

# Use of Location Data for the Surveillance, Analysis, and Optimization of Clinical Processes

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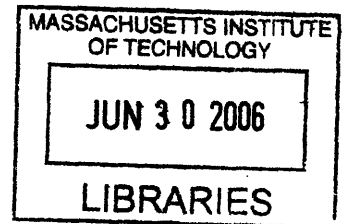
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SUBMITTED TO THE HARVARD-M.I.T. DIVISION OF HEALTH SCIENCES AND  
TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE  
DEGREE OF

MASTER OF SCIENCE IN BIOMEDICAL INFORMATICS  
AT THE  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

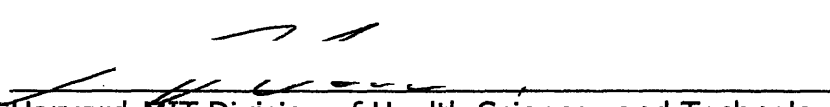
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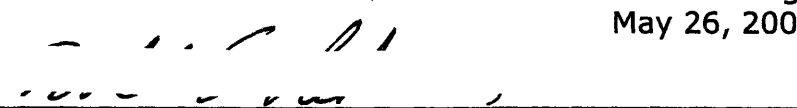



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Submitted to the Harvard-MIT Division of Health Sciences and Technology on  
May 26, 2006, in Partial Fulfillment of the Requirements for the Degree of  
Master of Science in Biomedical Informatics

## ABSTRACT

Location tracking systems in healthcare produce a wealth of data applicable across many aspects of care and management. However, since dedicated location tracking systems, such as the oft mentioned RFID tracking system, are still sparsely deployed, a number of other data sources may be utilized to serve as a proxy for physical location, such as barcodes and manual timestamp entry, and may be better suited to indicate progress through clinical workflows. INCOMING!, a web-based platform that monitors and tracks patient progress from the operating room to the post-anesthesia care unit (PACU), is one such system that utilizes manual timestamps routinely entered as standard process of care in the operating room in order to track a patient's progress through the post-operative period. This integrated real time system facilitates patient flow between the PACU and the surgical ward and eases PACU workload by reducing the effort of discharging patients. We have also developed a larger-scale integrated system for perioperative processes that integrates perioperative data from anesthesia and surgical devices and operating room (OR) / hospital information systems, and projects the real-time integrated data as a single, unified, easy to visualize display. The need to optimize perioperative throughput creates a demand for integration of the datastreams and for timely data presentation. The system provides improved context-sensitive information display, improved real-time monitoring of physiological data, real-time access to readiness information, and improved workflow management. These systems provide improved data access and utilization, providing context-aware applications in healthcare that are aware of a user's location, environment, needs, and goals.

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## **Introduction**

While retail industries and defense establishment, represented by Wal-Mart and the Department of Defense,<sup>1, 2</sup> have embraced RFID and location tracking systems, their application in the healthcare setting is still in its infancy. However, such systems hold great promise to streamline patient care, manage assets and provide a safer hospital environment. Location tracking systems and location tracking data may be derived from a number of different and diverse sources, including dedicated RFID solutions utilizing an independent infrastructure, wireless solutions utilizing an existing wireless 802.11 network infrastructure, "older" technologies such as bar codes, and a myriad of data sources that may be used as proxies for location including user logins, data that a user has entered, and door access through passive RFID or magnetic cards.

The ultimate goal of location tracking data is to understand a person's or asset's position in relation to other people and assets, a cornerstone of context-aware computing applications. Once this is elucidated, a number of relationships may be inferred and utilized to create a pervasive computing infrastructure that is aware of its context with the rest of the world, its current environment, and its resources available.

### ***Location Tracking Systems in Healthcare***

Location information in the healthcare setting may be used in a number of ways including tracking assets, monitoring patient flow, assessing workflow performance, and furthering the safety mandate of the institution. Massachusetts General Hospital has demonstrated that a tracking system can not only detect when a patient enters the incorrect operating room, but also provide alerting functions to notify a specific individual who is able to rectify the situation.<sup>3</sup> This facility utilizes an RFID location tracking system by Radianse, Inc. (Lawrence, MA) to track patients, personnel, and assets throughout the perioperative setting. Other work with the Radianse system has also determined the feasibility and resulting high accuracy of recording timestamps in the operating room.<sup>4</sup> These automatically recorded timestamps, including times for patient in and out of the room, were shown to be more accurate and more precise than manually entered data.

### **Dedicated Tracking Systems**

RFID tracking systems have become a popular solution and the typical infrastructure when thinking of hospital-based tracking. Active versions of these systems consist of a battery-powered tag that broadcasts its presence to a network of receivers that exists independent from and parallel to the

existing network structure. This separate network infers several advantages including the ability to use a frequency reserved for that use, thus decreasing interference, and the ability to tailor the network to one's particular needs in terms of coverage and receiver density. Other proprietary technologies also exist including the use of ultrasound, as is the case with Sonitor, Inc. (Oslo, Norway).

Another trend is using the existing wireless network infrastructure and utilizing updated hardware and specialized software to triangulate location based on the wireless signal. Utilizing a typical 802.11 standard, these systems take advantage of capital already invested to provide expanded functionality to infrastructure that is already in place. These tags have shorter battery life, occupy space on the existing wireless network, and require a higher density of receivers in order to accurately determine a tag's location.

## **Proxies for Location Determination**

Bar codes provide a complementary technology to more sophisticated location tracking systems.<sup>5</sup> RFID tracking systems do have several key advantages over this older technology. RFID tags can be read quickly, contain rich data and provide tracking at a distance and through obstructions. However, tracking applications can and have been developed that solely utilize bar codes as a mechanism of tracking patients and processes.

St. Joseph Health Services of Rhode Island developed an emergency department patient tracking application that relied on staff to scan the patient's bar code, either from their chart or wristband, and then scan a second bar code on a paper menu to designate the activity at that particular station; the paper menu selection was appropriately altered based on station, providing options specific for that location. Primary benefits of such a system include cost, with their system requiring only \$8,000 in expenditure, and limited complexity.<sup>6</sup>

The University of Pittsburgh has also utilized bar codes to benchmark the perioperative process.<sup>7</sup> Like the previous example, all patients receive a bar code, specific for that patient, through which timestamps for pertinent events are recorded and associated. These events cover the perioperative process from patient arrival in the facility through admission, transportation, induction, surgery, recovery and ultimate discharge. These data are then utilized for a number of applications including real-time identification of events occurring at a location, anticipation of schedule changes and delays, and analysis of time-interval variances to determine areas of potential improvement.

These bar code systems, along with other manual data entry systems, provide a proxy for true location tracking systems that, by virtue of the technology and their ubiquitous nature, are more economical, fit better into current workflow practices, and do not require a sizeable investment in added infrastructure. However, they also incur the inherent penalty of relying on manual, human intervention to add data. When added to a dedicated location tracking system, such limitations are removed and together, these systems provide a solid foundation for context-aware computing in the healthcare environment and the ability to more completely provide information in a just-in-time manner to healthcare providers, staff, administrators, and patients.

## ***Real World Applications of Location Data***

A number of applications are ideally suited for the inclusion of location data, especially given a broader definition of the term by utilizing location by proxy. Dedicated location tracking systems have found use in mass casualty response programs, patient safety efforts, asset tracking and equipment utilization, theft prevention, and general patient tracking between departments and clinical areas.<sup>5, 8-11</sup>

## **Patient Flow and Process Surveillance**

Healthcare processes are particularly prone to delays due to a combination of a queuing system, leading to requisite coordination between multiple players and clinical steps, and the plasticity of the patient's state, requiring not only patient's physical presence but also recognizing that the patient may require care while waiting, may be adversely affected by the wait, and may have their process of care disrupted due to unanticipated events. These factors, in addition to the extreme congestion typical of modern healthcare, lead to a system where bottlenecks and grid lock can produce extreme delays in patient care and advancement through a clinical process.<sup>12</sup>

Optimization of patient flow requires a foundation of quality information sources, necessitating the integration of existing systems and technologies and removing barriers that create silos of data that are unavailable to outside systems.<sup>13</sup> The addition of location tracking information, whether by proxy or by a dedicated system, provides a useful source of data to help elucidate patient and staff position and relationship, and determine real and optimal process performance.

## **Applications and Settings Currently in Use**

In this manuscript, we report two settings in which location data is currently in use at Massachusetts General Hospital. In the first, no specific, dedicated location tracking system is utilized and instead, timestamps of key steps in a patient's clinical process create a proxy for the patient's actual location. Timestamps indicating the point when a patient enters and exits an operating room along with timestamps indicating key events in the procedure create enough information to indicate a patient's location within a clinical process and indicate the patient's physical location without necessitating a dedicated location system. By tracking the patient in this manner, it is hoped that the intervention will provide better communication between clinical areas and expedite transfer of the patient from one clinical unit to another. Use of location data in this regard is beneficial since no additional work is created in collecting the information due to timestamp recording already being standard procedure in the perioperative setting.

In the second setting, we integrate location data into a system that collects, displays, and analyzes a number of digital OR and hospital information sources including, but not limited to, hospital information systems, physiologic monitors, surgical devices, a location tracking system, the perioperative record, and a scheduling system. Use of a dedicated location tracking system provides specific information on staff in the room caring for the patient, provides additional checks for correct patient/room/staff combinations, and provides information on patient presence within the operative environment, allowing indications and progression of information flow when a new patient arrives or a current patient leaves the operative setting.

## **Tracking Without a Tracking System**

Many institutions currently do not have a dedicated location tracking system and are waiting to commit the significant investment toward a developing technology.<sup>14</sup> In addition, location tracking systems are a potentially disruptive technology and, due to the pervasiveness of the data, may be integrated into any number of existing applications, requiring significant programming time and effort. However, process tracking and limited patient tracking may be achieved by consuming and integrating data from existing systems. We have developed a system to track patients through their PACU course and facilitate their transfer to the patient floor utilizing existing data sources and manually entered data.

## ***PACU Congestion in Healthcare***

Hospitals face increasing demands to deliver cost-effective, high-quality care with limited resources. Large inner-city academic hospitals have increasing capacity demands with little room for growth. Analysis of patient flow can identify bottlenecks in the system. The post-anesthesia care unit (PACU) represents one such area. Furthermore, in congested hospitals, delays in discharging patients from the PACU lead to backups in the operating room suite, with consequent disruptions propagating backwards through the system leading to delays and case cancellations.

## **Reasons for PACU Discharge Delay**

Previous analysis at other institutions demonstrates that as many as 20% of patients experience delayed discharge from the PACU.<sup>15</sup> Over half of delays may be personnel-related and three-quarters due to identifiable personnel shortages or inefficiencies.<sup>15, 16</sup> Reasons for delay include lack of bed availability, lack of transport assistance, PACU nurses being busy, rooms not being prepared, receiving staff busy, staff shortage, and poor communication.<sup>15-17</sup> The inability of receiving floor nurses to accept a transfer causes the most significant delays.<sup>17</sup> While such events are not the most prevalent, they cause a disproportionate increase in PACU length of stay (LOS) and associated charges compared to other causes of delay. It is suggested that staffing and transport factors may be used to help limit delays in PACU discharge<sup>18-20</sup> and that even simple interventions, such as notifying the receiving unit of an impending patient transfer 15-30 minutes before the transfer is to take place, would address many of the reasons for delay in discharge.<sup>16</sup>

## **Technological Interventions to Combat Delays**



Technological interventions to improve patient flow have shown promising results and may facilitate improved efficiency in delivering care.<sup>21</sup> Starting from the premise that PACU length of stay can be optimized with improved communication with the surgical floors, we developed and piloted an automatic data gathering and messaging system to manage PACU patient flow. The system, dubbed "INCOMING!", was developed as an integrated real-time system to monitor patient flow between the operating room suite, the recovery room and the surgical floor, and to facilitate a reduction in the time between patient eligibility to leave the PACU and the time when they actually leave. INCOMING! automatically alerts surgical floor nursing staff when PACU patients are about to be ready for discharge. The system is accessed through the standard personal computers widely deployed for clinical use in our hospital and seeks to improve workflow by: (1) providing estimated PACU lengths of stay, (2) assigning patients to floors rather than individual beds, (3) initiating PACU transfer by the surgical floor (as opposed to by the PACU), and (4) providing a single point of contact between the surgical floor and the PACU.

In this chapter, we describe the architecture and function of INCOMING!, and report the result of a partial-deployment pilot study whose main goal was to demonstrate the technical feasibility of the project. In addition to the feasibility demonstration, we hypothesized that this tool would decrease the average PACU LOS for assigned patients.

### ***INCOMING! Design and Development***

A computer generated web-based platform was constructed. The system was meant to replace a fully manual approach in which PACU nurses establish that a patient is ready for discharge, after which they telephone the floor to which the patient is to be discharged and arrange for transfer. This process is simply illustrated in Figure 1, panel A. We sought to replace this manual process by one in which certain tasks were automated or given decision support, as illustrated in Figure 1, panel B. This was done by integrating, re-packaging and propagating data that was already collected and entered into clinical and administrative information systems by clinicians during the course of their regular work. Our institution uses an internally developed computerized system called the Nursing Perioperative Record (NPR) for perioperative documentation. The NPR includes time stamps for key milestone events, including the start and end of surgery, and the time of a patient's arrival in the PACU. These time stamps have been validated.<sup>22</sup>

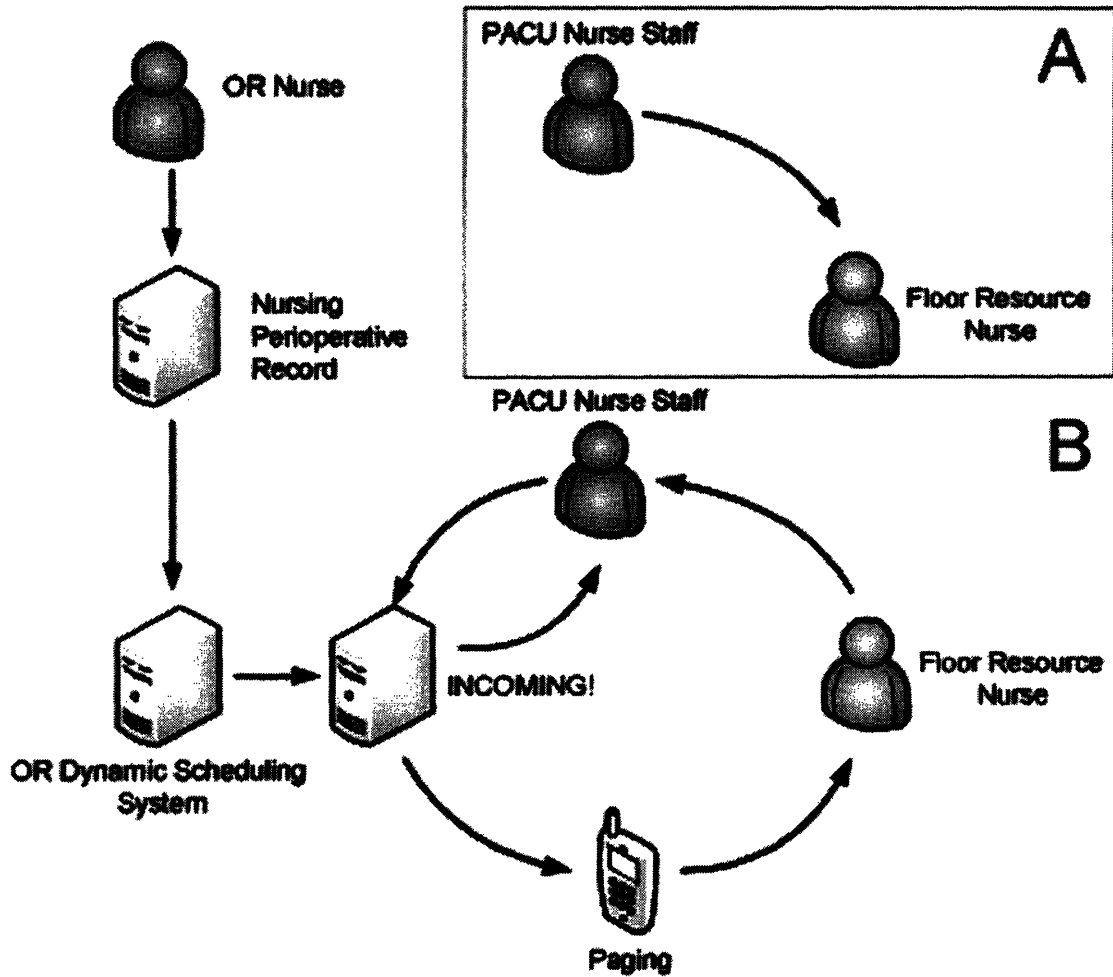


Figure 1 The original workflow (A) was initiated only when the PACU nurse had determined that a patient met discharge criteria to leave the PACU. It placed the burden of initiating PACU transfer on the PACU nursing staff to contact the floor resource nurse arrange the transfer. The new system with INCOMING! (B) propagates information initially entered by the OR nurse to the PACU and then allows the PACU nursing staff to assign floors and enter an estimated PACU stay length. The system then pages the floor resource nurse prior to the patient being ready to leave the PACU. The floor resource nurse then initiates PACU transfer by contacting the PACU nursing staff.

## INCOMING! System Use

Users on the surgical floors select the floor to which the patient will be transferred. Preliminary floor assignments for the day's cases occur at a centralized meeting at the beginning of the workday with the option for floor resource nurses to modify selections and choose additional patients throughout the day. PACU nurses interact with INCOMING! to provide an estimate of the total PACU stay, thus harnessing the experience of recovery room nurses to refine the quality of the estimate. The resource nurse or

other specified user on the receiving care unit receives an automatically generated page 15 minutes prior to the estimated time for the patient being ready to leave the PACU. This page notifies the resource nurse to arrange transport from the PACU for the patient.

## INCOMING! Data Sources and Integration

The system is designed as a collection of Active Server Pages integrating data from other clinical systems (NPR) and from PACU nurses. The NPR communicates the timestamps entered in the OR to another system, the OR Dynamic Schedule, via a closed interface. The OR Dynamic Scheduling system exposes these time stamp data for consumption by other systems, such as INCOMING!, via an XML interface (Figure 1, panel B). The platform is supported by a back-end database (Microsoft SQL Server 2000) that is updated throughout the day with case information gathered through Visual Basic Scripts that extract information from the OR Dynamic Scheduling System's XML feed.

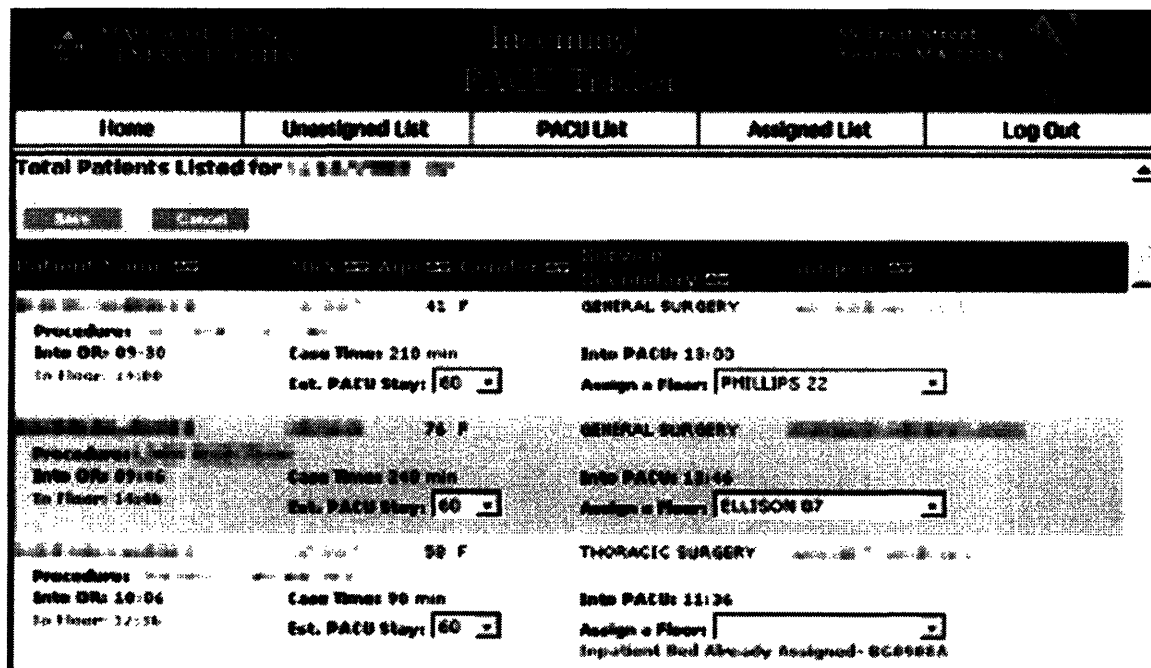


Figure 2: INCOMING! presents patients in the PACU to the PACU nursing staff and allows them to assign an estimated PACU stay for each. Additional pertinent patient information is also displayed with ability to sort and save changes.

An automated scripting system is used to cull new cases daily from the XML feed from OR Dynamic and enter them into the SQL database, to update case information already present in the database as the cases progress throughout the day, and to send pages to appropriate hospital floor resource nurses concerning upcoming transfers from the PACU (Figure 2). INCOMING! makes time stamps from the pre-existing scheduling system accessible to

PACU staff and patient floors. A default PACU stay of 60 minutes is assigned to each patient, but this can be modified by the PACU staff. The estimated PACU stay is used to calculate the projected time out of the PACU by integrating NPR surgical milestone timestamps and PACU staff projections. This estimate of time to readiness for discharge is then used by the automated scripting system to send machine-generated pages through the hospital paging system 15 minutes prior to patient departure from the PACU (Figures 1 & 3).

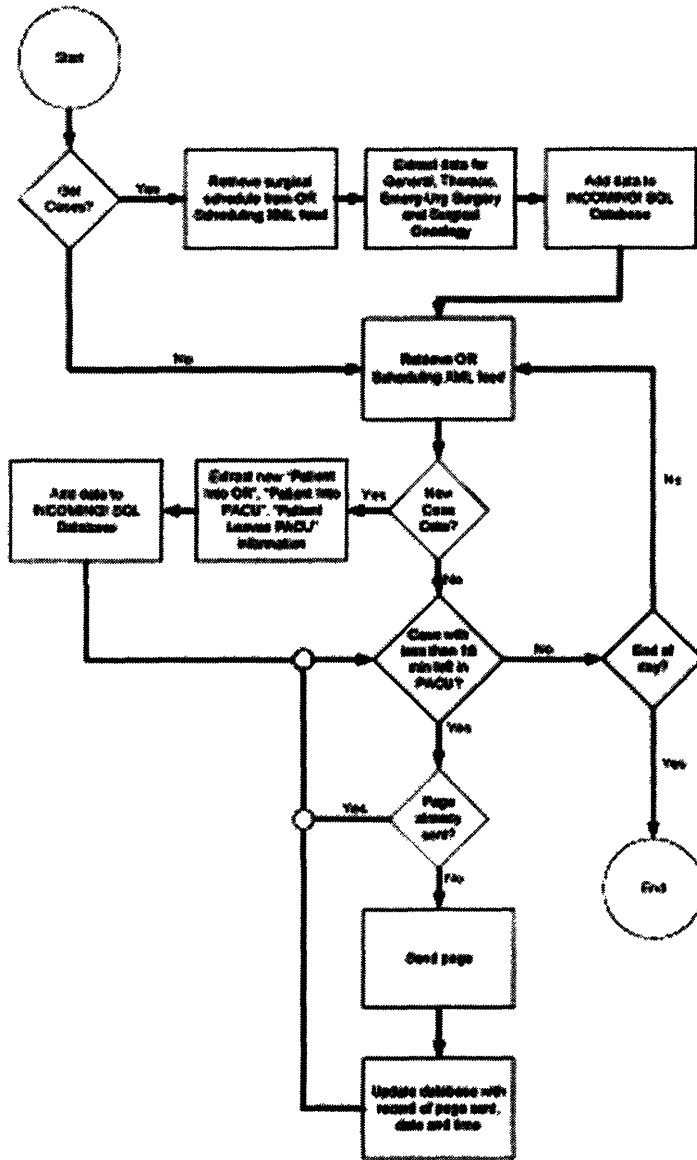


Figure 3: Logic flow of the INCOMING! application. The INCOMING! tool works by first retrieving the day's cases and then updating its database as the day progresses. When a patient is soon to leave the PACU, a page is sent to the resource nurse on the appropriate floor to initiate patient transfer.

## ***Pilot Study Design***

INCOMING! was piloted on the general surgery and surgical overflow services beginning in December 2004 with paging functionality added in mid-March 2005. We compared PACU LOS between three groups: a general surgery intervention group with an INCOMING! selection, an orthopedic surgery control group without INCOMING! and a general surgery control group without an INCOMING! selection. At our institution, orthopedic surgery and general surgery have similar workflow and physical resources; both possess two floors of the hospital, have roughly equivalent bed number and patient census, similar lengths of stay, a similar number of case managers, and relatively few patients requiring use of the surgical intensive care unit. Groups were defined by discharge floor. Patients being discharged to the ICU or home from the PACU were not included in the analysis. We compared groups for the time period prior to paging (12/1/2004 – 3/22/2005) and the time period following paging introduction (3/23/2005 – 5/31/2005). Mean LOS was compared using analysis of variances techniques with log transformed data to improve the normality assumption. In addition, the proportion with LOS > 6 hours was compared between groups and between periods using  $\chi^2$  tests. To assess the impact of the INCOMING! system over time, we repeated the analysis of mean LOS and proportion with LOS > 6 hours with selected periods after paging functionality had been implemented (3/23/2005 – 9/30/2005).

## ***Study Results and System Performance***

The INCOMING! system performed as expected. Users interacted with the interface shown in Figure 2. Information displayed by the system includes patient demographics, surgical information including procedure, service and surgeon, and pertinent timestamps including the time into the OR, the surgical time, and time into the PACU. These times start as estimates generated by the scheduling system (based on the surgeon's historical performance) and change to reflect reality as new information becomes available through the OR Dynamic scheduling system's XML feed.

A total of 3084 patients were included in the analysis between general surgery control and intervention groups and the orthopedic surgery control group. Even though the mean PACU LOS in the general surgery intervention group with INCOMING! selection was shorter after initiating the INCOMING! paging function, the difference did not reach statistical significance ( $p=0.59$ , Table 1). There was no significant difference in LOS between the general surgery with INCOMING! selection group and the orthopedic surgery control group during the pre-paging period ( $p=0.95$ ); however, the mean PACU stay in the intervention group was significantly less than the PACU stay in the orthopedic surgery control group after paging was initiated ( $p=0.001$ ). The mean PACU LOS decreased in the INCOMING! general surgery intervention

group by 26 minutes while the mean LOS increased by 28 minutes in the general surgery control group. However, this difference of the change over time did not reach statistical significance ( $p=0.27$ ).

**Table 1 Mean PACU LOS ( $\pm$  standard deviation) between intervention and control groups both before and after paging functions were enabled.**

Service	Pre-Paging	Paging
General Surgery Service with INCOMING! Selection	211 $\pm$ 191 (n=369)	185 $\pm$ 95 (n=210)
General Surgery Service without INCOMING! Selection	185 $\pm$ 156 (n=536)	213 $\pm$ 214 (n=318)
Orthopedic Group	212 $\pm$ 199 (n=985)	235 $\pm$ 210* (n=666)

\*  $p = 0.001$  vs. General Surgery Service with INCOMING! selection.

We also examined the proportion of patients with PACU LOS > 6 hours. Patients with PACU LOS > 6 hours decreased from 8.9% to 2.9% for the intervention group ( $p=0.004$ ) compared to an increase of 6.3% to 8.5% for the general surgery control group and an increase of 9.1% to 11.7% for the orthopedic surgery control group. There was no significant difference between the intervention and the control groups during the pre-paging period ( $p=0.14$ ); however, the proportion with PACU LOS > 6 hours was significantly smaller in the intervention group than the two control groups (both with  $p<0.01$ ) after initiating the INCOMING! paging function.

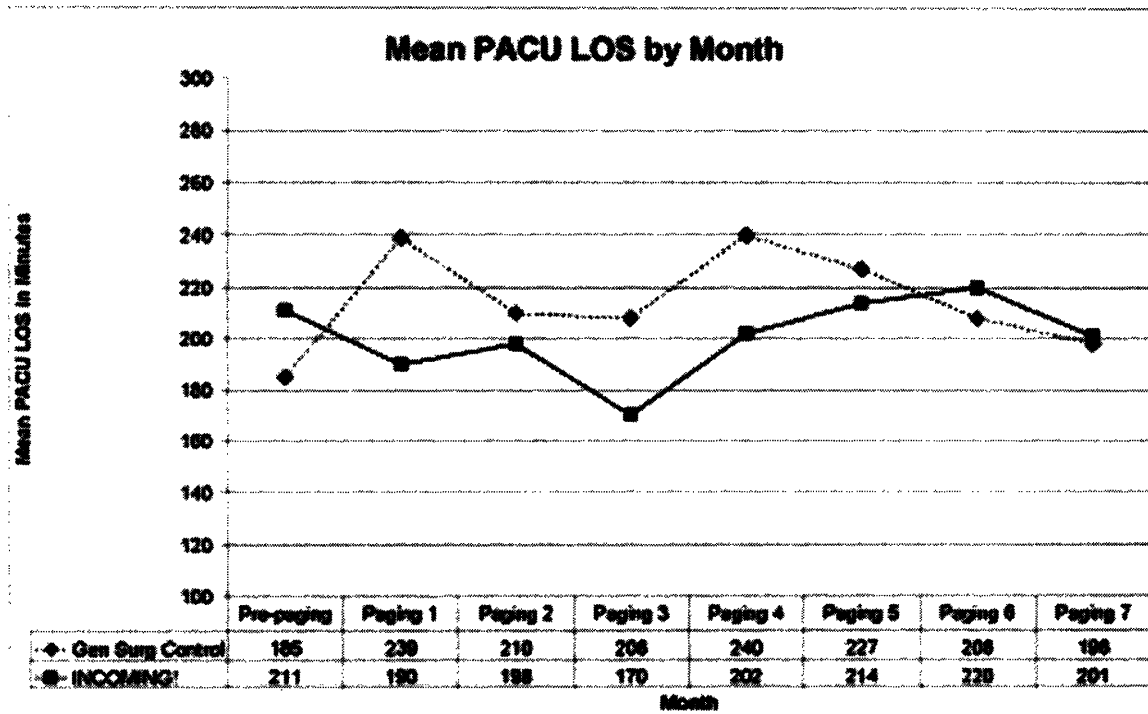


Figure 4 Mean PACU LOS for all groups both before and after paging. Differences in the groups disappeared by the end of the study.

We conducted a time series analysis of General Surgery service patients' LOS in the PACU with and without the benefit of an INCOMING! selection. In the time series analysis, a total of 2411 patients were included. Figure 4 shows a time series of mean LOS between two groups during this limited pilot: General Surgery Service with INCOMING! selection vs. General Surgery Service without INCOMING!. The mean LOS for the intervention group was less than for the general surgery control group during the initial five months after paging was introduced, although the differences were non-significant ( $p=0.96$ ). The proportion with PACU LOS > 6 hours was lower for the intervention group for the entire time after initiating the INCOMING! paging function (Figure 5).

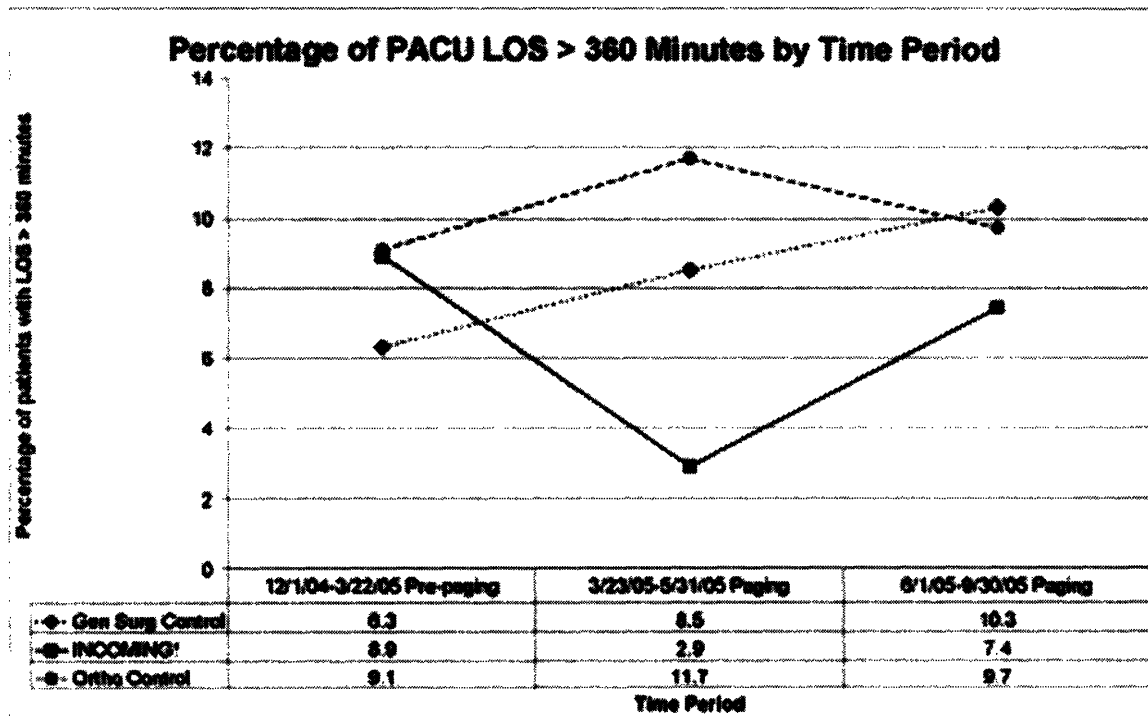


Figure 5 Percentage of PACU LOS > 360 minutes. There was a significantly smaller percentage of patients in this category for the INCOMING! group following paging being added to the system compared to either of the two control groups.

## ***Benefits of the INCOMING! System***

We have demonstrated a system that gleans data from existing OR information systems, augmented by a time-to-discharge-readiness estimate to harness the clinical experience of our PACU nurses in order to improve and systematize communication between the OR, PACU and surgical inpatient units. Although the INCOMING! workflow is more complex than the fully manual system it is intended to replace, INCOMING! has the advantage of being fully automatic. Thus, INCOMING! should uniformly succeed in carrying out this more complex workflow. Furthermore, unlike the standard procedure it replaces (i.e., nurses telephoning the inpatient unit only after the patient is ready for discharge), INCOMING! provides some advance warning (i.e., that a patient has entered the PACU, with an estimated time to discharge readiness) to the inpatient units about future workload. Finally, INCOMING! reverses the direction of the telephone calls, potentially unloading the PACU staff.

## **INCOMING! Performance and Effectiveness**

From a technical standpoint, the INCOMING! system worked as designed. The system successfully consumed the XML data from the OR Dynamic



scheduling system, retrieved pertinent case information and timestamps throughout the day, and propagated this data to PACU staff and patient floors through the hospital intranet and the INCOMING! web tool. Additionally, the paging functions worked as intended and successfully paged resource nurses on patient floors prior to presumed discharge from the PACU so they could initiate 'pulling' their patients from the PACU instead of requiring PACU staff to 'push' patients to the floors.

Our pilot study of INCOMING!'s effectiveness for reducing PACU length of stay demonstrated a significant PACU LOS difference between the INCOMING! intervention group and an orthopedic surgery control group. While the two groups had similar mean PACU LOS prior to initiating the paging feature, the INCOMING! general surgery intervention group LOS was significantly less than the orthopedic surgery group LOS after the paging functions were enabled. The relatively small individual contribution of each service to the PACU workload and the resulting small number of calls from the general surgery floors during the pilot study limited potential contamination between the orthopedic and general surgery intervention groups. The orthopedic surgery and general surgery control groups also had similar increases in mean PACU LOS between pre- and post-paging, while the INCOMING! group was the only group of the three to demonstrate a decreased mean PACU LOS. Therefore, we do not believe that the increased mean PACU LOS in the orthopedic group is related to priority being given to the INCOMING! group to the detriment of the timely transfer of orthopedic patients.

## **Study Limitations**

Due to the limited size and scope of the deployment, the study was underpowered to detect differences between the more similar general surgery control and intervention groups. Using baseline pre-INCOMING! data, we had 80% power to detect a 46 minute change in mean PACU LOS between the pre- and post-paging periods with a two-sided 0.05 significance level for the INCOMING! group and a 48 minute difference between the general surgery control and INCOMING! groups post-paging. Our results were a 26 minute decrease in mean PACU LOS in the INCOMING! group between the pre- and post-paging periods and a 28 minute difference between general surgery control and INCOMING! groups post-paging. However, review of Figure 4 suggests that even this limited and inhomogeneous implementation might have had a favorable effect on PACU discharge times between general surgery groups. After paging was enabled, the intervention group (General Surgery Service with INCOMING! selection) had a mean PACU LOS that was less than the general surgery control group (no INCOMING! selection) for a period of months, although the differences were not statistically significant. Such differences may have been dampened somewhat by patients crossing over from the non-INCOMING! general surgery group to the INCOMING! group if a floor nurse asks about other

patients when calling the PACU after a page from the INCOMING! system. Thus, the implementation of INCOMING! may have resulted in improved communication between general surgery floors and the PACU for all general surgery patients and therefore, differences between the groups may be harder to detect.

The regression of mean PACU LOS toward a single, common value over time reflects a limitation in our study and implementation. Being a pilot study to test the technical performance of the system, some confusion was generated among staff due to uneven application of INCOMING! across PACU patients. To alleviate confusion on the surgical floors, paging was initiated at the request of floor nurses to help isolate patients for which INCOMING! selections had been made and limit their need to manually check the system to determine when to initiate PACU transfers; a similar change to INCOMING! could not be made for the PACU staff. Since only a subset of patients passing through the PACU was included, staff members were not uniformly reinforced to enter estimated PACU LOS into the INCOMING! system since only a fraction of their patients would be listed in INCOMING! at any time. This led to decay in system use over the course of the pilot.

## **Future Direction**

Future plans for INCOMING! include hospital-wide deployment to cover all surgical patients, all surgical services, and all surgical floors. This will address the limitation of the pilot study with a restrictive initial deployment that diminished the penetration and sustained effect of the system. We believe the observed early benefits of the intervention will be sustained when we achieve system-wide deployment that ensures the INCOMING! system is utilized.

We also plan to remove the automatically-populated time estimate of readiness to leave the PACU. For the pilot study, a value of 60 minutes between transfer to the PACU and presumptive readiness for discharge was automatically entered in the INCOMING! system as a default value which could then be changed by PACU staff. In a hospital-wide deployment, every nurse in the PACU will have to interact with INCOMING! to discharge their patients. We expect it will be easier to train the PACU nurses to consistently provide and modify this estimate, alleviating the need to automatically populate the field. This will allow the experience of PACU nurses to provide a more accurate estimate of PACU LOS.

## **Conclusion**

INCOMING! is our first attempt at automatic, real-time communication between the OR, PACU, and surgical floor. As a pilot study, it can be

considered a technical success whose effect decayed over time due to uneven implementation. Only by addressing the limitations of the initial deployment can we confidently measure the system's potential impact on PACU throughput. However, significant reductions in PACU LOS were found early after INCOMING!'s paging functions were enabled, and these results support a positive effect by the INCOMING! intervention. The basic architecture and logic to apply INCOMING! uniformly to all patients leaving the PACU are in place. Thus, given that the cost of full implementation is negligible, and the potential benefits in terms of increased PACU throughput are large, we plan to expand the system to all surgical services. We anticipate that in the future, integrated real-time systems will achieve consistent application and significantly improve hospital efficiency.

This demonstrates an instance where the location of a patient in a clinical process, and a general idea of the physical location of the patient, may be obtained without a dedicated location tracking system but instead through existing systems. Through the integration and reuse of existing data, the location data of the patient is made available to stakeholders in the clinical process utilizing data already being entered into a variety of clinical systems. This integrative approach underscores not only the power of existing data silos when brought together, but also helps one understand the importance and benefit of additional location tracking data that could be overlaid onto existing systems.

## **Computerized Perioperative Data Integration**

Systems that integrate dedicated location tracking systems with other data sources provide a more complete picture of location, state, and process status. The ability to overlay location data on top of other data sources enables sophisticated context-aware computing applications and when used in aggregate, these data allow one to better investigate sophisticated and complex areas such as workflow processes, patient flow, and asset management and planning.

### ***Information Needs in the Surgical Setting***

Surgery is a complicated event where just-in-time access to vital information is instrumental for optimal team functioning. The operating room itself is uniquely risky in that not only is an invasive procedure taking place, but also the patient is unconscious and therefore unable to represent themselves. The smooth and safe functioning of an operating room depends on the coordinated action of a large team of caregivers including physicians, nurses, technicians, transport personnel, and housekeeping personnel, all of whom need ready access to patient and system information that must be integrated from many disparate data sources. The additional emergence of high throughput operating rooms<sup>22-24</sup> requires a solid culture of teamwork to facilitate the increased throughput. The need for comprehensive and continuous OR team synchronization underscores the importance of complete and total patient data, integrated and presented to all team members at the point of care when clinical decisions are being made.

In a typical operating room, most patient information passes through unrelated systems, going unrecorded and underutilized.<sup>25</sup> Benefits of integration are numerous and would yield tremendous advantages, yet many information systems remain far from this goal.<sup>26</sup> The various monitoring and treatment delivery systems do not communicate with each other, so fragmentation of data with redundancy is unavoidable. Information systems require independent log-ins and information display is limited to small screens meant for individual data consumption. Furthermore, many team members must divide their attention between displays. For example, the anesthesiologist interacts with many separate displays, each attached to its own individual computer, for needs such as physiologic monitoring, automated anesthesia record keeping, hospital information system access, order entry and drug/supply chain management.<sup>27</sup> These varied systems divert caregivers from patient care and lead to duplicative effort by staff who are striving to create a comprehensive clinical picture of the patient. This effort could potentially be directed toward other endeavors to increase safety, efficiency, and clinical excellence in the perioperative period.

Issues of communication create a significant barrier to operative and perioperative efficiency and situational awareness. Coordinating equipment and patient preparedness, staffing, room assignments, and scheduling make up the bulk of communication needs.<sup>28</sup> Over a third of communication failures in the operative environment result in visible effects on system processes including inefficiency, team tension, wasted resources, delays, patient inconvenience and errors.<sup>29</sup> Many communication failures occur because of suboptimal timing of information exchange, when information is requested or provided too late to be optimally useful. To diminish the possibility of adverse events, improved information displays should assist in matters of patient preparedness and equipment management, and provide information as it becomes relevant, decreasing interruptions to the operative team's work.<sup>28</sup>

We have undertaken a project to address these issues and develop a system to record all data passing through an operating room, provide unified displays of that data in real time, and create real-time tools to provide augmented vigilance and decision support in the operative setting. The project is a collaborative effort by Massachusetts General Hospital, LiveData, Inc. (Cambridge, MA), and Aptima, Inc. (Woburn, MA) with support from the Telemedicine and Advanced Technology Research Center, U.S. Army Medical Research and Materiel Command. The goal of the project was to develop a prototype system to perform integration and display of information from a variety of disparate systems, ultimately to provide information needed by the healthcare provider at any time, from any location, and in any format necessary. It aims to improve situational awareness and to facilitate the capture and consumption of medical data in the Operating Room of the Future (ORF), a high throughput operating room at Massachusetts General Hospital (Figure 6).

## ***Operating Room of the Future***

The ORF is a 1,315 sq ft space designed specifically to support advanced minimally invasive surgery; it provides a test environment to explore new and innovative perioperative patient / personnel movement and workflow processes and to develop and evaluate new technologies in a live, patient care environment.<sup>22</sup> The ORF accomplishes parallel processing of workflow facilitated by a redesigned operative suite floor plan that includes separate induction, operating, and recovery areas. This allows for preoperative preparation and induction of anesthesia concomitantly with instrument setup in the operating room. Anesthetized patients are then transferred to the operating room as OR setup is completed. At the end of surgery, patients are taken to the early recovery area for emergence from anesthesia or immediately following emergence, allowing the operating room to be turned over more promptly for the next patient. In addition, improved equipment including mobile operating room tabletops with integrated monitoring and dedicated, integrated endosurgical equipment mounted from ceiling booms

facilitates rapid patient transfer and improved OR turnover. The redesigned perioperative and operating room processes lead to improved throughput, allowing additional cases per day in the operating room. The improved throughput derives from a 40% reduction in the non-operative time (i.e., the sum of all intervals not devoted to the operation itself). The non-operative period is when most OR team members prepare for the subsequent case, so reducing non-operative time magnifies the information load on clinical staff and increases the information demand required to provide optimal clinical care.

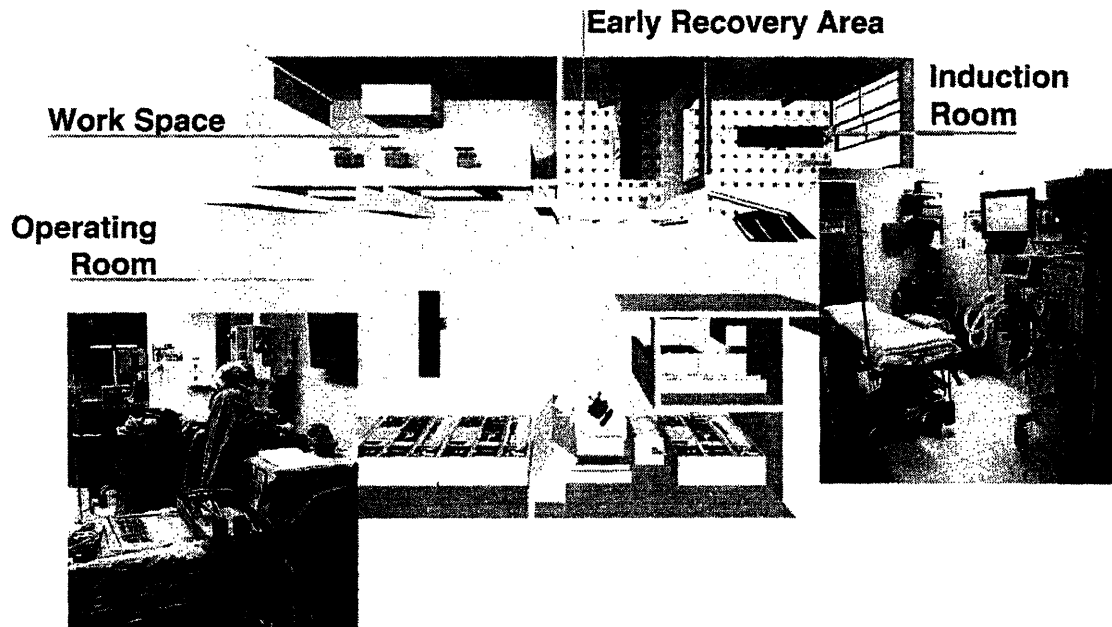


Figure 5 The Operating Room of the Future at Massachusetts General Hospital consists of several separate rooms that help facilitate parallel processing of workflow. The operating room is separate from induction and early recovery areas, allowing equipment to be set up concurrent with anesthesia induction. Once the procedure is complete, patients emerge from anesthesia and are immediately moved to the early recovery area or emerge in the early recovery area itself, allowing the operating room to start turning over more expeditiously.

### ***Prototype System Design and Development***

There is considerable variation in situational awareness by members of the operative team leading to a limited number of individuals in the room holding critical but only partially overlapping information about the case.<sup>30</sup> Having detailed patient and case data prominently displayed in the operating room by a dynamic and collaborative system can help improve coordination, communication, efficiency, and safety, and enhance the quality of information present in information systems.<sup>31</sup> Thus, the case for an integrated, real-time, collaborative display of perioperative and operative data is compelling. In this chapter, we describe the initial prototype of such

a system, starting with the initial specifications and concluding by describing the functionality of the working prototype installed and in daily use at the OR of the Future Project.

## **System Specification Methodology**

The proposed system was required to have three major capabilities: (1) complete data capture and recording, (2) integrated data display and (3) augmented vigilance with decision and workflow support. Methods of system specification development, prototyping, implementation, and evaluation are detailed below. Additionally, the system was intended to run on readily available desk-top personal computers and to be implemented using relatively minor modifications of commercially available software.

The Operating Room of the Future at Massachusetts General Hospital is typical of new operating rooms that are constructed to support minimally invasive surgery and of other ORF initiatives seeking to address the information needs of the perioperative team.<sup>32</sup> We began with a search for input data sources in this technologically advanced operating room. All equipment in the operating room was catalogued and each device's communication capabilities were determined and recorded. Operating room administrative, patient care and hospital information systems were also catalogued and their interface opportunities determined.

Since device data sources under investigation mostly did not implement the IEEE 1073 Medical Information Bus, each device's communication protocol and data definition were analyzed to ascertain that it could be read by a commercially available data integration system. Using the physiologic monitor as an example, we determined that the chosen integration software (LiveData OR RTI Server, LiveData, Inc., Cambridge, MA) could capture all device data, including detailed physiological waveform data and all critical data elements, without data loss and in real time. Similar analyses were performed for data coming from the other OR equipment, as well as administrative, patient care, and hospital information systems.

Specification of the integrated displays was a collaborative effort between human factors designers (Aptima, Inc., Woburn, MA) and the clinicians who would be the end users. A "human factors engineering" approach was undertaken, which is an approach to medical system design that centers on the user and the workflow.<sup>33</sup> Initial characteristics of the physical displays, the information presented on the display, and the form of the information was synthesized from expert opinion and understanding the work domain and workflow. A multidisciplinary team of operative room physicians and nurses, medical informatics experts and user interface designers then worked iteratively to create the prototype display.

## ***System Development and Deployment***

### **Input Data Sources**

Most devices in the Operating Room of the Future with digital user interfaces have a digital output including such key devices as the laparoscopic surgical insufflator, physiologic monitors, breathing circuit gas analyzers, level-of-consciousness monitors, the anesthesia machine, and medication infusion pumps. Communication protocols have been obtained for all of these devices. At the time of this report, data capture and integration for all devices except the infusion pumps has been achieved.

Hospital information systems provide a rich source of patient data awaiting integration. At the Massachusetts General Hospital, part of the Partners Healthcare network, most of these information systems were internally developed, and so presented something of an integration challenge. Our institution also uses an internally developed computerized system called the Nursing Perioperative Record for perioperative documentation including time stamps for key milestone events. An OR Dynamic scheduling system provides administrative data for each case including procedure, patient name and scheduling surgeon. An Anesthesia Information Management System (Saturn, Drager North America, Telford, PA) records anesthesia interventions, but without integration with other systems. Patient drug allergy data are obtained from a system-wide database called the Partners Enterprise Allergy Repository. An internally developed computerized provider order entry system forces recording of allergy information before patient orders can be written, ensuring that allergy data are available. Interfaces with each of these systems have been developed, utilizing XML and HL-7 messaging where possible.

Several operating rooms at Massachusetts General Hospital, including the Operating Room of the Future, are equipped with a location tracking system (Radianse, Lawrence, MA) to track patients, assets and OR personnel. The tracking system uses dual active radiofrequency / infrared technology to achieve room-level spatial and 10-second temporal resolution. Integration is through an XML messaging system. Patients and OR staff are tracked throughout the OR suite, and the tracking data are used to populate a dynamic staff list included in the integrated OR information display. The list of personnel present is updated throughout the case; personnel no longer present are designated as such. Timestamps of tracking system events, such as changes in location, are broadcast via an XML feed and stored in a SQL database, allowing improved auditing of patient progress through the perioperative workflow and more accurate and timely representation of patient movement into and out of the operating room.



Using a fast, consumer-level personal computer with a consumer-grade video card (dual Xeon processors 3.06GHz, 2GB RAM, Nvidia Quadro FX5200), the computerized data integration system successfully captures, records and displays real-time data simultaneously from a number of devices including the laparoscopic surgical insufflator, physiologic monitor, breathing circuit gas analyzers, level-of-consciousness monitors and the anesthesia machine, along with information systems including the Nursing Perioperative Record, the Anesthesia Information Management System, the Radianse location tracking system, the Partners Enterprise Allergy Repository and the OR Dynamic scheduling system (Figure 7). Work continues to identify and integrate additional devices and information sources.

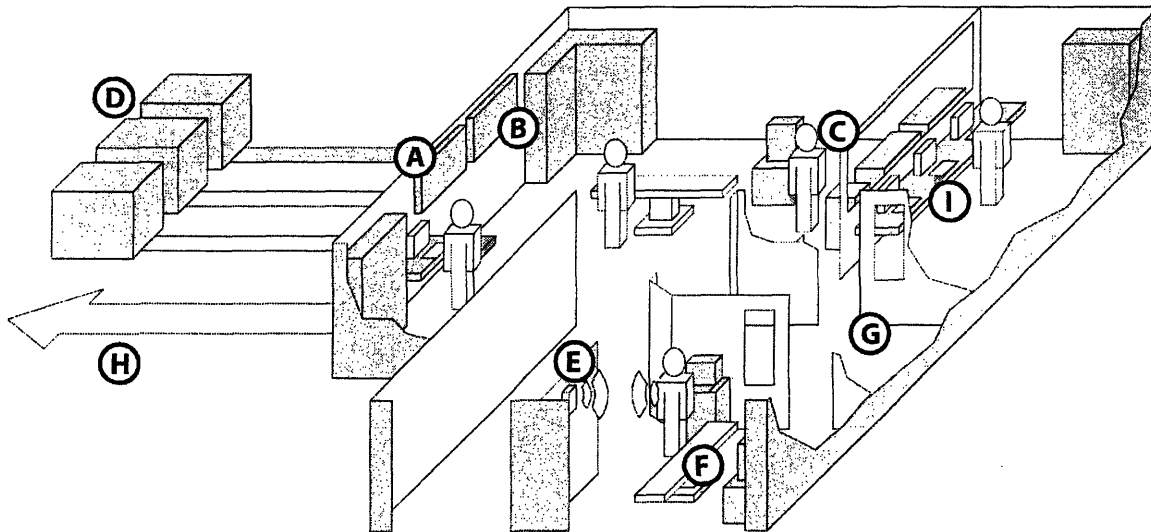


Figure 6 The integrated information display (A), positioned directly adjacent to the surgical video display (B), collects information from a number of devices and information systems present within the operative suite (C) such as the physiologic monitor and Nursing Perioperative Record along with external information sources (D) including the Partners Enterprise Allergy Repository and OR Dynamic scheduling system. A Radianse location tracking system (E) also provides input to the system. Information sources from other areas of the operative environment, including the induction room (F) and early recovery area (G), also integrate into the system and provide valuable hooks into the operating room. Data created by the system, such as the imminent end of surgery deduced from entries into the OR computers and from OR equipment status changes, can ultimately be made available to other applications outside of the operative environment (H) or the system, as a whole, can be made available for viewing on a personal computer (I).

## Display of Real-Time Integrated Data

The characteristics of an ideal display are based on the experiences of ORF personnel. Large OR display boards need to address flexibility, task management, problem solving, resourcing, shared awareness, orientation, communication, and collaboration.<sup>34</sup> Specifications that the display must be

visible and legible in any point in the operating room, up to 9 meters away, dictate a large aspect display to maintain adequate font size and graphical resolution. This requirement of legibility, along with the demand for information content balanced by available wall space, requires use of a large, 42" LCD screen.

Prior to starting this project, the ORF already had a large aspect plasma display for live display of the surgical procedure. This provides continuous display of images from laparoscopes or cameras mounted in the OR lights when surgery is being performed in the ORF. This allows team members not directly in the surgical field to "self-update" to surgical events. It also minimizes interruptions of the surgical team's work by reducing other team members' need to ask for progress updates. A continuous visual display of the operation also allows the rest of the team to see most of what the surgeons see when a visually-manifesting surgical complication develops.

The second display for the integrated perioperative data system is positioned directly adjacent to the surgical monitor (Figure 8). The integrated data display contains a number of persistent and dynamically advancing elements based on the stage of the current case (Figure 9). The objective of this display is to present an at-a-glance "Gestalt" understanding of the patient and the case to complement the surgical video.



Figure 7 The integrated display resides directly adjacent to the surgical display. The close proximity of two large displays mandated that the design avoid detracting from the pre-existing surgical display, which is often in use during cases. The system is designed to provide adequate size of text and graphical resolution to be visible and legible to anyone in the room, requiring the use of a large 42" LCD display.

Persistent information panes are arranged framing the tabbed, dynamically advancing panes. Persistent information panes include patient demographics

including name, age, weight, and medical record number, case information such as diagnosis, procedure, laterality, and type of anesthesia, and staffing information including nursing, anesthesia, and surgical teams. This information serves to uniformly orient members of the team to the procedure, patient, and personnel during the case and during staffing changes. Allergies and precautions are also displayed throughout the case along with a progress log that provides a timeline of the case with events recorded and time stamped. The progress log allows for easy knowledge acquisition of events that have occurred in the procedure and what the current stage of the procedure is. We are currently investigating other information that would be deemed sufficiently important in the high level orientation of team members to warrant continuous display, such as laboratory values, current orders, and comorbid conditions.

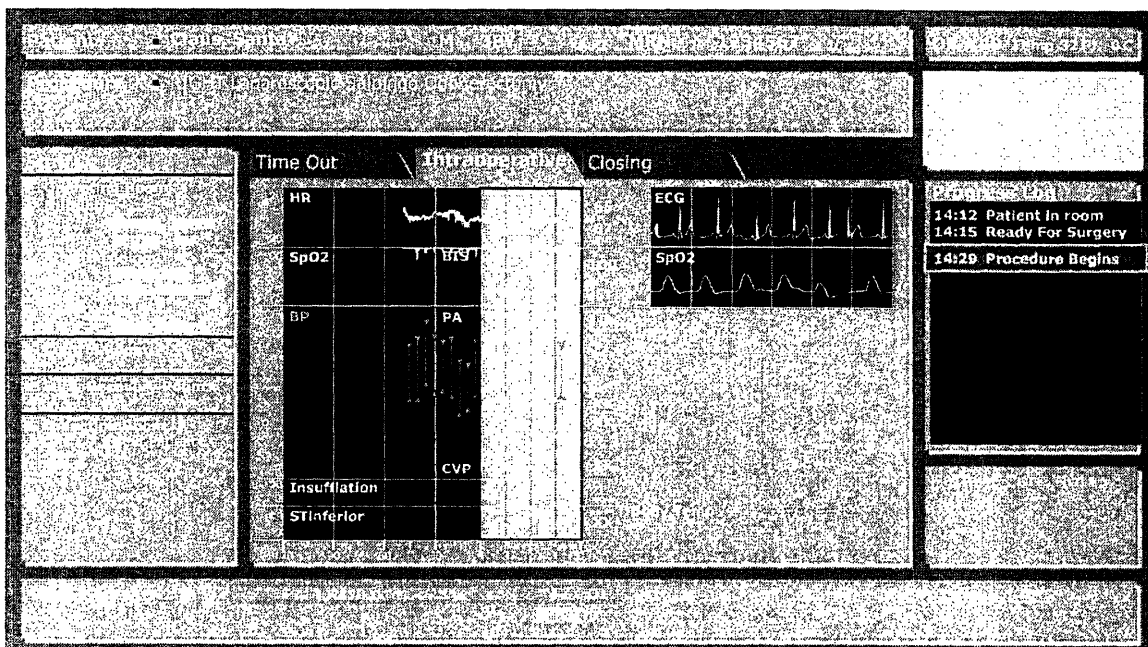


Figure 8 The integrated display consists of a series of persistent and dynamically advancing panes. Information such as the patient's name and demographics, procedure and laterality, staffing list, allergies and progress log remain consistent across all stages of the case. Information in the pane may change, such as new events in the progress log or staffing changes updated via the location tracking system, but the panes themselves are always present and provide the same information. The central area consists of dynamically advancing tabbed panes which present the time out information, physiologic trends and real-time information, and end of case information concerning post-op needs, orders, and assignments depending on the stage of the case. Tabs progress automatically based on case events collected from attached systems.

Dynamically advancing panes are organized through a tabbed scheme at the center of the display to illustrate the current, prior, and future stages in the case progression. Tabs for the "time out" process, intraoperative, and closing time periods progress automatically based on the stage of the case. The time out pane provides case verification to reinforce such data elements

as patient identity, procedure and laterality. The intraoperative pane provides real-time physiologic monitoring with trend data over the last two hours and detailed data over the last five minutes. Additional information such as estimated blood loss and urine output can be presented graphically and numerically along with time stamps to provide an estimate of data staleness. The closing pane provides information on the post-anesthesia care unit (PACU) assignment and post-op notifications, needs, and orders.

## **Use of SVG and System Flexibility**

Flexibility of the entire system is a design mantra that informs the display. The display itself is created using scalable vector graphics (SVG) and as a result, is able to also be displayed in a web browser that has the Adobe SVG viewer installed. SVG is an XML markup language for creating vector graphics and is an open standard created by the World Wide Web Consortium. This allows for very rapid changes to the system display, especially crucial when prototyping from user feedback, and a practically infinite degree of customizability. With an arbitrary granularity possible, from having unique displays for each surgical team to having a single display standard for the entire institution, we provide a small subset of screen display options to cover the basic types of procedures that would have significantly different subsets of data available. For example, a laparoscopic case would require display of the surgical insufflator while a case not using the insufflator need not display that blank screen real estate for a device that will not be used.

## ***Context-Sensitive Information Display***

We have successfully created a system that displays all critical perioperative data pertaining to the OR patient, as well as key elements of upstream and downstream workloads, on a single large format display. These data include: surgical field video, output from surgical devices, physiologic and level of consciousness monitors, anesthesia delivery systems, infusion pumps and hospital information systems. We also incorporate data from an active RFID patient and personnel tracking system, thus populating the OR personnel roster with instantaneous data.

Presenting the vast amount of information from hospital information systems, anesthesia and surgical systems, surgical equipment, and workflow support systems in a usable and cohesive way on a single wall-mounted display is a challenge. The information must be rich, complete, accurate, and useful for team situational awareness and also visible and legible anywhere in the operating room, up to nine meters away. We have accomplished this cross platform and cross disciplinary integration of digital information sources in the operative and perioperative environment. This

allows for improved context-sensitive information display and decision support where a concise subset of critical data is projected, improved access to information through real-time equipment, material and personnel readiness information, and sophisticated utilization of information to improve workflow, safety and visualization of information that was previously unattainable.

## ***User Assessment Plan***

The immediate next step in this project is to assess users' perceptions of the system's success at achieving the goal of creating a unified picture of critical perioperative patient data. We are doing this through pre- and post-installation surveys. Pre-installation surveys administered prior to the prototype installation introduced members of the clinical team, including physicians and nursing staff, to the system through educational material and then questioned them on their perceived utility of such a system. Personnel also completed the Safety Attitudes Questionnaire (SAQ), a derivative of the Flight Management Attitudes Questionnaire (FMAQ) used in commercial aviation, to assess attitudes about safety. The SAQ was generated by focus groups of healthcare providers, review of literature and discussions with experts to generate a tool designed to assess six scales: teamwork climate, job satisfaction, perceptions of management, safety climate, working conditions, and stress recognition. Thus we used it to obtain baseline data about ORF team members' perceptions about the safety climate prior to system prototype installation.

Post-installation questionnaires will again assess utility of the system and its component elements after clinical teams have used the system for ten weeks. We will also conduct a second administration of the Safety Attitudes Questionnaire. Also included is a modified version of the Questionnaire for User Interaction Satisfaction (QUIS). This tool was designed to assess users' subjective satisfaction with specific elements of the human-computer interface. The QUIS measures overall system satisfaction along six scales along with eleven specific interface factors including screen factors, terminology and system feedback, learning factors, system capabilities, technical manuals, on-line tutorials, multimedia, voice recognition, virtual environments, internet access, and software installation. As designed, the questionnaire has been configured according to the needs of our interface analysis, only including sections of interest to us.

## ***Future Direction and Decision Support***

Looking farther ahead, we believe that part of the overall benefit of the system will be the creation of new information and data streams through the integration and processing of information. By integrating with the hospital

patient record, OR scheduling information, and patient location information obtained through the indoor positioning system, completely automatic process monitoring and exception detection functions will be enabled in the perioperative environment. As a proof-of-concept, we have demonstrated fully automatic detection and notification of wrong patient / wrong location errors.<sup>35</sup> More fundamental applications of this concept include sending automatic alerts to provide necessary surgical equipment to ORs about to start cases for which the needed devices are missing.

These forms of decision support need not be purely geographically based. For example, Xiao, et al, have demonstrated the use of vital signs data flowing from networked monitors to help establish the patient in- and out-time for real-time operating room management.<sup>36</sup> With additional complementary information including real-time location tracking and events from an anesthesia information system, sophisticated and intelligent PACU scheduling may occur for better utilization of available bed space and improved bed management with patient turnover. Through the use of physiologic information and automatically generated events through several clinical sources, the system could evaluate parameters indicating readiness for patient transport to the PACU. As a result, PACU bed management could be informed through the system of when a patient is actually likely to be ready and adjust accordingly for procedures taking an undue length of time. Other opportunities to utilize the integrated data to provide new information are being investigated.

Decision support presents fertile ground for utilizing the summation of operative and perioperative data to provide additional information concerning the patient. Utilizing physiologic information, it has been shown that decision support applications can be augmented through expert systems that help create and validate alarms based on physiologic parameters; the integration of information from several sources improves reliability of alarms, decreases false alarms, has fewer missed alarms, and creates alarms that are more clinically acceptable.<sup>37-39</sup> This provides a basis for utilizing integrated medical data to provide clinically relevant "smart" alarms during the perioperative process for decision support and augmented vigilance in the operative environment. Algorithms to extract relevant information from patient, procedure, and OR data to help guide intraoperative processes are required and future work will focus on this area.<sup>26</sup>

## **Opportunities for Decision Support**

We are developing augmented vigilance and decision support components by cataloguing input sources, including devices and information system interfaces, and systematically seeking opportunities for data integration and synthesis of available information. The goal is to identify instances in which clinicians and staff in the operating room manually perform this integration during patient care, and also to investigate new opportunities for data

integration and synthesis. A near miss catalogue is being created based on expert experience from anesthesiologists, surgeons and nurses; near misses are events or situations that could have negatively impacted patient outcome if not detected and corrected. The data source and integration catalogue is being cross-referenced with the near miss catalogue to identify instances where near-miss detection and correction could be improved through more comprehensive recording and integration of operating room data.

The cataloguing and cross referencing of data sources against typical near miss events is revealing potential targets for near miss reduction. Clinical scenarios are being developed to be used in proof of concept demonstration and testing under a simulated operative setting based on feasibility of decision support algorithm, frequency of near miss event, and impact of timely intervention.

## **Total Perioperative Process Coverage**

Additional interfaces and data sources are being investigated to extend the system beyond the operating room and ultimately, be able to provide a complete picture of the patient throughout the entirety of the perioperative process. Opportunities for data integration and processing are being investigated to increase the value provided by the system as a whole to provide decision support, augmented vigilance, and workflow support, increasing both efficiency and safety in the perioperative environment by sophisticated utilization of information that was previously unattainable.

## Summary

Location data may be utilized for a number of functions in the healthcare setting. Dedicated location tracking systems, while still not prevalent, afford a potent source of data for sophisticated decision support, workflow surveillance, and asset management. At the same time, utilizing an accurate source of time-stamped data, entered manually or through a bar-coded scheme, may be used as a suitable proxy for physical location detection.

We have demonstrated the development and use of both of these types of systems, one utilizing a location tracking system to track staff and patients in an operating room and the other utilizing existing data sources manually entered by perioperative personnel as a proxy for location. These systems demonstrate the real-world application of a multitude of data sources integrated together into a single cohesive unit. Location data is only one part of such a system, with dedicated tracking information a subset of that.

Other modalities of location data, such as bar codes and manual timestamps, provide information not available through an item's actual physical presence. While raw location data speaks toward an individual's or an asset's physical location, it is not as useful in determining a position within a clinical process as, for instance, a manually entered timestamp denoting a particular step in a process. At the same time, a timestamp does not guarantee a patient's physical position in the same way a dedicated tracking system does. However, together they provide a more complete representation of a patient's location, both in space and within a workflow process.

Ultimately, the goal of such systems demonstrated in this manuscript is to provide information consistent with local resources and variables, leading to context-aware applications that are not only able to provide information, but provide information based on the users local environment, current needs, and opportunities for intervention. This leads to more useful information and decision support functions due to the improved contextual nature of provided information. This type of application holds the promise of increasing workflow efficiency and improving the quality of and satisfaction in healthcare delivery.



## Works Cited

1. Navy field hospital tests patient tracking in Iraw. 2003. (Accessed at [http://www.dcmilitary.com/army/standard/8\\_11/national\\_news/23364-1.html](http://www.dcmilitary.com/army/standard/8_11/national_news/23364-1.html).)
2. Want R. RFID. A key to automating everything. *Sci Am* 2004;290(1):56-65.
3. Sandberg WS, Hakkinen M, Egan M, et al. Automatic detection and notification of "wrong patient-wrong location" errors in the operating room. *Surg Innov* 2005;12(3):253-60.
4. Marjamaa RA, Torkki PM, Torkki MI, Kirvela OA. Time accuracy of a radio frequency identification patient tracking system for recording operating room timestamps. *Anesth Analg* 2006;102(4):1183-6.
5. Glabman M. Room for Tracking: RFID technology finds the way. In: *Materials Management in Health Care*; May 2004.
6. Amber R, Everett VB. Emergency department patient tracking: a cost-effective system using bar code technology. *J Emerg Nurs* 1996;22(3):190-5.
7. Rotondi AJ, Brindis C, Cantees KK, et al. Benchmarking the perioperative process. I. Patient routing systems: a method for continual improvement of patient flow and resource utilization. *J Clin Anesth* 1997;9(2):159-69.
8. MASCAL: RFID Tracking of Patients, Staff and Equipment to Enhance Hospital Response to Mass Casualty Events. (Accessed at <https://www.wiisard.org/papers/events.pdf>.)
9. Becker C. A new game of leapfrog? RFID is rapidly changing the product-tracking process. Some say the technology--once costs drop--could displace bar-coding. *Mod Healthc* 2004;34(28):38, 40.
10. Davis S. Tagging along. RFID helps hospitals track assets and people. *Health Facil Manage* 2004;17(12):20-4.
11. Neil R. On a roll. RFID moves toward patient safety. *Mater Manag Health Care* 2005;14(3):20-3.
12. Modeling Patient Flows Through the Healthcare System. (Accessed at <http://www-rcf.usc.edu/~maged/publications/chapter1text.pdf>.)
13. Mahaffey S. Optimizing patient flow in the enterprise. Hospitals can combine process management with information technology to redesign patient flow for maximum efficiency and clinical outcomes. *Health Manag Technol* 2004;25(8):34-6.
14. Schuerenberg BK. Keeping tabs With RFID. *Health Data Manag* 2005;13(10):39-40, 2, 4 passim.
15. Waddle JP, Evers AS, Piccirillo JF. Postanesthesia care unit length of stay: quantifying and assessing dependent factors. *Anesth Analg* 1998;87(3):628-33.
16. Zollinger TW, Saywell RM, Jr., Smith CP, Highland D, Pfeiffer B, Kelton GM. Delays in patient transfer: postanesthesia care nursing. *Nurs Econ* 1999;17(5):283-90.

17. Tessler MJ, Mitmaker L, Wahba RM, Covert CR. Patient flow in the Post Anesthesia Care Unit: an observational study. *Can J Anaesth* 1999;46(4):348-51.
18. Dexter F, Epstein RH, Penning DH. Statistical analysis of postanesthesia care unit staffing at a surgical suite with frequent delays in admission from the operating room--a case study. *Anesth Analg* 2001;92(4):947-9.
19. Dexter F, Tinker JH. Analysis of strategies to decrease postanesthesia care unit costs. *Anesthesiology* 1995;82(1):94-101.
20. Marcon E, Kharraja S, Smolski N, Luquet B, Viale JP. Determining the number of beds in the postanesthesia care unit: a computer simulation flow approach. *Anesth Analg* 2003;96(5):1415-23, table of contents.
21. Horak D. Designing and implementing a computerized tracking system: the experience at one level I trauma center emergency department. *J Emerg Nurs* 2000;26(5):473-6.
22. Sandberg WS, Daily B, Egan M, et al. Deliberate perioperative systems design improves operating room throughput. *Anesthesiology* 2005;103(2):406-18.
23. Hanss R, Buttgereit B, Tonner PH, et al. Overlapping induction of anesthesia: an analysis of benefits and costs. *Anesthesiology* 2005;103(2):391-400.
24. Torkki PM, Marjamaa RA, Torkki MI, Kallio PE, Kirvela OA. Use of anesthesia induction rooms can increase the number of urgent orthopedic cases completed within 7 hours. *Anesthesiology* 2005;103(2):401-5.
25. Merrell RC, Jarrell BE, Schenkman NS, Schoener B, McCullough K. Telemedicine for the operating room of the future. *Semin Laparosc Surg* 2003;10(2):91-4.
26. Rattner DW, Park A. Advanced devices for the operating room of the future. *Seminars in Laparoscopic Surgery* 2003;10(2):85-9.
27. Sandberg WS, Ganous TJ, Steiner C. Setting a research agenda for perioperative systems design. *Seminars in Laparoscopic Surgery* 2003;10(2):57-70.
28. Moss J, Xiao Y. Improving operating room coordination: communication pattern assessment. *Journal of Nursing Administration* 2004;34(2):93-100.
29. Lingard L, Espin S, Whyte S, et al. Communication failures in the operating room: an observational classification of recurrent types and effects.[see comment]. *Quality & Safety in Health Care* 2004;13(5):330-4.
30. Guerlain S, Adams RB, Turrentine FB, et al. Assessing team performance in the operating room: development and use of a "black-box" recorder and other tools for the intraoperative environment. *Journal of the American College of Surgeons* 2005;200(1):29-37.
31. Plasters CL, Seagull FJ, Xiao Y. Coordination challenges in operating-room management: an in-depth field study. *AMIA Annual Symposium Proceedings/AMIA Symposium* 2003:524-8.
32. Marvik R, Lango T, Yavuz Y. An experimental operating room project for advanced laparoscopic surgery. *Seminars in Laparoscopic Surgery* 2004;11(3):211-6.

33. Dain S. Normal accidents: human error and medical equipment design. *Heart Surg Forum* 2002;5(3):254-7.
34. Lasome CE, Xiao Y. Large public display boards: a case study of an OR board and design implications. *Proceedings / AMIA Annual Symposium* 2001:349-53.
35. Sandberg WS, Hakkinen M, Egan M, et al. Automatic detection and notification of "wrong patient-wrong location" errors in the operating room. *Surgical Innovation* 2005;12:253-60.
36. Xiao Y, Hu P, Hu H, et al. An algorithm for processing vital sign monitoring data to remotely identify operating room occupancy in real-time. *Anesthesia & Analgesia* 2005;101(3):823-9.
37. Oberli C, Urzua J, Saez C, et al. An expert system for monitor alarm integration. *Journal of Clinical Monitoring & Computing* 1999;15(1):29-35.
38. Krol M, Reich DL. Development of a decision support system to assist anesthesiologists in operating room. *Journal of Medical Systems* 2000;24(3):141-6.
39. Navabi MJ, Watt RC, Hameroff ST, Mylrea KC. Integrated monitoring can detect critical events and improve alarm accuracy. *Journal of Clinical Engineering* 1991;16(4):295-306.