Bed Management System Implementation: Experimental Study

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Keywords: Bed Management, Patient Throughput, Hospital Administration, Hospital Admission, Hospital System Deployment.

Abstract: Many hospitals today use bed management systems that are primarily manual and paper-based. This inhibits efficiency and informed decision making, as communication is constrained. Hence these systems are essentially memoryless as lessons learned reside with individuals but are lost to the organisation as a whole. Electronic systems that can capture and record checkpoints on the patient pathway allow that data to be analysed. This can help with improving efficiency and prediction, allowing "what if" scenarios to be examined with data to support it. This paper presents the outcome of developing a bed management system and deploying it in a hospital for a live trial over a period of approximately three months. It also highlights improvements suggested through system usage over the period of the deployment and presents a novel efficiency measure.

1 INTRODUCTION

The Global COVID-19 pandemic has caused a large spike in patient numbers in hospitals due to the high number of emergency patients suffering with the virus. Another impact of the pandemic is a deferment in elective patient treatments due to pressure from treating pandemic patients. The need to reduce patient waiting lists will cause further pressure on hospitals once pandemic patient numbers decline.

Globally, efficiencies in hospitals are being sought, to improve the service and treatment of people while controlling the cost of providing the service.

This paper discusses the implementation of a hospital bed management system, developed in association with a local hospital, part of the largest provider of private healthcare in Ireland. The system tracks the patient movement along the patient pathway, allowing an examination of the system as a whole and creates a novel measure of efficiency, occupied versus unoccupied times with unoccupied time being further divided into idle time and out of service (OOS) time.

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2 HOSPITAL SYSTEMS

Hospitals use a system, commonly referred to as a Hospital Information System (HIS), which is primarily a billing system, as the basis for supporting paper based manual systems for bed and patient management. The level of information retained, on the patient journey, by the HIS is generally minimal, such that different individual patient journeys cannot be compared accurately.

A patient arriving in a private hospital, having been referred by a Consultant, for an elective procedure or a General Practitioner (GP) as an emergency patient, will first approach the Admissions personnel. Once processed, they will be escorted to their bed, by a Healthcare Assistant (HCA) in preparation for any procedure or observation as part of their treatment. They may also have had to attend for preadmission tests.

Once their treatment is complete, the multidisciplinary team will coordinate discharge. The patient's Consultant will authorise it and the Nursing staff will manage it. Once discharged, the preparation of the bed for the next patient, bed renewal, will commence. This will involve the HCA, stripping the bed and later dressing the bed. Housekeeping will clean the bed area and / or the room and bathroom. Sometime after the bed renewal is complete, the Bed Manager will be

Noonan, F., Hanlon, M., Nogales, J., Doyle, C., Broderick, E. and Walsh, J.
Bed Management System Implementation: Experimental Study.
DOI: 10.5220/0012346700003657

In *Proceedings of the 17th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2024) - Volume 2*, pages 370-377
ISBN: 978-989-758-688-0; ISSN: 2184-4305

advised of the bed being available and the cycle will repeat.

The HIS generally does not record the checkpoints above, but the deployed system, discussed in the paper, does.

2.1 Communications and Data

Noonan *et al.* (2019), provides an overview of the literature on Bed Management. It highlights the issues recorded and the solutions suggested in the domain of Bed Management. The solutions broadly align under addressing the areas of communications, process change or modelling and prediction. Balaji & Brownlee (2018), suggests that critically the process needs to be understood and the process is complex, spanning multiple departments requiring departmental workflow and inter-departmental process optimisation. It also stresses the need for measurement and communication, particularly given the interdisciplinary teams managing the patient care. However, systems that are predominantly manual and paper based are not conducive to easy measurement and therefore communicating these measurements can be burdensome in the absence of a dedicated communication mechanism.

Discharge Before Noon (DBN) is another area investigated for its impact on Length of Stay (LOS), a measure of how long a patient stays in the hospital. The impact is around getting patients discharged early in the day, to avoid impact on placing the next tranche of patients in a bed. One early study Wertheimer *et al*. (2014) implemented a system that recorded a reduced mean LOS and a non-statistically significant reduction in 30-day readmission rates. However, Rachoin *et al.* (2020), James *et al.* (2019) suggest that while DBN does reduce patient LOS for surgical patients, the reduction is not necessarily the same for medical patients. In all cases, an easy mechanism for capturing patient admission and discharge enables easy implementation of studies such as this.

2.2 Modelling and Prediction

Modiuddin *et al.* (2017) reviews literature on simulation of patient flow within Emergency Departments (ED). The studies reported on, show that simulation modelling can be used to pretest the impact of workflow / process changes in a safe way.

Novati *et al.* (2017) records the long term achievement of reduction in mean LOS through a previous implementation of a bed management model.

Modelling techniques rely on data for both model development and testing. Extracting this data from paper based records or relying on the minimal data checkpoints available for HIS type systems limits the effectiveness of the model. Thus greater data capture allows for better modelling to achieve better efficiencies.

3 SOLUTION ADOPTED

An electronic system was developed to manage the bed / patient flow in the hospital. This system allowed a real-time view of hospital occupancy and captured data to allow subsequent analysis as a means to improve bed management and patient throughput.The following provides an overview of the system. For a more comprehensive account see Noonan *et al.* (2023).

Fig. 1 is the model for the system using a Model-View-Controller (MVC) pattern with an SQL database for data capture, storage and interrogation. The main system is a web based application for use by the bed managers and hospital administrators. The web element allows elective patients to be preassigned to beds, emergency patients details recorded pending agreement to admit and bed availability to be determined. Each ward has a graphical view that can be used to determine the available beds. Additionally there are views that provide a synopsis of the bed status throughout the hospital.

There is a mobile device element to facilitate mobile elements of data capture such as escorting a patient to the bed they are going to occupy. This duty is generally performed by HCA staff. Both Housekeeping and HCA staff are involved in bed renewal, ensuring the bed is available for the next patient and they are mobile when moving from room to room. They record bed renewal job completion using a mobile device.

Fig. 2 illustrates the checkpoints for data capture. For a given patient, a request is made to the hospital

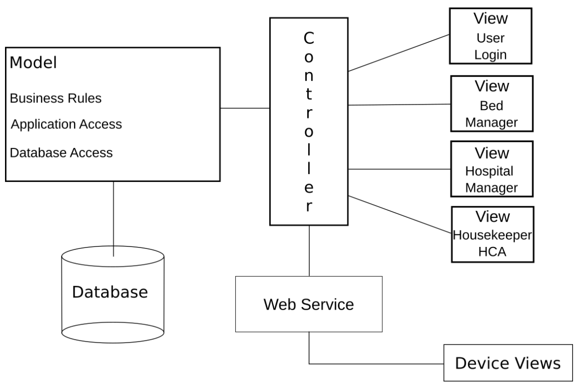

Figure 1: Design Model for Bed Management Application.

Bed Manager, to accommodate a patient, from either a Consultant for an elective patient or a General Practitioner (GP) for an emergency patient. The Bed Manager enters the patient data on the web application and ultimately allocates the patient a bed.

Table 1 defines the status cycles for the patient-bed relationship and their triggers corresponding to Figure 2.

The Web Application, Graphical User interface (GUI), displays the status of the bed and any of the activities occurring above will update in real-time.

4 SOLUTION IMPLEMENTATION

In an initial trial, in which the developed system was tested on 450 actual patient presentations, names and dates of birth were anonymised. All data entry was performed by a single person, mostly by the project manager but also the Hospital Manager. This data being entered after the fact, albeit on the same day, did not reflect accurate timestamps for events such as arrival at the bed but the concept of capturing timestamp was proven. The hospital manager also entered test data, to better understand the system and was impressed with the ease of use of the system. A very basic system of a laptop computer containing the web and database servers, and functioning as the data entry terminal for patient data was used along with a WiFi virtual local area network to connect two Android based mobile devices to carry out the mobile elements of the checkpoints.

A number of issues were identified from this trial, prior to the live trial:

- One issue raised was that the colour used for non-gender beds (green) caused confusion with the colour used in the ward dashboard pie chart to indicate "available". The the colour to indicate gender neutral beds was changed to orange.
- A second issue was the graphical refresh of the ward views. The Scaleable Vector Graphics (SVG) files representing the wards are embedded pictures. Their state of not being current, or being stale, is not reported via the normal server client HTML process. This was resolved using dedicated refresh methods and a refresh button.

Table 1: Bed Status Transitions.

Status Steps	Status Change	Notes
Patient Allocated to Bed	Available → Allocated Pending	Bed Manager; ADON; Dayward CNM
Patient scanned at Admissions	Allocated Pending → Allocated On Site	Patient Details Captured
Patient Admitted via Scan at Bedside	Allocated On Site → Occupied	HCA Patient Escort
Patient Treated	Occupied	No Data Collected
Patient Discharged	Occupied → OOS Pending	Captured at Ward or Reception
Bed Accepted for Cleaning Or Dressing	OOS Pending → OOS In Progress	HCA & Housekeeping Accept via Application
Bed Recorded Cleaned & Dressed	OOS In Progress → Available	HCA & Housekeeping Confirm via Scan

4.1 Live Trial Pre-Deployment Checks

Based on the non-live trial, some checks were implemented and changes were required

The application was run via two servers, IIS and MS SQL allowing for deployment in the hospital IT Centre. However due to time constraints to get that enabled it was agreed with the Hospital Manager to proceed using the server on the laptop in the hospital, for the duration of the live trial.

An unknown from the previous in-hospital testing was how data entry, using mobile devices from dispersed locations, would perform. The connectivity via WiFi to the laptop was trialled from various points in the hospital, including the ward, the Admissions area and the reception area. This highlighted an issue with reception not having a reliable wireless network signal for bed release. This was raised with the IT department in the hospital and arrangements were made to deploy an access point there. However, this took some weeks to get implemented.

As staff using the mobile applications needed to be recorded as users on the system database, all staff associated with the trial were identified and added as users to the system.

An issue of connectivity from the phones to the server presented itself spuriously while preparing for going live. Frequently, the phones would not connect to the server. This issue had not materialised in the system development or in the earlier trial.

Significant effort was put into rectifying this, including bringing in a third party to review the fault localisation procedures and suggest actions to remedy the issue. No definitive root cause was established. The Public firewall on the laptop, was set to "off" as firewall issues were suspected. The use of the "Zoom" video conferencing application, popular during the COVID-19 pandemic using the thin clients connected to the Citrix farm, caused major issues on the hospital TCP/IP network volumes. The IT Department did comment that this issue caused degradation and outage to other network services. Once use of "Zoom" on this service was stopped, the issue did not manifest again.

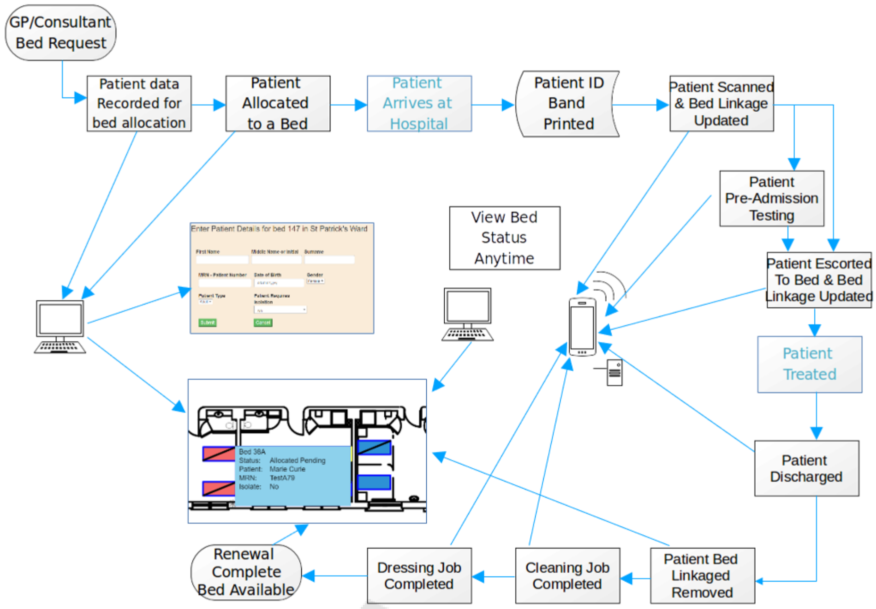

Figure 2: Data capture and flow for the bed management application.

A single ward was chosen as a pilot site for deployment. This constraint was due to the number of devices available for operation, the limited ability to supply support over the whole hospital and the ability to manage the operation and volume over the whole hospital. This decision was on balance a positive one as it allowed the objectives to be met but without major impact on the hospital overall. It also allowed a defined focus for determining the impact the system produced.

4.2 Trial Objectives

The primary objective was to establish the data detail that could be gathered using the application in a live environment and determine the usefulness of the data to improve the patient throughput in the hospital. Success can be measured in terms of the core features being available and functioning to capture and record the required data and timestamps.

Establishing timestamp data at the points in Figure 2 and to record them as they occur, was thought to be important to establish timing for patient movement. Equally, generating feedback to Housekeeping and HCA staff regarding beds requiring renewal was key.

On the use envisaged for the application by the hospital, the Hospital Manager indicated that bed occupancy figures were a major criteria in senior manager review of hospital operation. Thus, a view of the occupied time of the beds and provision of a breakdown of the occupied time versus idle time was required. It was also thought that a further breakdown on unoccupied time could be achieved by separating the idle time from the out of service time. Out of service time was recorded as commencing once a patient had departed the hospital having been scanned on exit. This additional time breakdown is a novel element.

A further objective was to establish a basis for a critical evaluation of the system as implemented against the inherent paper-based system and HIS to assess its potential and capabilities, shown in tables 2 and 3.

4.3 Personnel Training

A brief overview of the system was developed for the hospital's Heads of Department (HoDs), to provide them with an understanding of the input required of their staff. Once their agreement was obtained and they identified employees that should be trained, the names were added as users on the system. A training plan was established and a one-sheet training overview was produced per role. As an example, the one-sheet overview for the Admissions role is shown in Figure 3.

The individuals to be trained, were then approached, to identify a suitable time for training and given a QR code with their name and role. Due to the teams working different shifts in the hospital, the training was arranged for the evening or weekends as appropriate.

The level of interest was very positive. Forty-

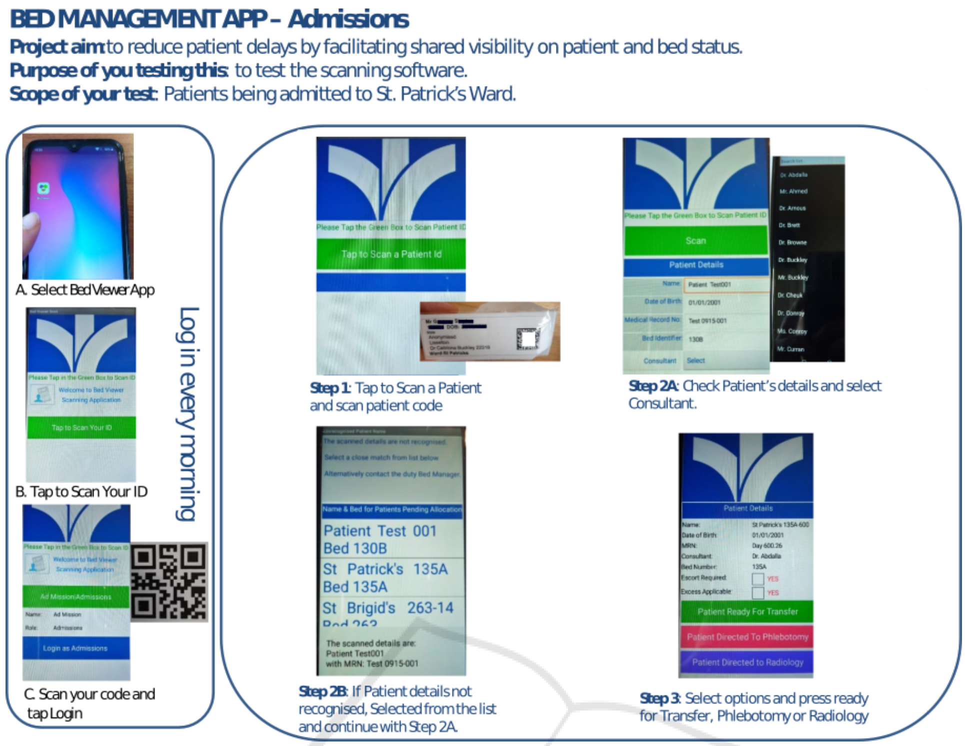

Figure 3: Training Document One-sheet Overview.

three members of staff were trained initially, consisting of the Housekeeping and Health Care Assistant team members, the Admissions team in its entirety and a Receptionist team member. Additional training was provided as required.

The bed manager initially declined to be trained citing a lack of time and a period of a high level of stress. This was due firstly, in managing the bed allocations but also due to an additional task of assigning patients to undertake COVID-19 Polymerase Chain Reaction (PCR) tests and the follow up to ensure the patients tested negative. Thus the author assumed the bed manager data entry role, initially, with a goal of passing the role over to the Bed Manager after the trial was up and running and had achieved a level of stabilisation.

Before trial start, training was carried out using the trial system itself. At trial start a second system was deployed on another laptop with a separate dedicated private IP sub network provided by a mobile phone hotspot. This system was also used to test changes made to the software prior to applying changes to the live server, as the trial progressed.

A series of QR codes based on cartoon character names were created, as patients, for training. This was done to highlight that the patients were not real patients and to lighten the atmosphere. The mock patient status was set to that pertinent to the role being trained and the one-sheet procedure was walked through. The personnel then retained the one-sheet overview as a reference. The preferred option was to train people on a one-to-one basis but given the time constraints and personnel availability, sometimes up to a three-to-one ratio was used.

5 TRIAL COMMENCEMENT

As mentioned earlier, the author assumed the role of "bed manager" to input the data for the trial. This introduced an element of latency into the system, due to the logistics of meeting with the actual Bed Manager for updates. Further complications arose when the position of Bed Manager evolved to include a second individual. The newcomer to the role would ideally have had trial system training in addition to their standard training. This was too onerous for the incumbent Bed Manager, but as the trial progressed, both individuals received system training from the author. Currently, to maintain an updated view of bed status, the Bed Manager must walk the hospital. This conflicted with the need for constant contact, by the author to the Bed Manager to ensure optimal data entry. Thus bed moves were sometimes missed and GP referrals entered after the fact. Consultation with the Admissions personnel, particularly at the commencement of the day, proved a less onerous route for entry of data for patients due to be admitted.

It emerged that accessing the application server from computers on the existing hospital network had been "blacklisted". A request to get this issue rectified triggered concern regarding exposure of patient data to a potentially vulnerable web-server. An agreement to proceed was reached by undertaking "hardening" of the server and moving the infrastructure onto the most secure WiFi VLAN network, with an associated change in endpoint IP address, which "white-listed" the server allowing access. The trial had to be stopped for four days while this work was completed. The plan to move the system to servers created in the operations centre was not implemented due to the eight weeks minimum lead time involved.

Another complication was that the Medical Assessment Unit (MAU), which functioned as the private hospital equivalent of an Emergency Ward, was provided with one or more beds on the trial ward on a daily basis. This was to allow them admit patients at their discretion. These patient details were difficult to obtain, generally being entered on the trial system after the fact. Additionally, the MAU used linear barcodes for their admissions process, which were not readable by the scanning devices used for the system. When the primary Admissions department changed from linear to 2D barcodes, QR codes, the MAU retained the linear codes, a fact discovered by the Receptionist scanning patients on exit. This was not resolved by the end of the trial, but a work around was to produce a separate QR code for these patients to allow their beds to be released.

The new Bed Manager highlighted her difficulty with identifying which bed was which from the ward graphic. Placing the cursor over a bed triggered a pop-up with the bed details but lack of familiarity with the ward layout meant that she struggled to find a specific bed for patient placement. The graphic was updated to include the bed number adjacent to the bed, to resolve this.

To address the issue of patients being allocated to a bed that is not yet ready, a view of the trial ward was created. This view, or web page, listed the available and out of service beds. Thus, the Admissions role could login to the application, to validate beds being allocated to patients as available and in-service. Since the view auto refreshed, it could be left open for quick access.

Another change arose from the preparation of a daily report to the Hospital Manager. It was found challenging to review the status of the ward historically, either earlier in a same day or previous days. To this end, a view was produced that allowed a historic view of the ward, on a given date and time for comparison with the current status, both shown in the same view.

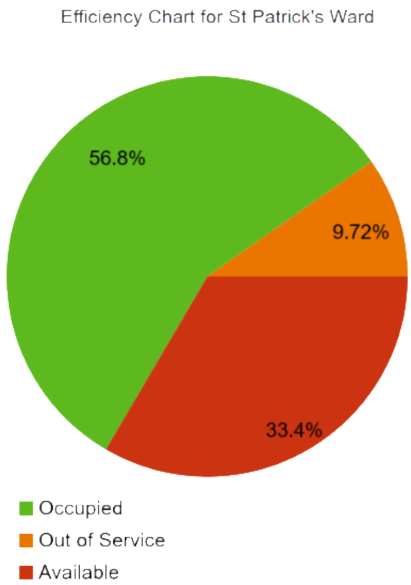

Figure 4: Bed Usage and Unoccupied Time (%).

This comparison page was very well received by the Hospital Manager. The comparison page provided a basis for a view, summarising the bed usage, bed idle and bed out of service, from commencement of the trial. This was seen, by the Hospital Manager, as a key tool to examine the efficiency of the functioning of the ward. The graphic in figure 4 is the actual data over the period of the trial.

5.1 Trial Outcomes

The trial was implemented from 07:00 until 19:00 Monday to Friday as outside of these hours it was difficult to get buy-in from the staff. Ultimately very few patients would be admitted outside these hours and at weekends. Discharges are, however, common at the weekend and the Receptionist was not available to release the bed. The process of bed renewal automatically released the bed-patient linkage. The discharges are captured but without a valid patient egress timestamp.

A total of five hundred and seventy four (574) patients were recorded for the trial ward between November 15th 2020 and February 26th 2021, when the trial ended. A total of four thousand one hundred and thirty one (4131) StatusLog records, linking a patient with a bed, were generated over the same time period. Given that one patient visit accounts for six StatusLog records, it would be expected that 6 times 574 = 3444 StatusLog records should exist. The additional records are associated with patient moves and patients visiting the hospital more than once over the period of the trial.

A total of forty seven (47) patient moves were recorded, which underestimates the number of patient moves that occurred by about 50%. This was chiefly because patients allocated beds in the trial ward were often admitted to a different ward initially and then moved to the trial ward. This allocation of patients to alternative wards, was often due to the trial ward operating at capacity but also being the optimum ward for the patient type, an orthopaedic patient. A patient would be admitted pending surgery and a bed would be available in the trial ward on surgery completion.

Patient moves were also missed due to the author adopting the “bed manager” data entry role. On occasion, the first indication of a move would be due to the release of a bed through the bed renewal process, and the released patient appearing in a different bed. This necessitated the patient being readmitted. This scenario would be negated by the bed manager operating the system.

A total of sixty nine (69) patients were “Earmarked”, that is assigned to a bed that was either already occupied but pending an imminent discharge, or the bed was “Out of Service” pending cleaning. Subsequently releasing the bed for the existing patient and/or completing the renewal of the bed, allowed the “Earmarked” patient to automatically take on the status of “Allocated Pending” and then followed the normal status cycles presenting at admission.

The trial was arranged on the understanding that bed stripping and redressing were implemented by the HCA role. In practice, both Nurses and Student Nurses contributed significantly to bed stripping and redressing. QR codes, for the HCA role to allow scanning for completion of the bed dressing, were provided to the Nursing staff on the ward once this was highlighted, but uptake was negligible.

One particular area of concern was the variable approach to completing scanning. Housekeeping compliance was very high initially but changed following the stopping and recommencing of the trial to harden the server. This was addressed by retraining sessions and highlighting the continuation of the trial. This restored the high compliance by Housekeeping.

The HCA contribution was more difficult to correct due to Nursing staff and students making the beds. Additionally, low staffing level on some days hampered compliance. The Ward Clerk was trained on the use of the system and tasked with engaging the HCAs and Nursing staff, but this was not a notable success. An effort to deploy a screen on the ward, that would provide feedback to both HCAs and Housekeeping on their contribution, was implemented but ultimately was not completed by the end of the trial due to staffing issues in the IT Department.

In terms of the objectives, the detail that could be gathered proved successful. Patient bed release was seen to highlight beds requiring renewal, before Housekeeping and HCAs were apprised of this verbally by the Nursing staff. Additionally, the lack of availability of beds prior to patient admission was shown to reflect the true situation, providing Admissions with an accurate view of the situation on the Ward. Both these improvements in the flow of information contribute significantly to a positive patient experience.

Accurate timing of patient movements was not fully achieved in the trial, as it was hampered by lack of Bed Manager engagement, issues with HCA scanning, and the limitation of having a single ward as the focus of the trial missing patient transfers. However, for patients being admitted to the ward, status change from “Allocated On Site” to “Occupied” could be used to provide a mechanism to trigger patient preparation for their procedures by the Clinical staff both on an “is present” and “known location” basis.

Both occupied and unoccupied times are useful metrics, which provide a breakdown on bed efficiency. The unoccupied time is broken down further in terms of beds being unoccupied due to being “vacant” or “out of service”. This allows focus on the bed usage and is a broker for discussion on how efficiency can be improved.

6 RESULTS

In the existing system it is difficult to quantify the accuracy of timestamps, for events. Events entered on the HIS will be available to other users of the system, once entered, but there may be a delay between an event occurring and being entered. Information on some events are held locally and timestamp information is not necessarily recorded.

In comparison, the new systems automatically records events and timestamps, once tasks have been completed and scanned. The information is then available to all system users. The new system captures additional events and their timestamps.

Table 2 lists the data capture comparison for the existing system and the new system.

It is difficult to define times for events to be recorded, for the existing system. Not all events recorded by the existing system have recorded timestamps. Generally, the existing system can be regarded as best effort and only events recorded on the HIS can be regarded as having a hospital-wide or global view. A comparison of the timing of events is provided in Table 3 below for the existing and new systems and is discussed below.

7 CONCLUSIONS

This paper describes the deployment of an application and devices to gather and record data for the purposes of study and review of the patient pathway.

It highlights the difficulties and complexities of data networks in remote data gathering.

The results section, Section 6, shows that the new system coherently captures events and their timestamps for patients' journeys through the patient pathway. This not only provides a hospitalwide view of a given patient status but also, over time, allows accumulation and analysis of data for patterns and trends as a basis for improving efficiency of patient throughput.

The efficiency can be measured by:

- reviewing the occupation level
- the amount of idle beds, or
- measuring the time that beds are out of service

The checkpoint data captured with this efficiency measure can drive change for increasing efficiency.

In terms of future work, the development of a Higher Level 7 (HL7) interface would be key.

It would enable integration of the application with an existing HIS, as a subsystem. Data transfer of existing information would be facilitated, allowing a single data repository and, at the same time, adding all the functionality offered by this application.

Table 2: Event Capture Comparison.

Desired Feature	Existing HIS	System Local / Individual	New System Global View
Pre-Allocate Bed to Patient	No	Yes - Bed Manager	Yes
Record Admission	Yes	No	Yes
Record Arrival at bed	No	No	Yes
Capture Patient Egress From Hospital	No	No	Yes
Capture Bed Renewal Requirement	No	Yes - Nurse	Yes
Bed Available Notification After Renewal	No	Yes - Nursing / H'keeping	Yes
Graphical View of Patient Fill	No	No	Yes

Table 3: Event Capture Timing Comparison.

Features	Existing System Timings	New System Timings
Pre-Allocate Bed to Patient	Local Communication varying	Global Immediate
Record Admission	Global Immediate	Global Immediate
Record Arrival at bed	Not Available	Global Immediate
Capture Patient Egress From Hospital	Not Available	Global Immediate
Capture Bed Renewal Requirement	Local - Verbal Communication	Global Immediate
Bed Available Notification After Renewal	Local - Verbal Communication	Global Immediate
Graphical View of Patient Fill	Not Available	Global Immediate

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