Automatic Detection and Notification of “Wrong Patient—Wrong Location” Errors in the Operating Room

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When procedures and processes to assure patient location based on human performance do not work as expected, patients are brought incrementally closer to a possible “wrong patient—wrong procedure” error. We developed a system for automated patient location monitoring and management. Real-time data from an active infrared/radio frequency identification tracking system provides patient location data that are robust and can be compared with an “expected process” model to automatically flag wrong-location events as soon as they occur. The system also generates messages that are automatically sent to process managers via the hospital paging system, thus creating an active alerting function to annunciate errors. We deployed the system to detect and annunciate “patient-in-wrong-OR” events. The system detected all “wrong-operating room (OR)” events, and all “wrong-OR” locations were correctly assigned within 0.50 ± 0.28 minutes (mean ± SD). This corresponded to the measured latency of the tracking system. All wrong-OR events were correctly annunciated via the paging function. This experiment demonstrates that current technology can automatically collect sufficient data to remotely monitor patient flow through a hospital, provide decision support based on predefined rules, and automatically notify stakeholders of errors.

Key words: **radio frequency identification tracking, wrong-operating room events, automated patient location system, hospital process monitoring.**

Perioperative systems design describes a rational approach to managing the convergent flow of patients having procedures from disparate physical and temporal starting points, through the operating room (OR), and then to such a place and time (eg, hospital bed or home) where future events pertaining to the patient have no further impact on OR operations.[1] In a complex, large OR suite, getting the correct patient to the correct OR almost always happens without problems. However, when procedures and processes to correctly locate patients based on human systems fail, patients are brought incrementally closer to a possible “wrong patient—wrong procedure” error. To the extent that wrong-location events disrupt the smooth flow of patients through the OR suite, cause anxiety for patients and staff, and create disruption in the general workflow, good perioperative systems depend on suppressing them and averting their effects as quickly as possible.

Despite the widespread use of automatic tracking technologies in most other fields that involve moving assets between locations, monitoring and controlling the movement of patients in the medical environment remains almost entirely a manual process. This is partly due to the lack of a tracking technology that is suited to the unique features of the health-care environment.

Reports of patient tracking technologies being used in the OR have begun to appear that describe both the limitations of the technology and anecdotal reports of their effectiveness.[2] The recent advent of automatic tracking systems based on active radio-frequency identification (RFID) raises the potential to provide real-time, room-level patient location data. Proof-of-concept installations to track patients in emergency departments have been reported, albeit without results to date,[3] and active RFID tagging of patients has been used to deter elopement and abduction of high-risk patients in hospitals for some time. Our own experience with active RFID tracking systems in the OR environment suggests that the data they provide are robust and can be compared with a process model of expected procedure to prevent wrong-location events or to automatically flag them as soon as they occur.

In this paper, we demonstrate that active RFID patient tracking accurately and quickly detects the location of dummy patients and that inclusion of an auto-paging function reliably alerts designated personnel when wrong-location events occur. This specific example proves the concept that sufficient data

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can be automatically collected with the use of current technologies to

1. remotely monitor a complex process such as patient flow through a medical environment,
2. provide decision support based on predefined rules, and
3. automatically notify process managers in real time when error conditions are detected.

Although we have chosen the specific example of a rare event that is always caught before it can have any impact on patient outcomes, we believe that this demonstration can be generalized to any medical situation in which proper execution depends on having assets in the right place at the right time.

Methods

Automatic detection of errors requires a way to distinguish an error from expected events. One way to achieve this is to continuously compare actual events with those that are expected under normal conditions.

Process Modeling

A process model that is developed to describe the routine functioning of the system can be used in a multistep process to compare the sequence, timing, and location of actual events. For this proof of concept demonstration, we developed a process model that included the assigned OR for a patient's case and a designated starting point in the patient check-in and gowning area. All other locations were considered erroneous, except for transient localizations on the way to the assigned OR. The process model is shown in Figure 1.

Location Data

We deployed an active infrared (IR)/RFID indoor positioning system (IPS) (Radianse, Lawrence, MA) in four adjacent ORs and their associated preoperative preparation areas. These are shown in a map in Figure 2. Additionally, the upstream check-in and gowning area, the hallways between the ORs, upstream and downstream areas, and the postanesthesia care unit were all covered by the IPS. The IPS has a 10-second temporal resolution and room-level spatial resolution. The IPS uses small transmitters (known as 'tags') whose locations are continuously detected by wall-mounted receivers placed on the

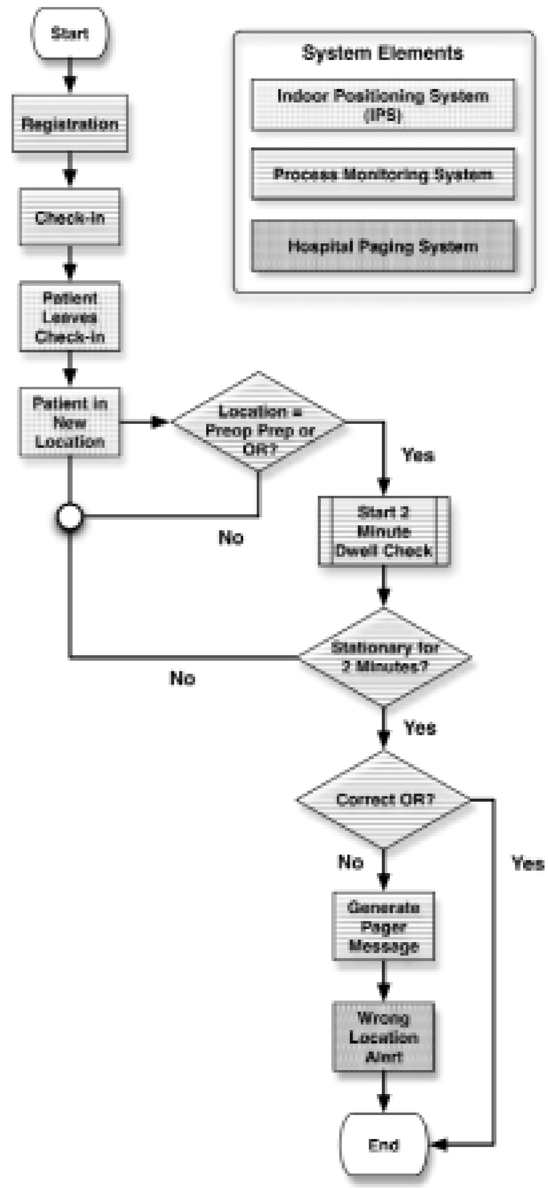

Figure 1. Process model of the used to support actual vs expected comparisons of patient location during transport from the check-in and gowning area to the preoperative preparation areas for the assigned and wrong operating rooms. Three systems—the active radiofrequency identification indoor positioning system, the process monitoring system, and the hospital paging system—are invoked in an integrated fashion to support the actual vs expected comparisons and propagate alerts to process managers.

information system's local area network (LAN). The IPS tags use active radiofrequency and infrared co-transmission to achieve robust room-level patient and staff localization.

Wrong-Location Detection Software

This project was done as part of a technology demonstration effort whose goal was to integrate, in real time, multiple sources of information to enable process monitoring and error detection and to propagate alert messages (Captus) (G.E. Healthcare, Milwaukee, WI). These data are manually gathered in computerized databases by personnel during routine perioperative care. Data are also gathered from automatic systems, including the IPS described above.* Expected patient locations were obtained via interface with the Dynamic OR Scheduling system in routine use at our institution. For the purpose of this study, dummy patients with fictitious medical record numbers were scheduled into ORs equipped with the IPS during off hours when no actual patients were present.

Figure 2. Ground plan map of the four operating rooms (ORs) and associated preoperative preparation areas monitored by the indoor positioning system. ORs and their associated preoperative prep areas are labeled, as are the locations of the active radiofrequency identification (RFID) indoor positioning system receivers (denoted by "IPS"). During testing of the wrong-location detection system, active RFID tags representing dummy patients were scheduled into one of the four ORs. Next, each tag was actually taken to the preoperative preparation area of an OR different from that which was scheduled, and the correct functioning of the system was assessed. In the case of OR 41, which has no preoperative preparation area, the tag was taken into the OR.

Inspection of the OR map in Figure 2 reveals that some patients pass by many ORs on their way to the correct location. This traffic pattern raises the likelihood that nuisance alerts of wrong-location events will be generated if the system is too sensitive. Preliminary work in which routine transports of actual patients were monitored indicated that requiring a dwell time of 2 minutes in a given location was sufficient to prevent spurious wrong-location detections caused by patients passing IPS-equipped ORs on the way to their correct locations.

Error Annunciation

The process monitoring software displays patient locations on a dynamic map of the IPS-monitored space that updates automatically as locations change. Additionally, the process monitoring software generates alert messages to be sent to pagers and other short messaging devices. Our hospital uses a commercial paging system to send short alphanumeric messages to clinicians and process managers. This system has a web interface that supports machine-generated automatic paging. We used this interface to automatically pass text messages from the process monitoring system to study personnel when wrong-location errors were detected.

Wrong-OR Testing

We assessed the sensitivity and specificity of the wrong-OR location detection function implemented in the Captus process monitoring system. We also measured the system latencies. The functionality of the IPS and the location monitoring and display software were verified before the testing sessions by an investigator wearing an IPS tag. The tagged investigator went to each area monitored by the IPS and used the clinical computer workstation in that area to verify that the location was correctly detected and displayed on the dynamic map of the OR area that would be visible to OR personnel.

After the investigator had assured that all system components were operational, assessment was accomplished as follows: IPS tags were given dummy patient medical record numbers, registered

*The ultimate goal of the Captus development project was to create a process flow control tool that could provide managers and administrators with a complete situational awareness of perioperative functioning, including preoperative, OR, and postanesthesia care unit status, workload, and capacity.

into the scheduling system, and assigned to one of the four IPS-monitored ORs (see Figure 2) before the test. To signal the start of the perioperative process, dummy patients were checked into the Captus process monitoring system. The check-in procedure activated the location surveillance algorithm.

Next, single IPS tags were taken by an investigator from the OR check-in area to an IPS-monitored OR different from the assigned OR. Specifically, tags were taken to the relevant wrong OR pre-op holding area (see Figure 2) and placed on an OR table. For a dummy patient assigned to any one of the four IPS monitored test ORs, there were three possible wrong locations: namely, the preop preparation areas of the other 3 ORs. OR 41 (see map) does not have a formal pre-op prep area. When OR 41 was the planned wrong location, the dummy patient tags were placed on an operating table within OR 41.

Accurate localization to the planned wrong OR preparation area was assessed by the investigator, who viewed the wrong location on a dynamic map of the ORs and tag locations generated by the Captus process monitoring software. A stopwatch was used to note the elapsed time (in seconds) between the arrival of the dummy patient in the wrong pre-op holding area and the first accurate localization of the tag.

Next, the investigator measured the elapsed time between the arrival of the dummy patient in the wrong pre-op holding area and the arrival of the expected error message on the pager. The content of the alpha-message in the page was also assessed for accuracy (ie, the wrong location described by the page was the actual location of the dummy patient). These data were used to calculate the sensitivity and specificity of the test system for detecting wrong-OR events. The latencies of the IPS and the hospital paging system were also calculated.

During proof-of-concept testing, the system was used observationally in our ORs. All patients receiving care in ORs monitored by the IPS are routinely tracked from the pre-OR check-in area, through their assigned pre-op preparation areas and ORs, and then to the postanesthesia care unit. With institutional review board approval, IPS tracking data from routine patient OR encounters was made available to the Captus process monitoring system.

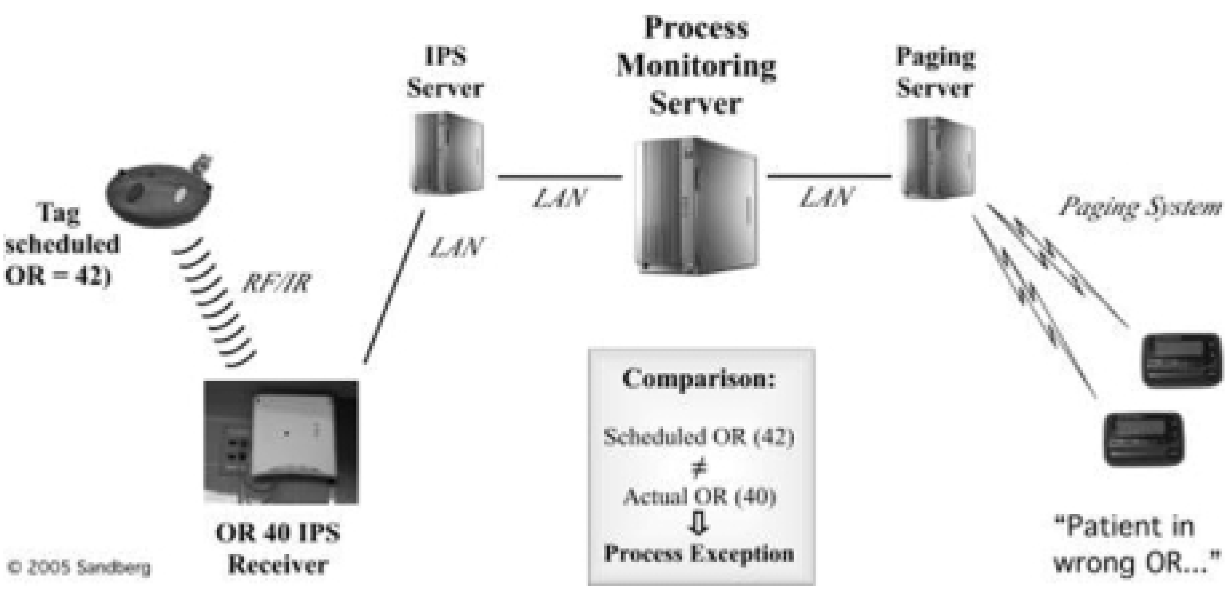

Figure 3. Illustration of the signal paths for information flow in the wrong-location detection system. Location information first travels via radiofrequency and infrared dual emission from the indoor positioning system (IPS) tags to an IPS receiver. Only the serial number of the tag is transmitted. The IPS receivers are connected to the IPS server via the hospital local area network (LAN), behind the hospital firewall. Tag serial numbers are associated with patient identifiers by the IPS server. Because no patient identifiers are transmitted, the IPS link is compliant with the Health Insurance Portability and Accountability Act of 1996. Patient location data is passed to the process monitoring server by via secure LAN connection. The actual vs expected location comparison is made by the process monitoring server by making reference to operating room schedule data. Alerts are passed through secure LAN connection to the paging service server, and sent by radiofrequency link to individual pagers.

Results

A schematic representation of data flow between technologies and servers is shown in Figure 3. Tags representing dummy patients were recognized and localized by the IPS system whenever a tag was within range of an IPS receiver. The IPS server made location data available to the process monitoring server with a 30-second refresh rate. The process monitoring software compared expected vs known locations for IPS tags according to the process model shown in Figure 1. If a tag remained in an unscheduled location for more than 2 minutes, the process monitoring software generated an error message. Error messages contained all relevant information needed to recover from the error, including an error alert and type, patient medical record number, planned location, and actual location (see Figure 4, Panel A). This message was sent to the paging system server and then via the paging system to a researcher's pager (Fig 4, Panel B). The beeper to page was configurable within the Captus process monitoring software.

An example of the dynamic map generated during wrong-location testing is shown in Figure 5. The dynamic maps were based on the actual floor plans of the ORs. This can be appreciated by comparing Figure 5 with Figure 2. The dynamic maps are simplified for clarity, however. Additionally, visual cues guiding the user's attention to the area of interest, such as selective enlargement, borders and shadowing, and color-coding (not apparent in the grayscale reproduction) are all used to make the dynamic maps simple and intuitive to read.

Dummy patients were correctly located when taken to their correct OR 100% of the time. The system detected all wrong-OR events (sensitivity = 100%). All wrong-OR locations were correctly assigned, both on the dynamic map of OR locations and in the content of the pager alert messages (specificity = 100%). In separate experiments, the system localized and annunciated all

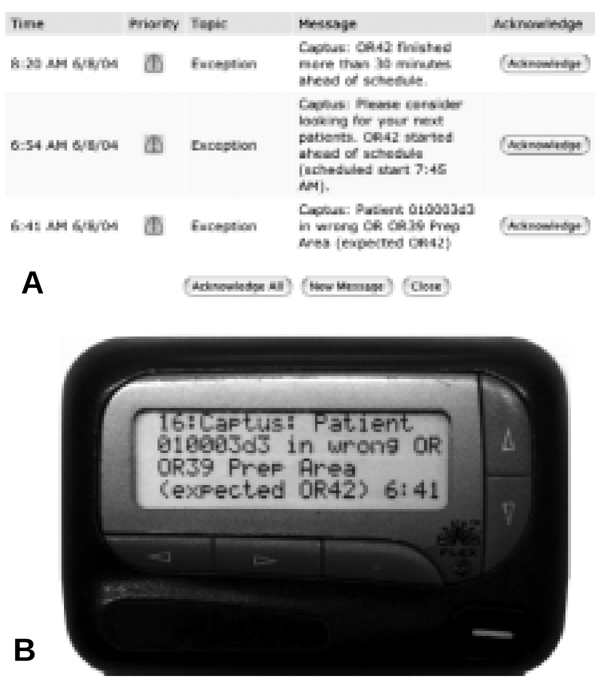

Figure 4. Panel A shows an example of a series of alerts generated by the process monitoring software. The process monitoring software interface is available as a Web page from any personal computer running an Internet browser from inside the hospital firewall. Note that multiple types of process exceptions are detected and generate alerts. **Panel B** shows an example of a wrong-location alert that appears on the screen of a process manager's pager. In the test setting, the system was configured to pass only the indoor positioning system tag serial number via the paging system to assure compliance with the Health Insurance Portability and Accountability Act of 1996.

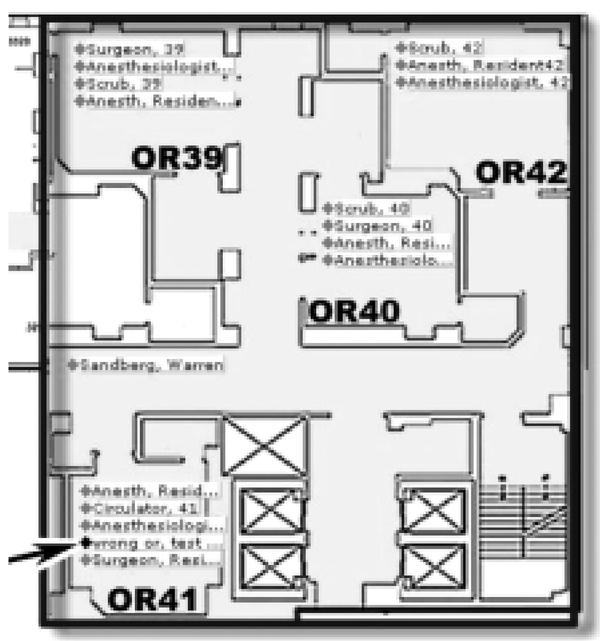

Figure 5. Screen shot of the dynamic location map presented to the user by the process monitoring software. A tag representing a dummy patient scheduled for operating room (OR) 39, 40 or 42 is actually located in OR 41 (arrow). Also shown are the locations of OR staff. Having staff location data available allows alerts to be passed directly to the appropriate person actually closest to the patient who triggered the alert.

erroneous locations when as many as 13 wrong-location events were created simultaneously. All error messages were received within the latency period determined for single location error events (see below).

We measured the latency of the IPS and process monitoring software to display the location of a tag taken to the wrong OR and the latency of the complete system, including the paging function. The latencies for the display and annunciation of wrong-location events are broken down by scheduled and actual OR in Table 1. For all wrong-location tests combined, the average time from arrival in the wrong location to visualization of the tag location in the dynamic map generated by Captus was 0.51 ± 0.28 minutes (mean ± SD). This corresponded to the measured latency of the RF/IR tracking system version deployed at the time. For all locations taken together, the time from arrival in the wrong OR to receipt of page was 3.66 ± 0.28 minutes, which is the sum of (1) the tracking latency, (2) a required 2-minute dwell time in the wrong OR (set in Captus to avoid spurious alerts), and (3) the paging system latency. We independently measured the paging system latency at 60 seconds.

When broken down by scheduled and actual locations, there were no significant differences between specific scheduled/wrong OR pairs and the group mean time between arrival in the wrong location and receipt of page (Table 1). However, for one scheduled/wrong OR pair, visualization of the wrong location in the dynamic map was significantly faster ($P < .001$) than the group mean for all wrong location detections, whereas for another scheduled/wrong pair, visualization was significantly slower ($P < .05$) (Table 1).

Table 1. Performance of the wrong location detection and annunciation system

Assigned OR[a]	*Actual OR*[b]	*Time to detection in actual OR*[c] *(min, avg ± SD)*	*Time to page received*[d] *(min, avg ± SD*	*Location message correct*[e]
39	40	0.39 ± 0.22	3.63 ± 0.26	10/10
	41	0.62 ± 0.26	3.71 ± 0.25	10/10
	42	0.46 ± 0.15	3.65 ± 0.14	10/10
40	39	0.29 ± 0.08[f]	3.60 ± 0.06	10/10
	41	0.51 ± 0.16	3.67 ± 0.15	10/10
	42	0.46 ± 0.29	3.77 ± 0.47	10/10
41	39	0.42 ± 0.16	3.81 ± 0.29	10/10
	40	0.50 ± 0.25	3.72 ± 0.35	10/10
	42	0.47 ± 0.31	3.52 ± 0.24	10/10
42	39	0.98 ± 0.47[g]	3.77 ± 0.26	10/10
	40	0.45 ± 0.22	3.44 ± 0.37	10/10
	41	0.60 ± 0.27	3.69 ± 0.16	10/10

[a]The operating room (OR) to which the dummy patients were assigned.
[b]The OR areas to which the active RFID tags representing patients were actually taken.
[c]The average time (in minutes) for the tag to appear in the process monitoring system's dynamic map display after arriving in the actual OR location.
[d]Average time (in minutes) between arriving in the actual OR location and the receipt of an error message on the investigator's pager.
[e]The accuracy of the message (stated location matches actual location).
[f]Average time to detect and display dummy patients in this actual OR location was statistically significantly less ($P < .001$) than the group mean for all wrong location detections.
[g]Average time to detect and display dummy patients in this actual OR location was statistically significantly greater ($P < .05$) than the group mean for all wrong location detections.

Discussion

Use of computerized process monitoring and automatically generated reminders in medicine dates back to least 1976, when McDonald[4] noted that practice performance by medical house officers improved when automated reminders tailored to individual patients were offered but declined to baseline when they were not provided. Regardless of level of training, performance was uniformly bad in the absence of reminders and rose dramatically—again independent of training level—when they were provided. From this, McDonald concluded that poor performance was caused by overwhelming task demands rather than by any remediable characteristic inherent to the practitioners themselves.[4] In today's OR environment, this must be more true than ever. Recently, it has been demonstrated that process monitoring and automatic alerts yield clinically important improvements in outcomes when applied to medical care ordering.[5] There is no reason to believe that other aspects of the care process, including seemingly mundane items such as patient location, would not benefit from automatic process monitoring, error detection, and alerting.

Our hospital has 50 contiguous ORs, each performing two to three cases daily. Thus, there are many opportunities for wrong-location events involving patients to occur. Interestingly, during interviews with the OR staff, most individuals had personal or indirect experience with a wrong-location event involving a surgical patient. Of course, such events are always caught by the system of checks and double checks put into place to prevent site, side, and procedure errors in surgery.

However, this project was less concerned about detecting and flagging wrong-location events in the OR and more about proving that available technology can support automatic safety systems that extend to the entire hospital, without limitation by building and care unit boundaries. This specific example proves the concept that current technology can automatically (1) collect sufficient data to remotely monitor a complex process such as patient flow through a hospital, (2) provide decision support based on predefined rules, and (3) automatically notify process managers in real time when errors are detected. That being said, the Captus process monitoring system did function as expected when it was used in an environmentally valid setting such as tracking actual patients having surgery. During the testing period, an actual wrong-location event was detected when a patient was legitimately taken by the anesthesia team to an unscheduled area for preoperative preparation.

The process monitoring system described in this report has limitations. For example, surgery and OR assignments came from an interface to the hospital OR dynamic scheduling system. Thus, this information was highly unlikely to be subject to errors beyond those present in the original systems. However, IPS tracking tags were assigned manually the night before surgery and placed on the patient during the check-in process. Thus, the application of the tracking technology as implemented for this study was subject to typographic errors during tag assignments and misidentification errors during tag placement. If the system were deployed for production purposes, we would use a bar code reader to scan the barcodes on the patient ID band and the tracking tag to make the assignments via machine reading, and we would assign and place tags during the check-in process.

A further limitation of this study was that we did not fully use the localization potential of the IPS. During the study and going forward, selected staff at our institution wear IPS tracking tags at work. In future iterations of such a tracking project, we would use the staff location data to send pager alerts to the designated staff person nearest to the geographic site of the error.

Conclusions

Automatic process control systems require high-quality data input, a process model of normal procedure, and a way to alert managers when errors occur. Active tracking systems are the essential data input source to provide real-time, room-level patient location data in the health-care environment. These data are robust, meaning that data collection is complete because it occurs automatically, without the need for human intervention, and the system is reliable. Robust patient location data can be compared to a process model of expected procedure using process monitoring software and business rules written to prevent wrong-location events or to automatically flag them as soon as they occur. By incorporating an annunciation pathway that also does not require human interaction to retrieve information (ie, by using the paging system to send alerts about process exceptions), we have created a system that can be used to automatically monitor and control patient care processes spread over the entire hospital.

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