A Simulation Application to Analyze the Utilization of Computer Laboratories

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Abstract

Efficiency is a widely used term in industry, education, economics and science to define the wisely use of input to achieve a certain level of output with minimum waste. In terms of material usage, efficiency is working with the optimum number of resources to provide the required service. Computer labs are one of the main facilities of modem universities. Efficient usage of computer labs in terms of utilization is one of the factors that affects the quality and performance of the education. The problem of this study is to investigate the efficiency of selected computer centers at a Midwestern university.

A SIMULATION APPLICATION TO ANALYZE THE UTILIZATION OF COMPUTER LABORATORIES

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CHAPTER 1

INTRODUCTION

The invention and extensive usage of computers in education have resulted in significant changes to the communication, research and reporting of studies. One indication of this is the popularity of internet, or aptly named information highway. Another indication is the increased availability of computer access. As one of the most important educational facilities, computer labs are becoming vital parts of all universities. At this point, wisely planning and management of these facilities are a major concern of the universities, which requires more concentration and analysis on them. This study was prompted by the need to analyze the efficiency of computer labs at a Midwestern university in terms of utilization.

Statement of the Problem

Efficiency is a widely used term in industry, education, economics and science to define the wisely use of input to achieve a certain level of output with minimum waste. In terms of material usage, efficiency is working with the optimum number of resources to provide the required service. Computer labs are one of the main facilities of modern universities. Efficient usage of computer labs in terms of utilization is one of the factors that affects the quality and performance of the education. The problem of this study is to investigate the efficiency of selected computer centers at a Midwestern university.

Statement of Purpose

Because of the nature of the universities and campuses, the number of the user of computer centers varies during the day. While in the early morning most of the computers are waiting idle, at noon and after noon it becomes hard to find an available computer to use. The purpose of this study is to analyze the efficiency of the computer centers in order to avoid overloading and waste of equipment.

Statement of Need

No matter what kind of facility is being considered, there are some typical planning objectives that can be applied. Tompkins et al. (1996) states these two objectives as "Effectively utilize people, equipment, space, and energy. Minimize capital investment."

Moreover, according to Herman J.J. (1995) essentiality of educational facility design and functionality have remained unchanged in America for over 100 years. However, designing functional facilities is not an easy task; it requires expertise and organizational structures. During the interview with the Coordinator of Information Technology Services (ITS) S. Brasch (personal communication, February 20, 2003) explained how they have decided on the design, location and the equipment of the computer labs. According to S. Brasch, this study will be very helpful for them to see how scientifically they have designed the computer labs and how efficiently these centers are working, because there hasn't been done any study for the design and planning of the computer labs in the past.

Elimination of waste is another aspect of the study. Waste, which is originated from excessive usage of material and equipment, is one of the major problems of governments. According to the research of Citizens Against Government Waste (2002), State of Iowa has spent $200,163,642 because of waste, mismanagement and inefficiency in the federal government.

Research Question

Based on the required utilization of the computer labs, the research question is how many computers would be enough to prevent overloading or waste at computer labs.

Assumptions

The following assumptions were made in pursuit of this study:

1. In this system the calling population is infinite; that is, if a unit leaves the calling population and joins the waiting line or enters service, there is no change in the arrival rate of other units that may need service.
2. In this system, arrivals for service occur one at a time in a random fashion and once they join the waiting line, they are eventually served.
3. Service times are of some random length according to a probability distribution which does not change over time.
4. The system capacity is unlimited.
6. For this study, the data which is provided by ITS covers only two month period. It is assumed that this two-month period contains possible maximum and minimum points of utilization.

Limitations

The following delimitations are inherent in the study:

1. The input data of this study is directly related with the population of the school, the number of other computer labs and their locations at the time of the data collection process.

2. This study is limited to the weekdays of spring and fall semesters. During summer semesters and weekends the arrival rate of the students will be affected by the number of students on campus.

Statement of Procedure

The procedure for this study was as follows:

1. Problem formulation
2. Model building
3. Data collection
4. Coding
5. Verification
6. Validation
7. Experimental Design
8. Trial Runs
9. Documentation and reporting

Definition of Terms

Discrete-system: Discrete system is one in which the state variable(s) change only at a discrete set of points in time (Mitrani, 1982).

Model: Model is defined as the body of information about a system gathered for the purpose of studying the system (Gordon, 1978).

Simulation: A simulation is the imitation of the operation of a real-world process or system over time. Whether done by hand or on a computer, simulation involves the generation of an artificial history of a system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system. (Banks, Carson, 1984).

State: The state of a system is defined to be that collection of variables necessary to describe the system at any time, relative to the objectives of the study (Banks, Carson, 1984).

System: A system is defined as a group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose (Banks, Carson, 1984).

CHAPTER 2

LITERATURE REVIEW

Since the 1950s computer simulation has been used to tackle a range of business problems leading to improvements in efficiency reduced costs and increased profitability (Heilala, 1999). Simulation studies have been carried out in most business sectors, including manufacturing and service industries as well as in the public sector. As for many concepts of a general nature, there are different definitions of simulation. Pegden (1995) defines it as "the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behaviour of the system and/or evaluating various strategies for the operation of the system."

The behaviour of a system as it evolves over time is studied by developing a simulation model. This model usually takes the form of a set of assumptions concerning the operation of the system. These assumptions are expressed in mathematical, logical, and symbolic relationships between the entities, or objects of interest, of the system. Once developed and validated, a model can be used to investigate a wide variety of "what if" questions about the real world system. Potential changes to the system can first be simulated in order to predict their impact on system performance. Simulation can also be used to study systems in the design stage, before such systems are built. Thus, simulation modelling can be used both as an analysis tool for predicting the effect of changes to existing systems, and as a design tool to predict the performance of new systems under varying sets of circumstances.

When is Simulation the Appropriate Tool?

The availability of special purpose simulation languages, massive computing capabilities at a decreasing operational costs, and advances in simulation methodologies have made simulation one of the most widely used and accepted tools in operations research and system analysis. Circumstances under which simulation is the appropriate tool to use have been discussed by many authors, including Naylor, Balintfy, Burdick, and Chu (1966). According to Naylor et al.(1966) simulation can be used for the following purposes:

1. Simulation enables the study of and experimentation with, the internal interactions of a complex system, or of a sub-system within a complex system.
2. Informational, organizational and environmental changes can be simulated and the effects of these alterations on the model's behavior can be observed.
3. The knowledge gained in designing a simulation model may be of great value toward suggesting improvement in the system under investigation.
4. By changing simulation inputs and observing the resulting outputs, valuable insight may be obtained into which variables are most important and how variables interact.
5. Simulation can be used as a pedagogical device to reinforce analytic solution methodologies.
6. Simulation can be used to experiment with new designs or policies prior to implementation, so as to prepare for what may happen.
7. Simulation can be used to verify analytic solutions.

Areas of Application

Discrete event simulation is used for wide range of applications, which are summarized by Robinson(1994) in eight categories:

1. Facilities planning: when designing a new facility, simulation is used to check that it performs correctly.

2. Obtaining the best use of current facilities: potential solutions could be tested and identified.

3. Developing methods of control: more than just physical equipment, for example experimenting with different control logic as MRPII or kanban.

4. Material handling: experiments can be performed to control the flow of materials to find for example bottlenecks.

5. Examining the logistics of change: to minimize interruptions simulation can be used to examine the logistics of change.

6. Company modelling: high-level model showing for example the flows of resources and information between sites.

7. Operational planning: simulation can be used in day to day planning and scheduling.

8. Training operations staff: supervisors and operators are trained in the operation of the facility.

Systems and System Environment

To model a system, it is necessary to understand the concept of a system and the system boundary. A system is defined as a group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose. Production system manufacturing automobiles can be a system. The machines, component parts, and workers operate jointly along an assembly line to produce a high quality vehicle.

A system is often affected by changes occurring outside the system. Such changes are said to occur in the system environment (Gordon, 1978). According to Gordon (1978) in modelling systems, it is necessary to decide on the boundary between the system and its environment. This decision may depend on the purpose of the study.

Components of a System

In order to understand and analyze a system, a number of terms are defined. An entity is an object of interest in the system. An attribute is a property of an entity. An activity represents a time period of specified length. If a bank is being studied, customers might be one of the entities, the balance in their checking accounts might be an attribute, and making deposits might be an activity.

The collection of entities that compose a system for one study might only be a subset of the overall system for another study (Law and Kelton, 1991).

The state of a system is defined to be that collection of variables necessary to describe the system at any time, relative to the objectives of the study. In the study of a bank, possible state variables are the number of busy tellers, the number of customers waiting in line or being served, and the arrival time of the next customer. An event is defined as an instantaneous occurrence that may change the state of the system. The term endogenous is used to describe activities and events occurring within a system, and the term exogenous is used to describe activities and events in the environment that affect the system. In the bank study, the arrival of a customer is an exogenous event, and the completion of service of a customer is an endogenous event.

Discrete and Continuous Systems

Systems can be categorized as discrete or continuous. "Few systems in practice are wholly discrete or continuous, but since one type of change pre-dominates for most systems, it will usually be possible to classify a system as being either discrete or continuous" (Law and Kelton, 1991). A discrete system is one in which the state variable(s) change only at a discrete set of points in time. A continuous system is one in which the state variable(s) change continuously over time.

Model of a System

To predict how the system will operate under new conditions, it is necessary to study the system and its components. However, most of the time it is impossible or impractical to experiment with the system itself. The new system may not yet exist, it may be at the design stage. Even if the system exists, it may be too costly or unfeasible to experiment with it. Consequently, most of the time systems are studied with a model.

A model is defined by Law and Kelton (1991) as a representation of a system for the purpose of studying the system. Although, model is a simplification of a system, the model should be sufficiently detailed to permit valid conclusions to be drawn about the real system.

Quality of a Discrete Event System Simulation

In the literature, simulation quality is often described in terms of three attributes: validity, credibility, and acceptability. There is general agreement over the meaning of validity. Banks and Carson (1984) describe a model as valid if it is sufficiently accurate for the purpose at hand. Balci (1997) describes the process of validation as one of substantiating that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the study objectives. The key theme is the accuracy of the model and its intended use. A model can only be valid for the purpose for which it is built; it is not possible to think in terms of universal validity.

Although the meaning of validity is generally agreed, there is less agreement over the meaning of credibility and acceptability. One view of credibility is that it is the confidence or belief someone is willing to place in a model and its results. This is often reflected in a persons willingness to make decisions based on what they have learned from a simulation (Banks, Carson, 1984). Such a view sees credibility as an attribute of the decision maker. Another view, adopted by Balci (1997), is that credibility is the confidence that should be placed in a model and its results, thereby making credibility an attribute of the model and the simulation study.

Acceptability is often described in terms of its attributes, for instance Balci (1997) believes that acceptability involves the credibility, cost effectiveness, timeliness, and comprehensibility of the simulation study.

Beyond these three concepts, other concepts are also used to describe the quality of simulations. Balci (1997) found 16 terms that are in common use, for example, accuracy, calibration, certification, confidence, performance, and qualification. He concludes that there is little agreement on the exact definition of these terms.

Simulation Tools

Simulation models can be built with general programming languages such as FORTRAN, TurboPascal or C/C++. Currently there are several commercial simulation tools available. Law and Kelton (1991) divide these tools into three basic classes: general purpose simulation language, simulation front ends and simulators. The general-purpose simulation language requires the user to be a proficient programmer as well as competent simulationist. The simulation front ends are essentially interface programs between the user and the simulation language being used. Simulators offer graphical presentation and animations.

The discrete event simulators are well suited for the simulation of a serving system. (Hauge and Paige 2001). Simulators can reduce the time required to develop a simulation model and they may exceed the capabilities of the average engineer. Recent development in simulator packages provides them with the flexibility to meet the needs of the development effort. The newest versions of simulator packages have a graphical user interface. The names of some simulators and their web addresses are in the Appendix A. (There are also other simulators or simulation languages on the market.)

CHAPTER 3

METHODOLOGY

To answer the research question, discrete event system simulation technique was applied to the analysis of the model. The simulation methodology included:

Problem Formulation

Every research study begins with a statement of the problem (Banks, Carson, Nelson, 1999). As it was stated in the proposal, the problem of this study was to find the number of required computers for certain computer labs.

For this study, two computer centers were analyzed: Library and Lang Hall computer centers at the university campus. Before the study, it was known that there was an overloading at Library computer center, while Lang Hall computer center was working with half capacity. Another aim of the study was to be helpful for the planning of the new computer center at Maucker Student Union.

During the formulation phase, there are some suggested topics other than the problem that can be discussed. According to Banks et al. (1999) determining the performance measures that will be used to evaluate the efficiency of different system configurations is one of the topics to be discussed. In this research study there are two main performance measures used: average waiting time of the computer users in the queue, and daily average usage of computers.

Model Building

In the literature, it is hard to find a set of instructions that will help to build successful and appropriate models for every instance. Most of the time, modelling depends on the type of the system to be modelled, and the skill of the modeller.

According to Gordon (1978) it is best to start with a simple model and to build toward greater complexity. It is also suggested to enhance the model by abstracting the essential features of the problem, and selecting and modifying basic assumptions that characterise the system.

Although, it is not necessary to have a one to one mapping between the model and the real system, the system was modelled by one to one mapping. The simplicity of the real system and the power of the simulation program enabled the system to be modelled by one to one mapping.

The actual outlines of the systems are given in Figure 1 and Figure 2. Each number represents a computer terminal. Print, scan and SU stand for printer, scanner and student assistant. Although, there were 67 terminals in the library, only 57 computers were placed and working properly. In the Lang Hall there were 24 computers working properly.

For the modelling of Maucker Union some simplifications were assumed. During the class times and breaks, most of the students spend their time in the vicinity of Library, Lang Hall and Maucker Union. In that region, when a user needs to use a computer s/he selects one of these centers. So, in terms of computer usage, the area that includes these three buildings can be thought as one separate region. It was also assumed that, after building the Maucker Union computer center the distributions of inter-arrival rates would not change. By the help of these two assumptions, inter-arrival rate distributions were combined to produce one calling population and to model one computer center. With this assumption, it was studied to find the number of required computers for new Maucker Union computer center.

Considering the outline of the system and the general characteristics of the multiserver queuing systems, the system was modelled as in Figure 3. In the model, calling population is the possible users of the computer labs.

The model was constructed, using the SIMUL8® software model building tool (Hauge and Paige 2001), as a series of storage (queue), work centers (computers), and entrance-exit points. Users entering the system were not provided any attribute or priority, all users were assumed to be equal in all aspects. If there is no queue in front of the entrance point, users are routed to any of the available computers. If there is a queue, users in the waiting line are placed by first-come first-serve principle. Snapshot of the model which was created by the simulator program is as in Appendix B.

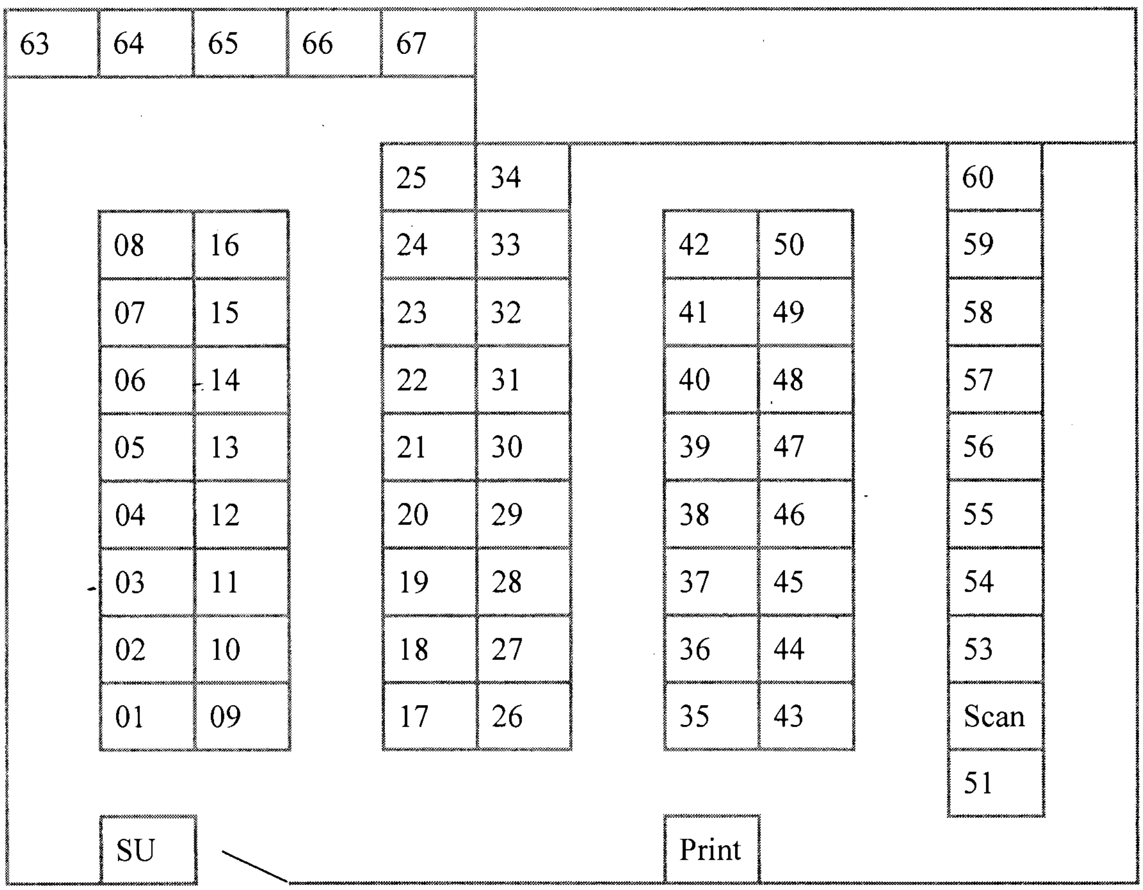

Figure 1. Outline of Library computer center

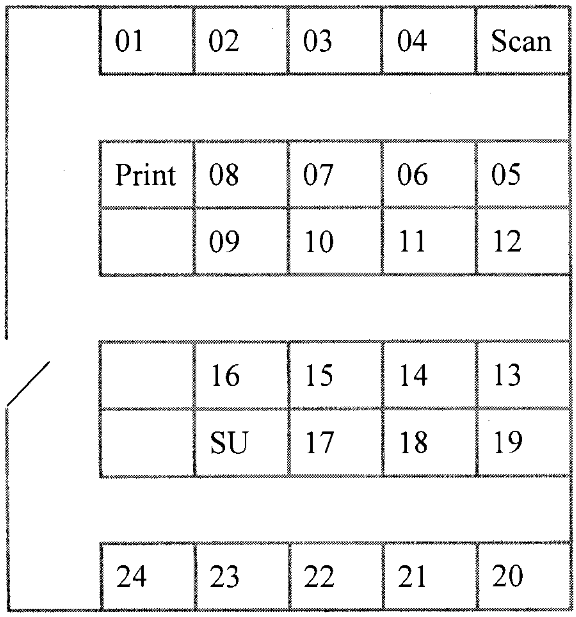

Figure 2. Outline of the Lang Hall computer center

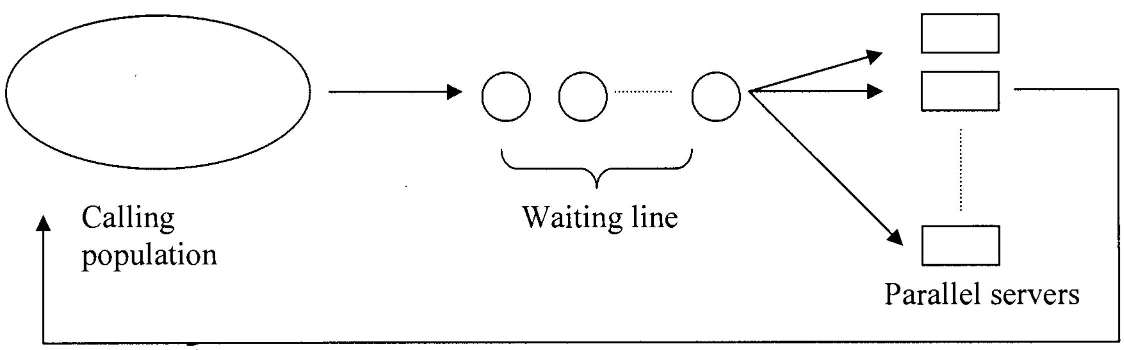

Figure 3. Queuing model

Collecting Information and Data

The kind of the data to be collected is directly related with the objectives of the study. In this situation the desire was to learn the length of the waiting lines as the number of the users, and the average waiting time of the users. Thus, the distribution of inter-arrival times, the service time distributions for the computers, and historic distributions of queue lengths under varying conditions were the kinds of required data.

Information Technology Services management shared long term data for January and February 2003. At this specific time period the busiest week was determined as the 4th week of January, between the 20th and the 24th of January. Weekdays and weekends have different inter-arrival and usage characteristics. Because of the high use rate of weekdays, weekends were excluded from the study. These data comprised the distribution of inter-arrival time of the computer users, and distribution of the time spent on a computer.

These data were fitted to distributions using the BestFit® distribution fitting software tool (Jankauskas & McLafferty, 1996); exponential, normal, log-normal and the Pearson 5 often characterized data well for this model. The most important model for random arrivals is the Poisson arrival process (Banks et al. 1999). The arrival process for the model is fitted to Poisson arrival process. Probability distributions of serving times and inter-arrival times are as in Appendix C.

Verification and Validation

Although verification and validation are conceptually distinct, they are usually conducted simultaneously. The purpose of model verification is to assure that the conceptual model is reflected accurately in the computerized representation. Validation can be described as the overall process of comparing the model and its behaviour to the real system and its behaviour. Naylor and Finger (1967) formulated the following three-step approach for model verification and validation:

1. Build a model that has high face validity.
2. Validate model assumptions.
3. Compare the model input-output with corresponding real system input-output.

For model verification and validation, the computerized representation was checked by one of the student assistants working at Library computer center (Oibek Ibragimov, personal communication, May 20, 2003). The SIMUL8® programmer enables to collect many statistics about model components. This model output was closely examined for reasonableness under a variety of settings of the input parameters. At this step, it was determined that the average queue length and the average waiting time in queue were very low or close to zero. However, it was known that at noon usually at least four or five users were waiting in the line. After detection of the problem, tracing was used to make a more sophisticated analysis. Trace is a detailed computer print out, which gives the state of a selected variable as it changes overtime. The problem was corrected by refitting the inter-arrival time data to distributions for different time periods. At the beginning of the model building, the inter-arrival time data was fitted for the whole day. However, frequency of arrivals is changing during the day. Computer labs are open between 8AM and 12PM weekdays. This time period was divided into four parts and each part was analyzed separately for arrival rate distributions. The distributions and parameters are shown in Table 1.

Table 1. Library inter-arrival time distributions

Time Period	Distribution	Parameter
8AM – 10AM	Exponential	Mean = 0.95
10AM – 2PM	Exponential	Mean = 0.81
2PM – 10PM	Exponential	Mean = 1.5
10PM – 12PM	Exponential	Mean = 10

After the verification of the model, input-output transformation validation was conducted by using the past historical data, which was reserved for validation purposes. The validation test consists of comparing the real system response (S), namely average waiting time, to the model responses (M). Formally, a statistical t test of the null hypothesis:

H_0 : Expected (M) = 2.13 versus H_1 : Expected (M) $\neq$ 2.13

was conducted. If H_0 is not rejected, then on the basis of t test there is no reason to consider the model invalid.

If H_0 is rejected, the current version of the model is rejected. The appropriate statistical test is the t test, which was conducted in the following manner: The level of significance α was chosen as 0.05 and the model was run for 30 times. (Law and Kelton, 1991). Average waiting times for trial runs were found as in Appendix D.

Sample mean of runs: 2.22

Standard deviation of runs: 1.22

t_0 = (sample mean – system response) / (standard deviation / square root of number of runs) = 0.39

$t_{0.025,\,29} = 2.04$

For the two sided t test, since $| t_0 | < t_{0.025,\,29}$, it can be concluded that the model is adequate in its prediction of average waiting time.

Verification and validation were done in collaboration with the student lab assistant; he was shown both model animation and quantitative model predictions. Upon successful completion of this step, the model had attained not only validity, but also face validity and credibility.

CHAPTER IV

RESULTS

Multiple replications (at least thirty replications per model) of the models were run and analyzed. The two most significant performance measures of the models are average waiting time in queue and average queue length. To predict these performance measures the output data generated by the simulation was analyzed.

Simulation for Library Computer Center

At the time of data collection process, the number of available computers at library was 57. The computer center was opened at 8AM and closed at 12PM, so it was open for 16 hours (960 minutes). The SIMUL8® simulated the number of used computers on 960-minute time scale. From the graph (see Figure 4), it is obvious that before noon the number of occupied computers is increasing and it reaches to the total number of available computers.

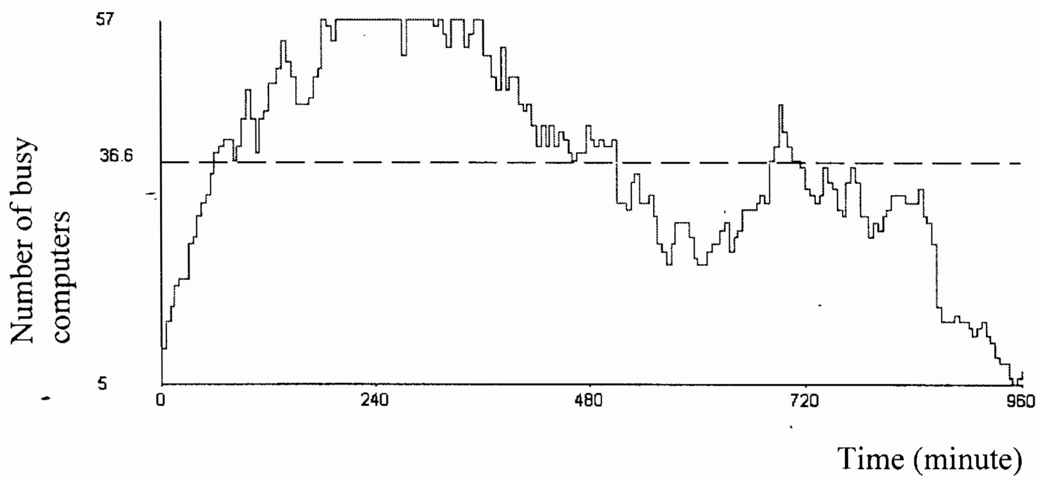

Figure 4. Number of computers being used at library.

When the utilization of computers is at the maximum, the queue started to be increased. During 960 minutes, simulation program created 824 users, and 174 of these users waited in the line. The maximum queue length is five, (see figure 5) but the average queue length is 0.6 person, which was calculated for total simulation time. The maximum waiting time is 6.23 minutes and the average waiting time is 0.43 minutes. However, the average waiting time for non-zero 174 users is 2.22 minutes.

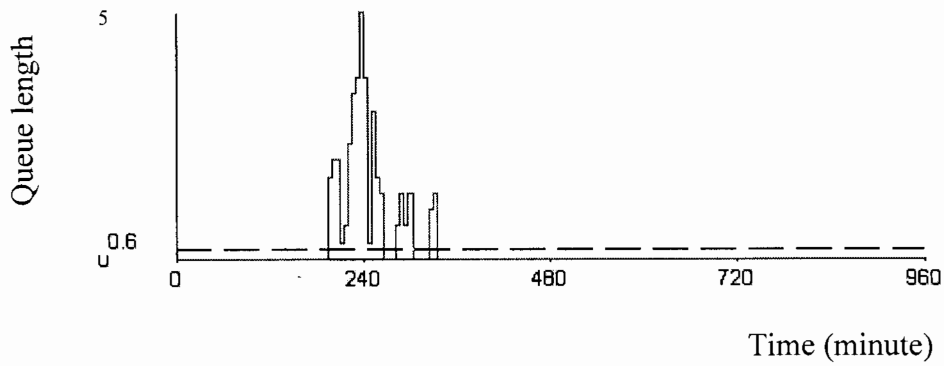

Figure 5. Queue length at library computer center.

To find the number of required computers, the number of computers were increased one by one, and each time, model was run for thirty times to calculate the simulation average and confidence intervals for the number of required computers. Trial was stopped when the maximum number of occupied computers was 66 (see Figure 6). The results of thirty trial runs are in the Appendix D.

The output analysis of the simulation were done for both the point estimate of the average (the average of 30 trials for the maximum number of required computers) and the confidence interval estimation of this average as follows:

Average number of computers = A = Total number of computers / 30 = 65,92733

Standard deviation of A = σ (A) = 0,36192

95% confidence interval for A = A $\pm$ $t_{0.025,\,29}$ σ (A) $\Rightarrow$ 65,18901< A < 66,66565

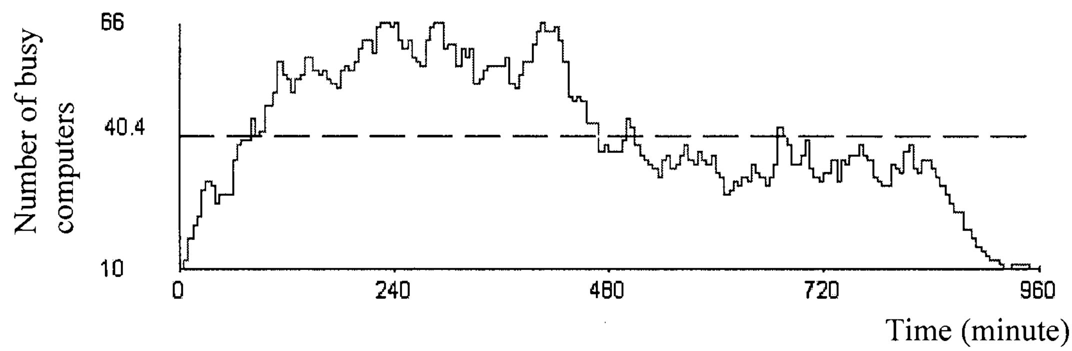

Figure 6. Number of computers being used at library without overloading.

Simulation for Lang Hall Computer Center

At the Lang Hall Computer Center there were 24 available computers. The center was open between 8AM and 10:30PM for 870 minutes. Output analysis of the Lang Hall model was done for 30 trial runs and the result was graphed as in Figure 7. During the day the maximum number of occupied computers at the same time is 19 and the daily average is 11.2. There were 220 students using Lang Hall computer center daily.

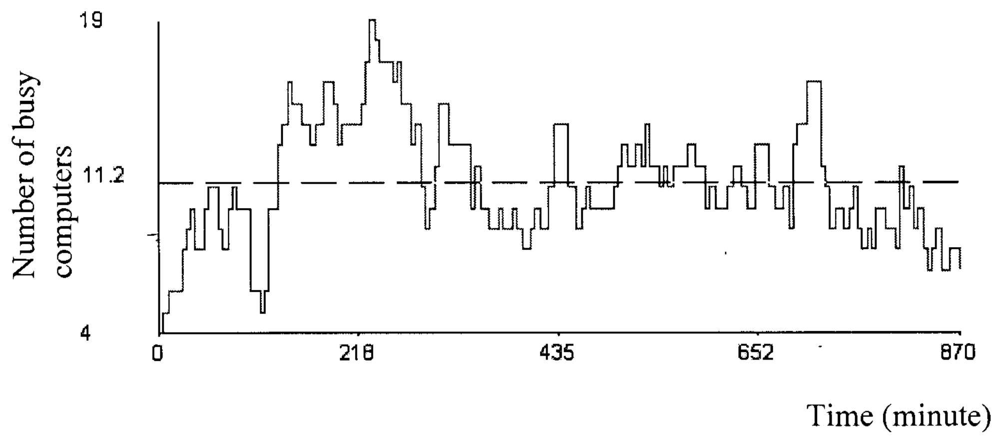

Figure 7. Number of computers being used at Lang Hall

Output analyses are as follows:

Average number of computers = A = Total number of computers / 30 = 18,99167

Standard deviation of A = σ (A) = 0,594388

95% confidence interval for A = A $\pm$ $t_{0.025,\,29}$ σ (A) = 17,77912 < A < 20,20422

Simulation for Maucker Union Computer Center

Under the assumptions given in the previous chapter, it was computed that there were only 84 computers used at the same time (see Figure 8). According to this finding, increasing the number of computers in this region by 3 will be enough to prevent bottleneck and waste. It does not mean that Maucker Union computer center will need only three computers. Because, each computer center has its own popularity and after the Maucker Union lab is opened, it is expected to decrease the number of users at other labs. Data is available in the Appendix D.

Output analyses are as follows:

Average number of computers = A = Total number of computers / 30 = 83,73367

Standard deviation of A = σ (A) = 0,784059

95% confidence interval for A = A $\pm$ $t_{0.025, 29}$ σ (A) = 82,13419 < A < 85,33315

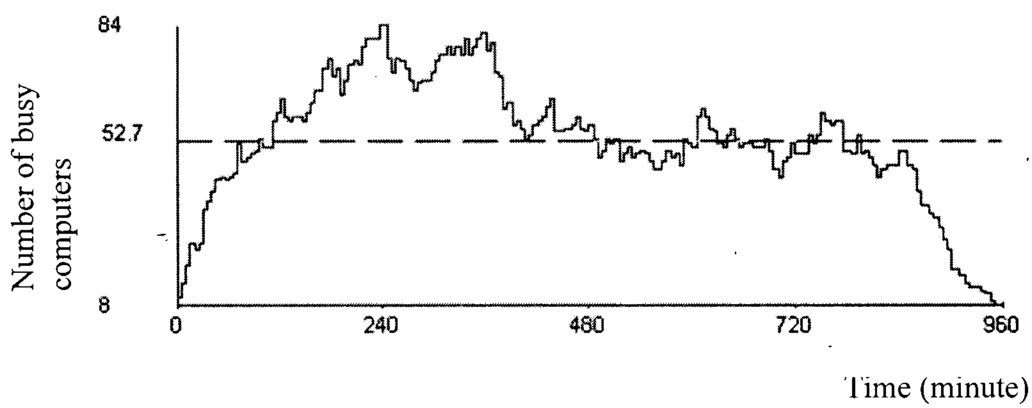

Figure 8. Number of computers being used at the vicinity of library, Lang Hall and Maucker Student Union

CHAPTER V

CONCLUSION

This study proved itself an excellent example of using discrete-process simulation to model a service facility. The Information Technology Service managers, now that they have become acquainted with the availability of and power of simulation analysis, are much more likely to extend its use in the future as changing conditions warrant.

Research results revealed that library computer center was overloaded during midday and it needed nine more computers. Whereas, Lang Hall computer center was working under its capacity and it has five extra computers than needed. Simulating the model showed that the solution to these problems is very easy and can be done with very low or no cost. The solution needs only rearranging the number of computers in each lab.

The model of Maucker Union computer lab is very general, and to get more precise results it needs to be more detailed. For example, to model the inter-arrivals to the combination of three computer labs, library inter-arrivals and Lang Hall inter-arrivals were combined. But, it is unknown if the new computer lab would increase the inter-arrival rate of the students in total or not. However, it is out of the scope of this research how the human psychology and behaviours affect social habits, thus it is not included in the study. Under this assumption, after rearranging other two computer labs, Maucker Union would need only three computers. But, it is known that sometimes supply creates its own demand.

This research was the first study about the utilization analysis of the computer labs at a university campus. After this study, it is expected to be easier and more precise to predict the size and utilization of computer labs.

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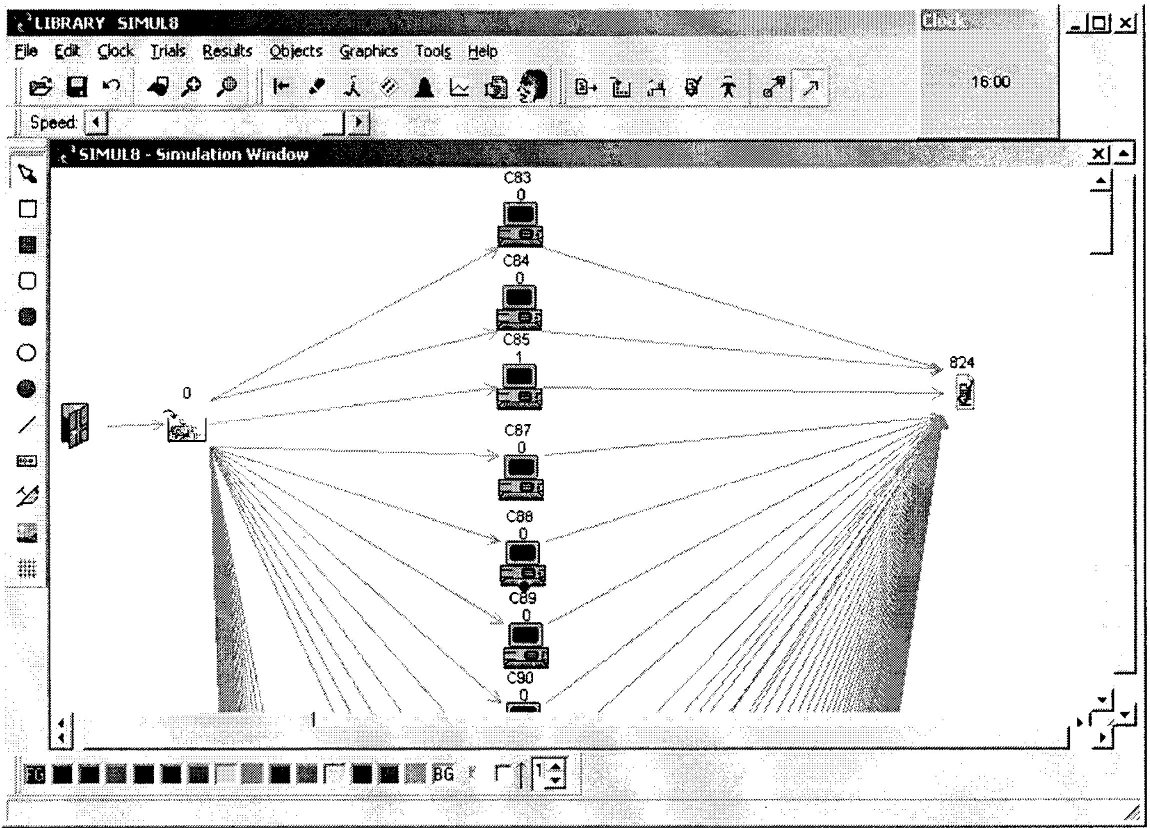
APPENDIX A – A list of simulators in the market.

Simulator	Web addresses
Automod / Autosched	www.autosim.com
Promodel	www.promodel.com
Areena	www.sm.com
Factor / AIM	www.pritsker.com
Witness	www.lanner.com
TaylorII	www.taylorii.com
TaylorED	www.taylor-ed.com
Micro Saint	www.madboulder.com
Quest	www.deneb.com
Simple ++	www.aesop.com
Extend	www.imaginethatinc.com
MODSIM III	www.modsim.com
SIMUL8	www.VisualT.com

APPENDIX B – A Snapshot of the SIMUL8 model.



APPENDIX C – Computer service time distributions

Table 2. Computer service time distributions for library SCC (in minutes)

Computer ID	Distribution	Parameter 1	Parameter 2
001	Exponential	Average =52.028	
003	Exponential	Average =61.351	
004	Exponential	Average =51.163	
005	Exponential	Average =34.483	
006	Exponential	Average =43.499	
007	Lognormal	Average =46.676	Std Dev =37.981
009	Exponential	Average =118.557	
010	Lognormal	Average =22.207	Std Dev =45.987
011	Exponential	Average =23.547	
012	Exponential	Average =26.083	
013	Lognormal	Average =50.079	Std Dev =139.262
014	Lognormal	Average =35.204	Std Dev =33.69
015	Exponential	Average =41.704	
017	Exponential	Average =31.789	
018	Exponential	Average =37.516	
019	Exponential	Average =42.187	
020	Exponential	Average =48.063	
021	Exponential	Average =38.58	
022	Lognormal	Average =69.569	Std Dev =40.968
023	Lognormal	Average =27.072	Std Dev =43.901
024	Exponential	Average =31.621	
025	Exponential	Average =29.55	
026	Exponential	Average =34.918	
027	Normal	Average =63.262	Std Dev =23.307
028	Lognormal	Average =78.276	Std Dev =44.166
029	Exponential	Average =38.008	
030	Lognormal	Average =42.628	Std Dev =163.04
031	Exponential	Average =27.015	
032	Exponential	Average =36.732	
033	Exponential	Average =49.634	
034	Lognormal	Average =41.434	Std Dev =90.429
035	Lognormal	Average =24.854	Std Dev =57.913
036	Lognormal	Average =35.54	Std Dev =60.523
037	Exponential	Average =31.892	
038	Normal	Average =2.377	Std Dev =32.17
039	Exponential	Average =58.978	
040	Exponential	Average =57.472	
042	Lognormal	Average =49.375	Std Dev =51.286
043	Lognormal	Average =53.411	Std Dev =39.485
044	Lognormal	Average =79.063	Std Dev =85.011

Table continues

Computer ID	Distribution	Parameter 1	Parameter 2
045	Exponential	Average =47.993	
046	Exponential	Average =37.332	
047	Exponential	Average =39.106	
048	Exponential	Average =38.781	
049	Exponential	Average =43.719	
054	Normal	Average =83.235	Std Dev =66.706
055	Exponential	Average =51.781	
056	Exponential	Average =38.58	
057	Pearson 5	Alpha =4.6680	Beta =243.5034
058	Lognormal	Average =29.116	Std Dev =72.179
059	Exponential	Average =52.729	
060	Exponential	Average =39.415	
063	Exponential	Average =43734	
064	Lognormal	Average =37.539	Std Dev =129.454
065	Exponential	Average =38.629	
066	Exponential	Average =59.298	
067	Lognormal	Average =98.603	Std Dev =87.101

Table 3. Computer service time distributions for Lang Hall SCC (in minutes)

Computer ID	Distribution	Parameter 1	Parameter2
001	Exponential	Average 10.93	
002	Exponential	Average 26.25	
003	Exponential	Average 19.34	
004	Exponential	Average 16.88	
005	Exponential	Average 26.49	
006	Lognormal	Average 23.91	Std Dev =20.869
007	Lognormal	Average 18.13	Std Dev =34.114
008	Exponential	Average 74.71	
009	Exponential	Average 21.92	
010	Exponential	Average 18.14	
011	Normal	Average 17.46	Std Dev =37.073
012	Lognormal	Average 6.32	Std Dev =34.771
013	Exponential	Average 68.72	
014	Lognormal	Average 2.04	Std Dev =63.03
015	Exponential	Average 14.35	
016	Exponential	Average 24.44	
017	Exponential	Average 16.87	
018	Lognormal	Average 56.71	Std Dev =73.279

Table continues

Computer ID	Distribution	Parameter 1	Parameter 2
019	Lognormal	Average 48.65	Std Dev =43.173
020	Lognormal	Average 44.26	Std Dev =27.335
021	Exponential	Average 27.74	
022	Normal	Average 18.08	Std Dev =44.23
023	Exponential	Average 71.31	
024	Exponential	Average 19.61	

APPENDIX D – Replication results (in minutes)

Library waiting time averages	Library maximum number of used computer	Lang Hall maximum number of used computer	Regional maximum number of used computer
2.66	65	18	84
6.23	65	18	82
2.31	65	18	85
3.08	65	19	83
2.13	65	19	84
2.02	65	18	83
1.02	66	18	82
1.96	66	19	84
2.52	65	19	83
1.20	65	19	83
4.24	65	19	82
1.41	65	18	84
0.73	66	19	84
2.72	65	19	83
2.50	65	19	83
1.05	65	19	82
3.45	65	18	83
2.01	66	17	82
1.57	66	19	82
3.90	66	19	84
3.01	66	19	84
2.24	65	18	83
3.20	66	18	84
3.99	65	20	85
1.95	65	18	84
1.12	66	18	84
1.55	65	19	84
3.14	65	19	83
1.66	66	18	83
0.43	65	19	83