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SIMULATION METAMODELING TO SUPPORT HOSPITAL CAPACITY PLANNING

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ABSTRACT

A metamodeling approach is used to reduce the run time of a simulation-based decision support system targeted to healthcare administrators for capacity planning. However, the lengthy simulation run time precludes practical use. A least-squared regression equation is used to find the optimal server utilization, which is found at the "knee" of the server utilization-wait time curve. The regression model fits the simulation output data well and confirmation runs that compare simulation results with regression model predictions confirm accuracy.

1 INTRODUCTION

A decision support system (DSS) provides great opportunities for assisting decision makers in complex or dynamic environments. A DSS includes an embedded tool E.G., a knowledge base or mathematical model) that provides the intelligence that creates recommendations. When the problem setting does not conform with assumptions of an analytical model, a simulation is often employed. Simulations are especially useful when uncertainties need to be taken into account. The main disadvantages of DSS that uses a Monte Carlo simulation are: (a) computational time requirements, and (b) random outputs. In fact, computational times may require users to wait long period for results that are not affected by random variations.

1.1 DSS Description

Corlu et al. (2020) developed a DSS with an embedded Monte Carlo simulation to assist capacity planners in healthcare settings. The simulation mimics a variety of processes that may have random or deterministic arrivals, service times that follow a gamma distribution with a specific coefficient of variation, and any number of servers. The simulation model determines the optimal server utilization by determining the "knee" of the non-linear utilization-wait time function. It informs the user how to move from their current server utilization to the optimal utilization, either by changing the number of servers or by reducing the service time. It is useful because "wasteful practices" exist in many service processes. Often, relieving congestion can be done by eliminating relatively small amounts of time spent on wasteful practices.

1.2 Problem Statement

Simulation-based DSS can be time consuming. With 100,000 random arrivals, processing time on an IBM ThinkPad Carbon X1 took 77 minutes (5 servers) and 184 minutes (25 servers). With 250,000 random arrivals, processing time was 9.6 hours (5 servers). The aim of this project was to apply a metamodeling approach to determine if the simulation output could be duplicated using a suitable regression equation (Salemi et al. 2016). If successful, the DSS would be better suited for decision makers.

2 METHODOLOGY

The simulation was run for a range of values for number of servers (S) and service time coefficient of variation (CV). In this case, it was assumed that patients arrived at random (not based on appointments). The simulation was run for 100,000 iterations with the optimal server utilization (i.e., knee). The nine conditions included all possible combinations of S equal to 2, 8, and 14, and CV equal to 0.2, 0.6, and 1.0. Various regression models were explored, including linear, polynomial, and logarithmic. If several models provided statistical significant results, the model that best balanced simplicity and accuracy was chosen.

3 RESULTS

The regression analysis showed that the values of S and CV had a significant effect on the knee, but their interaction effect was not significant. The most useful least-squares regression equation is shown in Equation 1, which had an r-squared value of 0.9616. The model was confirmed by running intermediate points then using the regression equation to predict the model results. The intermediate values were 5 and 11 for S and 0.4 and 0.8 for service time CV (Figure 1). Statistical tests show that the responses are consistent with the regression equation prediction.

$$Knee = 0.5426 + 0.11211 \ln S - 0.0325 \ln CV \qquad (1)$$

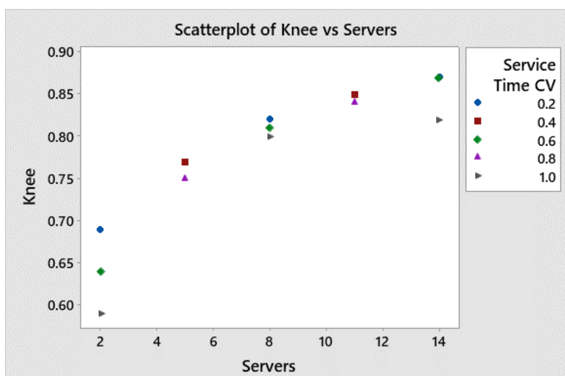

Figure 1: Confirmation Experiment Results.

To illustrate the use of the metamodel within the DSS, consider an example. A hospital administrator collects data showing that the average service time for patients, who arrive randomly at the rate of 6 per hour, is 65 minutes with a CV of 50%. Currently, 7 servers are assigned, which results in a server utilization of 92.9%. The regression equation indicates that the knee (i.e., optimal server utilization) is 78.3%. In this case, the DSS would inform the user that two choices exist to optimize server utilization: (1) increase the number of servers from 7 to 8 (resulting in a server utilization of 81.3%, which is the closest server number to 78.3%, or (2) reduce the average service time from 65 minutes to 54.8 minutes per customer.

REFERENCES

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