Quality Improvement With Discrete Event Simulation: A Primer for Radiologists

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Abstract

The application of simulation software in health care has transformed quality and process improvement. Specifically, software based on discrete-event simulation (DES) has shown the ability to improve radiology workflows and systems. Nevertheless, despite the successful application of DES in the medical literature, the power and value of simulation remains underutilized. For this reason, the basics of DES modeling are introduced, with specific attention to medical imaging. In an effort to provide readers with the tools necessary to begin their own DES analyses, the practical steps of choosing a software package and building a basic radiology model are discussed. In addition, three radiology system examples are presented, with accompanying DES models that assist in analysis and decision making. Through these simulations, we provide readers with an understanding of the theory, requirements, and benefits of implementing DES in their own radiology practices.

Key Words: Quality improvement, process improvement, workflow simulation software, discrete event simulation

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INTRODUCTION TO SIMULATION

The use of workflow simulation software has been transformative in moving industries from paper-and-pencil planning to optimized, automated system design. The growth in simulation is attributable to its numerous practical benefits, including the ability to manipulate and test systems without incurring service interruptions or large capital expenditures. As a result, simulation allows for a better understanding of the mechanisms and behaviors that underpin system performance and the repercussions of implementing alternative designs, plans, and policies.

Although various simulation algorithms have been successfully applied to health care, discrete-event simulation (DES) has shown particular promise for quality and process improvement. DES was originally developed in the 1960s for operations research and industrial engineering but has recently become a popular tool for health care improvement [1]. What makes DES unique is the ability to simulate systems in a stepwise, time-dependent fashion.

By focusing on the progression of time, resource utilization, capacity constraints, and incremental revenue, DES can provide insight into the health and well-being of medical imaging systems. As a result of its broad utility in health care, DES has become increasingly highlighted as a validated process improvement tool within the medical literature. More specifically, DES has shown promise in epidemiologic studies that evaluate treatment algorithms [2-4], health care workflow process and redesign [5-7], and capacity and demand management within medical delivery systems [8,9]. In an effort to bolster interest and heighten the quality improvement and process redesign efforts within radiology, we aim to provide an introductory guide to DES, with the objective of allowing novices to begin crafting their own simulated systems.

Discrete-Event Simulation

At its core, DES follows a unit of "work" through a system, with each unit of work carrying various queueing properties, service times, and routing decisions. By

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defining "work" units, and running the simulation over several iterations, the software collects output data that can be used to interpret system health. Depending on the simulation construct, output data can include statistics like wait times, utilization, capacity, throughput, cost and revenue, and work path probabilities. Output data will change with alterations in resources, constraints, or workflow patterns, allowing the user to evaluate the benefit and harm of interventions.

DES is particularly apt at modeling system workflows inherent in radiology. Packets of "work" typically take the form of patients or studies, with resources generally including scanning equipment and personnel. However, output data are reliable only when accurate input data are available—such as arrival and service times. Fortunately, the widespread adoption of PACSs and radiology information systems has led to the accumulation of imaging time stamps, which can either be referenced directly or manipulated into probability distributions. Although not required to build simulations, the adoption of universal workflow definitions provide a means to compare best-practices among institutions [10].

DES Software Options

Modeling radiology workflows can be accomplished with several kinds of software packages. While most contain the components required to build radiology service models, key software differences include open-source versus proprietary, graphical user interfaces versus command line, integration with third-party modules, help documentation, and ease of use.

We demonstrate two software packages known for ease of use and interoperability, namely Simul8 (Simul8, www.simul8.com) and SimEvents (MathWorks, www.mathworks.com). Both software packages contain a robust graphical user interface, which we felt was necessary given the introductory nature of this paper, and comprehensive online help files. Simul8 was included because of its easy learning curve and straightforward adaptability to health care. SimEvents was chosen because of its inclusion in the popular MatLab suite and its ability to communicate with Simulink (MathWorks). In general, we would expect a novice to be able to run introductory simulations within a weekend, and real-world simulations within a week, though inherent technical savvy will prove helpful.

For resources that display DES software in action, we recommend the introductory startup videos available from both the MathWorks and Simul8 websites. Although the introductory videos are industry neutral, many free videos are available online that focus specifically on health care, including an emergency department (ED) workflow example on the Simul8 website.

Building Basic DES Models for Radiology

Constructing a basic workflow is essentially the same in either software package (Fig. 1). At their most basic level, simulations consist of a "start point," a "queue," an "activity," and an "end point." As mentioned earlier, DES involves following a unit of "work" through a workflow. Frequently this work unit is defined as a patient or an imaging study. Each block is connected by one-way arrows, indicating the direction of workflow. MatLab contains additional modules connected to each block—these represent either the

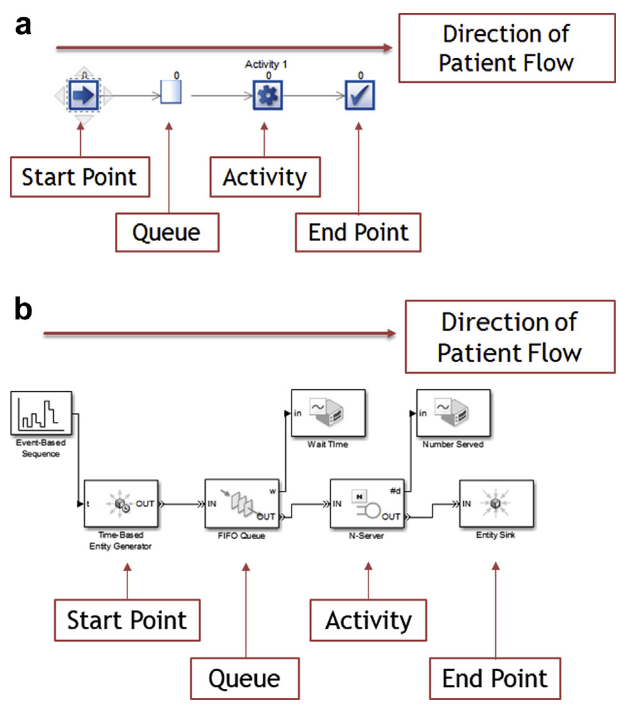

Fig 1. (a) Basic workflow design as displayed in Simul8 (MathWorks). Units of work begin at the "start point" and move through the system. In many cases, units of work can be thought of as patients, who begin at the "start point" (*box with arrow*), stop at a "queue" (*white bucket*), undergo a service "activity" (*box with gear*)—an imaging examination, for example—and exit the system through the "end point" (*box with checkmark*). (b) Basic workflow design as displayed in SimEvents (MathWorks). Note the similarities to Figure 1a. But unlike Simul8, SimEvents visually represents the fact that it is recording output measures, in this case "wait time" and "number served." FIFO = first in, first out.