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What is This?
Incorporating Discrete Event Simulation Into Quality Improvement Efforts in Health Care Systems

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Abstract
Quality improvement (QI) efforts are an indispensable aspect of health care delivery, particularly in an environment of increasing financial and regulatory pressures. The ability to test predictions of proposed changes to flow, policy, staffing, and other process-level changes using discrete event simulation (DES) has shown significant promise and is well reported in the literature. This article describes how to incorporate DES into QI departments and programs in order to support QI efforts, develop high-fidelity simulation models, conduct experiments, make recommendations, and support adoption of results. The authors describe how DES-enabled QI teams can partner with clinical services and administration to plan, conduct, and sustain QI investigations.

Keywords
quality improvement, discrete event simulation, performance improvement, health care delivery

Quality improvement (QI) is a basic mandate in nearly every health care setting. At their simplest level, QI efforts are intended to ensure that patients receive timely, indicated medical care in the appropriate setting. Many hospitals have independent QI departments to support the strategic goals of the organization as well as those of individual clinical services. QI departments are thus tasked with simultaneously addressing the quality of care and the sustainability of the institution providing that care, working to improve efficiency and maximize access and patient flow while safeguarding the primacy of patient safety and excellence of medical care. QI is therefore intimately tied to performance improvement; given the current climate of systemic change and pressure from financial and regulatory bodies, hospitals must do more with less. Targeted interventions, even of seemingly small inefficiencies, can have profound impact on both patient care and the institutional bottom line.

QI initiatives are commonly structured as an objective to deliver an intervention in a predefined patient population, a certain percentage of the time. Such well-defined objectives are simple in concept but may require considerable revision of standard workflow to achieve. The complexity and difficulty involved in meeting such challenges argues for the role of predictive modeling. Discrete event simulation (DES) provides a data-driven approach to improve the likelihood of success in such interventions and to evaluate important trade-offs. For example, although it may be possible to estimate the change in mean waiting time in response to a staffing change, prediction of the variation in waiting time at varying times of the day is likely beyond intuitive assessment; DES allows such metrics to be examined as a function of staffing resources.

DES is a computer modeling tool that replicates complex systems in silico and allows prospective patient flow interventions to be studied without committing to real-world change prior to knowing the likely effects. As such, it is an ideal tool for testing many systems-level QI initiatives. DES is particularly effective when an intervention may be expensive to implement or may have unknown risks to patients related to unforeseen consequences to flow interventions, or when 2 mutually exclusive interventions are under consideration. Multiple iterative tests of change may be too expensive, complex, or time consuming to attempt. In these situations, DES provides a rapid and less expensive alternative to identify...
those interventions most likely to provide quality improvements. There is extensive literature on the academic use of DES in hospital environments and case reports of individual uses of DES to address quality improvements; for further reading, the authors recommend the excellent review articles by Günal and Pidd and Jacobson et al. However, the authors know of no general instructions on how to incorporate DES into QI efforts. In brief, DES is a graphical, interactive computer simulation that provides a dynamic model of clinical operations within a health care setting. These models are collaboratively built by a DES developer, medical and administrative personnel, and data support services. This article provides a general overview for planning, operationalizing, and maintaining DES models for QI initiatives. However, it must be noted that DES is not a QI method unto itself; rather, it is a tool for enhancing existing QI frameworks (eg, Lean, Six Sigma). In these methodologies, testing the interdependencies within a system is difficult (eg, how a change in an operating room process might affect preoperative and postoperative care). Simulation allows the depiction and illumination of the nuances of relationships between different parts of large-scale systems. Although traditional methods often are based on average performance and standard deviations, DES models interactions dynamically, allowing for realistic depictions of system variation. As such, they can be useful when traditional methods fail to properly address sophisticated system dynamics.

The impact of DES-modeled interventions can be dramatic. In previous work by the authors’ group, a change to the triage system of an emergency department (ED) was simulated. Making a wholesale change to patient flow such as the one described (placing a provider at triage and treating and discharging a significant number of patients directly from triage) has many potential benefits and drawbacks. Although it was a priori believed that the intervention would reduce length of stay, the complex effects of removing a provider from the main ED and placing him or her in triage were not known; would the ED be able to fully accommodate all patients admitted to a treatment bed? As shown in that investigation, which required roughly 3 months of developer time to simulate, validate, and predict, mean length of stay was reduced by some 37 minutes per patient, resulting in more than 12 000 hours of patient bed time saved annually. In terms of patients seen, the time saved represents enough time to treat in excess of 3500 additional patients annually (from a baseline of 20 000 per year). Although that setting was a Veterans Health Administration hospital, and thus does not represent a fee-for-service model of health care delivery, it seems clear that the return on investment of developer services was significant. It also is worth noting that the DES analysis might have shown that the intervention would have been ineffective or deleterious, thus preventing a costly change to workflow that then would have to be dismantled.

Planning

Most systematic QI methodologies include at least 4 phases: (1) definition of the problem to be addressed, (2) measurement and analysis of the system to be improved, (3) testing and implementation of strategies for improvement, and (4) ongoing maintenance of the newly designed process. DES is naturally suited to support steps 2 and 3 of this framework. However, it is useful to include a DES developer at the outset (ie, problem definition) so that expert advice may be provided on whether DES is appropriate for the project under consideration. Finally, because DES entails the creation of a sophisticated model of the system in which the QI effort is embedded, there are often opportunities for ongoing improvement and analysis, leading to iterative improvement efforts.

To assure high-quality, high-fidelity, and ethical modeling practices, the authors advocate employment of a DES developer and purchase of a modeling software license by larger medical centers. The authors believe DES development consultant services are better suited to supporting smaller ambulatory facilities. The advantages of having an in-house DES developer include direct access to the resulting models, ease of communication, a vested interest in institutional performance, and no incentive to recommend DES when traditional tools may be preferred. Additionally, efforts to utilize DES necessitate a long-term interest, as DES models routinely undergo iterative refinement, in order to address new QI objectives. Having an in-house developer facilitates this process by maintaining relationships between this developer and the clinical and administrative stakeholders within a system. The DES developer must have uninterrupted access to the systems being modeled, data sources, and the personnel who work within the systems in order to ensure that the final simulation is valid and operationally deployable. The authors recognize that this represents a significant institutional investment; a DES developer salary is on par with other dedicated QI personnel, and software licenses may cost anywhere from a few thousand up to nearly $20 000. However, as already described, the return on this investment can be significant.

DES development requires extensive access, data support, and oversight by both administrative and medical personnel. Additionally, as with all QI initiatives, DES-supported improvement projects require engagement from medical and administrative stakeholders to propose ideas for change, agree on scenario development to test those ideas, and then adopt and implement recommendations from simulated analysis. For these reasons, in large,
urban medical centers the natural position for a DES developer is within an institution’s QI department. The developer should serve as a team member in support of QI projects. Smaller ambulatory facilities and clinics—or larger facilities seeking to evaluate DES as a dedicated tool—may be better served with targeted DES-supported interventions utilizing a consulting arrangement. Most DES software companies offer consulting arrangements as well as short training courses. These courses will not be sufficient in themselves to train a developer but may be instructive for those seeking to understand how DES may benefit their institution.

**Project Management**

A DES-enabled QI team should consist of 1 or 2 QI specialists, the DES developer, and a data support analyst. In a large medical center, the QI specialists and data analyst will likely already be extant; in smaller facilities these may be included as part of a consulting arrangement. This team engages with a client department—generally a clinical service—in need of QI support, as shown in Figure 1. Namely, the client department identifies a need, nominates a project group led by an executive sponsor, and requests QI support. The QI team partners with the client department through the definition, measurement, and analysis phases of the improvement framework, and they jointly determine if DES is an appropriate tool to deploy on the project. If so, they assign a DES-enabled QI team to collaborate with the client department’s project group to identify metrics by which to gauge success, build a model capable of assessing system performance according to those metrics, and assess the effects of proposed changes in process. If such a change is determined to be beneficial, then the client department’s project group and QI team work jointly to implement proposed interventions and assess any unforeseen challenges. Once implementation is complete, the QI team withdraws, allowing the client department to assume full responsibility for their new operational plan.

**Initial Development**

Best practices for DES development and validation have been proposed by the Good Research Practices Task Force of the Society for Medical Decision Making, and the authors endorse them as guiding principles. DES development is the process of enumerating the locations (physical and virtual locations required for delivery of care), resources (personnel and equipment required to provide care), and entities (patients to whom care is delivered, and other items on which work is done to provide care to patients [eg, medical records, radiographic images]), and then analyzing the flow of objects through the system. That is, the authors define the manner in which entities consume resources at particular locations and then proceed from one location to the next through the system. Once this flow has been determined, it is coded using one of several commercially available DES software suites.

This model is then informed by data from the real world (eg, how many patients are seen and what mix of resources they require) and then validated. Generally, validation has at least 3 facets: face validation, internal validation, and external validation. Face validity is established by allowing system stakeholders to view and critique the simulation. Internal validation is an “under-the-hood” code review of the simulation model.
performed by the DES developer, and external validation is ensuring that when provided with real-world inputs, the simulation produces results sufficiently similar to real-world outputs. Once this initial development has been accomplished and the simulation is validated, the simulation may be used to make inferences about perturbations to the real-world system, such as to assess how process flow is influenced by resource availability. For example, one might examine the cost and limits of reducing length of stay in an ED as a function of the number of available nurses or portable X-ray machines. In the authors’ experience, the validation process is often truncated, to the detriment of model accuracy and utility. In particular, external validation is often omitted; the authors believe that thorough validation processes, involving the mutual agreement of both model developers and clinical stakeholders in the process being modeled, are necessary to ensure that the resulting simulation (and subsequent updates) adequately reflects the process in question.

Deployment and Ongoing Analysis

Deploying a validated simulation for use as a QI decision aid consists of performing experiments using the simulation as a test bed for prospective changes. Several versions of the simulation are made: one that replicates the current state of the real-world system to be used as a control, and others that are modified according to the proposed systems-level changes identified by the client department as a potential improvement. For example, changes might be made to staffing levels, patient flow, or equipment availability. In this way, the cost of an intervention or investment may be evaluated by estimating the likely return, for example, in terms of increased patient throughput. Additionally, the type of analysis that DES can support is not limited to process interventions. Chen et al have employed DES to demonstrate how varying blood glucose levels in patients with diabetes can be used to trigger different treatment options, thus predicting outcomes such as time to cardiovascular events. Each model is run for an appropriate length of time or for a number of independent simulation runs, and the results are compared according to predefined metrics of interest. If the results are suitably promising, the QI team and client department group choose the most suitable of the models tested and then work together to implement the recommendation.

Once a change is made to a system, the results of that change should be recompared to the simulation’s prediction. The simulation may then be revalidated to the new baseline and used to support iterative systematic improvement within the modeled system. Candidate scenarios for improvement generally will require the attention of the DES developer; however, it is possible to build models so that very simple scenarios may be tested by persons without development experience. This being said, more than passing familiarity with computer modeling is needed to test scenarios of any sophistication. There is, in many respects, an art to modeling systems well, and to understanding the assumptions and trade-offs made in developing a robust model that is sophisticated enough to answer relevant questions but not so complex as to be unapproachable. It should be noted as well that the process of developing a simulation model of a system may reveal small inefficiencies that may be addressed rapidly with traditional methods. Model development requires looking carefully at processes and data, which frequently identifies localized candidates for improvement. Although software vendors frequently stress the ease of use of their products, the authors’ experience is that active use of DES in a hospital for QI efforts will require either an extensive ongoing consulting relationship or dedicated on-site development personnel. As mentioned, for smaller facilities seeking to implement targeted DES-supported initiatives or institutions seeking proof-of-concept pilot programs, a short-term consulting relationship may be best suited to the task.

Conclusion

DES is a powerful tool for examining health care delivery systems. It can lead to important, sometimes surprising insights—for example, increasing the number of treatment rooms leading to longer length of stay because of greater competition for other scarce resources, such as imaging—and can provide valuable, data-driven predictions for the results of potential changes. The inclusion of DES developers within a hospital QI department allows for detailed, complex, and useful models to be deployed and utilized to improve quality of care while safeguarding patient safety and minimizing the risk of negative unintended consequences. The graphical, approachable nature of DES and the collaboration needed to develop, validate, and oversee its use helps foster good working relationships and builds connections between clinical, QI, and administrative assets. This assists with ongoing change management and investment by all stakeholders by providing an evidence base to support indicated scenarios and change. DES-supported QI can thus substitute speculation and opinion about the outcome of interventions with data-driven, quantitative methodology in support of increasingly crucial efforts to improve care while reducing costs.

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