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Sensitivity Analysis of Optimum Tutor Staffing Schedule using Discrete Event Simulation

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Introduction

The Unified Tutoring Center

The Unified Tutoring Center (UTC) was created in the Fall of 2009 at the Daytona Beach campus of Embry-Riddle Aeronautical University. Several distinct campus tutoring programs were combined into one university wide and centrally located tutoring program. Some of the included tutoring programs include the Athletic Department's Braddock Education Success Team (BEST), First Year Programs, the Naval ROTC program, the Writing Center, the Math department's MATRIX Lab and the Physical Science department's Physics and Chemistry Lab. These different programs were combined into one, unified tutoring center to make more efficient use of funds and resources. It is anticipated that the number of students seeking UTC services will continue to increase, which may cause the current tutor staffing schedule to become inefficient and obsolete. By studying the UTC process using discrete-event simulation (DES), it is expected to determine an optimal staffing schedule for the center's current usage and prepare the UTC for future student demands.

Advantages and Disadvantages of Simulation

A simulation refers to a broad collection of methods and applications to mimic the behavior of real systems, usually on a computer with the appropriate software. Computer simulation brings many benefits that are unique to system modeling and assessments. Law and Kelton (1991) identified several advantages that simulation and modeling has to offer. Most real-world systems have stochastic elements (random input) that are very difficult, and sometimes impossible, to be analytically evaluated with mathematical models. Moreover, modeling provides the flexibility and ease of evaluating a system under different operating conditions to predict alternative performance measures and/or find a better solution. Simulation also provides better control over experimental conditions, compared to testing a change through physical system changes. Taking the UTC as an example, experimentation with the staffing schedule using the real system would be a waste of resources and could negatively impact student performance if the schedule is not verified. In addition to evaluating a system under different conditions, numerous system designs or layouts can be simulated, with the different results being compared to determine the best design or layout, without disturbing the actual system operations. Another one of the advantages to computer simulation is the ability to study a long period of "simulated time" for a model in a relatively short amount of actual time. This provides a quick assessment, which a real system cannot provide. For example, a 24-hour period of simulated time could be run in a matter of minutes and for dozens of replications.

In addition to the many benefits and advantages that simulation has to offer, there are also some disadvantages. One of the biggest deterrents for computer simulation is the amount of time and expense involved in creating and developing a functionally realistic and accurate system model (Banks, Carson &

Nelson, 1996; Law and Kelton, 2000). If management elects to skimp on resources or reduce the level of detail for the model, the end result may be a model that is insufficient for the task or analysis.

Another disadvantage of modeling and simulating complex real-world systems is that stochastic simulation only produces estimates of how the system will perform, not guaranteed or factual information (Law and Kelton, 2000). Furthermore, because stochastic models contain random input, it means that the output data is typically random in one way or another (Kelton, Sadowski & Sturrock, 2007; Law and Kelton, 2000).

An additional disadvantage is the difficulty in determining the initialization bias and warm-up period for a simulation run as every project is different (Kelton, Sadowski & Sturrock, 2007). A further disadvantage for simulation is the inability to run a simulation for long periods of time to calm the output. This is inappropriate if the system has operational constraints that only allow it to be open during certain times, which is the case for the UTC (Kelton, Sadowski & Sturrock, 2007).

While there were no simulation studies found in the tutoring domain or with a system model similar to the UTC, several simulation studies relating to service centers, hospitals, airports and restaurants were found in the literature, which possess various elements that are similar to this study (e.g. Tateno, Toshitake, Shimizu, and Keiko, 2007; Kontoyiannakis, Serrano, Tse, Lapp and

Cohn, 2009; Chong, Grewal, Loo, and Oh, 2003; Cao, Nsakanda, and Pressman, 2003; Sickinger and Kolisch, 2009; Centeno, Giachetti, Linn, and Ismail, 2003; Bieger et al., 2009; Brann and Kulick, 2002). Many of these studies, in some way, directly relate to the current investigation to determine an optimum tutor staffing schedule based on tutor utilization and student wait time. This investigation will determine a better staffing schedule for the UTC, while also adding to the body of scientific knowledge.

Method

Conducting a Simulation Study

According to Law & McComas (2001), there are seven steps that are essential to conducting a successful simulation study:

- Formulate the problem,
- Collect information/data to construct a conceptual model,
- Determine if the conceptual model is valid,
- Construct the model based on the understanding of the previous steps,
- Validate the model,
- Design, make and analyze simulation experiments, and
- Document and present the simulation results.

All of these steps were followed during the course of this study.

The objective of this study was to determine an optimal tutor staffing schedule by modeling the Physics & Chemistry Lab and the General Study room through discrete event simulation. The data for this study was collected through the reviewing/observation of video recordings for each room under investigation. The student arrival rate, subject percentage, as well as the time spent between a tutor and student were carefully analyzed and then input into the Arena simulation model. The conceptual model of the UTC was shared during a committee meeting for it to be validated. Afterwards, a higher simulation model was created. To check this new model's validity, the model's performance measures were compared with data collected from the actual system. This performance output, along with the new model, was shared with the major decision makers (the UTC committee) who considered the model to be valid. Once the model was validated, it was time to create and analyze simulation experiments. The UTC model utilized a termination condition, since it only operated from 6pm - 9pm. The model was run on a daily basis with an hourly schedule.

UTC Rooms under Investigation

Two rooms in the UTC were viewed during this study- the Physics & Chemistry Lab and the General Study Room. These two rooms have been chosen because the current staffing schedules in these rooms seem to be inadequate sometimes and the student demand varies from day to day. The General Study Room, in particular, was also selected because of its complexity. The subjects offered in this room (e.g., Business, Computer Programming, and Aviation

Maintenance Science) are not core class requirements, and, as a result, are not as popular as subjects like Math, Physics, and Chemistry.

Arena Simulation Software

The model of the UTC was developed using the modeling software Arena version 12, developed and distributed by Rockwell Automation®. Arena is a simple but powerful tool based on the common SIMAN simulation language, and it helps demonstrate, predict, and measure system strategies for effective, efficient and optimized performance (Rockwell Automation, 2010; Kelton, Sadowski, and Sturrock, 2007). The model was created via the GUI interface by using various modules, adding resources and process times, adding variables, connecting the different modules, and running the simulation. The final system model is essentially a process flow diagram with details on how different parts of the system are interacting. Notable features on the Arena Software package were Input Analyzer and OptQuest. Input Analyzer fits a given set of probability distributions to observed real-world data to specify model inputs (Kelton, Sadowski, and Sturrock, 2007; Rossetti, 2010). OptQuest is an application based on the Tabu search algorithm that can decide how to change model inputs to optimize a specified output performance measure empirically, while taking into consideration defined constraints (Kelton, Sadowski, and Sturrock, 2007; Rossetti, 2010).

Model Assumptions

The following assumptions were made when developing the Unified Tutoring Center model to help keep the model as simple as possible without losing any significant factors:

- Tutor breaks are ignored in the model.
- Tutoring can only happen between the hours of 6 - 9pm.
- The service priority is set to a first-in first-out (FIFO) rule.
- Tutors will only be allowed to help one student at a time.

UTC Simulation Model Structure

Figure 1 illustrates the high-level logic of the Physics & Chemistry Lab for the model used to simulate the Unified Tutoring Center. Students first enter the system and their arrival time is recorded. Upon arrival, students can either immediately seek help from a tutor or they can start studying on their own, based on their own individual needs. For the small percentage of students who never seek help from a tutor, they simply leave the system without any interaction time with the tutor. For those students who utilize the tutors, their tutoring session immediately begins if the tutor is available, otherwise the student must wait. The student continually checks for an available tutor, at which point the student's total wait time is recorded and the tutoring session begins. If a student is being tutored, the student and tutor are held for the duration of the tutoring session, as a tutor can truly help only one student at a time. When the tutoring session is complete, the total tutoring time is recorded and the student can continue studying or seek help again.

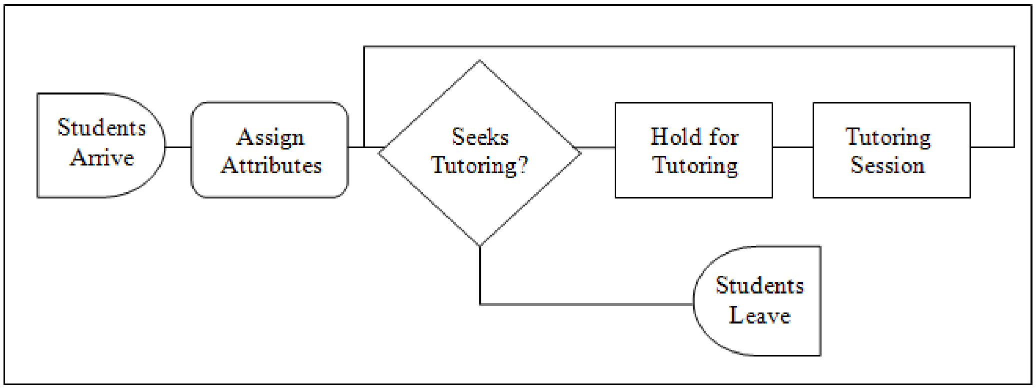

Figure 1. High-level model structure (Physics & Chemistry Lab).

Input Data Analysis

The input data used to build the Unified Tutoring Center model was collected through the observation of video recordings in the Physics & Chemistry Lab and General Study room over a four-week period. There were a total of three video cameras used throughout the videotaping process, including a Sony HandyCam DCR-SR68, a Sony HandyCam DCR-HC96, and a Canon PowerShot S5 IS. Each student's arrival time, wait time, subject tutored, service time and exit time were carefully extracted by reviewing the video recordings and documenting the data on the Data Collection form.

From the documented data, the independent variable information was extracted and analyzed, which describes the system behavior characteristics of the

UTC. These input data included the student demands and service information provided by tutors at the Unified Tutoring Center.

The decision dependent (or control) variable for this study is the tutor staffing schedule. The number of resources (tutors) scheduled by subject each evening was systematically manipulated to determine an optimal staffing schedule, while meeting the defined needs and constraints (maximum student wait time and tutor utilization threshold).

Evaluation Output Performance Measures

For the Unified Tutoring Center, there were three evaluation output performance measures. These included average student wait time, the average cost of tutors and the utilization of tutors, with all of these performance measures being broken down by subject. Student wait time is defined as the amount of elapsed time from when a student seeks help to when the tutor is free and the tutoring session begins. The daily cost of tutors was calculated by multiplying the number of tutors staffed by the tutor wage ($8.50). Tutor utilization is defined as the proportion of time a tutor is busy during the simulation run.

Statistical Analysis

Validation of the model. The input data used to build and run the simulation model was from actual observed data at the UTC, which included 20 nights (60 hours) of relevant data for determining an optimized staffing schedule for the UTC. The actual observed tutor utilization was compared against the model's output of tutor utilization. Per the recommendation of Law and Kelton (2000), Welch's t test was used to compare the actual observed data to the model's output data. Welch's t test is preferred over the standard t test because the two independent samples have unequal variances (Howell, 2007). The student wait time was not used due to the difficulty of identifying the exact time of tutoring requests by students.

Experimentation. Once the model was validated, experimentation was conducted to determine an optimum tutor staffing schedule. A theoretical approach to determining an optimum tutor staffing schedule would utilize a non-linear mathematical programming model as shown in Figure 2 (Blanchard & Fabrycky, 2006). However, due to the complexity and non-linear nature of the system, it would be impossible to obtain an analytical mathematical programming model for that optimization problem. As such, an empirical solution was applied as an alternative to approximate numerical solutions.

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Objective Minimum Daily Cost $$E = \sum_{i}\sum_{j} Cx_{ij}$$

Subject to

1. Waiting Time Constraints

$$\frac{\sum_{k=1}^{N} WQ_k}{N} \leq WQ_{average}$$

or

$$\max_{k} WQ_k \leq WQ_{max}$$

2. Utilization Constraints

$$Scheduled\ Utilization_j \leq Utilization\ Threshold$$

Where

$$x_{ij} = Tutor\ Capacity\ for\ i^{th}\ hour, j^{th}\ subject$$

$$i = 1, 2, 3\ Hour$$

$$j = 1, 2, \cdots 5\ Subject$$

$$N = Number\ of\ students\ finished\ Tutoring$$

$$C = \$8.50, Hourly\ Wages$$

Figure 2. Non-linear mathematical programming model.

A sensitivity analysis was then performed on the final results from OptQuest to determine the relationship between the cost and the varying constraints. Simulations were run under various tutor staffing schedules to obtain a finer picture of this relationship and determine the minimum number of tutors needed.

Results

Model Development

There were two separate models developed for this study: the General Study Room model and the Physics & Chemistry Lab model. Both models were simulated for a specified run-time length of 180 minutes (three hours). Each model was built using three separate sections.

The main section contains the main model logic and processes. This section takes care of generating the arrival of students each evening based on an arrival schedule, assigning student attributes (subject types), and then routing each student based on their attributes. Some students leave without ever getting help, while other students will go through a continuous cycle of studying and seeking tutoring before the night ends. These students progress through the decide modules to the studying and tutoring sessions and then back to the second decide module.

The second section contains model logic that creates and signals a student to request tutoring help. This signal is sent to a student in the hold for a tutoring block. When this signal is received, one student is released from the hold block and seizes a tutor (resource), at which point that tutoring session will begin if a tutor is available.

The third section of the model was used for validation purposes. This section instructs the Arena software to write the tutor utilization results from the simulation runs to a specified Excel file. How these utilization results were specifically used to validate the model will be discussed later.

Input Data Analysis

Although video cameras captured five weeks' worth of data collection, only four weeks of data were used in this investigation. The fourth week of data collection experienced some technical difficulties that resulted in several gaps of data loss. Therefore, weeks one, two, three, and five were used.

For the student arrival time, there were two different student arrival schedules used. One for the General Study Room model and the other for the Physics & Chemistry Lab model. Table 1 and Figure 3 show the aggregated arrival rate used in the simulation model for each half-hour time block for both the General Study Room and the Physics & Chemistry Lab. Please note that the arrival rate for the General Study Room was not broken down by subject.

Table 1

Student Arrival Rate Schedule for the General Study Room and the Physics & Chemistry Lab

	6:00-6:30	6:30-7:00	7:00-7:30	7:30-8:00	8:00-8:30	8:30-9:00
General Study Room	8.9	3.0	3.3	2.5	1.9	0.6
Physics & Chemistry Lab	9.9	5.5	3.9	2.5	1.5	0.1

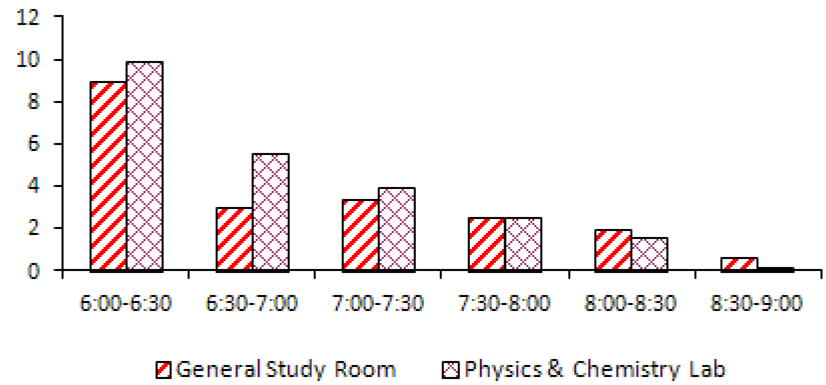

Figure 3. Student arrival rate for the General Study Room and the Physics and Chemistry Lab.

The student arrival rate varies over each 30 minute time period, making it difficult to find a distribution to accurately represent the arrival rate of students. From Figure 3, it is easily seen that the arrival rate is not stationary over the three-hour period, with the peak occurring in the beginning, thus an arrival schedule based on observed data was chosen over an arrival distribution.

The breakdown percentage of students seeking help in each subject or not seeking help in the General Study Room was carefully recorded through observation. Based on actual observed data, the discrete distribution of DISC(0.22,1,0.35,2,0.51,3,0.56,4,0.60,5,1,6) was used in the simulation model to assign subject characteristics to students upon arrival. A pie chart detailing these percentages can be seen in Figure 4.

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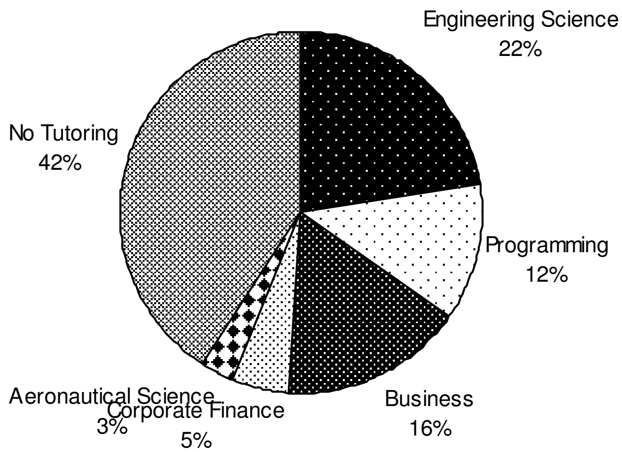

Figure 4. Percentage of students seeking tutoring by subject.

Note that the percentages of the DISC(0.22,1,0.35,2,0.51,3,0.56,4,0.60,5,1,6) distribution start at Engineering Science and accumulate in a clockwise fashion.

The Physics & Chemistry Lab followed a different percentage distribution of students seeking tutoring versus students studying and then leaving. A discrete distribution of DISC (0.65,1,1,2) was used to assign tutoring characteristics to students upon arrival. Specifically, 65% of students who attended the Physics & Chemistry Lab sought help from tutors before leaving, while the remaining 35% of students simply left the tutoring lab without ever seeking help.

Using the Chi-Square “goodness-of-fit” test embedded in Arena’s input Analyzer, the inter-arrival request rate and service rate for tutoring by subject was determined. The distributions use for each subject can be seen in Table 2. The data was only fitted to a distribution if a p-value of 0.15 or greater was found; otherwise, the data was represented empirically.

Table 2

Inter-arrival Request and Service Rate Distributions

Subject	Inter-arrival Request Rate	Service Rate
Engineering Science	0.5 + EXPO (16.5)	0.5 + LOGN (9.79, 17.2)
Programming	1.5 + LOGN (14.2, 25)	0.5 + LOGN (8.32, 15.2)
Business	2.5 + LOGN (13.4, 20.4)	0.5 + LOGN(5.88, 9.36)
Corporate Finance	0.5 + LOGN(17.7, 24.5)	Empirical
Aeronautical Science	Empirical	0.999 + WEIB(7.19, 0.348)
Physics & Chemistry	0.5 + LOGN(6.7, 11.3)	0.5 + LOGN(7.11, 13.4)

Note. EXPO denotes an exponential distribution, LOGN denotes a lognormal distribution, and WEIB denotes a Weibull distribution.

Model Validation

With the fitted data, both the General Study Room and the Physics & Chemistry Lab models were run 50 times with an operational run time of three hours (180 minutes) per run, as the Unified Tutoring Center is open from 6 – 9pm. Tutor utilization was used as the validation performance output measure. Each of the 50 runs was written into an Excel spreadsheet and compared against the actual historical data collected through observation at the Unified Tutoring Center. The following table (Table 3) presents the descriptive statistics used to validate the model.

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Table 3

Descriptive Statistics for Model Validation

Subject	Actual Observed Data		95% Welch's CI	Model Output Data	
	Mean	Standard Deviation		Mean	Standard Deviation
Engineering Science	0.095	0.096	[-0.025, 0.073]	0.118	0.091
Programming	0.255	0.250	[-0.147, 0.109]	0.236	0.195
Business	0.187	0.191	[-0.059, 0.115]	0.215	0.155
Corporate Finance	0.078	0.122	[0.075, 0.059]	0.070	0.128
Aeronautical Science	0.097	0.202	[-0.099, 0.854]	0.090	0.163
Physics & Chemistry	0.377	0.161	[-0.139, 0.022]	0.318	0.111

The Statistical Package for the Social Sciences (SPSS) was employed to analyze the statistical significance in the results generated from the Arena model to the actual historical data from the UTC. A two-sample independent t-test was used in the following analyses, since the results of the Arena model are independent of the actual observed data. An alpha level of 5% was used to test the difference between the two groups. A bigger p – value is desired for validation purposes in this study, because it indicates that the two samples are not significantly different, which means that the Arena model and actual data are similar and the model can be considered statistically valid. Table 4 presents an overview of the t-test results, whether the variances were equal, the degrees of freedom, and the p – value or level of significance between the data that was used for validating the model.

Table 4

T-test Results Summary

Subject	Equal Variance?	t-statistic/ Welch's T for Unequal Variances	Degrees of Freedom	p – value
Engineering Science	Yes	0.989	68	0.326
Programming	No	-0.308	28.7	0.761
Business	Yes	0.635	68	0.528
Corporate Finance	Yes	-0.245	68	0.807
Aeronautical Science	Yes	-0.152	68	0.880
Physics & Chemistry	No	-1.494	26.5	0.147

Hourly Schedule Sensitivity Analysis

Based on the validated model, OptQuest was used to study the sensitivity of minimizing cost to determine the best tutor staffing schedules under various constraint combinations. Initial tutor staffing experimentation consisted of varying the schedule on an hourly basis (6-7pm, 7-8pm and 8-9pm). Based on the non-stationary nature of the student arrival schedule and the tutoring request rate, it was decided to use an hourly staffing schedule to try and minimize the overall operational cost of the UTC. Both models minimize the total daily tutor wages under the constraints of student wait time (average and maximum) and maximum tutor utilization. The specific values used for the average wait time, maximum wait time, and maximum tutor utilization were based on results from the UTC Constraints Survey and sensitivity experimentation. OptQuest optimized the hourly tutor staffing schedule for the General Study Room by subject based on

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maximum tutor utilizations of 20%, 40%, and 65%. For each utilization, an average and maximum waiting time maximum was also defined as a constraint. Figure 5 illustrates the relationship between average and maximum waiting time constraints, maximum tutor utilization and the minimum daily cost: The left graph is based on the average wait times (in minutes) of 1, 2, 4, 6, and 10 while the graph on the right is based on the maximum wait times 5, 10, and 20 (in minutes).

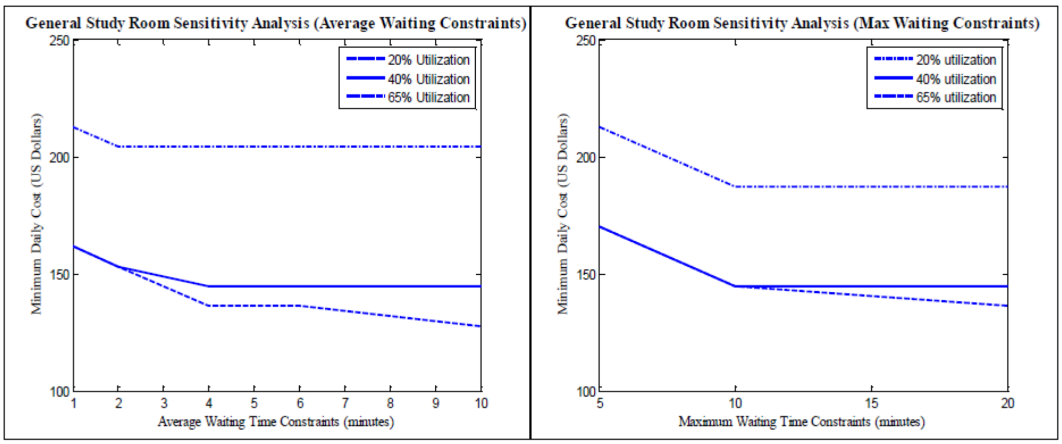

Figure 5. General Study Room cost sensitivity analysis (average waiting time and maximum waiting time).

The Physics & Chemistry Lab model was run through OptQuest in a very similar fashion to the General Study Room model, with some changes to the actual constraints. OptQuest optimized the hourly tutor staffing schedule for the General Study Room by subject based on maximum tutor utilizations of 20%, 40% and 65%. For each utilization, an average and maximum waiting time maximum was also defined as a constraint. Figure 6 illustrates the relationship between average and maximum waiting time constraints, maximum tutor utilization and the minimum daily cost: The left graph is based on the average wait times (in minutes) of 5, 10, and 15 while the graph on the right is based on the maximum wait times 1, 2, 4, 6, and 10 (in minutes).

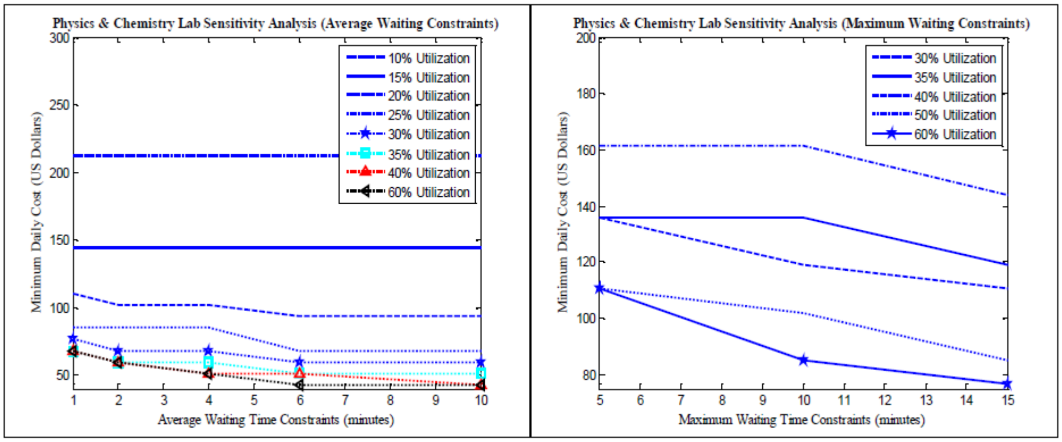

Figure 6. Physics & Chemistry Lab sensitivity analysis (average waiting time and maximum waiting time).

Practical Consolidated Evening Schedule Sensitivity Analysis

Originally, the data was analyzed to fit it to an hourly schedule. However, when considered practically, a varying hourly schedule did not seem to be applicable. Since the Unified Tutoring Center is only open from 6pm to 9pm, it would be difficult to ask some tutors to come to work for only one hour, while others may work an entire shift. Many of the tutors live off campus, which would make coming in for only one hour of work inconvenient. Therefore, a further analysis was conducted with the consolidated evening schedule, run on both the General Study Room and the Physics & Chemistry Lab models. These analyses were run to find an optimal staffing schedule on a nightly basis (from 6-9pm).

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Table 5 shows the optimization results for the General Study Room based on the relationship between maximum tutor utilization and average student waiting time. Similarly, for average waiting time constraints a sensitivity analysis was run on the General Study Room model for the interaction of tutor utilization and the maximum student waiting time, which is shown in Table 6.

Table 5

General Study Room Practical Sensitivity Analysis (Utilization versus Average Waiting Time)

Utilization	Constraints Time	ES 6 - 9	Prog 6 - 9	Bus 6 - 9	CF 6 – 9	AS 6 - 9	Total Cost
≤ 40%	Avg. Wait ≤ 1 minutes	2	2	1	1	2	$204.00
	Avg. Wait ≤ 2 minutes	2	1	1	1	1	$153.00
	Avg. Wait ≤ 5 minutes	1	1	1	1	1	$127.50
≤ 65%	Avg. Wait ≤ 1 minutes	2	2	1	1	2	$204.00
	Avg. Wait ≤ 2 minutes	2	1	1	1	1	$153.00
	Avg. Wait ≤ 5 minutes	1	1	1	1	1	$127.50
≤ 85%	Avg. Wait ≤ 1 minutes	2	2	1	1	2	$204.00
	Avg. Wait ≤ 2 minutes	2	1	1	1	1	$153.00
	Avg. Wait ≤ 5 minutes	1	1	1	1	1	$127.50

Table 6

General Study Room Practical Sensitivity Analysis (Utilization versus Maximum Waiting Time)

Utilization	Constraints Time	ES 6 - 9	Prog 6 - 9	Bus 6 - 9	CF 6 – 9	AS 6 - 9	Total Cost
≤ 40%	Max Wait ≤ 5 minutes	2	1	2	1	1	$178.50
	Max Wait ≤ 10 minutes	1	1	1	1	1	$127.50
	Max Wait ≤ 15 minutes	1	1	1	1	1	$127.50
≤ 65%	Max Wait ≤ 5 minutes	2	1	2	1	1	$178.50
	Max Wait ≤ 10 minutes	1	1	1	1	1	$127.50
	Max Wait ≤ 15 minutes	1	1	1	1	1	$127.50

≤ 85%	Max Wait ≤ 5 minutes	2	1	2	1	1	$178.50
	Max Wait ≤ 10 minutes	1	1	1	1	1	$127.50
	Max Wait ≤ 15 minutes	1	1	1	1	1	$127.50

The final two sensitivity analyses were conducted on the Physics & Chemistry Lab model to determine the practical tutor staffing schedule on a nightly basis. Table 7 depicts the optimized staffing recommendations based on tutor utilization and the average student wait time per tutoring session. Table 8 illustrates the results for the optimal number of tutors to staff in the Physics & Chemistry Lab, based on the interaction of tutor utilization and maximum student wait time.

Table 7

Physics & Chemistry Lab Practical Sensitivity Analysis (Utilization versus Average Waiting Time)

Constraints		Physics	Total Cost
Utilization	Time	6 - 9	
≤ 40%	Avg. Wait ≤ 1 minutes	3	$76.50
	Avg. Wait ≤ 2 minutes	3	$76.50
	Avg. Wait ≤ 5 minutes	3	$76.50
≤ 65%	Avg. Wait ≤ 1 minutes	2	$51.00
	Avg. Wait ≤ 2 minutes	2	$51.00
	Avg. Wait ≤ 5 minutes	2	$51.00
≤ 85%	Avg. Wait ≤ 1 minutes	2	$51.00
	Avg. Wait ≤ 2 minutes	2	$51.00
	Avg. Wait ≤ 5 minutes	2	$51.00

Table 8

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Physics & Chemistry Lab Practical Sensitivity Analysis (Utilization versus Maximum Waiting Time)

Constraints		Physics	Total Cost
Utilization	Time	6 – 9	
≤ 40%	Max Wait ≤ 5 minutes	5	$127.50
	Max Wait ≤ 10 minutes	5	$127.50
	Max Wait ≤ 15 minutes	5	$127.50
	Max Wait ≤ 20 minutes	5	$127.50
≤ 65%	Max Wait ≤ 5 minutes	5	$127.50
	Max Wait ≤ 10 minutes	4	$102.00
	Max Wait ≤ 15 minutes	3	$76.50
	Max Wait ≤ 20 minutes	3	$76.50
≤ 85%	Max Wait ≤ 5 minutes	5	$127.50
	Max Wait ≤ 10 minutes	4	$102.00
	Max Wait ≤ 15 minutes	3	$76.50
	Max Wait ≤ 20 minutes	3	$76.50

Discussion

Sensitivity Analysis

Hourly schedule sensitivity analysis.

The sensitivity analysis for the interaction of tutor utilization and average student wait time in the General Study Room revealed drastic differences in the number of tutors to staff each hour and the overall nightly cost. To ensure that tutors are not overworked and students don't have to wait for long periods, the overall tutor staffing cost would be around $212.50, based on a utilization maximum of 20% and an average student wait time of one minute or less. Alternatively, tutor utilization could be restricted to 65% (allowing for bathroom breaks and such) and the average student wait time maximum could be increased to 10 minutes, reducing the overall cost to $127.50 per night. Looking at the relationship between tutor utilization and maximum student wait time per session for the General Study Room, the overall minimum tutor staffing cost increases when tutor utilization and student wait time are reduced. For instance, a tutor utilization maximum of 20% and a student wait time maximum of five minutes results in a nightly cost of $212.50, while increasing the utilization maximum to 65% and the wait time maximum to 20 minutes would reduce the cost to $136.00.

Taking a closer look at the sensitivity analysis results taken from the Physics & Chemistry Lab, the most expensive staffing plan has a tutor utilization threshold of 10% and an average wait time of 10 minutes or less, totaling to $212.50. Likewise, the most inexpensive staffing schedule employs a utilization maximum of 60% and an average wait time of less than 6 minutes, which totals to $42.50. There are many other staffing suggestions listed, however, they may not be very practical. For instance, a 35% utilization threshold and an average wait time maximum of 6 minutes suggests staffing two tutors from 6-7pm, three tutors from 7-8pm and then cutting back to only one tutor from 8-9pm. In addition to the inconvenience that would be placed upon the tutors and students, roughly two thirds of tutors' time will be spent idle or doing their own homework, which is not cost effective for the UTC. Latter reasons called for a further investigating of the practical aspect of the tutoring schedule.

Practical consolidated evening schedule sensitivity analysis.

While results showed a wide variety of staffing schedules from which to choose based on the desire to minimize cost based on an hourly schedule, it is not very practical to staff the center each night based on an hourly schedule. Although it may be more expensive, less flexible, and less sensitive, it is more practical to hire tutors for an entire three-hour shift, rather than just one hour. Asking tutors to come in for only one or two hours may be inconvenient, especially for student employees who live off campus and would have to drive in for only one hour of work. Additionally, having tutors come in and out could become a distraction to the students who are trying to focus on studying.

Therefore, additional sensitivity analyses were conducted on the two models to determine the near optimal tutor staffing schedules for each subject, based on an entire (three-hour) shift. For the General Study Room model, the results for the interaction of tutor utilization and average student wait time are identical, based on tutor utilization. The staffing recommendations for 40% maximum utilization at one, two, and five minute wait time maximums are identical to the staffing recommendations at 65% and 85% maximum utilization. Similarly, the recommended staffing schedule for the General Study Room (utilization versus maximum student wait time) did not change across utilization maximums. The staffing recommendation for a utilization constraint of 40% and a maximum wait time of 5, 10, and 20 minutes did not change when analyzed at

65% and 85%. This is likely due to the fact that the tutors are not utilized more than 40% of the time, making 40% the higher limit of the utilization, even with a minimum staff.

Based on the optimized schedules from OptQuest and the feedback from the UTC Constraints Survey, there are two recommended General Study Room staffing schedules from which the UTC committee may choose. The first schedule is based on feedback from students, who reported that they would be willing to wait up to five minutes, on average, for help. The second schedule is based on feedback from the committee who would like the tutor utilization maximum to be 85% and the maximum student wait time to be five minutes. Table 9 presents the recommended staffing schedule.

Table 9

Recommended General Study Room Staffing Schedule

Constraints Utilization	Time	ES 6 – 9	Prog 6 - 9	Bus 6 – 9	CF 6 - 9	AS 6 - 9	Total Cost
≤ 65%	Avg. Wait ≤ 5 minutes	1	1	1	1	1	$127.50
≤ 85%	Max Wait ≤ 5 minutes	2	2	1	1	2	$204.00

Based on these recommendations, the most cost effective approach to staffing the General Study Room, while still providing a quality tutoring service would be to staff one tutor per subject per night. Accordingly, this would cost the UTC $127.50 per night for the General Study Room.

Results for the Physics & Chemistry Lab indicate that tutor utilization is between 40% and 65%, as the staffing recommendations change between these two thresholds, but not between 65% and 85% utilization, suggesting that 65% is the upper limit. The results show that for a maximum utilization of 40%, the staffing schedule does not change for any of the average wait time thresholds. This is likely due to the fact that the staffing schedule is more sensitive to the tutor utilization and not the average wait time maximum. For the utilization maximums of 65% and 85%, however, it appears that the average wait time threshold seems to determine the number of tutors to staff, since the tutor utilization lies somewhere between 40% and 65%.

The sensitivity results of tutor utilization and maximum student wait time for the Physics & Chemistry Lab, also show that responsive tutor utilization for minimizing daily cost lies somewhere between 40% and 65%, as this is where the staffing schedule changes. For 40% utilization, the maximum student wait time does not appear to have an effect on the staffing schedule, likely due to the utilization cap. In other words, an additional tutor must be staffed if the utilization threshold is 40%. In this case, there are so many tutors staffed, that students will not have to wait very long, indicating that tutor utilization has a dominating effect for this sensitivity analysis. However, examination of the staffing schedule for

65% tutor utilization shows that the maximum student wait time threshold varies the number of tutors needed. For instance, a maximum wait time of five minutes requires five tutors, a maximum wait time of ten minutes requires four tutors, and a maximum wait time of 15 or 20 minutes requires only three tutors. A maximum wait time above 20 minutes was not investigated, as this would not provide quick service to the students. Based on the constraint thresholds investigated, four recommendations are offered in Table 10 below.

Table 10

Recommended Physics & Chemistry Lab Staffing Schedule

Constraints Utilization	 Time	Physics 6 - 9	Total Cost
≤ 65%	Avg. Wait ≤ 1, 2, 5 minutes	2	$51.00
	Max Wait ≤ 5 minutes	5	$127.50
	Max Wait ≤ 10 minutes	4	$102.00
	Max Wait ≤ 15 minutes	3	$76.50

All four recommendations are based on a 65% tutor utilization, as this provides the tutor time to take a restroom break, get something to drink, or take a minute to stretch. The first recommendation is to staff two tutors, based on an average student wait time maximum of 5 minutes. When considering the maximum student wait time, the recommended number of tutors to staff ranges from three to five. Three tutors are needed if the wait time maximum is 15

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minutes, but five tutors are needed if the wait time is reduced to five minutes or less. Based on these recommendations, the cheapest way to staff the Physics & Chemistry Lab is to hire two tutors each evening.

Limitations

There were three primary types of limitations associated with this study: 1) assumptions that were made at the beginning of the study, 2) method of data collection, and 3) amount of data collected. The first limitation relates to the assumptions that defined a student's wait time and service time. For example, a student seeking help was defined as "a student who raises their hand or verbally asks a tutor for help." Such definitions/assumptions can limit the accuracy of a student's true wait time, because if a student knows the tutor is busy, they will likely wait until the tutor is available before seeking help. The second limitation refers to the various problems with collecting data by means of video recordings. For example, technical difficulties resulted in the loss of a week's worth of data and only "observed" data could be analyzed. The final limitation in this study was the amount of data collected. These sample sizes were limited by the frequencies of different subjects being tutored, some subjects have more request for tutoring than others. For example, subjects like engineering science, computer programming, and business had adequate sample sizes (about 100 requests/sessions), other subjects such as corporate finance had about 35 observed data points, while aeronautical science only had about 13 observations.

Areas of Future Research

One area of future research may investigate the operational demand on the tutoring center of busy versus normal weeks. Another direction of research could examine the relationship between peak demand nights and test schedules. If a future study were to examine the correlation between peak nights and when tests are given, an even better tutor staffing schedule could be developed at the beginning of each semester, based on the test schedules for different departments. If a correlation is found, additional tutors could be brought in on the nights before tests, providing a higher level of service to the students, while also minimizing the operational cost on non-peak evenings. A minimum of one semester of data, preferably two semesters of data, should be used in any future studies.

Conclusion

The results from this study provide the Unified Tutoring Center with scientifically based tutor scheduling changes that can reduce operating costs while still providing a high level of service to students. Specifically, the weekly cost of tutors for the General Study Room can be reduced from $688.50 to $586.50 (if corporate finance is still only offered three nights a week), a savings of $102. Similarly, the weekly cost of tutors for the Physics & Chemistry Lab can be reduced from $331.50 to $255, a savings of $76.50. Given that the Unified Tutoring Center is open for 13 weeks a semester, implementing these recommended staffing changes can save the UTC $2,320.50 per semester. While

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these results provide a good starting point for helping the tutoring center reduce operational costs, these models can be adapted and used again for future investigations. For instance, the constraints on tutor utilization and/or student wait time could be strengthened or relaxed, based on future student demands or on the capacity of the budget. The method applied in this study can also be easily expanded to other areas of scheduling, such as hotel and hospital service, pilot training and aircraft maintenance scheduling. Using discrete event simulation (DES) provides the advantage of being able to analyze the system under a specific set of operating conditions, propose and test alternative conditions and run the simulation for a long period of simulated time in a matter of minutes or even seconds, so that decision-maker has the ability to manipulate and test system design or staffing changes in the simulated model, before implementing the change on the real system.

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