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The SmartOR: a distributed sensor network to improve operating room efficiency

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Abstract

Background Despite the significant expense of OR time, best practice achieves only 70% efficiency. Compounding this problem is a lack of real-time data. Most current OR utilization programs require manual data entry. Automated systems require installation and maintenance of expensive tracking hardware throughout the institution. This study developed an inexpensive, automated OR utilization system and analyzed data from multiple operating rooms.

Study design OR activity was deconstructed into four room states. A sensor network was then developed to automatically capture these states using only three sensors, a local wireless network, and a data capture computer. Two systems were then installed into two ORs, recordings captured 24/7. The SmartOR recorded the following events: any room activity, patient entry/exit time, anesthesia time, laparoscopy time, room turnover time, and time of preoperative patient identification by the surgeon.

Results From November 2014 to December 2015, data on 1003 cases were collected. The mean turnover time was 36 min, and 38% of cases met the institutional goal of ≤30 min. Data analysis also identified outlier cases (>1 SD from mean) in the domains of time from patient entry into the OR to intubation (11% of cases) and time from extubation to patient exiting the OR (11% of cases). Time from surgeon identification of patient to scheduled procedure start time was 11 min (institution bylaws require 20 min before scheduled start time), yet OR teams required 22 min on average to bring a patient into the room after surgeon identification.

Conclusion The SmartOR automatically and reliably captures data on OR room state and, in real time, identifies outlier cases that may be examined closer to improve efficiency. As no manual entry is required, the data are indisputable and allow OR teams to maintain a patient-centric focus.

Keywords Laparoscopic efficiency · Patient safety · Operating room efficiency · Operating room management · Emerging technology · Wireless technology

Operating room management is a complex and dynamic process that requires extensive pre-planning and has to take into account very frequent and often significant changes during the operative day. With emergency add-on cases, cancelations as well as delays due to a myriad of reasons, keeping an operating suite functioning at optimal efficiency to maximize total case numbers per day while ensuring patient safety is no easy task. Timely room turnover and cases lasting longer than expected are metrics institutions regularly examine to look for opportunities for improvement [1]. From the moment the patient enters the operating room to the time they exit, numerous problems can arise which can all significantly delay the case.

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Recognizing this, many efforts and approaches have been made to attempt to address this issue, and to follow the steps of a surgical procedure and the cycle of the operating room. OR staff and hospital administration have both been documenting certain parts of an operation in the electronic medical record in an effort to have an idea of room turnover times as well as patient in-room and out-of-room times. In most institutions, an administrative board will meet regularly to evaluate these data to see whether certain goals are (or are not) being met, and decide what steps need to be implemented to improve any points of delays. There are also human factors involved in OR efficiency including the way an OR suit is organized and directed by the coordinator. Something as fundamental as staff personality traits, and being risk averse can result in unused OR time and inefficiencies [2].

There are many weaknesses of manually inputting OR information into the system. As it relies on an individual (typically nursing staff or anesthesia staff) to document times, there is always a risk of inaccuracy. With so many events, responsibilities and activities handled by all members of the OR team, data entry often falls to the wayside and details such as time points are often entered in the system after the fact. This leads to an unreliable retrospective analysis of OR data. At the same time, the data points documented by OR nurses typically only include patient in-room and out-of-room times, whereas anesthesia staff record intubation and extubation times. In our institution, the administrative board examines turnover times and any delays in first case of the day start times and base their evaluation of OR performance on these factors. Previous works tried to install measurement systems to track OR efficiency and assess workflow of new staff organization such as Rotondi et al. [3] who installed a patient tracking system around the perioperative area. Although this system is not OR specific and still requires some manual entry, it showed good results on assessment of new surgical teams. Other papers focus more on analyzing existing data from the OR such as patient vital signs [4] or anesthesia management systems [5, 6] to reach the same result.

There exists a need to further segment a surgical procedure and the OR cycle into more discrete components. This way, specific parts of an operation can be evaluated, statistical models built for each case type, and sources of delays and inefficiencies can be more precisely identified for improvement. In tandem, this information can also be used for more efficient scheduling once reliable case lengths for each type of surgical procedure can be obtained. A significant amount of OR scheduling and scheduling changes are done during the actual day of the cases because of all the decisions staff have to take. At the same time, it is also important to have OR suite and resource allocations defined up to 2–3 months before the day of surgery [7]. A generated statistical model of these procedures and OR organization can be used for real-time OR management and notification (e.g., if a case is taking longer than expected). In an effort to accomplish this, the SmartOR was created [8, 9].

Methods

Prior to installation of the sensors in the ORs, hospital administration, the nursing staff, as well as the surgeons that operated in the rooms planned to have the SmartOR installed in them were informed of the process. The complete system was demonstrated, and all concerns related to confidentiality and privacy were adequately addressed prior to system installation. The OR procedure-related data collection for this study came exclusively from the SmartOR sensor network. Each sensor was custom built and then installed into two high-volume operating rooms in the main OR suite at our institution. These rooms were considered to be the best representative sample of the OR suite due to the diversity and number of cases, especially laparoscopic, being performed there.

Three simple sensors were constructed to capture key activities and events in the OR which allowed for the data to be correlated with segments of the OR room cycle and room states (Fig. 1). A pressure mat was installed at the doorway to detect when the patient entered and exited the room, a motion and light intensity sensor to capture ventilator bellows movement as well as when the OR lights

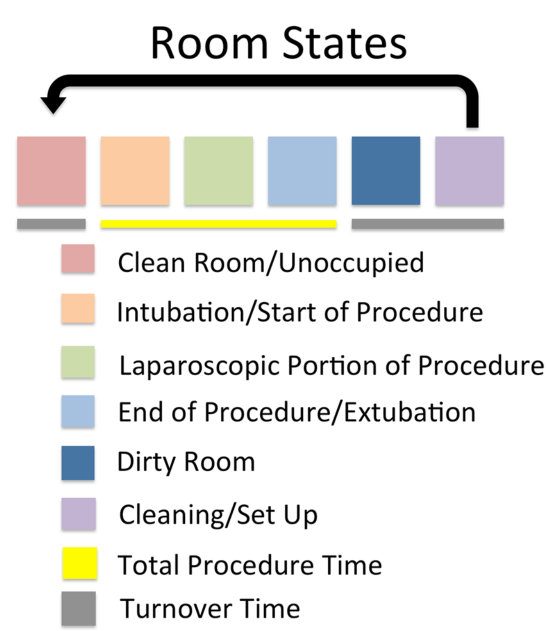

Fig. 1 Segments of the operating room cycle

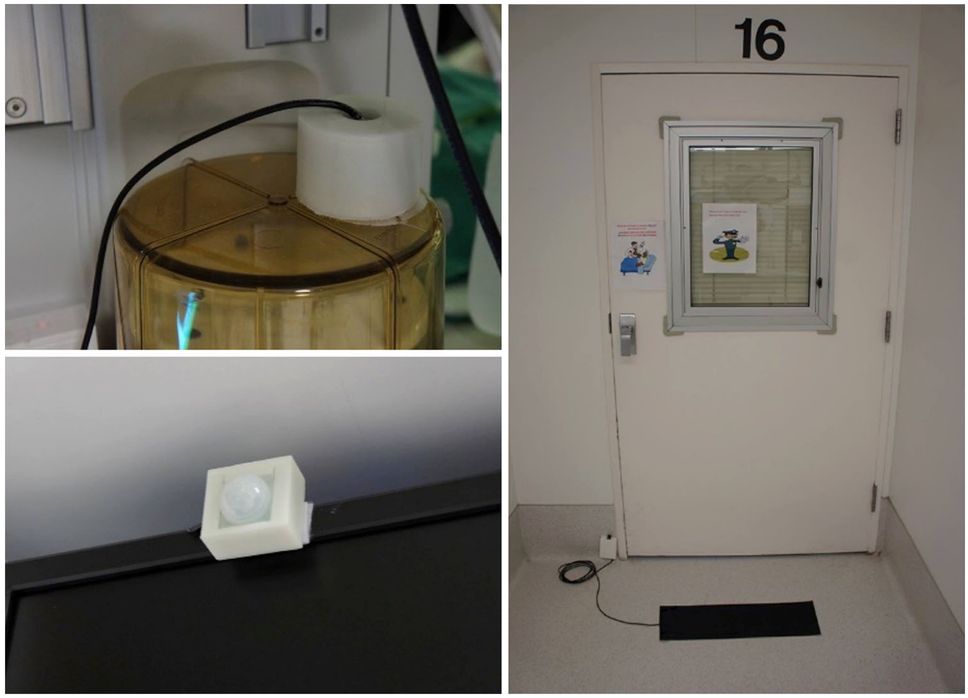

Fig. 2 Installed sensors of the SmartOR

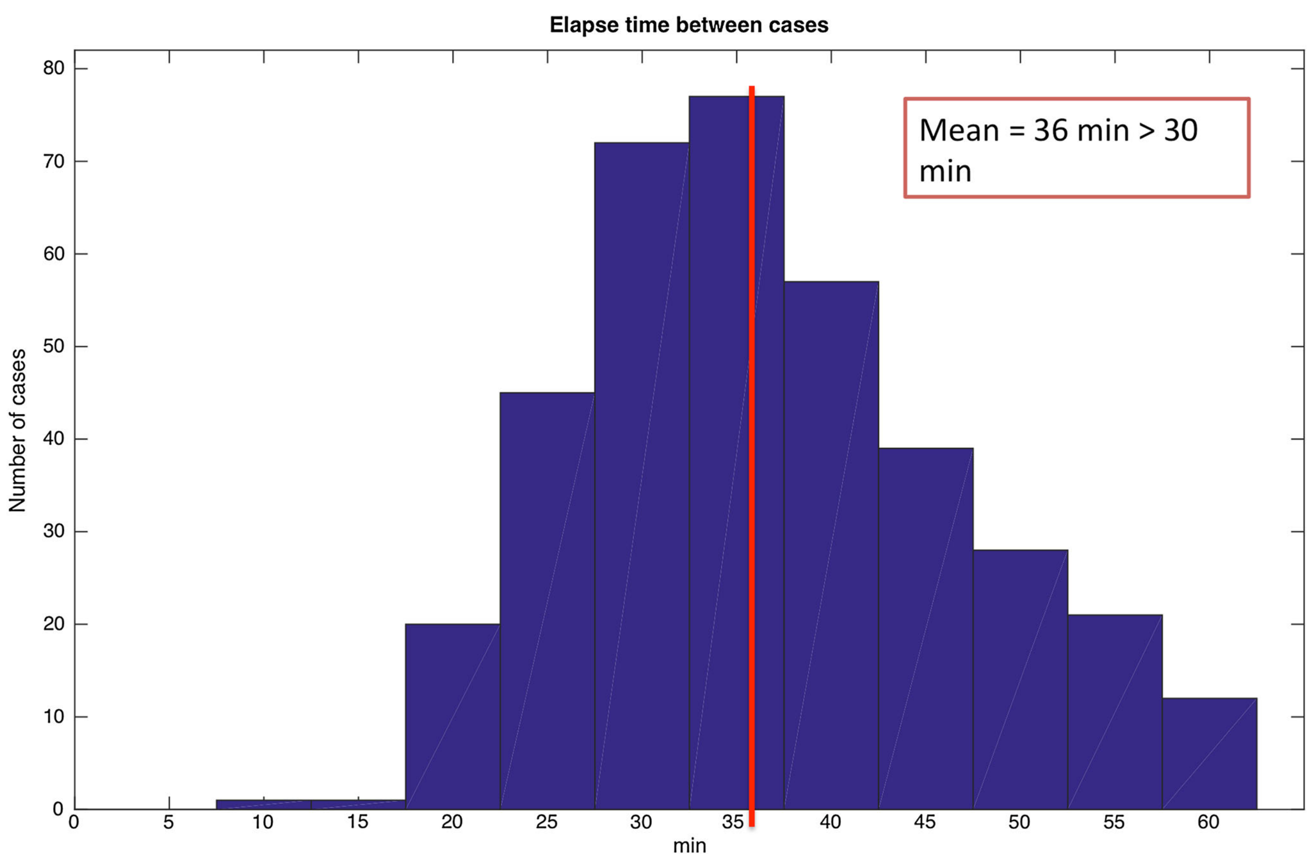

Fig. 3 Turnover time analysis indicating 72% of 374 captured turnover times exceed 30 min

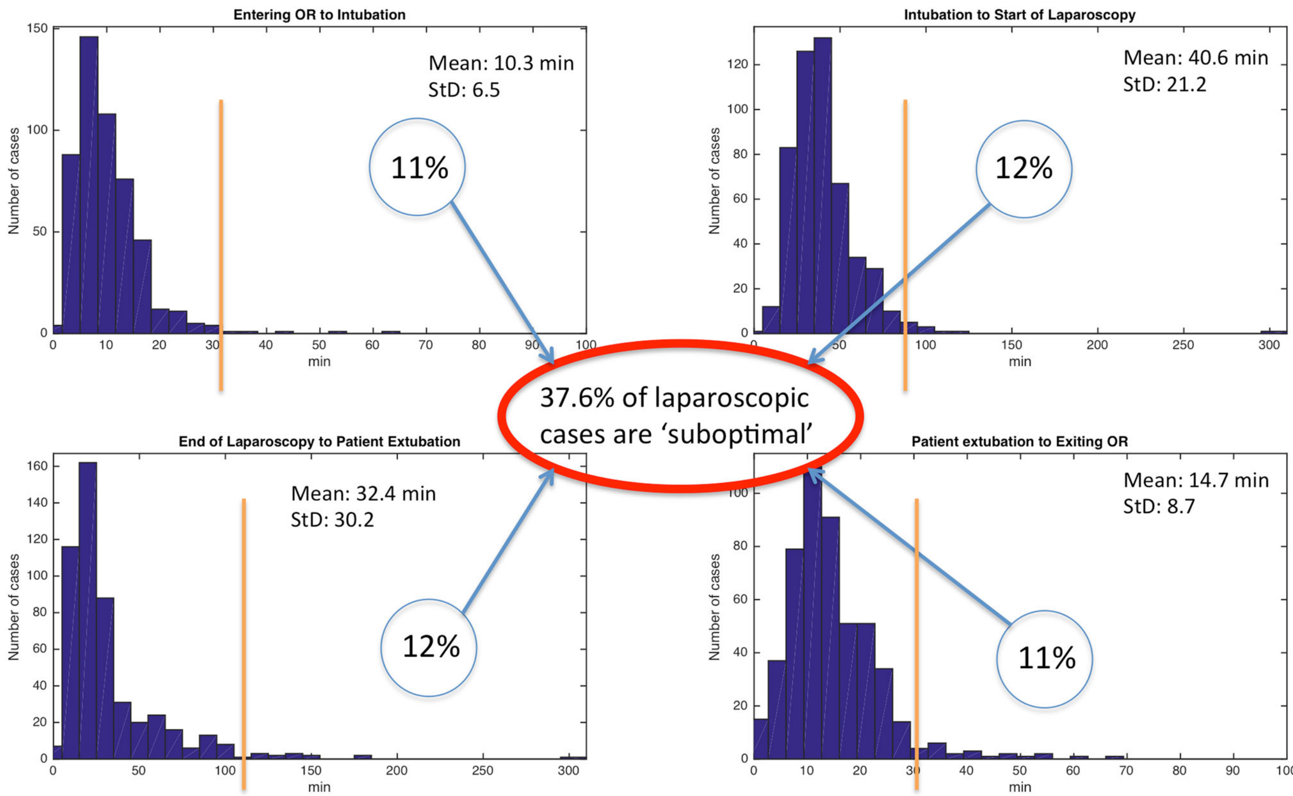

Fig. 4 Segmentation of the operation and identification of cases exceeding 1 standard deviation beyond the mean

were dimmed for the laparoscopic portion of the case was placed on the ventilator, and a general motion detector was placed in the corner of the OR to determine whether the room was occupied at any given time (Fig. 2). These sensors underwent several design iterations to ensure robustness and reliability prior to installation for this study.

The sensors were wirelessly networked in parallel to the institutional wireless internet, which allowed for remote access and system monitoring. The SmartOR was on and running continuously beginning in November of 2014 with data collection occurring 24 h a day, and seven days a week to ensure capture of weekend and evening cases. Data were consolidated and spreadsheets generated to be able to match sensor data with OR case data including procedure type and nursing/anesthesia notes and then processed using MATLAB.

To understand key events in the preoperative space, radio frequency identification (RFID) sensors were installed in the area of the hospital where patients were held prior to being taken to the OR. Three surgeons who predominantly operate in the two ORs where the sensors were installed had unique RFID tags placed on their pagers so that when they entered, the preoperative area to identify the first scheduled patient of the day that time point would be automatically documented.

Results

From November 2014 to December 2015, intraoperative data were collected on 1003 cases. Of these, 504 were laparoscopic, and the remainder a combination of general surgery, vascular, plastics, neurosurgery, and colorectal procedures. The first step of data processing was to compare sensor-triggered events with what was documented in the chart by the nursing staff. In comparing the SmartOR acquired times that the patient entered the room and exited the room to the nurse's manual-entry time, the Pearson's coefficient was 0.8 indicating that there was a consistent positive correlation between the sensor-acquired data and what was manually entered into the medical record.

Over 600 segments of time between cases were detected with the SmartOR system, and out of these, 374 turnover times were identified. Turnover time was defined as the time between two cases that were scheduled to immediately follow one another. Any time between 2 surgical cases that exceeded 60 min was deemed not to be a true turnover time and excluded from the analyses, as there would have been many potential alternative reasons for the extended time between those cases (purposeful scheduling, cancelations, room changes, etc.). Our institutional goal is a 30-min turnover time, and we determine the mean to be

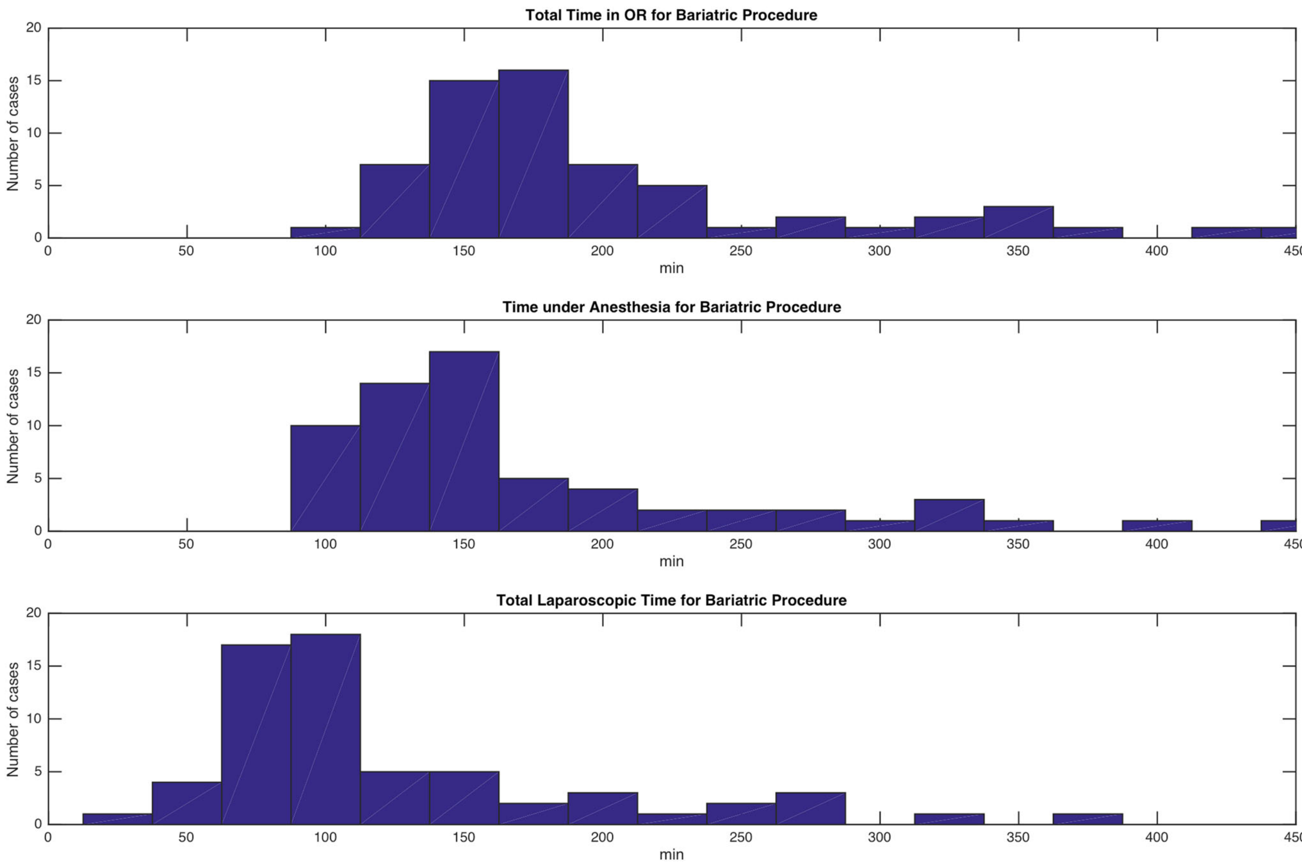

Fig. 5 Analysis of 63 laparoscopic Roux-en-Y procedures with intraoperative endoscopy with clear visualization of outliers

36 min with 72% of cases exceeding the 30-min threshold (Fig. 3).

As the SmartOR system is capable of segmenting the OR cycle, all laparoscopic cases were identified by looking for operations where there was the characteristic decrease in ambient light intensity after the operation was under way. Using this method, 504 laparoscopic cases were then segmented into 4 parts of the OR cycle, and means along with standard deviations calculated. Once mean values were calculated and standard deviations were determined, the percentage of case segments that exceeded 1 standard deviation from the mean were identified (Fig. 4). When isolating out the 63 captured laparoscopic Roux-en-Y procedures paired with intraoperative endoscopy, the average time spent on tracked segments of the OR cycle was calculated and clear outliers (greater than 2 standard deviations from the mean) identified. Outliers were isolated and the operative records for those cases were examined to determine potential causes for case prolongation (Fig. 5). In looking at how cases progressed through an operative day, a downward trend in the total case length along with decreases in laparoscopic times was observed.

When focusing on RFID acquired data, and correlating events in the preoperative area with OR start times, it was seen that an average of 22 min passed between patient identification in the preoperative area by the surgeon to the patient entering the OR. The data also showed that the sampled surgeons were visiting the patients on average at 7:19 a.m. for a scheduled 7:30 a.m. in-room time, which translated into consistently late case starts, beginning at approximately 7:40 a.m.

Overall, the system and hardware design was robust, with the only component requiring rare changes being the pressure sensor mat as it was subjected to direct wheel contact on a daily basis. Otherwise, all systems performed reliably on our dedicated wireless network.

Discussion

In reviewing the results captured by the SmartOR system, it was confirmed that the automatically detected turnover times were equivalent to what nursing and management were collecting and entering manually. The SmartOR data processing took longer at the beginning of the study, but as the sensor data output was refined and noise filtering implemented, data from weeks and months was able to be processed over the course of a few days. With the ultimate goal of the system being a platform that could provide real-time operating room state information, and serving as a system that may automatically notify OR management if specific case types have exceeded expected time lengths, this was a big step.

As the statistical analyses were completed, cases that deviated far from the mean (in excess of 6 standard deviations) were examined, and in nearly all situations, extenuating circumstances that resulted in excessive case lengths and/or delays were identified. To have the ability to track this, and notify OR management in real time as these events were occurring would allow for reallocation of OR resources more efficiently. Building a statistical model of OR behavior, case type lengths, and even personnel/resource allocation based on data collected from the SmartOR system also allows for the creation of OR optimization techniques in the future.

The authors envision the SmartOR as part of an operating room management system where the OR events are captured by the sensor arrays and transmitted as real-time status updates on a digital screen and paired with the patient and surgical data. At the same time, case-related data are continuously collected in a database for a statistical model generation that may ultimately guide operative scheduling and planning to increase OR efficiency.

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Compliance with ethical standards

Disclosures Albert Y. Huang, Guillaume Joerger, Vid Fikfak, Remi Salmon, Brian J. Dunkin, Barbara L. Bass, and Marc Garbey have no conflicts of interest or financial ties to disclose.

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