Judd Anderman

December 10, 2017

**Discrete Event Simulation of Patient Flow in a Large, Urban Ambulatory Care Clinic**

**Background**

Resource allocation optimization, effective appointment scheduling processes, and patient wait times in ambulatory care settings have long been of interest to both scholarly observers and daily practitioners in the medical field. However, achieving sustained and widespread improvements in efficiency, access, and the quality of patient experiences remains especially challenging in the face of the social, economic, and epidemiological complexity of most clinical systems. As Norman T. J. Bailey observed in an early application of queuing theory to appointment protocols and wait time in hospital outpatient departments more than a half-century ago, “A striking and widely observable feature of hospital out-patient clinics is the disproportionately long time which patients are obliged to wait compared with the average period devoted to actual medical examination treatment or advice,” (1952).

Rapid growth in the cost of health care over the last several decades, especially in the United States, has led to increasing pressure on provider organizations to achieve greater efficiency in the delivery of care without sacrificing quality or accessibility (Jun et al. 1999, Jacobson et al. 2006). In this context, researchers and health care professionals have welcomed the availability of increasingly sophisticated and user-friendly software packages for discrete event simulation and have applied these tools to address a wide variety of problems and domains, including patient scheduling and admissions in outpatient, inpatient, and emergency department settings and across networked systems; patient routing and flow schemes; and resource availability and allocation, i.e. bed, room, and staff sizing and planning (ibid.). In addition to discrete event simulation, a number of other methods drawn from operations research and related traditions have been leveraged in efforts to analyze and improve patient flow and other clinical system performance metrics, including steady-state and time-dependent queuing theoretic models and decision tree analysis (Lotfi and Torres 2014, Palmer et al. 2017).

Given the relative scarcity and high cost of medical staff and resources, the nature of health care financing in the United States, and persistent disparities in access to care and health outcomes across demographic and socio-economic lines, the pressures to control and contain health care expenditures noted above pose particular challenges for organizations that serve disproportionately poorer and sicker patient populations. This paper applies discrete event simulation and data sourced from the electronic health record (EHR) database of large New York City-based Federally Qualified Health Center (FQHC) ambulatory care network to model patient flow and wait time at the network’s largest adult primary care clinic and to evaluate the relative performance of a flexible, or doctor-to-patient, exam room allocation policy in comparison to the clinic’s existing fixed, or patient-to-doctor, exam room assignments (Hulshof et al. 2012).

**Methods**

The clinic under analysis serves approximately 12,000 predominantly low-income, publicly insured or uninsured patients at roughly 40,000 unique encounters each year. Flow charts of patient and information movement through the clinic and more detailed process maps of the status quo and intervention models were developed through observation and in consultation with clinical staff and directors (see appendix).

Data to specify model input distributions and parameters were extracted from the database of the EHR system used by the clinic and by the network as a whole prior to September 2016. These data were cleaned and analyzed using the open-source statistical computing and graphics software R and its integrated development environment R Studio. Candidate probability distributions for patient arrival time deviation and total time engaged in care in an exam room per patient visit were fit with maximum likelihood estimation (MLE) methods using the MASS and fitdistrplus packages. Goodness-of-fit between the fitted distributions and the observed data was evaluated using Kolmogorov-Smirnov testing and assessed visually against the empirical density and cumulative distribution of the observed variables as well as in probability plots. An input probability distribution for visit time with medical assistant was adapted from Vahdat et al. (2017), and Monte Carlo methods incorporating this sourced distribution and actual observations of total exam room time were used to simulate visit times with physician, and these simulated data were in turn fit to a distribution in the manner described above. Additional model input parameters, including rates of “no-show” visits, number of physicians in service on a typical day, and average number of patient arrivals per 15-minute appointment slot were obtained from examination and analysis of the collected data.

Given the complexity of the system at hand, model verification proceeded on the basis of comparison between simulation results and expectations derived from real-world output data rather than queuing theoretic or other analytic results, and so in this case coincided with the model validation process. Simulation results for total number of visits in 365 days (42,259), average time in system per patient visit (89.05 minutes), and average wait time between arrival and escort to an exam room (32.36 minutes) from the status quo model with fixed exam room assignment appeared reasonable when compared to real-world observations: 41,011.58 annual visits, here the average number of completed encounters per day in January 2016 extrapolated over the 260 weekdays in a year; average time in system of 65.35 minutes; and average wait time before care of 24.72. The discrepancies in these output metrics might reflect gaps between the simulated model and the structures and processes of the actual clinic environment, extrapolation beyond the observed data sample to estimate total visits, limited granularity of the EHR data used to specify model inputs, variation in the quality and accuracy of documentation over time and across EHR users, or some combination of these factors.

**Results**

Status quo and intervention models of the clinic were developed and simulated using Simio software with a Student License. Ten replications of both models were run for an interval of one year with patient arrivals occurring only during weekdays. The replications for each model used the same parameters for fixed model inputs and identically seeded random number streams and parameterized probability distributions for the medical assistant and physician service time and patient arrival time deviation controls. The only difference between the two sets of simulation runs was the exam room allocation process; for the intervention model with flexible, or doctor-to-patient, room assignment, this difference also involved utilization of the clinic’s full capacity of 22 exam rooms whereas 9 of these 22 rooms were unused in the status quo model with fixed exam room allocation.

The relative performance of the two models was assessed by comparing the mean wait time between arrival and initiation of care and the mean time in system averaged across the ten replications of each model. Two-sample student’s t-tests were performed on two null hypotheses: first, that average wait time between arrival and escort to an exam room under the status quo model is less than under the intervention model; and second, the that average time in system per visit under the status quo model is less than under the intervention model. Statistically significant differences were detected for both metrics between the two models, with one-sided p-values of 6.847\*10^-13 and 1.838\*10^-12 for the difference in mean average wait time between arrival and initiation of care and mean average time in system, respectively. Accordingly, both null hypotheses were rejected (see <http://rpubs.com/janderman/data604_project> for all statistical analyses and <https://github.com/juddanderman/Data-604-Simulation-and-Modeling/tree/master/Final%20Project> for Simio project files, R markdown, and raw data).

**Conclusions**

Health care researchers and practitioners are well aware of the many sources of variability in clinical systems: wait times and rates of resource utilization vary over the course of daily operating hours (Oh et al. 2016, Famigletti et al. 2017); variation in patient age and acuity (Kittipittiyakorn and Ying 2016) and in rates of walk-in and new patient visits (Chand et al. 2009) cause wide variation in time at registration and check-out and time engaged in care; variability in staff arrival times can trigger congestion and delays (Rohleder et al. 2011); no-shows and late cancellations can frustrate the best efforts to optimize staff and resource scheduling and planning (Kopach et al. 2007, Parikh et al. 2010); and attendance rates vary by payer status and type and, perhaps not surprisingly, with weather (Norris et al. 2012). These challenges to predictability are at the same time potential levers for performance improvement. Open-access scheduling can eliminate no-shows caused by long appointment lead times, and when demand and capacity are well balanced, can lead to gains in efficiency (Kopach et al. 2007). Automated appointment reminder systems are not quite as effective at ensuring attendance as telephone calls from staff members (Parikh et al. 2010), but nevertheless reduce no-show rates without imposing additional burdens on busy clinical staff. Dedicated call centers are an alternative mechanism for appointment scheduling and reminding which can reduce overflow demand on front-line clinic registration and clerical workers and so help to minimize variation in check-in and check-out times (Chand et al. 2009).

A number of the interventions indicated above have already been studied using discrete event simulation (Kopach et al. 2007); all are worthy of further analysis and may be of significant practical value in the right clinical contexts. This paper has focused on modeling a flexible exam room allocation policy and applying discrete event simulation in order to examine the policy’s potential to reduce wait time and improve patient flow in a large, urban ambulatory clinic. Statistical comparison of the results of the simulated status quo and intervention models in terms of average wait time between arrival and escort to an exam room and average total time in system provides strong evidence in support of the intervention model. With all other model inputs held constant, flexible exam room allocation reduced average wait time before initiation of care from 32.36 minutes (95% margin of error: 1.00 minutes) to 9.33 minutes (95% margin of error: 0.08 minutes). Maximum number of patients waiting to be escorted by a medical assistant to an exam room and engaged in care also decreased substantially.

In the outpatient context, wait time is not only an important determinant of patient satisfaction, but can also strongly shape experiences and morale among clinic staff (Rohleder 2011). In more acute care settings, long waiting times pose a clear risk to patient health. Discrete event simulation is a powerful tool for researchers and health care professionals studying clinical organization and processes with an eye toward achieving improved flow, better patient experiences, and more efficient use of scarce and costly resources. This paper demonstrates the potential benefits of one straightforward intervention in clinic operations in terms of decreased wait time and total time in system, and reduced congestion in the waiting area. The modeling and analysis performed here could be developed and extended through additional observation and continued consultation with clinic staff and management to improve the models’ fidelity to the real-world clinic’s physical characteristics and operating processes and thus increase the reliability of the results as well as explore alternative performance improvement initiatives and interventions.

**References**

Bailey, Norman TJ. "A study of queues and appointment systems in hospital out-patient departments, with special reference to waiting-times." *Journal of the Royal Statistical Society. Series B (Methodological)* (1952): 185-199.

Chand, Suresh, et al. "Improving patient flow at an outpatient clinic: study of sources of variability and improvement factors." *Health care management science* 12.3 (2009): 325-340.

Famiglietti, Robin M., et al. "Using Discrete-Event Simulation to Promote Quality Improvement and Efficiency in a Radiation Oncology Treatment Center." *Quality Management in Healthcare* 26.4 (2017): 184-189.

Hulshof, Peter JH, et al. "Analytical models to determine room requirements in outpatient clinics." *OR spectrum* 34.2 (2012): 391-405.

Jacobson, Sheldon H., Shane N. Hall, and James R. Swisher. "Discrete-event simulation of health care systems." *Patient flow: Reducing delay in healthcare delivery*. Springer US, 2006. 211-252.

Jun, J. B., Sheldon H. Jacobson, and James R. Swisher. "Application of discrete-event simulation in health care clinics: A survey." *Journal of the operational research society* (1999): 109-123.

Kittipittayakorn, Cholada, and Kuo-Ching Ying. "Using the Integration of Discrete Event and Agent-Based Simulation to Enhance Outpatient Service Quality in an Orthopedic Department." *Journal of healthcare engineering* 2016 (2016).

Kopach, Renata, et al. "Effects of clinical characteristics on successful open access scheduling." *Health care management science* 10.2 (2007): 111-124.

Lotfi, Vahid, and Edgar Torres. "Improving an outpatient clinic utilization using decision analysis-based patient scheduling." *Socio-Economic Planning Sciences* 48.2 (2014): 115-126.

Norris, John B., et al. "An empirical investigation into factors affecting patient cancellations and no-shows at outpatient clinics." *Decision Support Systems* 57 (2014): 428-443.

Oh, Chongsun, et al. "Use of a simulation-based decision support tool to improve emergency department throughput." *Operations Research for Health Care* 9 (2016): 29-39.

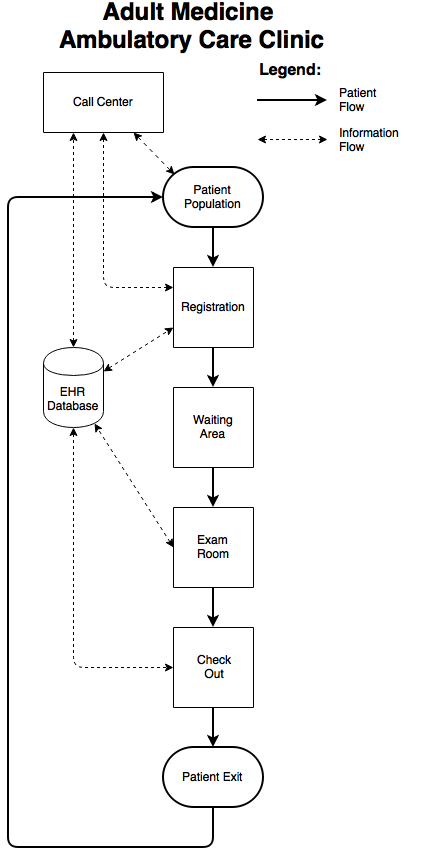
Palmer, Ryan, Naomi J. Fulop, and Martin Utley. "A systematic literature review of operational research methods for modelling patient flow and outcomes within community healthcare and other settings." *Health Systems* (2017): 1-21.

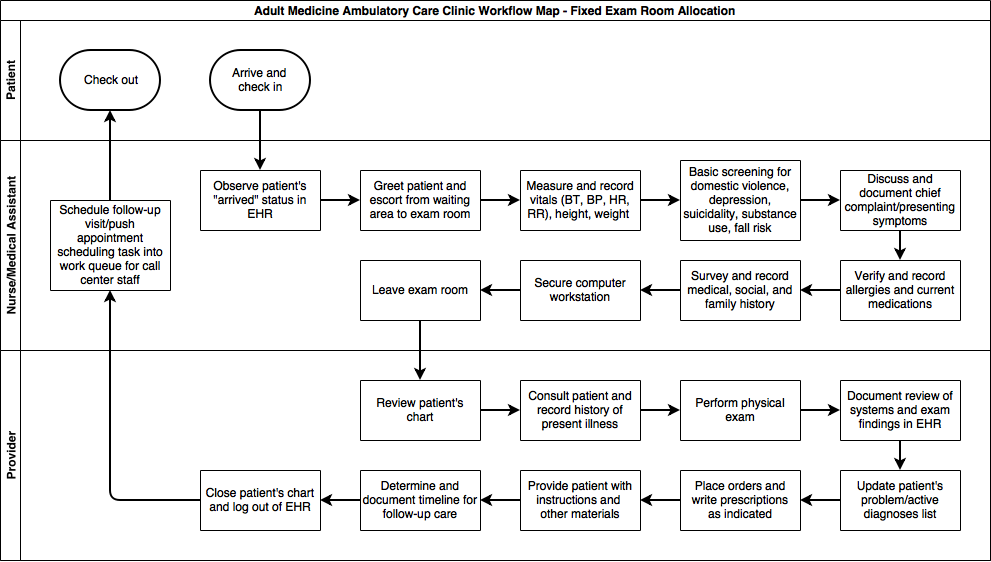
Parikh, Amay, et al. "The effectiveness of outpatient appointment reminder systems in reducing no-show rates." *The American journal of medicine* 123.6 (2010): 542-548.

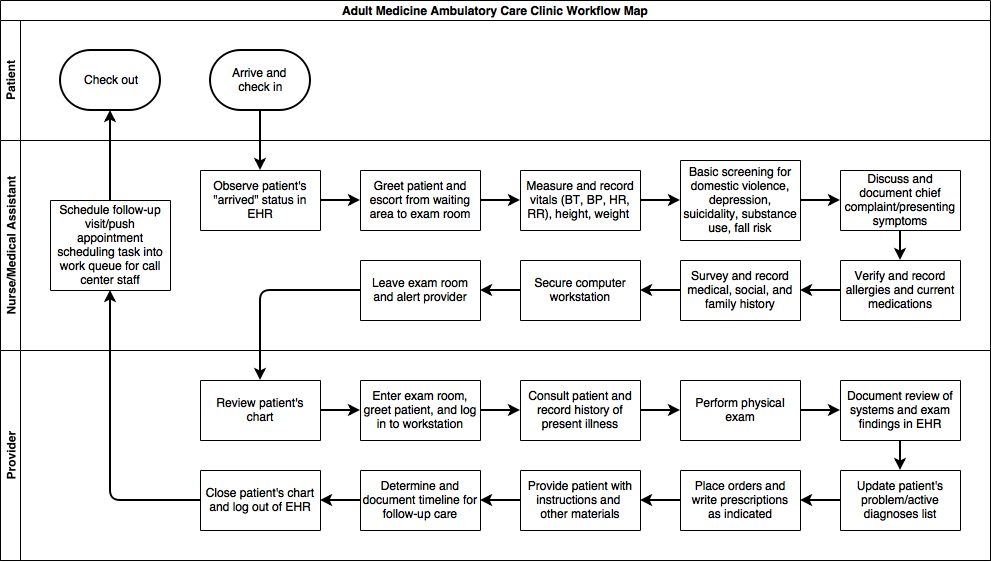
Rohleder, Thomas R., et al. "Using simulation modeling to improve patient flow at an outpatient orthopedic clinic." *Health care management science* 14.2 (2011): 135-145.

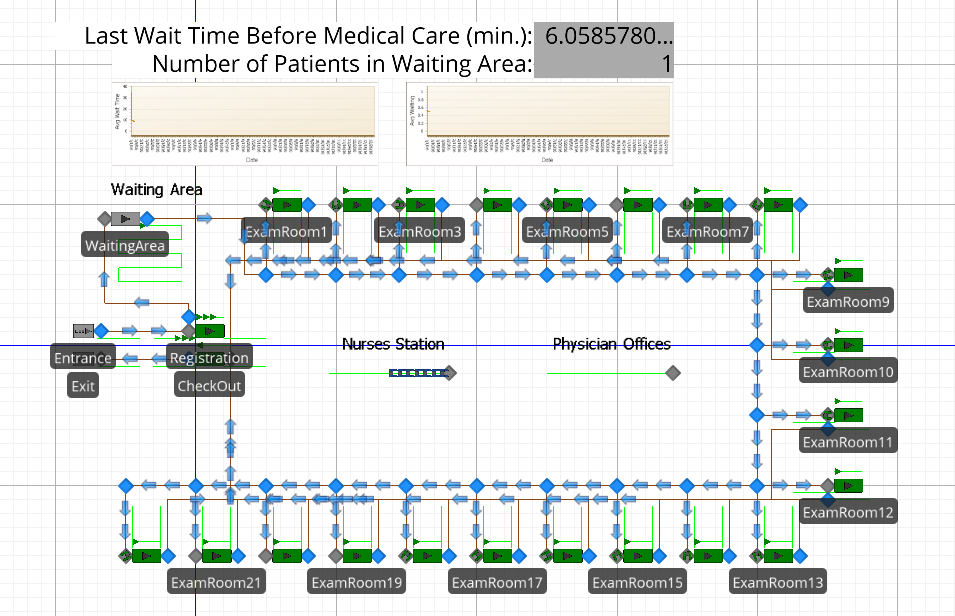
Vahdat, Vahab, Jacqueline Griffin, and James E. Stahl. "Decreasing patient length of stay via new flexible exam room allocation policies in ambulatory care clinics." *Health care management science* (2017): 1-25.

**Appendix**

****

****

****

****