anton, F.D.: QR code indentify replace paper based system information sharing using a technical platform, pp. 1–14. IEEE (2018)
64. Chu, L.-C.: Applying QR code technology to facilitate hospital medical equipment repair management. In: 2012 International Conference on Control Engineering and Communication Technology, pp. 856–858. IEEE (2012)