

Chapter 20

Queuing Theory and Discrete Events Simulation for Health Care: From Basic Processes to Complex Systems with Interdependencies

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ABSTRACT

This chapter describes applications of the discrete events simulation (DES) and queuing analytic (QA) theory as a means of analyzing healthcare systems. There are two objectives of this chapter: (i) to illustrate the use and shortcomings of QA compared to DES by applying both of them to analyze the same problems, and (ii) to demonstrate the principles and power of DES methodology for analyzing both simple and rather complex healthcare systems with interdependencies. This chapter covers: (i) comparative analysis of QA and DES methodologies by applying them to the same processes, (ii) effect of patient arrival and service time variability on patient waiting time and throughput, (iii) comparative analysis of the efficiency of dedicated (specialized) and combined resources, (iv) a DES model that demonstrates the interdependency of subsystems and its effect on the entire system throughput, and (v) the issues and perspectives of practical implementation of DES results in health care setting.

INTRODUCTION: SYSTEM-ENGINEERING METHODS FOR HEALTHCARE DELIVERY

Modern healthcare achieved great progress in developing and manufacturing of medical devices, instruments, equipment and drugs to serve individual patients. This was achieved mainly by focusing

public and private resources on research in the life sciences, as well as on design and development of medical clinical and imaging devices.

At the same time, relatively little technical talent and material resources have been devoted to improving operations, quality and productivity of the overall health care as an integrated delivery system. According to the joint report of the National Academy of Engineering and Institute of Medicine (Reid et al, 2005), the cost of this collective inat-

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tention and the failure to take advantage of the methods that has provided quality and productivity breakthroughs in many other sectors of economy are enormous.

In this report system-engineering methods have been identified that have transformed the quality, safety and productivity performance of many other large-scale complex industries (e.g. telecommunications, transportation, manufacturing). (Reid et al, 2005). These system-engineering methods could also be used to improve efficiency of health care delivery as a patient-centered integrated system.

Ryan (2005) summarized system-engineering principles for healthcare. A system is defined as a set of interacting, interrelated elements (subsystems) - objects and/or people- that form a complex whole that behaves in ways that these elements acting alone would not. Models of a system enable one to study the impact of alternative ways of running the system, i.e. alternative designs, different configurations and management approaches. This means that system models enable one to experiment with systems in ways that cannot be used with real systems.

The models usually include a graphic representation of the system, which is a diagram showing the flow of items and resources. A mathematical description of the model includes objective functions, interrelationship and constraints. The components of the mathematical model can be grouped into four categories: (i) decision variables that represent possible options; (ii) variables, parameters and constants, which are inputs into the model, (iii) the objective functions, which are the output of the model, and (iv) constraints and logic rules that govern operation of the system.

Large systems are usually deconstructed into smaller subsystems using natural breaks in the system. The subsystems are modeled and analyzed separately, but they should be reconnected back in a way that recaptures the most important interdependency between them. Lefcowitz (2007) summarized, for example, that ‘...maximization

of the output of the various subsystems should not be confused with maximizing the final output of the overall system’. Similarly, Goldratt (2004, p. 211) states that ‘a system of local optimums is not an optimum system at all; it is a very inefficient system’.

Analysis of a complex system is usually incomplete and can be misleading without taking into account subsystems’ interdependency (see section 3.3). Analysis of a mathematical model using analytic or computer algorithmic techniques reveals important hidden and critical relationships in the system that allows leveraging them to find out how to influence the system’s behavior into desired direction.

The elements included in the system model and required information depends on the problem to be solved. For the output of the model to be useful, the model must mimic the behavior of the real system.

According to the already mentioned report by The National Academy of Engineering and Institute of Medicine (Reid et al, 2005), the most powerful system-analysis methods are Queuing Theory and Discrete Event Simulation (DES).

Both methods are based on principles of operations research. Operations research is the discipline of applying mathematical models of complex systems with random variability aimed at developing justified operational business decisions. It is widely used to quantitatively analyze characteristics of processes with random demand for services, random service time and available capacity to provide those services. Operations research methodology is the foundation of the modern management science.

Health care management science is applied to the various aspects of patient flow, capacity planning, allocation of material assets and human resources to improve the efficiency of healthcare delivery.

For the last 40 years, hundreds of articles have been published that demonstrate the power and benefits of using management science in

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