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# INTEGRATING SIMULATION MODELING AND MOBILE TECHNOLOGY TO IMPROVE DAY-OF-SURGERY PATIENT CARE

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## ABSTRACT

Past studies have shown that there are communication and coordination delays that can disrupt delivery of care to the patient on the day of surgery. Hospitals have introduced information technology to improve the ability of staff to react in a timely fashion, but with mixed success. The research team is developing a mobile application that tracks patient progress, allowing staff to retrieve/send status instantly, and provide updates to others responsible for specific patients. In this paper, the researchers present how a detailed day-of-surgery simulation model (previously used for process improvement) has been integrated to communicate with the mobile app to provide day-of-surgery scenarios for user-testing the app at the hospital. This advancement in simulation capability is expected to provide significant research benefits resulting from the ability to test the app's usability and train staff without having to disrupt the actual delivery of care.

## 1 INTRODUCTION

Perioperative systems are among the most complex groups of healthcare services where a high volume of patients, each with specific characteristics and required tasks are required to be prepared for surgery. Perioperative systems refer to the collective group of services that are performed before, during and after a surgery. The process begins when a patient arrives at the surgical center or hospital, either the patient or the person acting on behalf of the patient is briefed, and finally the patient is prepped for surgery. This is referred to as the preoperative (Preop) phase. In the intraoperative phase, the patient is transferred to the operating room (OR) and administered anesthesia, the required surgical procedures are performed and the phase ends when the patient is transferred from the operating room for post-surgery recovery, typically with an initial stop in an intensive care unit. The postoperative phase includes the recovery period as well as the discharge process for the patient from the surgical center or hospital. Figure 1 represents an overview of the perioperative care process.

The entire process is complex not only because of the different stakeholders (patient, surgeon, clinician, nurse, hospital staff and administration) but also because all activities must be performed without compromising the patient's safety. The challenge lies with achieving efficient, cost-effective healthcare without compromising patient safety. This has an impact on both the operations as well as financial effectiveness of the hospital (Ryan et al. 2013). All in all, it can be a very daunting situation (Gilmour 2005).

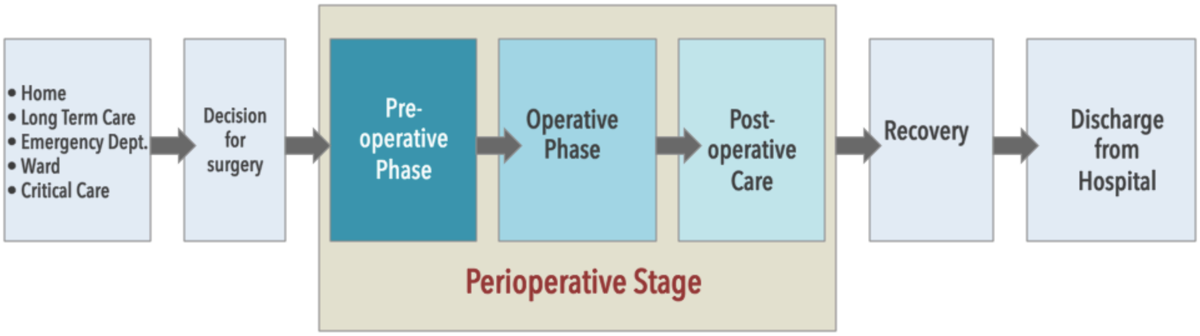



Figure 1: Perioperative care process overview (from Reference Guide and Toolkit for Improvements in Perioperative Practice in Ontario, 2010 and Report of the Surgical Process Analysis Expert Panel, 2005).

Hospitals have been introducing information technology (IT) to enhance the way information is displayed, sent, and recorded to improve coordination and communication among perioperative staff. While display boards are commonly used by healthcare professionals for accessing information, they aren't always conveniently located and deny users the ability to access information on-the-go. One key aspect of this research has been the design of a mobile application to allow users access to patient and support team status, as well as improve communication and coordination of the various staff roles. Without bringing the technology into a clinical setting, which requires extensive approval and testing, the researchers were able to integrate the mobile app technology with a detailed day-of-surgery simulation model, previously described in Pearce et al. (2010) and Taaffe et al. (2015). Through several enhancements to the simulation model, it can now be used as a platform for the testing of the mobile app with front-line staff, as well as a training tool to educate staff in the complications of coordinating tasks on the day of surgery. The main objective of this research was to develop a simulation-based training tool (SBT) using discrete event simulation to mimic the perioperative care processes and allow the end users, i.e., the hospital staff and clinicians to better understand how patient flow changes as their scheduled tasks are accomplished. A secondary objective was to improve the quality of communication between hospital staff using SBT.

## 2 BACKGROUND AND LITERATURE

### 2.1 Simulation-based training

To help streamline processes and eliminate the possibility of errors in practice, simulation-based training (SBT) has long been used in healthcare to augment skills-training with multiple benefits, such as faster rate of acquiring procedural skills, the ability to engage in crisis management, and the ability to train without placing a threat to patient safety. It is important to note that for healthcare professionals such as nurses and surgeons, practice with real patients can never be completely replaced by simulation-based training. Perhaps the most noticeable benefit of SBT is that it allows room for error while allowing users to work in a near-identical scenario, one where it is possible to learn from feedback (Burrows 2013). SBT can also help improve the quality of communication between hospital staff and patients (Sweeney et al. 2014).

Although SBT has been used extensively in manufacturing, aviation and the military (Brailsford 2007) relatively speaking, healthcare has been playing catch-up with the innovative uses of simulation for training. It is important to note that simulations in healthcare systems are of two types: physical simulators and computer-based mathematical simulation models. Physical simulators are often used in training nurses and doctors as it more closely resembles real-life scenarios and involves high-fidelity manikins fitted with sensors that provide feedback (O'Leary et al. 2015, Sonal et al. 2014). On the other hand, mathematical simulation models have been used for understanding the healthcare processes from a systems perspective, addressing issues such as optimizing patient flows, removing and reducing bottlenecks, and understanding the progression of diseases (Barjis 2011). Discrete-event simulation is a popular technique utilized to study healthcare processes. This might be due to the fact that it allows patients, surgeons, and/or nurses to be represented as entities or resources, easily allowing for modeling various features related to their roles within the hospital as well as how each of these interact within the system (Brailsford 2007). In particular, Taaffe et al. (2015) describes how a simulation model of the day of surgery accounted for unique staff roles (nurses, Preop support staff, CRNAs, anesthesiologists, and surgeons) and allowed those resources to make informed decisions based on the current state of the system. In this paper, the research in Taaffe et al. (2015) is extended to combine the SBT simulation model with mobile technology that will bring increased visibility of the process to the stakeholders.

### 2.2 Introducing technology in healthcare

Information technology (IT) has been in use in healthcare for a long time to handle many common tasks such as building and maintaining patient databases. Most of the hospital IT is in the form of desktop computers that allow clinicians and staff access to pertinent patient-related or system-related data within the hospital setting (Sellen and Harper 2002). However, the use of desktop computers hasn't been completely helpful in terms of improving convenience and efficiency in delivering quality healthcare to patients. This is mainly due to the fact that although desktop computers allow hospital staff to access a vast pool of information on patients (Sellen and Harper 2002), they are mostly static sources of data (Prgomet et al. 2009).

The quality of healthcare delivery can be largely dependent on the mobility and flexibility of how information is obtained and utilized in the hospital (Devaraj et al. 2013). This requires that any technology that is being used within healthcare must allow the hospital staff to access the information "on the go" and communicate with other stakeholders simultaneously to allow for seamless coordination (Prgomet et al. 2009). The use of mobile technology in all fields is increasing at a faster rate today largely due to technological advances in mobile computing as well as a simultaneous increase in their affordability (Gartner 2013). The mobile computers of today have faster processor speeds, longer battery lives, and superior networking capabilities and are extremely portable. This is what is speeding the move away from the use of desktop computers to mobile computers (Bonnington 2015). Even with all the benefits of IT and more recently mobile computing, the literature study shows that IT adoption in perioperative healthcare has been comparatively low, at just 6% (Britt 2008). It is important to appreciate how complex the perioperative care process can be, in order to understand the necessity of mobile technology to improve its efficiency. In a perioperative setting, several players interact with a patient throughout the process; a patient might be prepared and treated by more than five nurses, more than two physicians, pharmacists, blood bank staff and in addition janitors and other hospital staff that indirectly affect the patient's stay in the hospital. Even so, the physicians might only interact with the patient moments before the actual surgery begins and have very little time to get acquainted with the patient or their case history (Jacques and Minear 2016).

It is important to note that over the years, hospitals have given little attention to enabling mobile technology to integrate various functions such as clinical documentation, OR/ suite management, nursing perioperative documentation and even perioperative billing (Jacques and Minear 2016). In a review of case studies in the healthcare setting conducted by Prgomet et al. (2009), they found mobile handheld technology to positively impact physicians' work practices in the hospital by improving rapid response speed, error prevention, information accessibility, and data management. The survey provides ample evidence encouraging the use of mobile technology to make the perioperative care process more transparent to all stakeholders and to make data more accessible. In this study, the researchers attempt to describe the use of a mobile application to improve the understanding of the entire perioperative process to the hospital staff involved in the perioperative care process at the concerned hospital.

## 3 METHODOLOGY

The perioperative care process has important implications for both the patient in terms of perceived quality of care provided as well as for hospital management in terms of operational processes and financial gains (Ryan et al. 2013). Thus, it is critical that the perioperative process be studied in-depth and any bottlenecks or non-value-added activities be removed. A simulation model was built to model all phases of the perioperative process. The simulation model was then integrated with a perioperative mobile application. This allowed the researchers to adjust individual task completions as well as understand the effect of delays and task completions on how the day of surgery progresses.

### 3.1 Mobile application

Periop mobile learning system (Periop-MLS) application, is a suite of tools developed to capture, analyze and report patient-flow data quickly and seamlessly. The application was developed for use on Android cellphones and tablets as part of NSF grant IIS-SHB #1237007. The application's main functions include the ability to log in with a particular ID corresponding to different roles (surgeon, anesthesiologist, and nurse) and manage patient information and status. The app provides intuitive displays of real-time information for perioperative staff and managers and can be used as a daily performance dashboard. Periop-MLS provides detailed information on each patient in the system including preop and OR room numbers, surgeon/ anesthesiologist/nurse assignments, scheduled start time of the surgery, and checklist items for preop, OR, and PACU. Table 1 introduces the checklist items for PREOP, OR, and PACU. Note that Preop task completion is not necessarily sequential in nature, while the items in the OR and PACU lists are completed in sequence.

Table 1: Checklist items.

| PREOP | OR | PACU |
|---|---|---|
| 1. Consent obtained | 1. Operating room clean up | 1. Viral signs normal range |
| 2. Labs and diagnostic reports available | 2. Operating room set up | 2. Respiratory function stable |
| 3. Implants available | 3. Patient sent for | 3. Cardiovascular function & hydration status stable |
| 4. Films available | 4. Operating room ready | 4. Mental status recovered |
| 5. RN medications delivered | 5. Intra-op | 5. Pain control satisfactory |
| 6. RN complete | 6. Patient in room | 6. Nausea & vomiting control satisfactory |
| 7. Family waiting for surgeon | 7. Induction | 7. Anesthesiologist approved |
| 8. Surgical site marked | 8. Anesthesia start | 8. Patient room available for transfer |
| 9. H&P updated | 9. Procedure start | |
| 10. Anesthesia items complete | 10. Reversal | |
| 11. OR checklist | 11. Procedure finished | |
| | 12. Extubation | |
| | 13. Anesthesia end | |

Figure 2 shows samples of different screens of the Periop-MLS app, including the PREOP, OR, and PACU checklists. The outline color of the box around the patient represents the current location of the patient – blue indicates PREOP, green indicates OR, and purple indicates PACU. (In the figure, all three patients are currently in PREOP.) Each checklist item is represented with a numbered and color-coded square. Once the item is complete, the square will turn white. Staff using the application can check the boxes off next to each item when the task is complete.

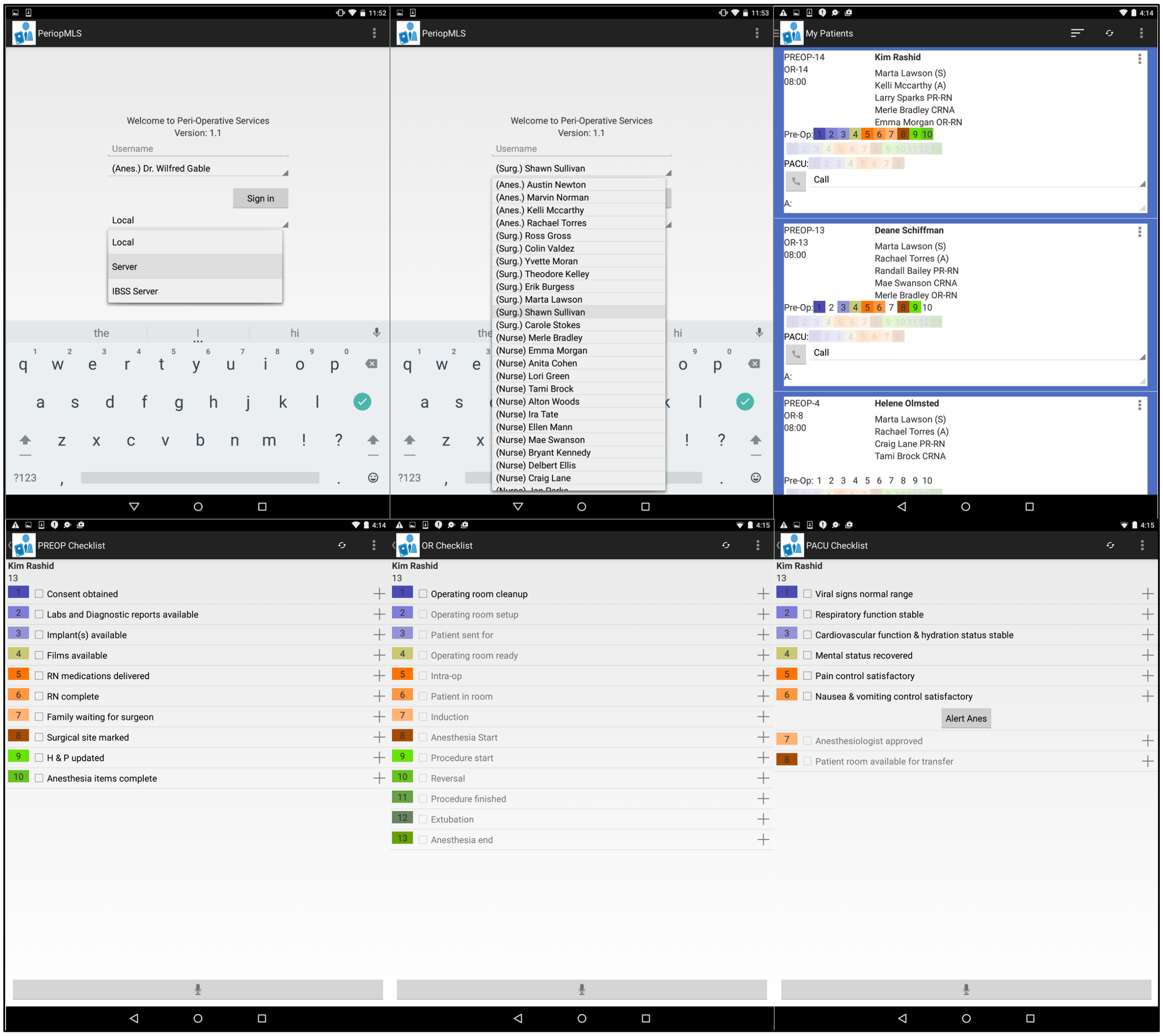



Figure 2: Screenshots of Periop-MLS application.

## 3.2 Simulation model

Within a typical simulation model, entities move throughout the system in the networks and pathways defined by the modeler, interacting with resources as they move along. The entities are responsible for triggering events that change the state of the system leading to the progression of the simulation (Rosetti 2016). Keeping the concept of entities and resources in mind, it is easy to see that the perioperative service process consists of several entities moving throughout the system in a complex yet coordinated fashion to perform activities on the patients as they progress through the system. The perioperative care process on the day of surgery is presented in Figure 3 as a process flow map. Figure 3 mainly represents how the perioperative system was modeled; the primary resources required at each step are shown below each process. While building this simulation model, Rockwell Software's Arena simulation software was used. In the original study, patients, nurses, physicians and other key persons of interest (along with informational units) were modeled as entities in the system (Pearce et al. 2010), with significant enhancements being included to allow the communication of this model to Periop-MLS.

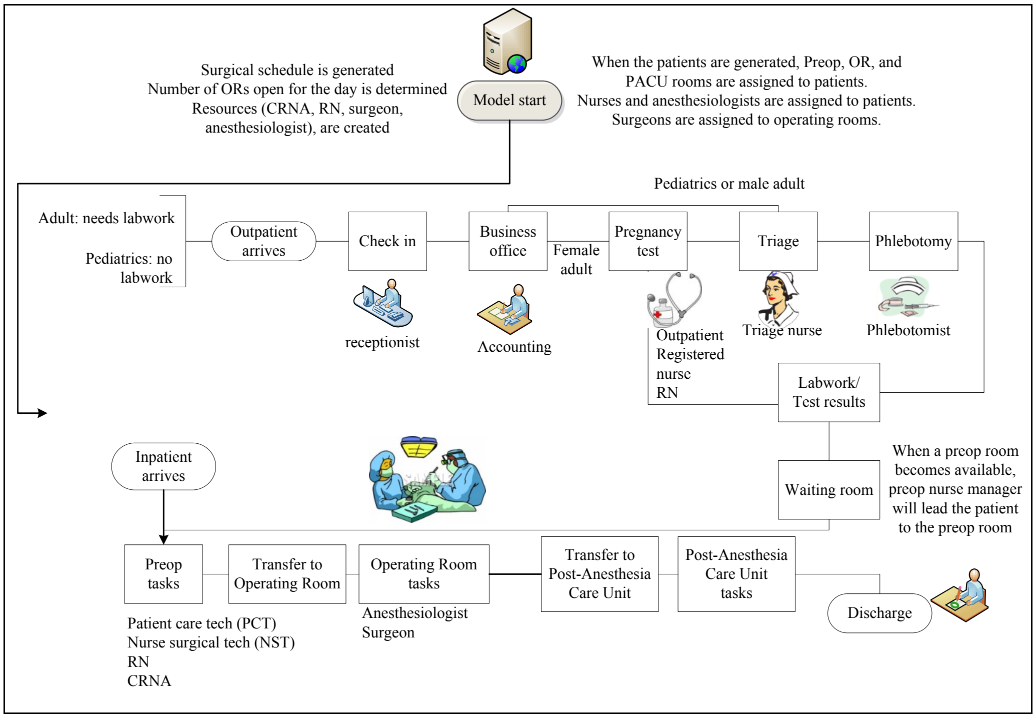



Figure 3: Process flow map.

Some of the groups represent activities such as creation of the various staff, physicians and nurses at the hospital, creation of the inpatient and outpatients, arrival of the patients to the receptionist, assigning various rooms to the patients, activities that occur within the business office at the hospital, creating tasks for the staff handling the patients and execution of tasks that occur within the operating room and the intensive care units, etc. During a simulation run of the model, communication between the staff as well as with the patients occurred stochastically based on distributions developed using the data collected from the hospital. This enabled the simulation to effectively represent the actual working of the perioperative care process.

In the simulation model, significant care was taken in modeling a single day so that the model responded like a typical day. To this end, surgical data from a 12-month period was used to create statistical distributions that allowed the sampling of the surgeon ID, frequency and duration of case types for each surgeon, room allocations and expected utilizations of the rooms, and standard turnover times. All of these elements were included when creating the surgery schedule. In addition, historical data was used to determine whether or not certain Preop tasks were required for a particular case. In essence, the simulation populates a complete day of surgery by sampling from distributional data on all of these parameters, appropriately assigning cases to the 26 rooms represented in the model. Given the variability in caseload from day to day, past research indicated that at least 30 replications was sufficient to achieve stability in the results (Taaffe et al. 2015).

At any given moment, the state of the system was determined by the interaction of various entities with one another and with the resources that are available or not available within the system. The patients progressed through the system as the staff related to a specific perioperative phase attended to them and finished the assigned tasks. For each patient entity, the tasks that have been completed and the pending tasks were monitored and displayed on a dashboard designed within the simulation. To simulate the activity of hospital staff engaging patients during a task, the hospital staff, which in simulation would be resources, were modeled as entities. When not busy, the staff entities would pick the next available patient from the waiting group, perform the assigned task and then move the patient to the next scheduled task as would be in the actual setting (Taaffe et al. 2015). Although the Arena simulation model is not intended for use directly by the end users, the dashboard designed within the simulation model allows researchers to track patients as they move ahead through the three phases of the perioperative care process and to confirm which tasks have been completed and which tasks remain. While developing and tweaking the model, the dashboard also allowed the researchers to see if there was any inconsistency between the results of the simulation and those that were being uploaded to the Periop-MLS web application.

### 3.3 Integrating simulation model and mobile application

Taaffe et al. (2015) demonstrated how the model was used to run a form of SBT where staff participated in an experiment that required the group to discuss and select which communication and coordination delays (inserted at certain key coordination points in the model) should be addressed and removed first. The model provided a convenient method for front-line staff to interact with a simulation tool in a non-clinical environment and receive SBT at the same time. However, the SBT did not include real-time interactivity. In order to explore task completion issues in real-time with the simulation, the research team developed a web-based application that provides connectivity between the simulation model and the mobile Periop-MLS application. For the purposes of the research, the web application stores a list of patients, along with current data concerning rooms, surgery time, staff assignments, and the three checklists for PREOP, OR and PACU. These checklist items are the same as those in the dashboard of the simulation model and represent an important subset of the actual task-dependent delays that occur in the perioperative care process of a patient. The web-based application can support Periop-MLS independently of the simulation model as well, for simple testing of how one staff member's task completions are immediately available for viewing by another staff member using his/her own device with Periop-MLS. However, the focus of this research is to demonstrate how the simulation model (and its current status) can communicate (receiving/sending data) with any device that has the Periop-MLS app installed.

In order to allow the simulation model to retrieve data from the web application as well as allow the simulation model to make changes to the checklist items, an application programing interface (API) was developed. An API is a standardized collection of protocols that allows a software application or program to communicate with other programs to send and receive data. Developers using the software or wanting to connect other software applications can use specific codes within their programs that help to create data requests to the API (Orenstein 2000). The requests and subsequently the data related to them are usually transferred over the Internet. In this case, the API is designed to retrieve the patient information that is stored on the web-application as well as change the data on the application as long as it is conforms to a specified set of rules and formats.

The research team selected JavaScript Object Notification (JSON) as the format of choice to store the data on the web application. JSON allows easy storage of the data in the form of key-value pairs for each parameter, ultimately building an entire data structure called a Dictionary. There are other formats for data storage and use in API's, however JSON has been increasingly gaining popularity most notably due to easy data retrieval. Some benefits include direct mapping of values to their keys, simpler data structure and ease of parsing data. In addition, Python was the language used to generate HTTP (Hyper Text Transfer Protocol) requests to the API. Python has plenty of packages that enable easy and quick parsing of the JSON data (Wyse 2014). The diagram below represents the mechanism by which data flows between the Arena simulation model, the web application and Periop-MLS.

Since Arena does not have the ability to communicate with API's, Python was used to write scripts and use HTTP requests to send and receive data between the API and Arena. The web-application is also directly connected to the Periop-MLS mobile application and users can manually change the patient-task information which is then downloaded into Arena and processed during the simulation run. After the simulation run, Arena invokes a different Python script to upload the results back onto the web application. The users will immediately be able to see the change in the tasks associated with each patient as well as the patient status within each phase of the perioperative care process.

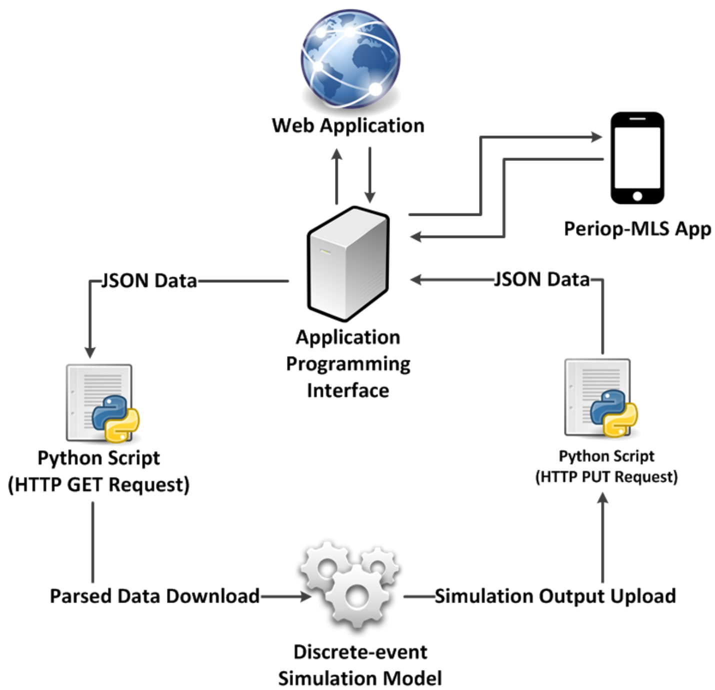


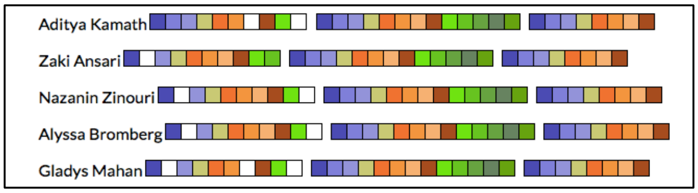

Figure 4: Mechanism of data-transfer between API and Arena Simulation Model.

## 4 MODEL DEMONSTRATION

The primary objective of this research was to develop a simulation-based training tool with the ability to digitally emulate conditions within the perioperative care process and allow the end users, i.e., the hospital staff and clinicians, to better understand how patient flow changes as their scheduled tasks are accomplished. In doing so, we provide the ability to complete tasks by "checking them off" the list provided on the app. To provide a more complete learning experience through this tool, a further research goal is to model the time required for hospital staff in the simulation model to complete tasks in a given scenario and see how the patient flow is affected. However, this is beyond the scope of this paper. To demonstrate the primary objective of this tool and to understand how the tasks affect the patient flow, a scenario was developed.

The user begins with the view of the task checklists as seen on the web application as seen in Figure 5 (can be accessed at tracker.cse.sc.edu), which provides a list of patients defined on the server. One does not need to modify the information on the web application.

Each colored box represents an incomplete checklist item while a white box denotes a checklist item that has been completed. The three groups of checklist items for each patient represent the tasks related to the three phases of the perioperative process, (PREOP, OR, PACU) respectively. As mentioned earlier, any changes to the checklist items on the web application correspond to the changes on the Periop-MLS application and vice versa. The state of the checklists at any time represents the changes made from previous uses of the simulation tool and will not affect the outcome as long as the simulation tool is restarted before every demonstration. Next, the user selects the appropriate staff name for a login; in this scenario, the user chooses 'Dr. Shawn Sullivan' from a set of pre-loaded usernames using the 'Server' option on the Periop-MLS application (refer to Figure 2 login screens). This loads a 'My Patients' screen showing the list of patients assigned to the current surgeon. The user then selects one of the patients for more detailed viewing and analysis; for the demo, 'Alyssa Bromberg' is the selected patient. Figure 5



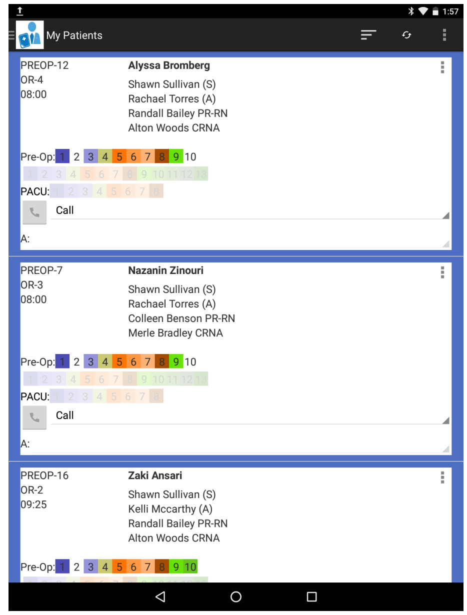




Figure 5: Left: Web application with checklists. Right: “My Patients” screen in mobile application

shows that Alyssa is scheduled to begin surgery at 8:00:00AM and is assigned room PREOP-12 for preoperative processes and OR-4 for the actual surgery. The simulation run is then initiated. The model is designed to pause for a selected patient (in this case patient #4, ‘Alyssa Bromberg’ as seen in Figure 6) whenever a task for that patient is completed. This allows the user to take note of the current status of the patient’s checklists and also track the patient’s location within the perioperative care process. With a pause at 5:59:23AM, there are 12 patients that have been generated in the system (Figure 6). All of the patients have a scheduled start of 8:00:00AM. At this time, the user can interact with any patient using the Periop-MLS app.

The simulation progresses until the next scheduled simulation pause is reached. At this time, the user can see that for Alyssa, some Preop tasks have already been completed by the simulation. To simulate that all of Alyssa’s Preop tasks have been completed, the user can manually check off all tasks in the PREOP list and continue the simulation again. In this case, the preoperative phase for Alyssa would have been completed at 05:59:23 AM, and she would have directly entered the OR phase. However, surgery would still not begin until all surgical resources are actually ready and available to allow incision to occur.

| Patient ID | Type of Surgery | Current Phase | Actual Start | Scheduled Start | Surgery Status |
|---|---|---|---|---|---|
| 5 | Neurosurgery | Preop | - | 8:00:00 AM | - |
| 16 | Pediatric surgery | Preop | - | 8:00:00 AM | - |
| 7 | General surgery | Preop | - | 8:00:00 AM | - |
| 8 | Plastic surgery | Preop | - | 8:00:00 AM | - |
| 10 | Neurosurgery | Preop | - | 8:00:00 AM | - |
| 1 | Gyn-oncology | Preop | - | 8:00:00 AM | - |
| 3 | Vascular surgery | Preop | - | 8:00:00 AM | - |
| 6 | Orthodepic surgery | Preop | - | 8:00:00 AM | - |
| 12 | Cardiovascular surgery | Preop | - | 8:00:00 AM | - |
| 9 | General surgery | Preop | - | 8:00:00 AM | - |
| 15 | Gastroenterology | Preop | - | 8:00:00 AM | - |
| 4 | General surgery | Preop | - | 8:00:00 AM | - |

Figure 6: Snapshot of patient status at 5:59:23AM (simulated time).

At a subsequent simulation pause, the user will be able to see the how the changes made during the previous pause affected the flow of patients. By the 9:23:00AM pause (Figure 7), all of the original 12 patients from Figure 6 have finished the Preop phase and have entered the OR phase. The user can see from the inbuilt dashboard that Alyssa, like some other patients, arrived early to the OR and began surgery early. Although not shown here, more patients have arrived in the Preop phase as the simulation progressed and in the following pauses some would arrive late for their surgeries as well. This would depend on the rate at which their tasks are completed as well as any specific interventions made by the users participating in the SBT.

| Patient ID | Type of Surgery | Current Phase | Actual Start | Scheduled Start | Surgery Status |
|---|---|---|---|---|---|
| 5 | Neurosurgery | OR | 8:36 AM | 8:00:00 AM | Late |
| 16 | Pediatric surgery | OR | 8:02 AM | 8:00:00 AM | On Time |
| 7 | General surgery | OR | 8:17 AM | 8:00:00 AM | Late |
| 8 | Plastic surgery | OR | 8:33 AM | 8:00:00 AM | Late |
| 10 | Neurosurgery | OR | 9:06 AM | 8:00:00 AM | Late |
| 1 | Gyn-oncology | OR | 8:05 AM | 8:00:00 AM | On Time |
| 3 | Vascular surgery | OR | 8:24 AM | 8:00:00 AM | Late |
| 6 | Orthodepic surgery | OR | 7:23 AM | 8:00:00 AM | Early |
| 12 | Cardiovascular surgery | OR | 9:07 AM | 8:00:00 AM | Late |
| 9 | General surgery | OR | 7:56 AM | 8:00:00 AM | Early |
| 15 | Gastroenterology | OR | 9:12 AM | 8:00:00 AM | Late |
| 4 | General surgery | OR | 7:14 AM | 8:00:00 AM | Early |

Figure 7: Snapshot of patient status at 9:23:00AM (simulated time).

There are several other scheduled model pauses before the simulation run comes to an end and during each of these pauses, the users can review the changes made and understand the state of the system. Considering that several users can access the patient checklists through the Periop-MLS app simultaneously, hospital staff can use this SBT tool during human-in-the-loop training sessions to understand how the patients move through the perioperative care process, and find out where bottlenecks are likely to arise within the system. As a result of this simulation/server/mobile app integration, the research team expects to conduct user testing of the Periop-MLS app later this year.

## 5 CONCLUSIONS

Experts closely related to the perioperative care process at Greenville Hospital System validated the simulation model. In addition to successfully simulating conditions within the perioperative process, the ability to manipulate the flow of patients within the simulation through changing the tasks performed for each patient allows the end users to have a bird's eye view of the patient flows within the system. It also enables the end user to see how the patient responded to different sequences of task completion within the perioperative process. In future research, this simulation-based tool will allow a large group of users to complete tasks as though they would during an actual scenario and observe how the patient flow is affected by the different groups working remotely to complete patient tasks and allow the patient to progress through the system. The research team was also able to successfully use this simulation tool for training on a mobile platform through testing working prototypes of the Periop-MLS application and the web application, thus successfully shielding the end-user from the complexities of the simulation model and allow for real-time multi-user collaboration through the mobile app.

With the first objective of this project achieved, the researchers aim to further this research by studying how the modeling of hospital staff as agent-based entities would affect the system as a whole. The aim of this further research would be to allow the hospital staff to interact with the simulation and see how they would behave as stochastic entities working to complete patient tasks and help them see the work patterns that would otherwise have not been recorded. As mobile technology continues to disrupt the healthcare sector, the researchers envision a transformative future for the Periop-MLS suite of tools.

For one, from currently just being a tool used exclusively for research and training, the researchers see this application or its future form being omnipresent in the perioperative care process, right from the nurses using it to pull up information about patients, their biography, their current location and status within the care process to patients and their families being sent information on the status of their cases or communicating directly to the physicians in charge of their case.

## ACKNOWLEDGMENTS

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