Optimizing Efficiency and Operations at a California Safety-Net Endoscopy Center: A Modeling and Simulation Approach

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ABSTRACT

Background: Improvements in endoscopy center efficiency are needed, but scant data are available.

Objective: To identify opportunities to improve patient throughput while balancing resource utilization and patient wait times in a safety-net endoscopy center.

Setting: Safety-net endoscopy center.

Patients: Outpatients undergoing endoscopy.

Intervention: A time and motion study was performed and a discrete event simulation model constructed to evaluate multiple scenarios aimed at improving endoscopy center efficiency.

Main Outcome Measurements: Procedure volume and patient wait time.

Results: Data was collected on 278 patients. Time and motion study revealed that 53.8 procedures were performed/week, with patients spending 2.3 hours at the endoscopy center. Using discrete event simulation modeling a number of proposed changes to the endoscopy center was assessed. Decreasing scheduled endoscopy appointment times from 60 to 45 minutes led to a 20.9% rise in the number of procedures performed/week, but increased patient wait time by 41.2%. Increasing the number of endoscopists by one each half day resulted in procedure volume rising, but there was a concomitant rise in patient wait time and nurse utilization exceeding capacity. In combining several simulations, the greatest improvement in performance metrics was created by moving patient appointments from the afternoon to the morning. In this simulation at 45 and 40 minute appointment times procedure volume rose by 23.4% and

34.2%and patient time spent in the endoscopy center declined by 17.4% and 13.0% respectively. The predictions of the simulation model were found to be accurate when compared with actual changes implemented in the endoscopy center.

Limitations: May not be generalizable to non-safety-net endoscopy centers.

Conclusions: The combination of minor, cost-effective changes such as reducing appointment times, minimizing and standardizing recovery time, and making small increases in pre-procedure ancillary staff maximized endoscopy center efficiency across a number of performance metrics.

INTRODUCTION

There has been a dramatic rise in the request for gastrointestinal (GI) specialty care, and in particular endoscopic services in the last decade[1-3]. This increase has been most notable in safety-net hospitals whereby GI is the most frequently requested specialty service[2]. At the same time, access to specialized GI care can be challenging within specific healthcare systems. For example, medical directors at safety-net hospitals report exceedingly difficult access in obtaining specialized care for their patients compared to patients with private insurance[4]. Such disparities highlight the need for creative and innovative ways to increase access to GI care for underserved patient populations in light of increasing demand for such services.

One potential method for addressing this inequality in care is to develop more efficient endoscopy centers that can provide increased, high quality endoscopic services while at the same time maximize patient and provider satisfaction. While the study of efficiency has been the cornerstone of many industries, it has not been until recently that incorporating efficiency models into healthcare has emerged. Anesthesia has been at the forefront of improving efficiency in healthcare through the re-engineering of operations and processes in the operating room with notable improvements in patient care and quality[5-9]. Employing time and motion studies (e.g. direct and continuous observation of a task) in conjunction with discrete event simulation modeling (e.g. modeling the operations of a system) has been pivotal to this success.

Yet, there is a dearth of information on the study of efficiency in endoscopy centers. Of the scant literature available there are varying conclusions about how to improve endoscopy center efficiency with no clear consistent message. Some studies have focused on altering staffing specifically focusing on the endoscopist[10-13] and utilizing additional staff in the pre-procedure

process[13]. While such changes improve physician efficiency and utilization, it does so at a cost of impairing non-physician staff utilization, sub-optimizing facility utilization and increasing patient length of stay[12]. Using simulation modeling others have discovered that identifying bottlenecks such as patient recovery[14,15], reducing room turnover time[10,14], modifying patient arrival schedule[11,16] or reengineering patient scheduling[16,17] can improve efficiency and decrease patient stay. However, there are a number of limitations to many of these studies; they are small, examine efficiency solely from a physician perspective with minimal to no input from other staff members, examine a limited number of time stamps within the endoscopy center, and all are set in an ambulatory endoscopy center or tertiary referral service. Given these deficiencies and with changes to the healthcare system occurring in the U.S., with more underserved patients being served, it is imperative to better understand endoscopy centers in such settings and to learn how to improve efficiency within them.

Our first objective was to conduct a time and motion study of clinic staff at work and to use this data in simulation modeling to study changes in scheduling, staffing models, and changes in the pre- and post-procedure process. Our secondary objective was to build a simulation model to understand the bottlenecks limiting the endoscopy center's current operational performance and, in turn, to identify opportunities to improve patient throughput while balancing resource utilization and patient wait times.

METHODS

Study Design, Setting and Population

There were three phases of the study. Engineers first conducted a time and motion study of the San Francisco General Hospital and Trauma Center (SFGH) endoscopy center in order to better understand the operations and processes of a safety-net endoscopy center. Second, using information from this study, we then created a discrete event simulation model to assess proposed changes to the endoscopy center in order to improve efficiency within it. The final phase of the study involved implementing some of the proposed changes at the SFGH endoscopy center and examining the impact of these changes on a number of performance metrics. The study was conducted between November 2011 and December 2013.

SFGH is a safety-net institution (i.e. provides a significant level of care to low income, uninsured, and vulnerable populations) affiliated with the University of California, San Francisco. Patients are ethnically diverse (20% African American, 20% Asian/Pacific Islander, 25% Caucasian, and 30% Hispanic), and many are immigrants with more than 20 different languages spoken by patients. Approximately 36% of outpatients at SFGH lack insurance, 34% have MediCal (California's Medicaid program), 16% have Medicare, and 14% report commercial payers or other sources. The SFGH Gastroenterology Division receives 7,200 referrals annually for a wide spectrum of gastrointestinal related conditions.

The SFGH endoscopy center is a hospital based center and performs both outpatient (82.1%) and inpatient (17.9%) endoscopic procedures. The endoscopy center performs standard endoscopic procedures (colonoscopy, upper endoscopy, flexible sigmoidoscopy), advanced procedures (endoscopic retrograde-cholangiopancreatography, endoscopic ultrasound, single balloon enteroscopy), capsule endoscopy, and esophageal and anal motility and manometry. The

majority of the endoscopy center's time is devoted to performing colonoscopy and upper endoscopies (EGD) (89.0% of procedure volume) with a no show rate of 17.7%. The annual volume of endoscopic procedures is 3,700.

Time and Motion Study

During the first phase of the study, multiple days of direct time observations and interviews were conducted to identify patient flow, key parameters and process attributes of the endoscopy center. Time was spent shadowing physicians, nurses, and support staff in order to develop an understanding of the endoscopy center's workflow.

Endoscopy center workflow

The endoscopy center has four distinct workflow processes: check-in, pre-procedure, procedure and recovery (**Figure 1**) with the relative number of patients traveling on each path shown as the thickness of the connecting arrows. A patient's visit begins at check-in after which patients move to a waiting room, where they remain until called to the pre-procedure room. . In situations where a procedure room is available and no prepared patients are waiting to begin a procedure, pre-procedure activities are conducted in the procedure room bypassing the pre-procedure room. From the pre-procedure process, a patient then moves to a procedure room. Here process time varies with the complexity of the patient's procedure, for example procedures involving therapy require additional time. At the conclusion of the procedure, patients either recover in the recovery room, or if a recovery bed is unavailable then patients are kept in the procedure room. Once in the recovery room, patients remain for at least 30 minutes as required by state and

institutional regulations. Patients are held in the recovery room until a ride home arrives to sign them out.

Layout and staffing of the endoscopy center

The following is a detailed account of the physical layout and staffing of the SFGH endoscopy center. There is one patient waiting area with 22 chairs available, one pre-procedure room with 3 beds where patients are prepared for their procedure (i.e. placement of intravenous catheter, pre-procedure paperwork completed), four procedure rooms, and one recovery room with 3 beds where sedated patients recover after their procedure is completed. The pre-procedure and recovery rooms are separate, but adjacent, and only one process is performed in each room (i.e. recovery process is only performed in the recovery room). The ratio of pre-procedure beds: procedure rooms and recovery beds: procedure rooms are 1:0.75. Across from the four procedure rooms are one disinfection room, one endoscope reprocessing room with three automated endoscope reprocessing machines that can reprocess two endoscopes per 45 minute cycle per machine, and one endoscope storage room (10 adult colonoscopes, 3 pediatric colonoscopes, 6 adult upper endoscopes, 1 pediatric upper endoscope, 3 duodenoscopes, 1 small intestinal videoscope, 1 radial electronic scope). With regards to staffing there are 1.5 full time equivalent (FTE) clerks at the patient check-in area, 5.5 nursing FTEs (1.0 FTE per procedure room, 1.0 FTE for the recovery room, 0.5 FTE for the pre-procedure room), 1.0 FTE licensed vocational nurse for the pre-procedure room, and 1.0 FTE endoscope reprocessor. There are 4.1 FTEs of clinical gastroenterologists at the endoscopy center. SFGH is a teaching hospital for the University of California, San Francisco's medical school and three GI fellows and one surgical resident rotate through the GI Division each month. Each procedure requires a staff of three - an

attending physician, nurse and a fellow/resident or one attending and two nurses. The hospital also uses nurse practitioners in lieu of a physician for some GI procedures, but without trainee involvement; there are 2 nurse practitioners who perform standard endoscopic procedures at SFGH (one of whom was in training during the initial study period).

For the vast majority of procedures performed in the endoscopy center, moderate sedation is used with a combination of a benzodiazepine (Midazolam®) and an opioid (Fentanyl® or Meperdine®) with Benadryl® given in some cases as an adjunctive medication. For colonoscopies performed during the study time period, the mean amount of Fentanyl administered was 79.9 mg, Demerol was 67.8 mg, Midazolam was 3.2 mg, and Benadryl was 43.9 mg. For upper endoscopies the mean amount of Fentanyl administered was 80.8 mg, Demerol was 79.7 mg, Midazolam was 3.3 mg, and Benadryl was 46.1 mg.

Hours of operation and scheduling of procedures in the endoscopy center

The hours of operation for the endoscopy center vary due to limited space and availability of providers. The hours of operation are as follows: Monday (8AM-12PM), Tuesday (8AM-4PM), Wednesday (no procedures), Thursday (8AM-12PM) and Friday (8AM-4PM); there are no weekend procedures performed except in cases of emergencies. The first case of the day is scheduled at 8AM with the last case being scheduled at 3PM. Upper endoscopy, colonoscopy or both procedures together are scheduled in 60 minute appointment slots. The front desk staff works in 8 hour staggered shifts (7AM-4PM and 8AM-5PM) five days a week. Nurses work in staggered 8 hour shifts (7AM-4PM and 8AM-5PM) five days a week. The endoscopy center is at

full workforce strength during these times of operation, but does vary based on the number of attending physicians/nurse practitioners available per endoscopy session. Given that attending physicians and nurse practitioners perform other duties, such as GI clinic and consultative service, their availability for performing endoscopy is limited. For example, staffing for each day with regards to attending/nurse practitioner availability is as follows: Monday (1 attending), Tuesday (2 attendings, 1 nurse practitioner), Thursday (2 attendings, 1 nurse practitioner), and Friday (2 attendings, 1 nurse practitioner).

Data collection

There have been a number of attempts to develop consistent operational measures for endoscopy centers with regards to efficiency; however there are no reliable and reproducible endoscopy center efficiency metrics. Recently, a conceptual framework that outlines endoscopy center efficiency was proposed and is divided into three domains: structure, process, and outcomes[18]. This framework was used to determine what inputs needed to be collected (using time and motion study) and what to study for efficiency outcome measures (using discrete event simulation modeling) during the study.

For the time and motion study we determined a priori to examine all of the endoscopy center structure domains (number of procedure rooms, number of pre-procedure and recovery rooms, number of procedure nurses, number of endoscopists, number of endoscopes, sedation type and unit layout) as well as the majority of the process domains (pre-procedure time, recovery time, procedure time, sedation time, room turnover time, first case start time)[18]. Observation and timing of the processes was done to provide a statistically significant picture of operations. Direct observation and use of the SFGH endoscopy center's electronic record keeping system

provided 278 patient arrival times, 257 procedure times and 257 recovery times. Arrival times were collected from the appointment scheduling system. Procedure time (time of endoscope insertion to removal), sedation time (time of first dose of sedation administered to when the procedure was started), and room turnover time (time when a patient leaves the procedure room to the time when the procedure room is ready for the next patient) was collected from documentation in procedure and nursing notes. The pre-procedure time (time from when a patient was taken from the waiting room to the time the procedure began) was quantified using a standardized form that nurses completed on every patient. Recovery time (time when the patient arrived in the recovery room to the time when the patient was discharged) was collected from time stamps present on discharge paperwork completed when patients departed.

Discrete Event Simulation Modeling

In the second phase of the study, Microsoft Visio was used to create a descriptive process model of outpatient procedure visits (**Figure 2**). The discrete event simulation model was built using the Process Simulator (Process Simulator is a Microsoft Visio add-on software from ProModel Corporation, 556 East Technology Ave., Orem, UT) software beginning with the process flow diagram shown in **Figure 2**. Process Simulator is used to create a simulation within the process flow diagram drawn in Microsoft Visio. Simulation properties, such as process time distributions and volumes, are added to the diagram so that various scenarios can be run. The objective of model development was to understand bottlenecks in the current operations of the endoscopy center and in turn to measure the impact of operational changes to improve throughput while balancing resource utilization and patient wait times. The key performance objective was to determine the staffing levels and operating policies needed to maximize patient

throughput by ensuring high utilization of the procedure rooms such that they were not idle either due to starvation or blockage.

Validation and verification of the model

Validation was performed in order to ensure the simulation was accurate and included the following steps:

- Baseline simulation results such as patient visit time, room utilization and equipment use were verified as correct by expert opinion. Such verification occurred over the course of several meetings with endoscopists, nurses, and front desk staff and unanimous consensus was reached on the final baseline simulation among this group.
- The workflow diagram's logic used to build the model was verified by the providers and nursing staff.
- An assumptions document was reviewed by the providers during regular meetings to discuss updates to the model.
- The outcome results were verified as logical with those experienced within the actual system.
- A more extensive analysis was conducted to ensure that the system was operating properly on Tuesdays, the most heavily scheduled day each week.
- Simulation animation was observed by providers, nurses and front desk staff to check that the patients were following the proper flow of events and feasible queuing at various points.

All the parameters and distributions were based on historical data and Minitab was used to develop statistical distributions that matched historical data with a high degree of confidence.

Scenario development

After validation of the base case model was completed, several scenarios were evaluated using the discrete event simulation model. Scenarios for the model were developed based on three key sources: 1) input and observations from staff members of the GI endoscopy center (endoscopists, nurses, front desk staff, endoscope reprocessors), 2) observations from the USC industrial engineering team who conducted the time and motion study and built the discrete event simulation model, and 3) changes to endoscopy center structure/processes that in the literature have been shown to improve efficiency[11-16]. Only modifiable factors (such as scheduling and staff) were considered given that facility factors (number of rooms) were fixed. The primary scenarios included altering the endoscopy appointment schedule from 60 minutes to 45-minute, 40-minute, 35-minute and 30-minute appointment slots and assessing outcomes. For the shorter appointment slot schedules, limited resources were added to avoid extremely high levels of queuing. Secondary scenarios examined included changes to room availability through the adding of additional staff (i.e. endoscopists and nurses).

Outcome statistics

Performance outcomes were calculated by running the various scenarios in the discrete event simulation model and were selected from the outcome domain (i.e. the desired results of the system) proposed in Gellad's framework for endoscopy center efficiency[18]. These outcomes included procedure volume (throughput), patient waiting time, patient time spent in the

endoscopy center (i.e. flow time), and resource utilization (provider, nurse and procedure room). Utilization was computed as the hours a resource was in use divided by the available hours for the resource. We did not include overtime or cost in our model. Overtime is rarely utilized in our center and given that we are a non-profit institution we opted not to include cost.

Real-Time Validation of the Endoscopy Center Simulation Model

In the final phase of the study, three of the proposed scenarios examined in the model were then selected and implemented at the SFGH endoscopy center in order to validate the model. Each scenario was implemented in two month block timeframes. However, due to the scarcity of resources not all of the potential changes in the three scenarios could be fully implemented and were slightly modified. The first scenario implemented was the reduction of endoscopy appointment times to 45 minutes, adding an additional 0.5 nursing to the pre-procedure process and extending the endoscope reprocessors hours to 4:30PM. In implementing the second scenario the endoscopy centers weekly schedule was modified by adding endoscopy appointments to Wednesday morning; however only one endoscopist could perform procedures on this day and thus a full day's schedule was not utilized (as proposed in the scenario used in the model). The last scenario implemented involved adding an additional endoscopist to each half-day endoscopy session. In this instance the schedule of the second nurse practitioner was expanded or an additional provider was added to the endoscopy schedule for Monday, Tuesday, Thursday and Friday; however the provider schedule was still not maximized on Monday or Wednesday as proposed in the original scenario. Outcomes from the simulation model were then compared with the outcomes from the actual changes implemented in the endoscopy center. The

implementation of these three scenarios occurred at the SFGH endoscopy center from June 2013 through December 2013.

Ethical Considerations

This study was part of an ongoing quality improvement project aimed at evaluating the performance of the SFGH endoscopy center with respect to a patient's experience. Given our study was related to quality improvement, and no personal health information was collected at any time, formal institutional review was not required per the policy of the University of California San Francisco Committee on Human Research.

RESULTS

Baseline Endoscopy Center Data

Utilizing data from the time and motion study, baseline endoscopy center statistics were determined for patient arrival patterns as well as a number of structural domains (wait time in waiting room, pre-procedure, procedure and recovery room times, sedation time, room turnover time, percentage of on-time starts for procedures) (**Table 1**). There was a significant trend of patients arriving earlier than their assigned appointment times; patients with afternoon appointments (after 1PM) arrived 179.4 minutes earlier for their appointment compared to patients at 8AM who arrived 28.5 minutes earlier. Little variation was noted in the pre-procedure time regardless of the planned procedure, although EGD/colonoscopy procedures required more time (31.2 minutes). Little variation was noted with recovery room time and required 34.6 minutes if recovery occurred in the recovery room. Procedure time itself differed significantly

depending on the type of procedure. The mean number of procedures performed per week was 53.8 (51.0-56.6) with patients spending 2.3 (2.2-2.5) hours at the endoscopy center with 22.3% of that time spent waiting.

In order to determine the optimal scenario(s) that would increase throughput, optimize utilization and minimize patient wait time a series of simulation models were run (**Table 2**). Scenarios included 1) revising endoscopy appointment times and overall endoscopy schedule, 2) increasing the number of nurses or providers, 3) minimizing recovering time and 4) a combination of these scenarios.

Revision of Endoscopy Schedule

The first scenario examined a revised endoscopy schedule using shorter appointment times. When appointment time was decreased to 45 minutes (from a baseline of 60 minutes) there was a 20.9% rise in the number of procedures performed/week with both patient time in the endoscopy center increasing to 3.2 hours and percentage of time waiting rising to 37.9%. Additionally, there was a rise in overall utilization with the greatest rise noted in procedure room utilization. At shorter appointment times of 40 and 35 minutes the model was not sustainable without additional resources to serve patients; at these times there was queuing of patients in the pre-procedure area as the day progressed to the point where a significant number of patients would not have had their procedures performed by the end of the day. If the appointment was decreased further to 30 minutes the simulation was not feasible since the appointment time was nearly identical to the procedure times and a queue built up infinitely.

An additional change included revising the overall weekly endoscopy schedule. Given that patients had a preference for earlier appointments and the endoscopy center was closed on Wednesdays - a half day of endoscopy appointments was moved from Friday afternoon to Wednesday morning in a simulation. In this simulation, there was no significant change (compared to baseline) other than procedure volume slightly increased to 55.7 procedures/week and procedure room utilization rose. Moreover, we found that when appointment times were shortened under this scenario to 45 and 40 minute intervals there was a steady rise in procedures performed/week (with nearly an increase of a third of procedures performed) as well as improved procedure room and nursing utilization. However, these changes did so at a cost of increasing the number of hours a patient spent in the endoscopy center and increased patient wait time by 32.6% and 46.0% respectively when compared to baseline.

Human Resources Expansion

The next area explored was to improve endoscopy center operational efficiency by expanding human resources. Patients spent a great deal of time in the pre-procedure area waiting for their procedure. Thus the number of staff dedicated to the pre-procedure area was modeled to determine if changes improved efficiency. Initially, the addition of 0.5 nurses to the pre-procedure area in the baseline model resulted in no significant differences with respect to outcomes. Yet, by increasing the number of pre-procedure nurses from 1.5 to 2 with an appointment time of 45 minutes there was a 21.3% increase in the number of procedures performed per week and a steady rises in provider (20.8%), and procedure room (19.3%) utilization with minimal impact on patient wait time. There was no significant change in outcomes with the addition of more nurses compared to 2 nurses in the pre-procedure area.

The number of providers that performed endoscopic procedures during the week was also varied; one additional endoscopist was added to each half-day of endoscopy. With appointment time held constant, procedure volume increased by 23.1% but it did so at a cost of increasing nursing utilization over 100%. The results were similar if appointment times were lowered further with procedure volume dramatically rising, but at the same time there was a concomitant rise in patient wait time and nursing utilization exceeding capacity.

Minimizing Recovery Room Time

The next simulation examined minimizing patient time in the recovery room. Two simulations were tested: 1) limiting recovery room time to 30 minutes (minimum required by state and institutional regulations) and 2) not allowing patients to recover in a procedure room. In either simulation at 60 minute appointments there were no significant differences with respect to outcomes when compared to baseline data. But when limiting recovery room time and changing appointment time to 45 minutes, procedure volume increased to 67.6 procedures/week with a slight increase in provider utilization, but there was also an increase in patient wait time. Similar results were observed in the model when patients were only allowed to recover in the recovery room.

Expansion of Endoscopy Center Simulation Models

Using the data gathered and information learned from each individual simulation, a number of simulations were expanded (**Table 3** and **Figure 3**). Individual simulations that were expanded included: 1) Reducing endoscopy center appointment times, 2) modifying endoscopy center

weekly schedule and 3) expanding human resources (adding more endoscopists). Additional resources were built into each of these expanded simulations and included increasing the number of pre-procedure nurses, minimizing recovery room time and expanding the hours of the endoscope reprocessor to increase equipment usage (in order to make shorter appointment times feasible). The first endoscopy center simulation included reducing the appointment time to 45 minutes, having 2 pre-procedure nurses, reducing recovery room time to 30 minutes, and extending the endoscope reprocessor day by 30 minutes. This change resulted in a 21.6% increase in procedures performed per week, 17.4%, drop in patient time in the endoscopy center, and no significant change in patient wait time. A second endoscopy center simulation incorporated the same changes except appointment time was lowered further to 40 minutes and there was a steeper rise in procedure volume with patient wait times and total time in the endoscopy center remaining unchanged.

The above changes were then incorporated into simulations whereby a half-day of Friday afternoon endoscopy appointments were moved to Wednesday morning. In this simulation the number of procedures performed rose significantly in conjunction with provider, nursing and procedure room utilization improving, yet patient time in the endoscopy center was not significantly changed. For example, in simulations at 45 and 40 minute appointment times procedure volume rose by 23.4% and 34.2%, while patient time spent in the endoscopy center declined by 17.4% and 13.0% respectively.

Finally, the same changes were also incorporated into an endoscopy center simulation whereby one additional provider was also made available on each half day of endoscopy. Procedure volume increased with a rise of 39.6% and 46.7% for simulations at 45 and 40 minute

appointment times with overall provider utilization increasing to its highest levels. However, nursing utilization exceeded capacity in both simulations. Furthermore, as appointment times were shortened under these simulations patient wait time steadily increased to one point where patients spent nearly a third of their time in the endoscopy center waiting.

During the validation phase the simulation model did quite well at predicting specific outcomes of the three proposed scenarios that were implemented in the endoscopy center. The implemented scenario where appointment times were shortened to 45 minutes had outcomes in line with those of the model. The model predicted fairly well the outcomes for the other two scenarios although procedure volume, provider utilization, and nurse utilization, while trending in the same direction as the model, were somewhat higher than what the model had predicted (**Table 3**).

DISCUSSION

Through observation, time and motion study and discrete event simulation modeling we demonstrated that in a large, diverse safety-net hospital endoscopy center that weekly patterns, although variable, are predictable and provide insight and recommendations as to what potential changes are beneficial. We illustrate that patient throughput as well as provider and nursing utilization are substantially increased with only simple changes such as decreasing endoscopy appointment times, realigning the endoscopy schedule with patient preferences for early morning appointments and minimizing and streamlining the recovery room and pre-procedure process. Additional improvements in throughput are possible but only with additional costly human resources, over utilizing nurses and unacceptable patient wait times.

With an emphasis on cost containment and improving efficiency in healthcare a number of methods, such as time and motion studies and discrete event simulation modeling, have been successfully advocated and implemented to attain these goals; specialties that have been at the forefront of this include anesthesia[19,20], primary care[21-24], emergency rooms[25-27], and pediatrics[28,29]. Our study is not the first to conduct a time and motion study or employ simulation modeling in the endoscopy center; however there is sparse and disparate literature on this topic. Some studies have used only a qualitative approach[10], conducted solely a time and motion study[13], incorporated only one endoscopic procedure in their models[11] or limited their simulations to only one component of the endoscopy center process such as scheduling[17]. In addition, all of these studies were limited by their setting; all examined large tertiary hospitals or a private setting, most included endoscopy centers outside of the U.S. and had minimal trainee involvement. Our study is unique in that we involved clinical staff in developing and testing changes while other studies generally utilized GI data and then worked on it separately from providers and staff. Additionally, we are the first to use such methods to examine efficiency and change in a large safety-net hospital system with significant trainee involvement.

Our study highlights the importance of two key areas in the endoscopy center: pre-procedure and recovery room processes. With respect to the pre-procedure process, no clear evidence exists on how to improve the pre-procedure process with only scant expert opinions available[30,31]. A number of factors influence this process including obtaining vitals, placing intravenous catheters, completing paperwork, patient changing, and in some cases the use of interpreting services. The majority of these tasks center on nursing/medical assistant roles[13] and in most cases these tasks are fixed and difficult to streamline. Previous work in the operating room has realized this

challenge and some work has demonstrated that parallel processing of tasks among staff members can lead to a dramatic reduction in operating room pre-procedure and room turnover time[6,7]. In this same light, we modeled an increase in the pre-procedure personnel in order to utilize this strategy of parallel processing which to date has not been modeled in endoscopy centers. We noted an increase in procedure volume by 14.6 procedures/week (mean increase of 730 procedures/year) while at the same time significantly improving nursing, provider and room utilization and keeping patient wait time constant. Other potential improvements in the pre-procedure process, but difficult to model, may focus on patient education for patient preparedness, prior communication with patients who do not speak English, and education programs aimed at improving pre-procedure processes for staff.

Another vital step in improving endoscopy center efficiency is the recovery room; specifically limiting recovery room time can profoundly help increase efficiency. Grossman modeled an ambulatory surgery center and demonstrated that recovery time was the main bottleneck. In fact, a 50% reduction in recovery time increased the number of patients per room per day and shortened the overall length of stay of patients[14]. Similarly, in our study by limiting recovery to the recovery room (which reduces room turnover time) and reducing recovery time to 30 minutes (a reduction of 13.3% from baseline) we observed an increase of 14.3 procedures/week with no effect on patient wait time. While some regulations require a specific recovery time, there is no clear method on how to address this bottleneck. Aside from increasing the physical space of the recovery room (which is quite costly in a resource limited environment) the only specific intervention proposed to reduce this time has been sedation related. The use of Propofol® in some centers and only using one sedating medication compared to two medications has been

demonstrated to help not only reduce sedation time, but overall recovery time as well[32]. However, these strategies present challenges of their own. Using only one sedating medication, rather than two, may result in the loss of synergy between sedative and analgesics and could also led to longer sedation times in order to achieve adequate sedation. Also, the use of Propofol® comes with the additional costs of utilizing anesthesiologists or certified nurse anesthetists given the current restrictions and inability of gastroenterologists to administer this drug themselves. Further research on strategies aimed at improving the endoscopy recovery process is warranted.

Lastly, unlike previous work we did not focus our changes solely on providers/endoscopists. Of the limited work on this topic, all studies have focused on two key outcomes: increasing patient throughput and improving physician efficiency. However, only focusing on physician efficiency doesn't translate into overall efficiency for the endoscopy center. Rex et al clearly illustrated this concept by showing that increasing patients served and physician utilization does so at a cost of the endoscopy center being sub-optimized with patient length of stays increased and non-physician staff utilization decreasing[12]. Our model echoed this point whereby in several simulations adding an endoscopist did increase procedure volume, but did so at a detriment to overutilization of the nursing staff, increasing patient time in the endoscopy center, and wait time ranging from a third to almost half of a patient's visit. Also, adding additional endoscopists is a costly option (mean salary of $321,575/year) especially in resource limited areas such as public hospitals. On the other hand, personnel such as nursing, medical assistants, or extending reprocessors hours, which can impact processes before and after a procedure, are far less costly and in our simulations not only provided improvements in volume and provider efficiency, but did so in a more balanced approach.

There are several limitations in our study. First, our study setting occurred in a safety-net hospital with a diverse, primarily non-English speaking patient population and may not be generalizable to other endoscopy centers. However, the techniques employed in our study and our team based approach to improve endoscopy center efficiency can be applied to any endoscopy center setting. Second, our study is a mathematical model and may not precisely predict reality. Yet in examining three of the proposed scenarios during a validation phase, the model did quite well in predicting reality within the endoscopy center; some variations were noted between the model and reality but this occurred in situations where a scenario had to be modified. Moreover, in some cases the differences were large, but were overall better. One possible explanation for such findings may be that the changes had a ripple effect on factors not included in our simulation, such as staff motivation. Nevertheless the model correctly predicted trends with regards to specific outcomes, even in those scenarios that were modified, thereby demonstrating the power and usefulness of it. Third, we did not model other possible, but more complex changes, such as assessing the impact of same day bowel preparation which may increase the desirability of afternoon appointments, scheduling complex procedures at the end of the day as is done in surgery[33], expanding the number of pre-procedure and recovery rooms to accommodate more patients, scheduling a mix of procedures that vary by time throughout the day, or evaluating the further impact of changes to arrival "earliness" as was noted in our patient population. Fourth, many of the procedures performed in our endoscopy center involved GI trainees and thus our center differs in this respect from many community and ambulatory endoscopy centers. The use of GI trainees may impact several aspects of endoscopy center flow, namely an increase in procedure time owing to teaching that occurs during the procedure and a

likely increase in the pre-procedure time as GI trainees may not be as knowledgeable with the systems and operations of the endoscopy center and/or may not be as familiar with the patients scheduled for a procedure. Finally, we observed that patients scheduled for an afternoon appointment arrived for their procedure appointment significantly earlier than did patients for morning appointments; an observation that is unlikely to occur in most endoscopy centers. A number of factors could explain this finding such as the majority of our patients did not speak English, many have substance abuse and psychiatric illnesses and many have low health literacy rates. Any one of these factors or a combination could have led to patients not understanding their instructions and thus showing up much earlier for their appointment. Additionally, many clinics within our hospital will evaluate patients on a "first-come, first-serve" basis despite their scheduled appointment and thereby this belief on the part of patients in our system may have impacted their decision to arrive earlier for their procedure appointment. Despite these limitations, our model has much strength in that it demonstrates that with only small changes to resource assignments one can dramatically improve patient volume and other performance metrics and can do so in a cost-effective manner especially in an endoscopy center where space and resources are limited. Furthermore, using time and motion studies and building a simulation model with input from all staff members, endoscopy centers can evaluate potential changes with a tool not currently being used in GI services.

In summary, through observation of workflow and analysis of simulation results we illustrate that weekly endoscopy center patterns are predictable and provide insight into what changes can be beneficial. Minor changes such as reducing appointment times, minimizing recovery room time and increasing ancillary staff in the pre-procedure area are effective tools that significantly

improve endoscopy center efficiency and do not substantially increase costs. By balancing pre and post procedure capacity a continuous flow is created and patient waiting is reduced. More costly decisions such as increasing the number of endoscopists can improve procedure volume, but at an impairment of endoscopy center functions and metrics. Overall, in a resource limited setting we discovered that understanding patterns and behaviors can be used to develop solutions in a cost effective manner.

Metric	Mean	95% Confidence Interval
Patient arrival (minutes early)		
8:00 AM	-28.5	-19.7 to -37.3
9:00 AM	-58.8	-49.1 to -68.6
10:00 AM	-70.5	-62.9 to -78.1
11:00 AM	-72.0	-63.7 to -80.3
> 13:00 PM	-179.4	-148.4 to -210.4
Wait time in waiting room (minutes)		
Colonoscopy	28.8	5.0-52.6
EGD[1]	38.6	8.0-69.2
EGD/Colonoscopy	31.9	1.4-62.4
Pre-procedure time (minutes)		
Colonoscopy	22.3	20.0-24.6
EGD[1]	20.9	14.9-26.9
EGD/Colonoscopy	31.2	21.0-41.3
On-time procedure start time (%)		
Colonoscopy	55.0	49.7-60.3
EGD	53.3	48.0-58.6
EGD/Colonoscopy	55.1	49.8-60.4
Procedure time (minutes)		
Colonoscopy	28.5	26.6-30.4
EGD	9.5	8.3-10.8
EGD/Colonoscopy	36.4	33.3-39.5
Sedation time (minutes)		
Colonoscopy	11.2	-0.9-23.2
EGD	10.0	0.1-20.1
EGD/Colonoscopy	23.7	1.9-45.5
Recovery time (minutes)		
Recovery room	34.6	32.5-36.6
Room turnover time (minutes)		
Colonoscopy	13.2	-3.3-29.7
EGD	9.9	7.1-12.7
EGD/Colonoscopy	8.2	4.5-11.9

Table 1. Baseline endoscopy center data.
[1] EGD = esophagogastroduodenoscopy

Individual simulation models	Procedures performed/week	Patient time in endoscopy center (hours)	Provider utilization (%)	Nurse utilization (%)	Procedure room utilization (%)	Wait time (%)
Baseline	53.8 (51.0-56.6)	2.3 (2.2-2.5)	24.0 (21.9-25.5)	40.0 (37.9-42.0)	49.8 (47.1-52.5)	22.3 (19.9-24.6)
Reducing endoscopy center appointment times						
45 minute appointment	68.0 (66.8-69.2)	3.2 (2.8-3.6)	28.9 (27.1-30.6)	48.0 (46.5-49.4)	55.8 (53.8-57.7)	37.9 (32.0-43.7)
40 minute appointment [1]						
35 minute appointment [1]						
30 minute appointment [2]						
Modifying endoscopy center weekly schedule[3]						
60 minute appointment	55.7 (53.8-57.6)	2.4 (2.3-2.5)	23.3 (21.3-25.4)	40.9 (39.4-42.4)	62.5 (58.4-66.5)	21.8 (18.7-24.8)
45 minute appointment	65.6 (64.5-66.7)	2.8 (2.6-2.9)	27.1 (24.8-29.4)	46.6 (45.3-47.9)	68.2 (65.9-70.5)	33.1 (29.1-37.2)
40 minute appointment	75.4 (73.6-77.3)	3.3 (3.1-3.6)	30.6 (28.2-32.9)	52.9 (50.4-55.4)	74.9 (71.7-78.2)	41.3 (39.1-43.5)
35 minute appointment [1]						
30 minute appointment [2]						
Expanding human resources						
Increase in pre-procedure nurses to 2[4]	68.4 (65.3-71.5)	2.4 (2.2-2.6)	30.3 (28.3-32.3)	65.6 (4.0-127.2)	61.7 (58.0-65.4)	22.4 (18.4-26.4)
Increase of 1 endoscopist to each half-day of endoscopy						
60 minute appointment	70.0 (67.2-72.8)	2.3 (2.1-2.6)	24.9 (22.8-27.1)	169.9 (158.2-181.7)	56.2 (52.7-59.8)	21.0 (18.2-23.8)
45 minute appointment	87.6 (85.6-89.5)	3.0 (2.6-3.4)	30.2 (27.5-32.9)	211.9 (198.3-225.4)	65.5 (61.3-69.8)	34.9 (29.1-40.7)
40 minute appointment	93.9 (92.3-95.4)	3.9 (3.7-4.2)	32.8 (31.1-34.5)	230.7 (218.4-243.0)	70.8 (66.3-75.3)	49.2 (45.2-53.1)
Minimizing recovery room time						
No recovery in procedure room[4]	68.1 (65.8-70.3)	2.8 (2.4-3.2)	29.5 (26.6-32.3)	42.5 (39.9-45.0)	49.6 (46.5-52.7)	35.0 (29.0-41.0)
30 minute recovery[4]	67.6 (65.8-69.4)	2.5 (2.2-2.7)	28.7 (26.5-30.9)	38.9 (37.2-40.6)	45.3 (43.1-47.5)	35.4 (30.8-40.0)

Table 2. Individual simulations performed in endoscopy center model and calculated outputs with regards to several performance and efficiency metrics.

[1] Simulation not feasible as a significant number of patients did not have their procedures completed at the end of the day.
[2] Simulation not feasible as appointment time was too close to mean procedure times.
[3] Shifting one afternoon half-day of endoscopy from Friday to a Wednesday morning session.
[4] Appointment time of 45 minutes.

Expanded endoscopy center simulations and validation	Procedures performed/week	Patient time in endoscopy center (hours)	Provider utilization (%)	Nurse utilization (%)	Procedure room utilization (%)	Wait time (%)
Baseline	53.8 (51.0-56.6)	2.3 (2.2-2.5)	24.0 (21.9-25.5)	40.0 (37.9-42.0)	49.8 (47.1-52.5)	22.3 (19.9-24.6)
Reducing endoscopy center appointment times						
45 minute appointment [1]	68.6 (66.2-70.9)	1.9 (1.8-2.0)	30.1 (27.4-32.7)	69.0 (-8.5-146.5)	51.2 (47.1-55.2)	21.7 (17.6-25.9)
Simulation validation[2]	71.8 (68.6-75.0)	2.2 (1.6-2.8)	41.6 (37.4-45.8)	69.3 (45.9-92.7)	56.2 (51.7-60.7)	14.0 (7.9-20.1)
40 minute appointment [3]	78.0 (76.4-79.6)	2.1 (2.0-2.3)	34.5 (32.5-36.6)	47.4 (44.8-49.9)	56.4 (53.2-59.6)	25.2 (22.4-28.0)
Modifying endoscopy center weekly schedule[4]						
45 minute appointment	70.2 (68.7-71.8)	1.9 (1.8-2.0)	29.6 (27.1-32.2)	41.9 (39.3-44.6)	61.9 (58.8-65.1)	18.2 (15.6-20.8)
Simulation validation[2]	89.0 (85.5-92.5)	2.4 (1.8-3.0)	47.3 (42.9-51.7)	71.1 (48.3-93.9)	58.9 (55.6-62.2)	17.1 (7.8-26.4)
40 minute appointment	81.8 (80.5-83.0)	2.0 (1.9-2.1)	35.1 (32.0-38.2)	49.6 (47.4-51.8)	71.0 (67.4-74.7)	22.7 (19.7-25.6)
Expanding human resources[5]						
45 minute appointment	89.1 (87.6-90.7)	2.1 (1.9-2.2)	32.5 (29.6-35.4)	175.8 (166.4-185.2)	55.9 (52.7-59.1)	25.3 (22.7-27.9)
Simulation validation[2]	101.3 (97.8-104.8)	2.6 (1.7-3.5)	59.4 (54.6-64.2)	100.7 (69.8-131.6)	68.5 (63.9-73.1)	19.9 (11.8-28.0)
40 minute appointment	101.0 (98.0-104.0)	2.5 (2.2-2.7)	36.4 (33.3-39.4)	201.9 (190.9-212.8)	62.1 (58.5-65.8)	33.1 (27.5-38.7)

Table 3. Expanded endoscopy center simulations (individual simulations with additional resources) and calculated outputs with regards to several performance and efficiency metrics.

[1] Additional resources added: 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 4:30PM.

[2] Implementation of specific scenario in the endoscopy center over a two month timeframe and calculated outputs (i.e. results from operations rather than simulation output)

[3] Additional resources added: 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 5:00PM.

[4] Additional resources added: Friday PM appointments moved to Wednesday AM, 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 4:30PM.

[5] Additional resources added: One additional endoscopist added to each half-day of endoscopy, 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 4:30PM.

Figure Legend

Figure 1. SFGH endoscopy center patient flow.

Figure 2. Process model of the SFGH endoscopy center developed for discrete simulation modeling.

Figure 3. Percentage changes from baseline in several performance metrics using various expanded endoscopy center simulations.

Simulation 1: Appointment time of 45 minutes, 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 4:30PM.
Simulation 2: Appointment time of 40 minutes, 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 5:00PM.
Simulation 3: Friday PM appointments moved to Wednesday AM, appointment time of 45 minutes, 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 4:30PM.
Simulation 4: Friday PM appointments moved to Wednesday AM, appointment time of 40 minutes, 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 4:30PM.
Simulation 5: One additional endoscopist added to each half-day of endoscopy, appointment time of 45 minutes, 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 4:30PM.
Simulation 6: One additional endoscopist added to each half-day of endoscopy, appointment time of 40 minutes, 2 pre-procedure nurses, recovery time of 30 minutes, recovery only in recovery room, and endoscope reprocessor hours extended to 4:30PM.

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