Patient Flow Monitoring Systems: Investigation of Alternatives

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Abstract . Hospitals need to reduce wait times in emergency rooms to ensure timely delivery of services. This paper provides an in-depth investigation and evaluation of three distinct approaches to provide real time monitoring of patient flow. The three approaches differ in the number and nature of their data sources. The results suggest that additional data sources provide only little improvements in the monitoring capabilities. Monitoring patient flow can be achieved in real time with potentially little need for expensive and complex integration with hospital information systems by collecting location data or by using data collected from electronic forms.

Keywords: Real Time Patient Flow Management System, Business Process Management, Wait Time, Business Intelligence, Complex Event Processing.

1. Introduction

Analysis of patients wait times is an activity typically performed by hospitals, long after a service has been delivered to patients. Analysis of wait times in real time has remained elusive to date. This is because the existing healthcare systems are fragmented and are not developed to address such a real-time requirement. In addition, the data logged in the existing healthcare systems are sometimes inaccurate as data entry may take place hours or even days after it is initially recorded on paper.

A number of approaches have emerged to address real time monitoring of patients flow. In the first approach, location data is collected and integrated with the existing hospital information systems to infer key patient states [1]. Once the states have been inferred, real time dashboards can report on patient progress along the clinical pathways in real time[1]. The second approach is a forms-only approach, which collects data from existing electronic clinical forms to monitor patient flow [2]. The third approach, we refer to here as location only approach, relies on the analysis of the location data of both patients and clinicians to infer patients states and flow. This approach does not involve hospital information systems or electronic forms, and relies exclusively on location data [3].

Each of these approaches represents a distinctive paradigm. The first approach attempts to achieve the most comprehensive monitoring, while at the same time minimizing any overhead to clinicians. This approach maximizes monitoring potential by correlating data from multiple sources. The down side is complexity and cost. Such an approach requires integration with hospital information systems and triangulation of location data with care operational data. The forms approach attempts to use electronic forms to collect operational data to report on patients flow. In most cases, new mobile apps have to be built to provide adequate monitoring support in real-time. The location-only approach utilizes location tags that track location and movements data. This approach attempts to avoid the costly integration with hospital information systems while providing adequate levels of flow monitoring.

This paper is organized as follows. Background and significance of the work is discussed, followed by a presentation of related work. The ACS clinical pathway is introduced as a reference clinical pathway for the empirical evaluation. We then introduce the empirical evaluation of the three approaches. The limitations of the work are then discussed. We conclude the paper in section 9.

2. Related Work

The value of workflow management tools and Business Process Management (BPM) technology is well identified and documented [14]. Becker el al. [11] has reported their work on using BPM technology to help coordinate disparate data sources in a large urban hospital in the U.S. Their work highlights the potential of BPM in supporting and automating clinical decisions. Hajo et al. [12] has deployed BPM technology to demonstrate flexible support for clinical pathways. Their approach relies on identifying 'flexible patterns' to accommodate the unpredictability of clinical processes.

Manfred [13] has articulated the unpredictability of clinical processes, and provides an analysis of recent BPM advancements that can better address some of this unpredictability. Specifically, Manfred identifies improvements in process adaptation, flexibility, and evolution.

Zhu et al. [4] has developed real time monitoring dashboards for a Radiology department in the central hospital in China. They relied exclusively on integration with existing hospital systems and BPM. They are able to monitor key states and patient flows. They did not include any location information, and hence, the identified states are at a high level. For example, this approach is not able to calculate how long the patient has been waiting inside the MRI room.

Yao et al. [5] proposed complex event processing to be used along with RFID technology to improve patient safety and procedural efficiencies for surgical procedures. They are able to infer key states for the identified surgical clinical pathway using location data alone. This is largely because in this clinical pathway, the patient is transported from room to room as they progress through the clinical pathway. Therefore, tracking the location of the patient is sufficient to infer the patient progress along the clinical pathway.

Long running care processes, those that can span months and years, can be sufficiently monitored using traditional forms applications [2]. This is because accuracy within a few days is typically sufficient. For example, typical operational guidelines may require that a referral be scheduled within 48 hours, and the patient appointment be within 14 days of referral. Such level of granularity may be sufficiently achieved using forms applications.

3. Background and Significance

In Canada, as well as in many parts of the world, healthcare organizations face challenges with patient wait times, particularly in Emergency Departments (ED). By their nature, EDs face fluctuating and unpredictable inflows of patients, many of whom require immediate attention. According to a study by the Canadian Institute for Health Information (CIHI) [6], a significant majority of patients whose condition requires urgent care end up in the ED. Ontario Ministry of Health made its top-priority health concern to address the wait time issue by launching “The Ontario Wait Times Strategy Program” which commenced in 2008. This program requires hospitals to report on patients wait times, and to facilitate access to key procedures and services, such as X-rays and MRIs.

A study of wait times at EDs [7] reveals significant unpredictability and variability in patient wait times. Achieving medical targets also exhibited significant variability. The study also finds that longer wait times for admission is highly correlated with longer visit duration. Another study has found high positive correlation between wait times, mortality and readmission rate [8]. The study reports that patients arriving at ED during shifts with longer wait times are more likely to be admitted to the hospital, even though they may be well enough to leave the hospital on the same day.

Despite the significant potential in monitoring patient flow, identifying bottlenecks, and discovering root causes, basic patient flow monitoring remains absent from most care institutions [9][10].

4. Reference Clinical Pathway

A detailed process model that documents the Acute Coronary Syndrome (ACS) clinical pathway at a large community hospital in Ontario has been developed [15]. The process model of the ACS clinical pathway details all the steps and tasks performed by every participating clinician. It also documents system interactions, medical forms, medical guidelines and best practices. This was achieved by shadowing all participating clinicians as they handle patients walking into the ED with a chest pain, and who are later diagnosed as ACS patients. The models and documentation were verified and validated by hospital staff.

The ACS process starts at patient triage, and ends at discharge. The process includes multiple patient assessments, blood tests, patient transportation to different hospital units. Table 1 summarizes only the key clinical pathway states. The complete ACS clinical pathway is published in another work [15].

Table 1: Detailed patient states along the ACS clinical pathway

	State name	Start	End
1	Triaged	Patient info entered in system, location tag assigned.	The nurse completes the triage and takes the patient to the waiting room.
2	Waiting for initial assessment	Triage ended.	Physician walks into the room and starts examining the patient.
3	In initial assessment	Waiting for initial assessment state ended.	Physician leaves room after examination and submits initial assessment form.
4	Waiting for lab results	Blood work is requested.	The lab sends back results.
5	Waiting for reassessment	Lab results have arrived.	Physician walks into the room and starts re-examining the patient.
6	In re-assessment	Waiting for reassessment has ended.	Physician completes re-examination, requests bed for patient.
7	Waiting for bed	In re-assessment ended.	A bed is available for the patient.
8	Waiting for transport	Transport is requested.	Transport personnel arrives.

5. Evaluation of Patient Flow Monitoring Approaches

We have developed three different implementations of the reference clinical pathway corresponding to each approach. The first implementation uses location data, and data coming from a simulation of the hospital information system. We refer to this implementation as *'combined approach'*. The second implementation, the *'forms only approach'*, implements the clinical pathway using forms application without using any location data. The forms are developed to mimic the hospital existing forms, with modifications and additions that compensates for the missing data required for the real time reporting. The third implementation utilizes location tags that are assigned to each participant in the clinical pathway, including the patient, nurses, physicians, transport and housekeeping personnel. We refer to this approach as *'location only approach'*.

5.1 Simulation Exercises

The *'combined approach'* was validated through a series of walk-through evaluations at the premises of a large urban hospital in Canada [16]. The walk-through evaluations took place in a section of the hospital that was not being used. Clinicians from the hospital participated. Clinicians had the choice to participate as patients, clinicians or staff. The walk-through evaluation did not include real patients and assumed zero variability. The walk-through evaluation included a simulation of the hospital electronic healthcare records (EHR). For example, when a lab test is requested, the lab and its tests results were simulated. No actual samples were taken or tested during the walk-through evaluation.

Once the *'combined approach'* was validated, we conducted a thorough analysis of all three implementations in a simulation exercise back at our university research lab. The lab space was divided up into several rooms and sections. The mapping included operating rooms, patients' rooms and beds. Open space was also utilized to represent similar open areas where patients arrive and wait for admission. For this exercise, the location tags were calibrated to use the existing Wi-Fi signal for open spaces. When high precision was required, we utilized infrared signals and beacons that were mounted on the walls. This simulation was conducted using student participants who played the roles of patients, clinicians, transport, and housekeeping. The goal of the simulation was to verify and compare the technologies in use. Our focus was on ensuring that locations and progress through the clinical pathway was being tracked effectively with reasonable delays and accuracy.

6. Evaluation Criteria

We evaluate the three implementations using the following three criteria.

1. Coverage of real time monitoring of patient states

This is measured by the number of states whose start and end can be identified. For example, the state number 4 in Table 1 '*waiting for test results*' starts when the test have been requested and ends when the results are sent back from the lab. In the same table, state number 6 *'In reassessment'* starts when the patient is waiting for reassessment by a physician after the test results has been received, and ends when the physician starts to reassess the patient. Table 2 below summarizes this evaluation criterion for these two states.

Table 2: State identification using the three paradigms

Approach		Waiting for Test results	In reassessment
Combined	Start	Form	Form and Location
	End	EHR	Form and Location
Forms only	Start	Form	Form
	End	N/A	Form
Location only	Start	N/A	Location
	End	N/A	Location

The evaluation criteria did not include reliability. For example, a physician may start examining the patient before he opens the reassessment form. In this case, the actual start of the state identification is inaccurate in the case of forms only system. Similarly, for the location only system, a physician may walk into the room for reasons other than examining the patient. This may result in unreliable data in the system, but for the purposes of this evaluation, it was not taken into consideration as it was hard to quantify. We assumed that all participants behaved in the same systematic manner.

2. Overhead to clinicians

This is measured by the number of additional forms and clicks that are required in order to identify the start and end of the patient states, as compared to the hospital existing system. Here, we distinguish between clicks and forms; additional clicks are required on *existing forms*. In other words, a new click is required to be added on a form that already exists in the current hospital system. The click is required to identify the beginning or end of a patient’s state. In other cases, a new click is required at a time where there is no existing form in place at the current system.

The distinction is important for two reasons. Both, a new click and a new form represent an overhead to clinicians. However, a new click means that the overhead is minimal, as the clinician is already interacting with the system. On the other hand, a new form poses additional overhead for clinicians who may need to access the system at a time where they do not typically do. A new form also represents additional development effort to integrate the new form into the system.

3. Complexity

This is measured by the number of integration points; i.e., the number of data sources that are required to support the implementation. In the case of the combined approach, the data sources are events from the existing health care system, location data, and forms data. In the case of forms only and location only approaches, there is only a single data source, forms and location data respectively.

The complexity associated with the integration points depends on the number and nature of the data sources involved. For example, if a system involves three integration points from the same source system, then this would be less complex if the three distinct systems involved. We do not take the nature of the integration points into consideration in this study.

7. Results and Analysis

The results of our analysis of the reference clinical pathway are summarized in Table 3.

Table 3: Summary of analysis results

Approach	**Identifiable start states**	**Identifiable end state**	**Identifiable start and end states**
Combined	23	23	23 (100%)
Forms Only (no extra clicks)	15	13	10 (43.5%)
Forms Only (with extra clicks[1])	23	23	23 (100%)
Location Only	15	19	14 (61%)

As shown in the table above, the combined approach is able to identify 100% of all start and end states. This is because this approach triangulates data from multiple sources to identify these states. On the other hand, using the forms only, the system is able to identify 43.5% of all start and end states. However, if we add 18 clicks and 13 new forms, we can compensate for the missing data sources to identify 100% of all start and end states. The third paradigm, the location only approach, can identify 61% of all starts and ends for all states.

These results highlight the potential of using the existing forms application to monitor patients flow. Theoretically, about 50% monitoring can be achieved without investing in additional infrastructure to track location or integrate with EHRs. In addi-

[1] Additional clicks are estimated to be 18 clicks and 13 new forms within the ACS clinical pathway.

tion, 29% of the state boundaries identified are bed related, and 16.6% are transportation related. If we were to exclude these two categories of states, then the monitoring potential increases to 70%.

8. Threats to Validity

Our study of the three approaches faces a couple of threats to validity. The effectiveness of the treatment in the ACS clinical pathway is time sensitive. The sooner a diagnosis can be established, the sooner the operation can be performed, the better the outcome. Studies show that delay beyond 90 minutes means that an operation may not be as effective as other secondary treatment options. This clinical pathway may not be a good representation for other clinical pathways. Therefore, one must be careful at generalizing the results to other clinical pathways.

There is an external validity threat that the forms in use at the targeted hospital may not be a good representation of how other hospitals implement the same clinical pathway. At the community hospital where the study was conducted, there was almost no paper trail and all forms were electronic. The results of this study may reveal different results in hospitals where a significant portion of the process is only documented on paper and not online. In addition, other hospitals may implement a variation of the ACS clinical pathway that may result in different patient states.

Finally, our estimate of the cost and complexity is based on the number of data sources and the number of extra clicks and new forms. This measure may not be a good representation of the actual complexity or cost.

9. Conclusion

Monitoring patient flow is a growing trend in urban hospitals for multiple reasons. Acute Coronary Syndrome (ACS) falls under the category of care services that must be delivered in timely manner. Hospitals struggle to meet their medical and regulatory guidelines for care delivery and patient wait times. When excessive delays occur, it is difficult for hospitals to identify the root cause of delays.

This paper evaluated three approaches for real time monitoring of patients wait times based on the ACS clinical pathway. Our analysis suggests that the combined approach is able to monitor all patient states without requiring additional burden to care givers. This is achieved at the cost of system complexity. A system that combines data from multiple sources is both complex and expensive. The forms only paradigm can monitor about half of patient states using only the existing medical electronic forms. Location only can monitor about 60% of patient states.

The wide variety of clinical pathways may result in different paradigm being more suitable for different group of pathways. Long term clinical pathways may be best suited for forms only paradigms, emergency and time critical processes may benefit from the combined paradigm. This variety of clinical pathways suggests that a study be performed to categorize the different type of clinical pathways in terms of their monitoring requirements.

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