# SIMULATION IMPROVES PATIENT FLOW AND PRODUCTIVITY AT A DENTAL CLINIC

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## ABSTRACT

The health care industry in the United States, and in many other countries as well, is undergoing unremitting pressures to improve standards of patient care and service, reduce costs, and increase efficiency. These pressures stem from higher expectations by health-care consumers, increased demands stemming from changing demographics (particularly the "graying" of populations), and more rigorous auditing of expenditures by both private insurers and government. In response, health-care industry practitioners, managers, and administrators are increasingly availing themselves of the analytical techniques, including simulation, provided by the discipline of industrial engineering. In this paper, we document a simulation study undertaken to improve patient service at a dental clinic. The simulation analysis validated innovative ways to improve patient throughput and decrease patient waiting times with zero incremental cost.

## INTRODUCTION

Historically, the first major application area of discrete-event process simulation was the manufacturing sector of the economy. More recently, and currently very vigorously, the health-care industry is availing itself of the analytical and predictive powers of simulation to reduce costs, improve efficiency, and enhance service to patients (Lowery 1996). Higher patient expectations, increased cost pressures from private and government insurers, and demographically induced increases in overall demand are all compelling reasons for this sector of the economy to improve its overall performance (McGuire 1998). Recent examples of simulation application to various aspects of health care are contributions from (Costantino, De Gravio, and Tronci 2005) (improvement of a supply chain for urgently needed provision of medical oxygen), (Martin, Grønhaug, and Haugene 2003) (evaluation of proposals to reduce overcrowding and improve patient care in the geriatric department of a large hospital), and (Kumar and Ozdamar 2004) (simulation in the service of business process reengineering of hospital operational complexities.

In the application documented here, simulation was applied to investigate and improve daily operational procedures at a dental clinic. Achievements of the study included both reducing patient waiting times and increasing the number of patients seen per day, with neither increase of cost nor compromise to quality of care.

## OVERVIEW OF ROUTINE PROCEDURES AT THE DENTAL CLINIC

The dental clinic under study comprises one dentist, two dental hygienists, and a receptionist. A heavy majority of the patients come by appointment (historically, patients have waited weeks or even months for their appointment day to arrive) to have their teeth cleaned (prophylaxis) and checked. Inasmuch as the patients have made their appointments far in advance, and a dental clinic will never be in contention for a favorite place to wait idly, patient impatience and intolerance for even relatively short waits is high.

The typical patient in good or at least stable dental health comes to the clinic approximately every six months for a dental prophylaxis (cleaning of teeth and assessment of dental health). On arrival, patients check in with the receptionist. After doing so, they will have to await the attention of one of the dental hygienists. If the patient needs dental X-rays, taking them and setting them aside for development of the film will be the first task performed by the hygienist. Except in rare cases (e.g., the patient complains of disquieting symptoms), X-rays are needed once a year, i.e. every other visit for prophylaxis. Next, the hygienist cleans (scrapes, scales, flosses, and polishes) the patient's teeth; while doing so, the hygienist will also document any presumptive problems observed for the attention of the dentist. Upon completing these tasks, the hygienist notifies the dentist, and the patient then may have to await the arrival of the dentist. Upon arrival at the patient's chair, the dentist will audit the

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hygienist's work and examine X-rays (those just taken, if the patient was X-rayed this visit, and/or X-rays in the patient's file, which may show trends in the patient's dental health). Further, the dentist questions the patient concerning any symptoms or complaints, and discusses any future needed dental work such as filling of cavities, referrals for root canal therapy (done by a different dental clinic specializing in endodontic dental work), provision for crowns, or extraction of teeth. After this consultation is complete, the patient returns to the receptionist to check out, arrange for bill payment, and often (even presumably) schedule the next appointment. The patient then leaves the clinic. The canonical flow process from the patient's perspective appears in the Appendix, Figure 1. Indeed, during later model construction, this figure, having been validated with the client, was the immediate guide for model construction.

## DATA COLLECTION AND ANALYSIS

Since the client had very little physical data archived, an early step in this project was on-site data collection at the dental clinic. First, it was noted that patients typically make their next appointment (usually six months hence unless problems found during the prophylaxis demand attention sooner) while checking out and settling accounts with the receptionist. At that time, patients may either specify which hygienist they prefer, or specify a preferred appointment hour; in the latter case, they will be assigned an appointment hour.

The simulation analysts then gathered data from 9am to 2pm on several Mondays and Wednesdays (skipping a one-hour scheduled lunch break). The receptionist agreed that data collected on these days at these times would be typical and representative, even across a calendar year ("a toothache can come on anytime!"). Gathering the data used typical time-study methods (Mundel and Danner 1994); at the conclusion of the study, the client specifically commended the data collection work, deeming it quiet, unobtrusive, and hence unlikely to provoke the Hawthorne Effect (Martin-Vega 2001). Most data observations were taken in the small office anteroom where patients sit while waiting for their hygienist to become available. Numerical data collected included:

1. The arrival times of patients
2. How long patients waited before going to the room for prophylaxis
3. Whether X-rays were required, and the time required to take them if so
4. The prophylaxis process time
5. The length of waiting time for the dentist to arrive subsequent to the prophylaxis
6. The time the dentist spent with the patient after the prophylaxis
7. The time required to book the next appointment.

Item #2 was particularly useful for later model validation; the others were all directly used to construct the model.

## CONSTRUCTION, VERIFICATION, AND VALIDATION OF THE SIMULATION MODEL

Owing to ready availability within both academic and industrial contexts, and ample software power to both simulate and animate the health-care service system in question (although the animation was two-dimensional only, an issue of trifling consequence), the Arena® simulation modeling software (Kelton, Sadowski, and Sturrock 2007) was used. This software provides direct access to concepts of process flow logic, queuing disciplines (e.g., FIFO), modeling of processes which may be automated, manual, or semi-automated, use of Resources (here, the receptionist, the dental hygienists, and the dentist), definition of shift schedules, constant or variable transit times between various parts of the model (e.g., patient walking time from the anteroom to the prophylaxis room), extensibility (in the Professional Edition) via user-defined modules (Bapat and Sturrock 2003), and an Input Analyzer (used as discussed in the previous section to choose between empirical and closed-form distributions). Observed data for the X-ray, prophylaxis, dentist's consultation, and next-appointment booking times were fitted using this Input Analyzer; in each of these cases, a triangular distribution fitted the observed data well.

Verification and validation techniques used included a variety of methods such as tracking *one* entity through the model, initially removing all randomness from the model for easier desk-checking, structured walkthroughs among the team members, step-by-step examination of the animation, and confirming reasonableness of the preliminary results of the model with the client manager by use of Turing tests (Sargent 2004). For example, relative to the base case model, the observed wait time average and maximum before being taken to an examination room for prophylaxis were 1.6 minutes and 9.5 minutes respectively for the first hygienist, and 2.7 minutes and 11.1 minutes for the second hygienist. Likewise, the observed wait time average and maximum for the dentist's consultation after prophylaxis were 40 and 7.0 minutes. The base case model matched all six of these numbers to within 5%.

## RESULTS AND INDICATED FURTHER WORK

The simulation model was specified to be terminating, not steady-state, because this service process, like most, "empties itself" each night and over weekends (Altiok and Melamed 2001). Therefore, warm-up time was always zero. Results and comparisons between the current and proposed systems were all based on five replications each of length five working days (one typical work week, since the clinic opens on Saturdays only for emergencies and hence on an ad-hoc basis), thereby making comparisons consistent despite slight and perhaps unobserved workload-trend patterns among the days from Monday to Friday inclusive (recall that the actual data collection had been taken only on Mondays and Wednesdays). Again corresponding to actual clinic practice, each work day lasted ten hours, including lunch times and very short break times.

In the current process (both in practice and in the base simulation model), patients have chosen, or are assigned, a hygienist prior to arrival, and must await the availability of that hygienist. In the proposed process as simulated, a patient, upon arrival, will be assigned to whichever hygienist first becomes available; i.e., the hygienists will be treated as a resource pool rather than as two distinguishable resources. The model simulating this proposed revision to the process predicted a *maximum* waiting time for *a* hygienist of less than 0.5 minute. This prediction (a delightful surprise to the client) is in keeping with classical closed-form results for M/M/n queues which demonstrate the benefit of "pooling resources and using one common queue" (Anderson, Sweeny, and Williams 2005) Furthermore, this proposed process model simultaneously predicted a 5% patient throughput increase, implying a proportionate revenue increase for the clinic.

Accordingly, the client (the dentist running the clinic, in conjunction with the office manager) has decided to implement a change from the current process to the revised and recommended process. The improvements predicted in important process metrics (average and maximum wait times, and total throughput of patients served) have been deemed sufficiently significant to justify gently "weaning" the minority of patients having a preferred hygienist away from a guarantee of receiving service from that hygienist. Indeed, the process shift has already begun, and improvements have already been noticed. Specifically, the process shift has been undertaken by asking the patients "What appointment time would you like?" – without any reference to "Which hygienist?" unless and until the patient explicitly "opts in" by volunteering a strong preference for one hygienist. In particular, the office manager has remarked that the unfortunate and exasperating frequent tendency of the office to run further and further behind its appointment schedule as the day progresses is diminishing most gratifyingly. Since scheduling has a six-month lead time, both client and analysts expect that process performance will gradually approach and reach the predicted improvements over that span of time – this approach has already begun.

## OVERALL CONCLUSIONS AND IMPLICATIONS

More broadly speaking, the benefits of this study extend beyond the improvement of service achieved in one dental clinic. Publicity accorded to the study by the university (as is routinely done for many "senior projects" or "capstone projects") has drawn beneficial local attention to the ability of simulation (and by implication, other analytical methods within the discipline of industrial engineering) to help the beleaguered health-care industry rise to the simultaneous challenges of cost containment and increased quality-of-service expectations. Additionally, the success of this study has increased the willingness of local business and management leaders to welcome and provide project opportunities for advanced undergraduate students. This willingness stems partly from the short-term attraction of having useful industrial-engineering work done, and partly from the long-term attraction of making an investment in the experience level of students who will shortly be entering the labor market as industrial engineers (Black and Chick 1996).

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**EDWARD J. WILLIAMS** holds bachelor's and master's degrees in mathematics (Michigan State University, 1967; University of Wisconsin, 1968). From 1969 to 1971, he did statistical programming and analysis of biomedical data at Walter Reed Army Hospital, Washington, D.C. He joined Ford Motor Company in 1972, where he worked until retirement in December 2001 as a computer software analyst supporting statistical and simulation software. After retirement from Ford, he joined PMC, Dearborn, Michigan, as a senior simulation analyst. Also, since 1980, he has taught evening classes at the University of Michigan, including both undergraduate and graduate simulation classes using GPSS/H™, SLAM II™, SIMAN™, ProModel®, SIMUL8®, or Arena®. He is a member of the Institute of Industrial Engineers [IIE], the Society for Computer Simulation International [SCS], and the Michigan Simulation Users' Group [MSUG]. He serves on the editorial board of the *International Journal of Industrial Engineering – Applications and Practice*. During the last several years, he has given invited plenary addresses on simulation and statistics at conferences in Monterrey, México; Istanbul, Turkey; Genova, Italy; and Riga, Latvia. He has served as Program Chair of the 2004, 2005, and 2006 Summer Computer Simulation Conferences, and also for the 2005 IIE Simulation Conference. His university web page is: http://www-personal.umd.umich.edu/~williame.

**APPENDIX**

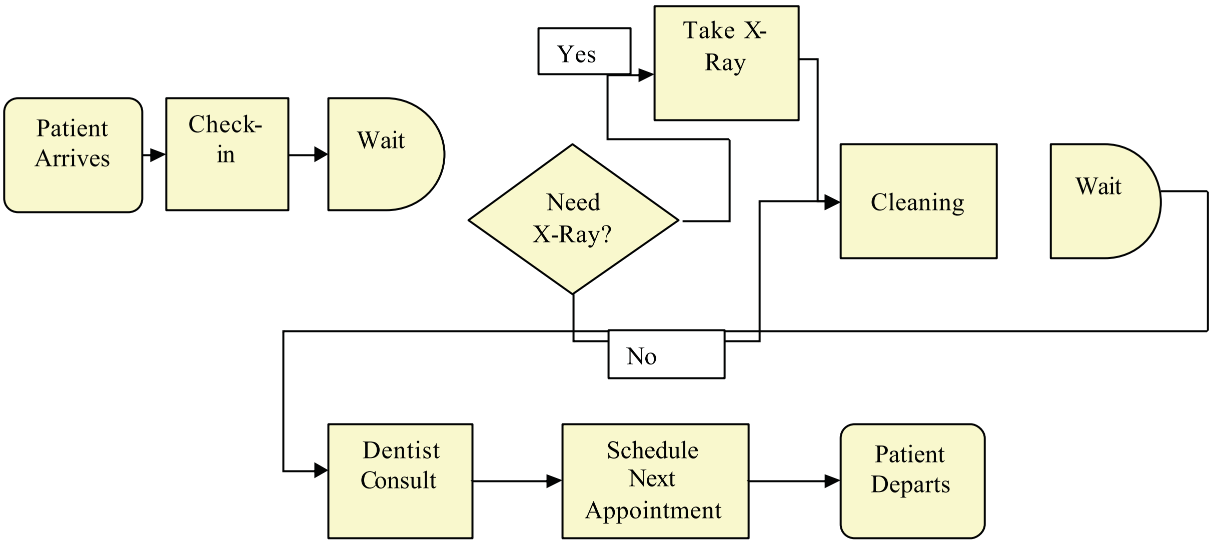


Figure 1. Patient Process Flow Chart