A Discrete Event Simulation Model to Evaluate Operational Performance of a Colonoscopy Suite

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<td>Gastroenterology &lt; INTERNAL MEDICINE, Colorectal cancer &lt; ONCOLOGY, PERFORMANCE MEASUREMENT</td>
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A Discrete Event Simulation Model to Evaluate Operational Performance of a Colonoscopy Suite

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Running Title: Colonoscopy Suite Simulation Model for Performance Evaluation

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Abstract

**Background & Aims:** Colorectal cancer, a leading cause of cancer death, is preventable with colonoscopic screening. Colonoscopy cost is high and optimizing resource utilization for colonoscopy is important. Our study aim is to evaluate resource allocation for optimal use of facilities for high volume colonoscopy screening. **Methodology:** We used data from a computerized colonoscopy database and discrete event simulation to determine the optimal number of endoscopists to staff a suite, the number of procedure rooms to open each day; and patient throughput, the number of patients served in a typical workday. **Results:** The maximum number of patients served is linearly related to the number of procedure rooms in the colonoscopy suite, with a fixed room to endoscopist ratio. Utilization of intake and recovery resources becomes more efficient as the number of procedure rooms increases, indicating the potential benefits of large colonoscopy suites. Turnover time has a significant influence on patient throughput and procedure room and endoscopist utilization for varying ratios between 1:1 and 1:2 rooms per endoscopist. **Conclusions:** Increasing the number of procedure rooms does not necessarily increase efficiency within the colonoscopy suite. However, utilization of intake and recovery rooms is more efficient as the size of the colonoscopy unit increases. The impact of reducing turn-over times for colonoscopy rooms is limited to scenarios where the endoscopist has less than 2 procedure rooms, while suites with higher ratios are not impacted by reducing turn over times. The maximal achievable endoscopist utilization is 90%; the maximal achievable room utilization is 67%.


**Introduction**

Colorectal cancer is the second leading cause of cancer death in the U.S., with over 50,000 deaths estimated in 2007, and the third leading diagnosed cancer with over 150,000 new cases estimated in 2005 \(^1\). Colonoscopy screening is an important prevention and detection method for colorectal cancer. It has been estimated that 17 million endoscopies were done in 2002 for colorectal cancer screening \(^2\). In the U.S. alone total annual costs of colonoscopy are estimated to be more than $15 Billion \(^3\). The high volume and high cost of health care delivery for colonoscopies motivates the consideration of best practices to improve operational performance of colonoscopy suites.

Careful planning of procedure rooms, staff, and other resources that make up the colonoscopy suite are integral to effective delivery of screenings. However, there is significant uncertainty in the time it takes for patient care activities related to colonoscopy such as the intake process, the procedure, and patient recovery, which makes resource planning a difficult task. Furthermore, a significant portion of the total costs are fixed (e.g. physical space, equipment, staff) and are incurred independent of average daily patient throughput through the suite. The high costs make the colonoscopy suite an undesirable environment in which to experiment with potential process improvements.

The need to evaluate colonoscopy suite design and staffing scenarios prior to putting them into practice makes *discrete event simulation* attractive. A discrete event simulation is a computer implemented quantitative model that is designed to emulate the process flow of a system. The logic and structure of the system is emulated using observational input data for activity durations, a process map defining the sequence of activities that define patient flow, and resource utilization at each stage of the flow.
process. Once the model is calibrated, the behavior of the system can be observed while changing the design characteristics of the system. In the colonoscopy suite system, for instance, performance measures such as procedure room utilization, patient throughput, endoscopist and nurse utilization, and patient waiting times can be compared under various scenarios that define different configurations of physical space, staffing decisions, operating policies, and durations of processes. Thus, simulation affords the opportunity to experiment with potential changes in a fast and inexpensive manner.

Key questions that we answer with this approach are as follows: (a) Given a certain number of procedure rooms, how does varying the number of endoscopists operating within the suite affect patient throughput? (b) Are there economies of scale associated with a larger endoscopy suite? (c) What is the maximum resource utilization? (d) Are there any recognizable relationships between these performance measures?

Methods

Discrete Event Simulation is among a collection of methods from the field of systems engineering. It has been broadly adopted in industry to improve operational performance of manufacturing and service systems. However, a recent study by the Institute of Medicine and the National Academy of Engineering\(^4\) recognizes a shortfall in the use of systems engineering for operational performance of health systems, and calls for a partnership between engineers and health care professionals to develop new methodologies to improve health care delivery.

There is a rich history of the use of systems engineering methods to improve efficiency of service systems such as airlines, amusement parks, hotel chains, care rental
agencies, and the natural gas and power industry. However, the use of systems engineering methods in health care has been more limited. Some notable exceptions are recent papers which consider the use of discrete event simulation for planning of outpatient surgical suites\textsuperscript{5, 6, 7, 8} and primary care clinics\textsuperscript{10, 11}.

In contrast to the above referenced literature, in our study we analyze resource allocation and operational planning decisions for a high volume colonoscopy service. We study several key operational questions. We evaluate the optimal number of endoscopists to staff a suite and we analyze how the size of the suite influences patient throughput and the average utilization of resources. In contrast to the above referenced literature we report on a discrete event simulation model of a complete colonoscopy suite including the check-in and intake process, the procedure itself, and recovery. Furthermore, our model uses a detailed representation of patient flow and critical resources (e.g. procedure rooms, endoscopist, intake nurses, recovery beds) to investigate the impact of uncertainty in process times and procedure room turnover times on colonoscopy suite throughput and resource efficiency.

System Description

Our simulation model was constructed based on the colonoscopy suite at Mayo Clinic in Rochester, MN. The simulator samples from historical data to emulate the flow of patients through actual stages of the system including a patient waiting room, preparation rooms, procedure rooms, and recovery rooms. Scheduling of an appointment can be made up to 12 weeks in advance. Schedules typically fill up within the last 48 hours and patients arrive at the colonoscopy suite according to a predetermined set of
assigned appointment times. Figure 1 provides a summary of the activities that comprise a patient’s flow through the colonoscopy suite. Following is a detailed description of the main activities that govern flow through the colonoscopy suite:

**Intake** - When a patient arrives for their scheduled procedure they are received at the check in desk where they are asked to have a seat in the lobby. At the patients scheduled arrival time, 1 of 6 nurses from the intake area takes the patient from the lobby to an intake area. Following consultation with a nurse, the patient is taken to a room for a change of dress. Following changing, the patient is taken to 1 of 2 holding rooms where there are 10 patient seats. The patient waits until the nurse from the next available procedure room comes to transfer them.

**Procedure** - Following holding, a nurse from a procedure room walks the patient to the procedure. An IV is started and the patient waits in the procedure room for the endoscopist to arrive. The procedure room activity begins when the endoscopist enters the room and ends when the patient leaves the procedure room. Sub-activities include discussion of the procedure, sedation, insertion of colonoscope, and colonoscope removal. Following the procedure, clean up and preparation for the next procedure in the room takes approximately 10-15 minutes.

**Recovery** – Following the procedure the patient is taken to the recovery area. The recovery area has 3 pods with 8 beds in each pod. As the patient is taken to recovery, the nurse checks the recovery display panel for directions on which pod the patient should be taken to in order to balance the load on each pod.

**Data**
Our simulation model is based on a comprehensive data set (n=4,024 operations) compiled over the year 2006, after obtaining appropriate research authorization. It is based on a single unit of 4 endoscopy rooms, representing a sample subset of the total number of procedures performed at the colonoscopy suite. The times at check in, intake area arrival, procedure room arrival, recovery room arrival, and discharge were collected for each patient. These patient flow time data points were fed into an electronic system as they occurred. From these data, probability distributions for the amount of time in the waiting area, preparation room, procedure rooms, and recovery room were fit using maximum likelihood estimation. The highest 1% of outliers were excluded as unreasonable time durations, most likely due to a time miscalculation. The resulting distributions for intake, procedure, and recovery shown in Figure 2 have means and standard deviations of 14.63 (7.24), 26.55 (11.89), and 59.18 (18.18) minutes, respectively.

Model

We developed the simulation model through an iterative process involving model construction, attaining feedback from those involved in the management of the colonoscopy suite, incorporating the feedback into the model, and validation. The discrete event simulation model was constructed by dividing the system into 3 separate stages. The first is intake which begins after a patient has checked in and includes recording patient vital signs, further explanation of the procedure, preparation, and a change of dress. The second stage is the procedure. This begins when the patient is taken to the procedure room and ends at colonoscope removal. The final and typically
longest stage is recovery. Because the recovery process begins immediately following
the procedure, this stage begins at colonoscope removal in the procedure room before the
patient is transferred to the recovery area and ends when the patient is discharged from
the recovery area.

When a patient arrives at her predetermined appointment time, she proceeds to the
arrival desk and is checked in with a time that is distributed uniformly between 1 and 3
minutes according to the expert estimate supplied by the colonoscopy suite director.
Following check-in the patient goes to a nurse intake station. The intake process is based
on the empirical distribution derived from the data set (intake, procedure, and recovery
distributions are estimated as lognormal based on maximum likelihood estimation). The
patient is then taken to the dressing room where they change dress, with a duration based
on a uniform distribution between 5 and 10 minutes. After changing dress, the patient
waits in the holding area for the first available procedure room. Next, the patient is taken
to the procedure room and an IV is started. The procedure begins when the patient’s
specific endoscopist joins the patient in the procedure room after dictation of the previous
procedure is finished. Immediately following the procedure, the patient is taken to the
recovery area. Turn-around time for the procedure rooms is treated as a symmetrical
triangular distribution with varying parameters (a, b, c), which corresponds to the
minimum, mean, and maximum duration of turn-around time. The turn-around time for
the endoscopist between cases is also a triangular distribution, based on estimates
provided by the colonoscopy suite director. Since empirical data was unavailable,
procedure room and endoscopist turn-around times were based on subjective expert
estimates. The recovery process is distributed based on the empirical distribution. Following recovery, the patient is discharged and is considered out of the system.

In our model we assume a finite number of procedure rooms and endoscopists are available, and patient flow is restricted based on their availability. Recovery beds and intake nurses were both given unlimited availability for the purpose of measuring maximum procedure room and endoscopist utilization in a stressed system based on a maximum number of procedures. The average utilization rates of recovery beds and intake nurses were then calculated as the average of the number of resources at peak utilization.

Patients arrive at the check-in area according to a user defined schedule of arrival times. We assume arrivals are deterministic and all patients arrive on time and have undergone appropriate preparation for the colonoscopy. This may vary among clinical environments for a variety of reasons. We make this assumption for two reasons. First, it is consistent with the practice we studied where no-show rates are very low and most patients arrive at or before their appointment time. Second, it favors a more straightforward interpretation of our analysis of varying design and operating policies.

The model was built using Arena 10.0 and all scenarios discussed in the Results section were run on a standard PC (Intel Core 2 Quad CPU, 2.39 GHz, 4 GB of RAM). Our validation of the model was based on a base case scenario corresponding to the typical operation of the clinic we studied. In the base case four endoscopists share eight procedure rooms. The day begins at 7:30am and finishes at 5:00pm. Calibrating the model using the sampled data above resulted in total patient throughput rates that match
closely with those observed in practice. Additional validation was done based on presenting results to experts including endoscopists and the suite director.

**Results**

Our numerical results include the base case, and additional scenarios were constructed by varying the number of procedure rooms and the number of endoscopists. Patient arrivals are based on a schedule where patients arrive in independent arrival streams for each endoscopist. Arrivals are spread out during the day by the mean procedure duration. Each of the scenarios was simulated for 500 replications to account for the stochastic nature of the intake, procedure, room and endoscopist turnover, and recovery times, which results in tight confidence intervals relative to the mean. Base case procedure room turnover times were based on expert estimates and assumed to be 15 minutes using a triangle distribution with parameters (10, 15, 20). Endoscopist turnover time was based on a triangle distribution with parameters (3, 4, 5).

**Operational Performance Evaluation**

Table 1 illustrates the results for several important performance measures. The results reported for each scenario include (a) the maximum number of patients that can be seen during the 9 hour period (7:30am – 4:30pm) (b) mean utilization of procedure rooms throughout the day and (c) mean utilization of endoscopists throughout the day. The utilization of procedure rooms and endoscopists is defined as the time the room is used for colonoscopy procedures divided by the total time they are available (turnover time is not counted as available time).
Based on the results in Table 1, we conclude that the maximum number of patients that can be seen on a given day is subject to diminishing returns when the number of endoscopists operating within a set number of procedure rooms increases. On the other hand, Table 2 shows that if a given procedure room to endoscopist ratio remains constant the maximum number of patients that can be seen increases approximately linearly as the suite increases in size. Table 2 also demonstrates the potential benefits of a larger suite. The shared resources of intake and recovery have higher utilization rates as the suite increases. Furthermore, Figure 3 illustrates that both the procedure room utilization and endoscopist utilization converge to the same maximum utilization as endoscopists are added to a suite of 8 procedure rooms. This is intuitive since as endoscopists are added, we approach the situation where each endoscopist is confined to a single procedure room.

Sensitivity Analysis

We conducted sensitivity analysis to evaluate the influence of turnover times on performance measures, since this is commonly identified as a detractor to overall efficiency. Figure 4 illustrates the influence of turnover time on performance measures relative to the base case assumption of a triangle distribution with parameters (10, 15, 20). In the figure, the percentage increase or decrease of a performance measure from base case is shown with the low and high assumptions for turnover time corresponding to a mean of 10 and 25 minutes with parameters (5, 10, 15) and (20, 25, 30) respectively. The base case corresponds to a scenario with 8 procedure rooms open. For example, when procedure room turnover time is assumed to be low, patient throughput increases
12% when there are 8 endoscopists and 5% when there are 6 endoscopists. That is, patient throughput is more sensitive to changes in procedure room turnover time when the procedure rooms available are being used by more endoscopists. From Figure 4 we conclude that performance measures are quite sensitive to mean turnover time when the number of endoscopists using the 8 procedure rooms is great than 4. However, there is little discernible effect of reducing turnover time for higher ratios (such as 2:1 illustrated in the figure). This indicates that the availability of a larger number of procedure rooms (2 or more per endoscopist) provides very little benefit.

By increasing the number of procedure rooms in the simulation, we observe increased efficiencies in both intake nurses and recovery beds. As shown in Table 2, while procedure room and endoscopist utilizations remain constant, intake nurse and recovery bed mean utilizations increase more than 75% and 40% respectively. Such results support potential efficiencies of having a high volume colonoscopy suite.

**Patient Perspective**

Measurable outcomes of this analysis can be extended to the patients’ perspective as well. For instance, operational decisions about staffing of the endoscopy suite influence patient waiting time for a procedure. We found that the patient arrival schedule has the most significant affect on patient waiting and resource utilization. Figure 5 illustrates the trade off of expected patient waiting time and the expected length of the day (time to complete all scheduled colonoscopies). These schedules were generated by varying the amount of time between each patient’s arrival between \((\mu - \sigma, \mu + \sigma)\) where \(\mu\) represents the mean procedure time and \(\sigma\) is the standard deviation. Each
schedule was run for 500 replications. The base case in Figure 5 uses the mean duration as the patient interarrival time, which is a commonly used approach in practice. As can be seen from the figure, as interarrival times increase expected patient waiting time decreases, while the opposite occurs for the expected length of day increases. Thus, these two criteria are competing.

**Discussion**

Based on the computational experiments described above we observe a number of important managerial insights. The key findings are as follows:

- **Economies of Scale:** There are no observed efficiencies in patient throughput due to increasing the number of procedure rooms in the colonoscopy suite. However, mean utilization and the maximum number of patients in the intake and recovery area indicates decreasing resources per patient (e.g. nurses, recovery beds) as the number of procedure rooms in the colonoscopy suite increases.

- **Diminishing Returns:** The increase in patient throughput per Endoscopist decreases as the number of Endoscopists added to an colonoscopy suite with a fixed number of procedure rooms increases.

- **Turn-over Times:** The impact of reducing turnover times for procedure rooms on all performance measures can be significant but is limited to staffing scenarios in which Endoscopists have less than 2 procedure rooms. The optimal ratio is dependent on the mean time for colonoscopy vs. turnover time.
- **Utilization:** The maximum achievable endoscopist utilization is 90% and the maximum achievable procedure room utilization is 67%.

- **Competing Criteria:** Expected patient waiting time and operational performance measures, such as total time to complete all scheduled colonoscopies, are competing criteria, i.e., increasing one results in a decrease in the other.

## Conclusions

The above findings are dependent on the mean and variance of activities within the endoscopy suite, which depends on a variety of factors, such as the experience level of the endoscopist and the complexity of typical cases. However, the simulation model we describe is transferable to any organization with a similar process flow and sufficiently large sample set of activity durations to calibrate the model. Furthermore, the model may be used to investigate how other factors influence performance measures, such as reductions in the mean and variance of intake and recovery time, and the effect of material resources constraints such as recovery beds, scopes, or supporting personnel. The application of these findings will potentially allow managers of colonoscopy suites to provide optimally effective staffing, determine the number rooms required, and may encourage the design of large suites to take advantage of the economies of scale that can be gained in the intake and recovery areas. Ultimately these data may lead to lower costs as facilities and staff are used more efficiently.

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References


Figure 1: Schematic representation of the sequence and flow of activities for a particular patient within a colonoscopy practice.
Figure 2: Distributions of duration times for Intake, Procedure, and Recovery processes.
Figure 3: Expected procedure room and endoscopist utilization and patient throughput over time as a function of the number of endoscopists in the suite.
Figure 4: Sensitivity analysis of performance measures with respect to the number of endoscopists staffing an 8-procedure room endoscopy suite.
Figure 5: Expected length of day (time to complete all cases) vs. expected patient waiting time (averaged over all patients) with respect to the interarrival time for the patient arrival schedule.
Table 1: Patient throughput, procedure room utilization, and endoscopist utilization for varying number of endoscopists in an 8-procedure room endoscopy suite.

<table>
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<tr>
<th>Procedure Rooms – Endoscopists</th>
<th>Patient Throughput (number of patients)</th>
<th>Procedure Room Utilization (%)</th>
<th>Endoscopist Utilization (%)</th>
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<td>56 (56, 56)</td>
<td>89 (89, 89)</td>
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<td>67 (67, 67)</td>
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Table 2: Patient throughput, procedure room utilization, endoscopist utilization, intake utilization, and recovery utilization with respect to increasing number of procedure rooms in the endoscopy suite.

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<tr>
<th>Procedure Rooms–Endoscopists</th>
<th>Patient Throughput (number of patients)</th>
<th>Procedure Room Utilization (%)</th>
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<th>Intake Utilization (%)</th>
<th>Recovery Utilization (%)</th>
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