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Using Discrete Event Computer Simulation to Analyze the Effects of Proposed Changes to Personnel in A Hospital Medical Laboratory

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USING DISCRETE EVENT COMPUTER SIMULATION TO ANALYZE THE EFFECTS OF PROPOSED CHANGES TO PERSONNEL IN A HOSPITAL MEDICAL LABORATORY

A Thesis

by

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ABSTRACT

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A discrete event computer simulation is used to model a portion of the medical laboratory at Doctors Hospital at Renaissance in order to assess the current situation as well as to review the planed personnel changes. The area under observation is the section in which the processor(s) receive, label and distribute the patient samples.

There are four cases modeled in the simulation: The main focus is to determine if one or two processors are needed per shift and if the high level of phone calls poses a significant delay to the processors' workflow. The simulation results indicate that having two processors per shift speed up the throughput by more than half the amount of time, furthermore the study also shows that the incoming phone calls do not present a significant source of delay in the processor workflow.

DEDICATION

The completion of my undergraduate as well as my graduate studies would not have been possible without the love and support of my parents. I would like to dedicate this thesis to my father, Jose Gerardo Morales and my mother, Maria Guadalupe Morales, who always sacrificed what little they had so that I may know a better tomorrow and taught me that knowledge is power. Gracias por todo su apoyo y por aguantarme todos estos años.

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Thank you Rosy for believing in me and pushing me to finish, and for all the help you gave me in those critical moments. Finally thank you to my two boys Manuel and Miguel whose priceless contributions sitting next to me "helping me" have made many long work nights a little bit more endurable.

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Chapter I

Introduction

1.1 Opening Statement

With demographic trends in the US, our aging population causes the increase in number of persons who need medical attention. Some hospitals are privately managed and are essentially businesses. The successes of the hospitals are measured in part by the number of patients they care for and how effectively that care is administered. Hospital waiting times play a fundamental part in the overall satisfaction of a hospital patient. In the business world, in order for a company to stay ahead of or in competition, it must outperform its competitors. Using discrete-event Monte Carlo computer simulation (a well understood manufacturing tool) hospital administrators can gain an advantage by modeling different departments of the hospital to see how they compare to desired performance. If changes are proposed these changes can be placed into the simulation model far easier and economically than if the changes were to be done with the actual department. Furthermore, the simulation lends itself to fine tuning, so that several combinations of adjustments can be tried to select an optimum setting. This method is clearly superior and should be given closer attention in the medical community if patient satisfaction is to be improved amidst an increasing demand for quality care.

1.2 Background

A brief history of the simulation is presented so the reader may have a better grasp of the nature of computer simulation and how it has developed through the years.

1.2.1 Simulation

The first type of Monte Carlo (random value) simulation performed dates back to 1733 when French mathematician Georges-Louis Leclerc, performed the now called "needle experiment" (Badger, 1994). This experiment was designed to calculate the probability that a needle would lie across a line between two strips of equal length supposing the needle was shorter than the two strips. The randomness of this experiment was later used to estimate the value of Π.

More than a century later William Sealy Gosset, a chemist who worked with brewing company Arthur Guiness, Son & Co. Ltd., published major statistical results under the pseudonym of "Student," in a 1908 paper formulating what is known as the student's t-distribution (Hotelling, 1930). Gosset used a form of manual simulation to confirm his assumptions about the probability density function for the t-distribution, because he had incomplete data.

As computer simulation began to mature, the next great contribution was credited to John von Neumann, Stanislaw Ulam and Nicholas Metropolis who developed and coined the phrase "Monte Carlo method" after the Monte Carlo Casino in Monaco because of the random nature of gambling. The experiment focused on using computers to solve the problems that arose in neuron diffusion when designing the fission bomb in the 1940's (Metropolis, 1987). Their

approach used one of the first computers developed, the ENIAC, to calculate the arduous arithmetic in the equations for generating pseudo-random numbers in order to predict how far neutrons would travel after an initial disturbance.

The methods used by the physicists at Los Alamos allowed others to use simulation in many other applications, increasingly in manufacturing. In 1960, Keith Douglas Tocher, a university professor, developed the first simulation program named the General Simulation Program (GSP). This program was a tool that allowed users to build a simulation of a manufacturing plant that consisted of machines each cycling through states such as busy, idle, unavailable, and failed. Over the next decades many more developers would create other software that would make the construction of a simulation model easier.

Starting in the 1980's, even simpler computer languages were developed such as Dennis C. Pegden's SIMAN. As the computer became more powerful and readily available, the use of computer languages gave to way to actual computer software that made simulation more accessible and presented the results in a way that management or non-engineering professionals could easily understand. These software packages used advanced animation techniques to display the model and the results in a visual manner. Today many companies develop discrete event simulation software that range from general uses to specialty software for a variety of specific markets such as the medical industry.

1.2.2 Time and Motion Studies

In order for most of the simulation languages or software programs to be of any real value the data utilized needs to come from the actual real life system. Statistical data such as distributions, means, and standard deviations are needed in order to develop the simulation model. What does this mean and where does the data come from? Firstly, the quality of the data

collected is central to the effectiveness of the simulation. For example, if a call center is being modeled and in the real life system, the phone calls have an average time of three minutes, then the model must have an average time per phone call to be equal to three minutes. Otherwise, the results would not be an accurate representation of the actual system, because the data input does not match the actual real life system. Secondly, the data can come from a variety of sources. Today many hospitals record information on the number of patients treated and arrival/dismissal times. These are generally kept in a computer network database and are quite reliable. Traditionally, the information is obtained by direct observation. Direct observation is when an observer is present while the process is running and records data. This is a form of time and motion studies first developed by Fredrick W. Taylor.

Fredrick W. Taylor was an American mechanical engineer who saw the value in studying work (motions performed to complete a task, mostly manual labor) in a scientific manner. Taylor's scientific management principles centered on the belief that there was a method to improve productivity by optimizing the way tasks were performed and that workers could be trained to perform the work in a series of specialized motions. Taylor performed several studies involving the steel industry in which he used his scientific management method (Taylor, 1911). Taylors' main tool in the scientific management method was the stopwatch; the stopwatch was used to time a worker's sequence of motions with the goal of determining the one best way to perform a job. This method is still used today when trying to determine the statistical data. Along with direct observation, video camera recorders are also used as a means of being less obtrusive or to eliminate the need of multiple observers. Whatever the method it is clear that the methods developed by Fredrick Taylor play an important role in discrete-event simulation.

1.3 Goals of This Study

Discrete-event Monte Carlo simulation is a common place tool used by the medical industry to improve customer satisfaction and as a cost reduction tool. Studies have been performed on maximizing patient throughput while minimizing patient wait times. The main focus of these studies has been to model and improve the triage (area where patients are registered and placed according to severity level) and examination areas of the hospital. However, if it is the goal of hospital administrators to truly minimize patient's waiting times, careful analysis must be given to other departments of the hospital, specifically the medical laboratory department. The laboratory is responsible for collecting and testing different types of patient samples. The delay in obtaining the results leads to a delayed stay and patient dissatisfaction.

This study models a portion of the medical laboratory department at Doctors Hospital at Renaissance, a medium-large medical facility servicing the southern region of Texas known as the Rio Grande Valley. This study focuses on the processors' function in the medical laboratory. The processors are responsible for receiving the specimen samples and entering them into the computer system. Also, they are responsible for delivering the samples to their respective areas for analysis.

The main focus of this study is to develop a model of the processor's activity and to use that model to examine different ways to operate and the results associated with those different ways of operating. For example, one concern by the medical laboratory manager is the high level of phone calls received throughout the day. Processors must take time away from their primary duties in order to answer the phone calls. Furthermore some calls received are not related to patient specimen sample information. By modeling the laboratory processor activity with and

without phone call interruptions, the effect of assigning processors to answer telephones can be directly determined. Additionally, either one or two processors are assigned on different days. The effects of having one or two processors are also examined. These comparisons allow the simulation to evaluate the effect of phone operations and number of processors on the specimen sample throughput. As a secondary focus a sensitivity analysis is performed in order to evaluate the effects of an increase in the number of specimen samples that are handled by the laboratory. Finally, the effects of increasing or decreasing the number of patient samples that need to be labeled or relabeled is also investigated.

The Medical Laboratory was observed over a period of 30 days, from 4am to 9am. This time period is the medical laboratory's peak hours of operation.

1.4 Thesis Content

This section serves as a guide to this study. The aim is to explain the methods and order in which the study is organized so that a clear understanding about the contents is provided.
The literature review which follows serves as a brief descriptive of the methods used in discrete-event type Monte Carlo medical simulation. More importantly however, the review serves as a reference and guide as to the proper techniques that are used by contemporaries.

The next chapter covers data gathering and reduction to statistical distributions. Each section gives an in detail explanation of the actual process being modeled for each important activity (as defined by the laboratory staff). Also covered in this section is how each piece of the simulation model correlates to the actual process in the medical laboratory. For example, the work performed by the processors that entails picking up the bags containing the specimen samples from the pneumatic bin area is represented by a process module in the Arena software.

Statistical data such as expressions for the different distributions calculated and cumulative probability functions (CDF's) are also given and explained.

The next chapter focuses on validating the model and execution of the model under different conditions for comparison. The verification process entails running the model before any changes are performed and comparing the results to the known results. If the results from the simulation fall within an acceptable level of the known values as determined by the medical laboratory administrators, then the model is verified.

There are four versions of the model that are analyzed for the primary study. Case one involves one processor on duty with phlebotomists assisting the processor for an average of 2.7 hours for the 5 hours observed. Phone calls are allowed in the model. Case two is identical to case one except that the phone calls are taken out of the model in order to determine the effects. Case three involves two processors on duty with phlebotomists assisting the processors for an average of 50 minutes for the 5 hours observed. Phone calls are allowed in the model. Case four is similar to Case three except that the phone calls are eliminated from the model. For the sensitivity analyses several simulations are performed. By varying the percentage of patient samples arriving as well as the percentage of patient samples that are not correctly labeled the effect on patient sample times is investigated.

Finally, once the results are obtained from the simulation model, they are interpreted and conclusions are drawn. Recommendations are also provided.

Chapter II

Literature Review

2.1 Simulation: Origins in the Medical Field

Simulation was first utilized during World War II and following the second Great War the industrial implications were realized. The ability to model the actual process via mathematical expressions was a breakthrough. The definition of a model came to mean an abstraction of reality. Models were used in problem solving because their use was generally cheaper, faster, and less disruptive than manipulating the real world system (Boxerman, 1996). Since the 1940's, the use of simulation has steadily increased, but still had remained limited to the industrial sectors. Starting in the early 1980's simulation made its way to the corporate and medical industries. According to a survey of applications by the Society for Computer Simulation International in 1981, it contained more than 400 references to computer simulation applications to health care management (Anderson, 2002). The early simulation studies focused on specific hospital departments, emergency services, and the simulation of mental and public health. Their aim was to improve the design of facilities, staffing and scheduling, and also to reduce the waiting times experienced by the patients. The medical field can be considered a dynamic entity having patients, employees, equipment and supplies. They all interact in different ways that are complex and difficult to understand. As such, dynamic analysis is required in order to understand the effects of normal variations or unexpected events on a hospital's operation.

This analysis can be done cost effectively by using simulation (Proctor, 1996). Medical simulation then can be described as a method that encompasses any techniques that realistically recreates clinical situations and maximizes experimental outcomes, while minimizing risk (Brinelly & Arabi, 2009).

It is important to note that the type of simulation covered in this thesis is analytical and mathematically based. This concept is not to be confused with "real life" simulation (i.e. actors playing as patients with medical professionals trying to practice proper diagnosis or a mock up surgery being performed on a dummy body or in a virtual environment).

2.2 Monte Carlo Discrete-Event Type Computer Simulation Software

Monte Carlo simulation has its beginnings in the late 18th century and began being widely used in the middle of the 20th century beginning in World War II. Essentially, Monte Carlo simulation uses a certain type of statistical distribution that defines the actual system being modeled and generates a random value based on the distribution. The value obtained is then used in the mathematical expression to obtain a result. Every time a result is derived it is called iteration. Every iteration has a new random value generated by the computer logic that follows the statistical distribution. A Monte Carlo simulation could involve thousands or tens of thousands of recalculations before it is complete. Probability distributions are a much more realistic way of describing uncertainty in variables of a risk analysis.

The discrete-event type is widely used in the medical field because it models most medical systems perfectly. In discrete-event simulation, the operation of a system is represented as a chronological sequence of events. Each event occurs at an instant in time and marks a change of state in the system. So for example, in a pediatric emergency department (PED)

patients arrive and are triaged (separated according to severity), then wait to see the attending physician, then they are taken to the appropriate ward or dismissed (Hung, et al. 2007). Each time an event takes place it marks the start of another event. This approach is a general model of what occurs in hospitals and medical clinics around the world, and is well documented in many journal papers and research articles.

2.3 Computer Simulation Packages

Now that the term simulation has been defined (within the scope of the medical field) it is important to understand what means are used to actually construct and run a simulation model. In the early days of computer simulation the model was constructed using a variety of computer languages that were developed for the use of simulation purposes. The first simulation specific language was the General Activity Simulation Program (GASP) which was a set of FORTRAN subgroups. From there several other languages were derived such as: Systems Analysis of Integrated Networks of Tasks (SAINT), Simulation Language for Alternative Modeling (SLAM), Simulation Analysis (SIMAN), and Modular Simulation Language (MODSIM). Many of these simulation languages are still used today, although the more common method is to use simulation software. The software offers the user a more concise and user-friendly method of constructing simple and complicated models in only a fraction of the time taken using the simulation language. There are a variety of programs available, some of the most popular software's are: ProModel (with MedModel attachment), Simul8, and Arena. Arena is a simulation package that is based on the SIMAN simulation language and is the software package used in this experiment.

There is another type of simulation called system dynamics simulation that is also used to model medical situations. This method is based on expressions of differential equations (Gillespie, et al. 2004; Hannon and Ruth 1994). These techniques are distinctly different from the methods used in this thesis.

2.4 Prevalent Simulations Done in the Medical Industry

Many of the discrete–event type simulation studies that have been performed can be classified into two categories:

I. To reduce the patient wait times.
II. To optimize specific equipment or departments (i.e. pneumatic delivery system or medical laboratory).

The most commonly executed simulation study is to decrease the amount of time the patient is waiting to see a medical professional. This is clearly a problem faced by health care providers all over the world. Studies from Taiwan (Huarng & Lee, 1996) to Brazil (Coelli, Ferreira, Almeida & Pereira, 2007) and even Singapore (Shim & Kumar, 2010) have been shown to utilize discrete-event simulation to decrease patient wait times. This is because discrete event simulation models provide insight into the complex relationship between patient acuity, treatment, and occurrence of queues and bottlenecks in the transfer of patients between the emergency departments and hospital wards (Pirolo et al., 2009). Several simulation studies have also been performed to analyze the performance of hospitals in crisis or natural disaster situations.

Several methods have been developed in order to achieve decreased wait times. One such method is to simulate the system with different numbers of resources and evaluate how the

addition of personnel impacts the system. Hung, et al. (2007) found that the addition of a hospital volunteer and an extra physician to a shift could reduce the average length of stay per patient in a pediatric hospital by 19% and 20% respectively. This approach can also be applied to the addition of workstations such as more medical equipment or reception areas. Another common method of improving the patient wait time is to manipulate the patient arrival schedule in order to determine the most optimum setting for the given hospital or medical clinic. Boxerman's study (1996) outlines a detailed analysis of optimal patient scheduling.

Hospitals also have a variety of other systems that need to run in order for the patients to receive quality service in a timely manner. Once such system is the delivery method in which patients' test samples are couriered to the medical laboratory.

In past years, the samples were delivered via a carrier, but more and more hospitals are using pneumatic tube systems as the preferred method of material handling. There are over 3,000 pneumatic tube systems installed in hospitals in the United States alone. These systems are costly and the importance of analyzing these systems is important. Isken and Littig (2002) offer a prime example on the use of simulation to analyze a pneumatic tube delivery system. Their study allows for the hospital to become aware of how the system can perform under a variety of conditions and provides for a method to discover optimal settings.

2.5 Data Collecting Methods

The data collected for a simulation is very important. The computer model gives results based on the data collected. If the results do not match the real life process with an acceptable degree of error, it is probable that the quality of data was substandard. It is up to the discretion of

the hospital manager and the model developers to determine what level of error is acceptable and still qualifies the model as valid. Clearly less error indicates a more accurate model.

There are several methods that have been used to collect data that have traditionally yielded acceptable results. The most reliable method is by direct observation. In direct observation an observer is present while the system or process is running in real time and records the different elements needed, the most common type of data recorded is arrival and duration times. Direct observation of a system also requires the most amount of time and man power depending on the number of observers needed. If the system for example is to be observed for eight hours then the observer must be present for the entire eight hours. This problem makes it difficult to directly observe the process.

It is not always possible to reallocate resources to collect the data. If it is not possible there may be alternatives to direct observation. Many modern medical facilities have good data tracking systems in which patient data is kept in computer repositories. The data collected varies by medical facility, but usually the number of patients entering the system can be obtained. Also, the check-in and checkout time may be available through the registration information. The Tan Tock Seng Hospital in Singapore uses radiofrequency identification (RF-ID) technology, which increases the accuracy of data on patients, particularly on their movements from one workstation to another (Shim & Kumar, 2010).

Finally, if the previous two methods discussed are not possible, the alternative is to meet with the medical professionals and staff who work in the system that is to be studied and obtain the statistics through their responses. Also, the researcher can refer to past literature on similar medical facilities (size and type) and use the methods used in those studies. There are many articles available on simulation studies performed in the medical industry. In most cases a

mixture of all three methods is used, some direct observation data is collected while the input from the medical staff is recorded. While in other studies the medical facilities' stored data is used in conjunction with staff surveys.

2.6 Model Verification

Model verification or validation is the foundation on which the model analysis can begin. Before changes can be made to the simulation model, it is a good practice to review the model with the medical administrator and medical staff to ensure the model represents the work and workflow of the actual system. Once the model has been verified for completeness, the current state (pre improvement/modification) must first be checked for accuracy. The resulting output data must match the data from the real life system. If the data does not match then the results from the simulation are not reliable. When validating the model, it is necessary to use formal statistical practices, in general at least 30 iterations are needed to get valid data. A simulation study performed by Huarng and Lee (1996) validated the model with 1,000 iterations and compared the average number of patients served, the model resulted in only a 0.6% error. Table II-1 shows the values obtained in the study.

Table II-1: Huarng and Lee Study: Model Validation Results (1996).

Average Patients Served	
Simulation	Actual
333	335
Percent Error	**0.60%**

2.7 Failure States in Medical Simulations

Failures in a simulation environment occur when a resource is not available to perform the assigned duties or work. In a manufacturing environment failures are common place and the addition of failures in a simulation model is also common place; however, an application of failure states to a medical study is not known. If the hospital or medical clinics are to continue to improve their facilities, it becomes apparent that more robust simulation models can result in more reliable results. It is important to note that one study conducted by Espinosa, et al. (2004) suggested the inclusion of failure modes as a follow up to the simulation model to address the impacts of failures in the process.

2.8 Simulation of a Medical Laboratory

The ultimate goal of any hospital is to deliver quality care to its patients in a timely manner. All simulations in the literature survey focus on these aspects and rightly so. However, the triage and examination areas are not the only departments of the hospital. The medical laboratory is responsible for receiving and testing patients' specimen samples. Without the medical laboratory the doctor would not be able to detect and diagnose many illnesses and deficiencies. Many times patients and medical physicians are waiting for results to arrive before they can assess the patients' condition. Since the medical laboratory is a critical component in achieving the hospital administrator's goals, it should then follow that more studies need to be performed on the medical laboratory in order to improve hospital performance.

One study performed by Couchman, Jones, and Griffiths (2002) realized the importance of analyzing the medical laboratory. This study was conducted at the Ysbyty Gwyneed General Hospital in Whales, UK. Although there are several similarities between the Couchman et al.

study and the research reported in this thesis, there are still several key differences. For instance, in Couchman's study the sample arrival time distribution is only estimated to be a negative exponential distribution and a Gamma distribution. In the current study the sample arrival time is derived from direct observation and a cumulative distribution function is calculated to generate the arrivals in the simulation model. Also, in the Couchman et al. study the medical lab proposed the addition of an automated system that would automatically send samples to various test machines and then store the samples. The results can then be analyzed and sent to the physician. The Doctors Hospital at Renaissance medical laboratory has been recently equipped with an automated conveyor system. In Couchman et al. study the medical laboratory is not yet equipped with the automated system; whereas, the current study is a post automation study. The Doctors Hospital at Renaissance experiences a higher volume of samples, but the results from this study can still be useful to any medical laboratory.

The following chapter discusses the methods used to collect the data. The distributions for each activity are also defined. The model constructed in Arena is also explained and related to the data as well as the actual process.

Chapter III

Data Collection and Model Construction

The medical laboratory processing station involves multiple actions which are modeled with the Arena software to simulate processor activity. These activities are best understood through groupings of modules that replicate actual laboratory actions. For example, the separation of specimens from bags of specimens is undertaken by several Arena modules that include a separate module, an assign module, and a decide module. Therefore, it makes sense to group these modules together as the overall laboratory model is explained. Due to the number of modules, the overall model is relatively small scale, but an overview of the entire model is shown in Figure III-1.

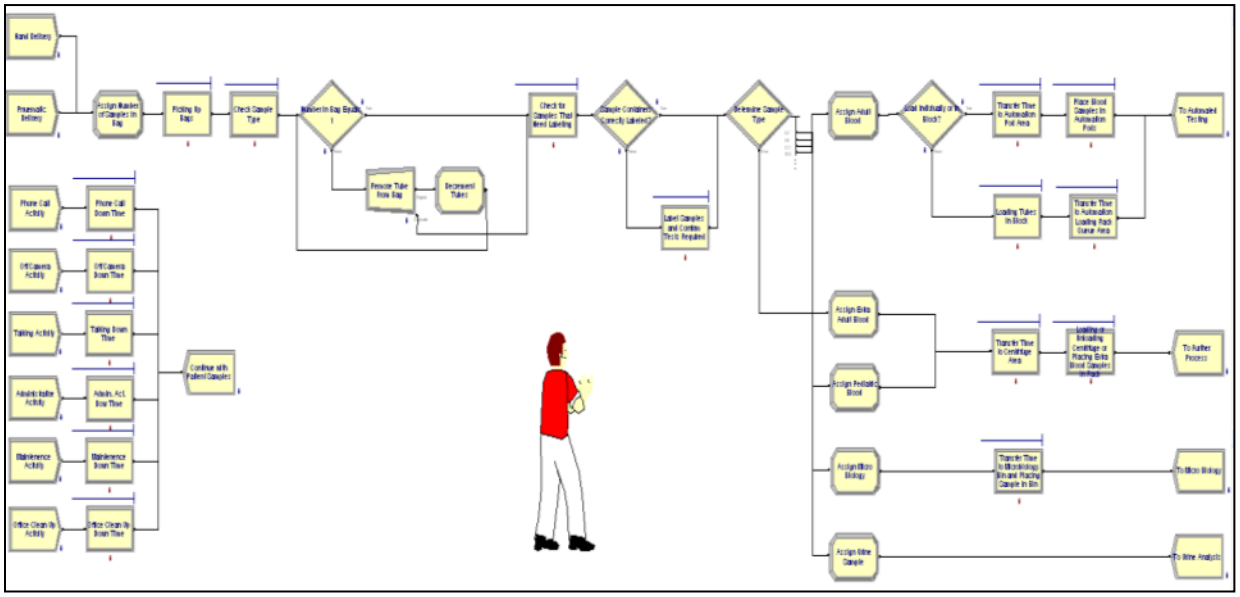

Figure III-1: Overview of the Entire Arena Model.

First among the groupings of modules are the first five modules which represent the arrival and acquisition of bags containing laboratory specimens. This group of modules is shown in Figure III-2. This grouping contains two create modules, an assign module, and two process modules.

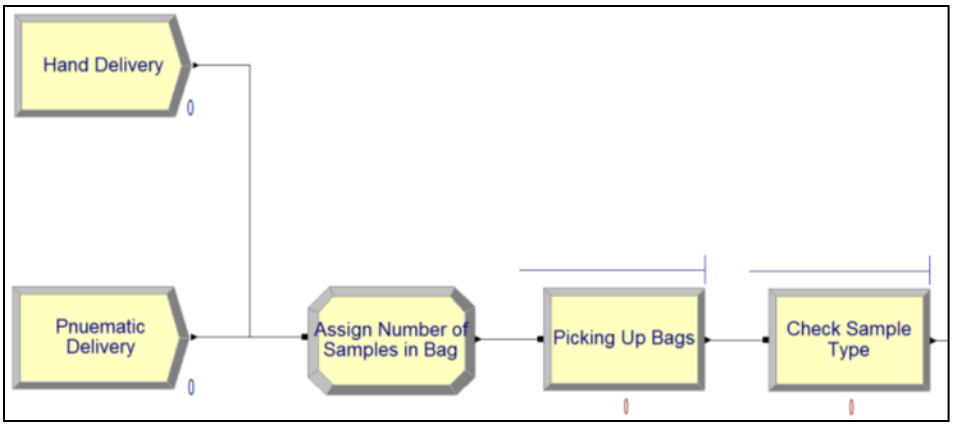

Figure III-2: First Group of Arena Modules.

3.1 Sample Arrival – Create Modules

The samples arrive in the medical laboratory in two ways: walk–ins and via a pneumatic tube delivery system. The walk-in method is when a phlebotomist or nurse delivers the samples to the medical laboratory. The pneumatic tube delivery system is the more common method of specimen delivery at Doctors Hospital at Renaissance (DHR), the hospital under study. The pneumatic tube system is a network of miles of pipe ending in stations within an area of a hospital. The carriers (tubes) travel through the pipe propelled by air. Each area of the hospital to be served by the tube system contains one or more stations that provide the mechanism for sending and receiving carriers (Isken et al., 2002). Samples arrive in small plastic bags along with a form, the form and the specimens are given a laboratory number, and are placed on the

samples with a sticker which has a barcode that can be scanned. This approach allows laboratory machines, computers and staff to know what tests are pending on which samples, and also gives a place (such as a hospital department, doctor or other customer) for results to be electronically transmitted. The tubes can arrive with multiple bags and in turn the bags can have multiple samples.

The system begins with two create modules to simulate the arrival methods. The create module labeled *Hand Delivery* describes the arriving characteristics of the patient samples walked in to the laboratory, while the create module labeled *Pneumatic Delivery* defines the arriving characteristics of the patient samples which are delivered by the pneumatic system. The create module allows the user to input the time between arrivals as well as the entities per arrival. The time between arrivals is determined by direct observation and the distribution is extracted from the direct observation data. For the entities per arrival, the number of bags that are hand delivered or that are brought in by the pneumatic tubes is also collected by direct observation. The data is then converted into a cumulative distribution function (CDF) and entered into the software as a discrete CDF expression.

Table III-1 indicates the output summary of the Input Analyzer (the software used to extract the distribution data.) An empirical distribution is used because based on the results there is not a distribution that properly fits the data. The output summary lists the intervals in the CDF function. Figure III-3 shows the CDF distribution graphically, while Table III-2 shows the CDF calculations for the hand delivery inter arrival time. The CDF expression for the inter arrival time is: CONT (0, 0.5, 0.4795, 8.5, 0.6918, 16.5, 0.7945, 24.5, 0.8904, 32.5, 0.9452, 40.5, 0.9795, 48.5, 1, 56.5). CONT in Arena provides for the direct input of a continuous CDF. The CDF expression for the number of bags per hand delivery arrival is: DISC (0.6770, 1, 0.8385, 2,

0.9006, 3, 0.9130, 4, 0.9317, 5, 0.9565, 7, 0.9752, 8, 0.9814, 9, 0.9876, 10, 0.9938, 11, 1, 12), DISC in Arena, provides for the direct input of a discrete CDF. Figure III-4 illustrates the CDF graphically and Table III-3 contains the CDF calculations.

Table III-1: Hand Delivery Inter Arrival Distribution Summary.

```
        Distribution Summary

Distribution:   Empirical
Expression:     CONT or DISC (0.000,  0.500,
                              0.479,  8.500,
                              0.719, 16.500,
                              0.795, 24.500,
                              0.890, 32.500,
                              0.945, 40.500,
                              0.979, 48.500,
                              0.979, 56.500)


        Data Summary

Number of Data Points   = 146
Min Data Value          = 1
Max Data Value          = 56
Sample Mean             = 13.6
Sample Std Dev          = 13.1

        Histogram Summary

Histogram Range         = 0.5 to 56.5
Number of Intervals     = 7
```

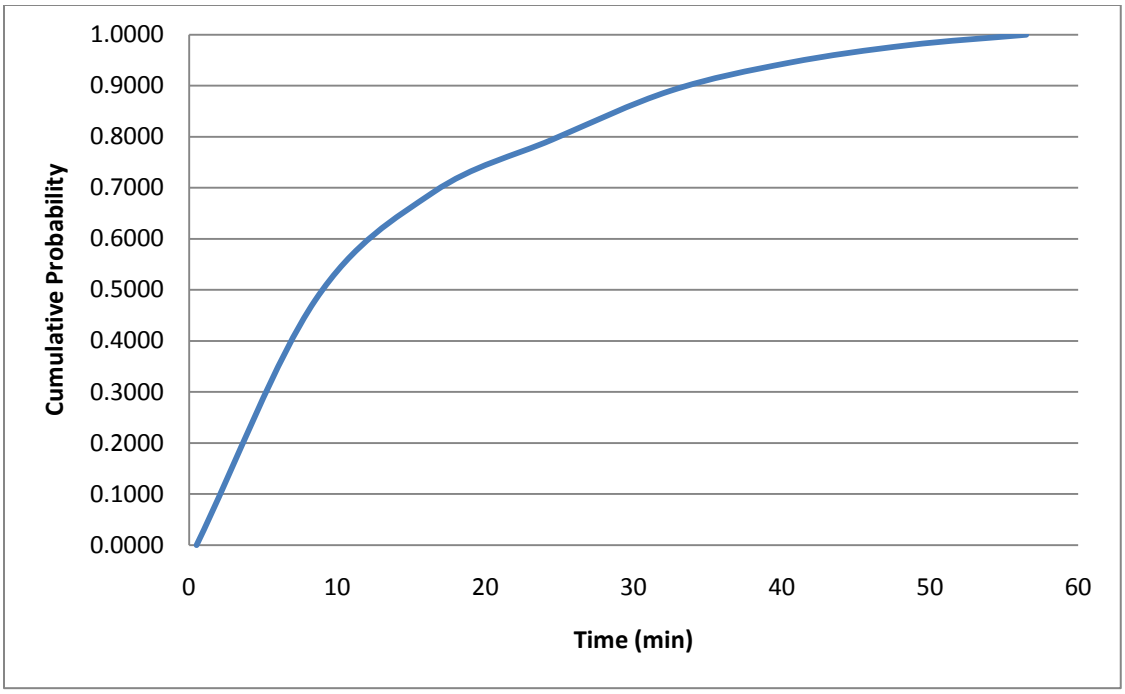

Figure III-3: Hand Delivery Inter Arrival Time - CDF.

Table III-2: Hand Delivery Inter Arrival - CDF Calculations.

Hand Delivery - Inter Arrival Time - CDF			
146	Total Data Points		
Data Points	Time Intervals	Probability	Cumulative Probability
0	0.5	0.0000	0.0000
70	8.5	0.4795	0.4795
31	16.5	0.2123	0.6918
15	24.5	0.1027	0.7945
14	32.5	0.0959	0.8904
8	40.5	0.0548	0.9452
5	48.5	0.0342	0.9795
3	56.5	0.0205	1.0000

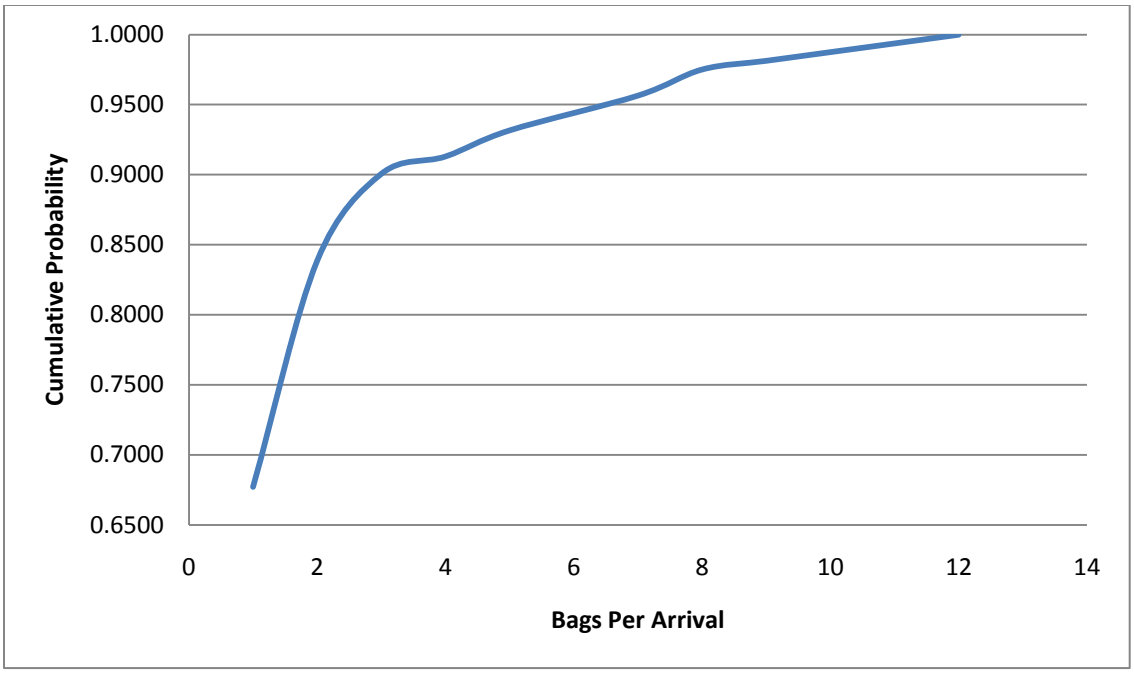

Figure III-4: Hand Delivery CDF for Bags per Arrival.

Table III-3: Hand Delivery Bags per Arrival CDF Calculations.

Data Points Observed	Observed Data	Probability	Cumulative Probability
109	1 Bag Per Arrival	0.6770	0.6770
26	2 Bags Per Arrival	0.1615	0.8385
10	3 Bags Per Arrival	0.0621	0.9006
2	4 Bags Per Arrival	0.0124	0.9130
3	5 Bags Per Arrival	0.0186	0.9317
4	7 Bags Per Arrival	0.0248	0.9565
3	8 Bags Per Arrival	0.0186	0.9752
1	9 Bags Per Arrival	0.0062	0.9814
1	10 Bags Per Arrival	0.0062	0.9876
1	11 Bags Per Arrival	0.0062	0.9938
1	12 Bags Per Arrival	0.0062	1.0000

Figure III-5 indicates the graphical distribution for the time between arrivals for the pneumatic delivery method, while Table III-4 lists the results of the distribution analysis. The expression for the distribution is: 0.5 + EXPO (4.43), where EXPO allows for the direct input of an exponential distribution function in Arena. There are a total of 577 data points observed for this distribution. The CDF expression for the number of bags by pneumatic delivery is: DISC (0.6627, 1, 0.8254, 2, 0.8847, 3, 0.9305, 4, 0.9458, 5, 0.9661, 6, 0.9814, 7, 0.9881, 8, 0.9898, 9, 0.9949, 11, 0.9966, 13, 0.9983, 16, 1, 17). Figure III-6 illustrates the CDF graphically and Table III-5 contains the CDF calculations.

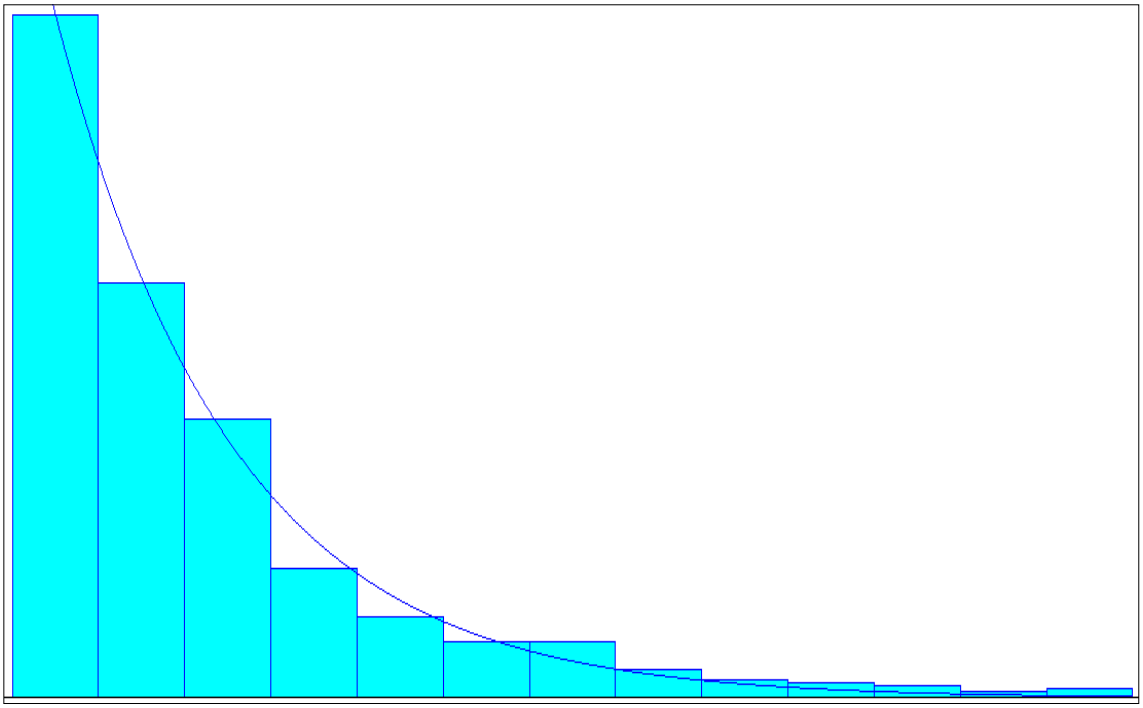

Figure III-5: Pneumatic Delivery Sample Arrival Data – Inter Arrival Distribution.

Table III-4: Pneumatic Delivery Sample Arrival - Distribution Summary.

```
        Distribution Summary

Distribution:    Exponential
Expression:      0.5 + EXPO(4.43)
Square Error:    0.001163

Chi Square Test
  Number of intervals   = 8
  Degrees of freedom    = 6
  Test Statistic        = 8.8
  Corresponding p-value = 0.199

        Data Summary

Number of Data Points   = 577
Min Data Value          = 1
Max Data Value          = 28
Sample Mean             = 4.93
Sample Std Dev          = 4.62

        Histogram Summary

Histogram Range         = 0.5 to 28.5
Number of Intervals     = 13
```

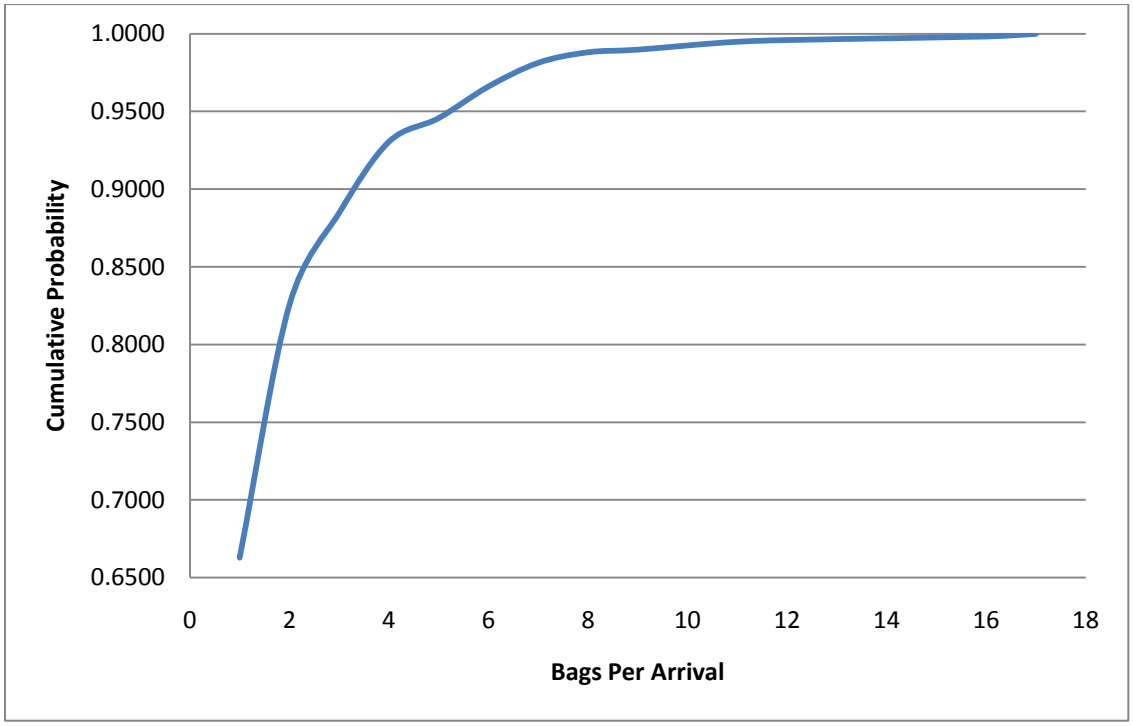

Figure III-6: Pneumatic Delivery CDF for Bags per Arrival.

Table III-5: Pneumatic Delivery Bags per Arrival CDF Calculations.

Data Points Observed	Observed Data	Probability	Cumulative Probability
391	1 Bag Per Arrival	0.6627	0.6627
96	2 Bags Per Arrival	0.1627	0.8254
35	3 Bags Per Arrival	0.0593	0.8847
27	4 Bags Per Arrival	0.0458	0.9305
9	5 Bags Per Arrival	0.0153	0.9458
12	6 Bags Per Arrival	0.0203	0.9661
9	7 Bags Per Arrival	0.0153	0.9814
4	8 Bags Per Arrival	0.0068	0.9881
1	9 Bags Per Arrival	0.0017	0.9898
3	11 Bags Per Arrival	0.0051	0.9949
1	13 Bags Per Arrival	0.0017	0.9966
1	16 Bags Per Arrival	0.0017	0.9983
1	17 Bags Per Arrival	0.0017	1.0000

3.2 Assign Number of Samples in Bag – Assign Module

The assign module allows for the assignment of new values to variables, entity attributes, entity types, entity pictures or other system variables. The assign module is labeled *Assign Number of Samples in Bag*. In this particular case the assignment type is an attribute assignment. The attribute name is *Number_in_Bag*, and the value given to this attribute is a discrete CDF expression. The purpose for this assign module is to separate the sample specimens from the arriving bags, recall that the CDF's in the create modules represent the number of bags arriving, in this assignment the number of specimen samples in each bag is identified through the CDF expression. The expression is: DISC (0.4829, 1, 0.6620, 2, 0.7991, 3, 0.8692, 4, 0.9283, 5, 0.9455, 6, 0.9533, 7, 0.9595, 8, 0.9642, 9, 0.9688, 10, 0.9720, 11, 0.9751, 12, 0.9766, 13, 0.9798, 14, 0.9813, 15, 0.9844, 16, 0.9875, 19, 0.9907, 20, 0.9938, 21, 0.9953, 22, 0.9969, 23, 0.9984, 29, 1, 33). Table III-6 contains the CDF calculations and Figure III-7 illustrates the CDF graphically. The CDF is calculated through data points obtained through direct observation.

Table III-6: Specimen Samples per Bag CDF Calculations.

Data Points Observed	Observed Data	Probability	Cumulative Probability
310	1	0.4829	0.4829
115	2	0.1791	0.6620
88	3	0.1371	0.7991
45	4	0.0701	0.8692
38	5	0.0592	0.9283
11	6	0.0171	0.9455
5	7	0.0078	0.9533
4	8	0.0062	0.9595
3	9	0.0047	0.9642
3	10	0.0047	0.9688
2	11	0.0031	0.9720
2	12	0.0031	0.9751
1	13	0.0016	0.9766
2	14	0.0031	0.9798
1	15	0.0016	0.9813
2	16	0.0031	0.9844
2	19	0.0031	0.9875
2	20	0.0031	0.9907
2	21	0.0031	0.9938
1	22	0.0016	0.9953
1	23	0.0016	0.9969
1	29	0.0016	0.9984
1	33	0.0016	1.0000

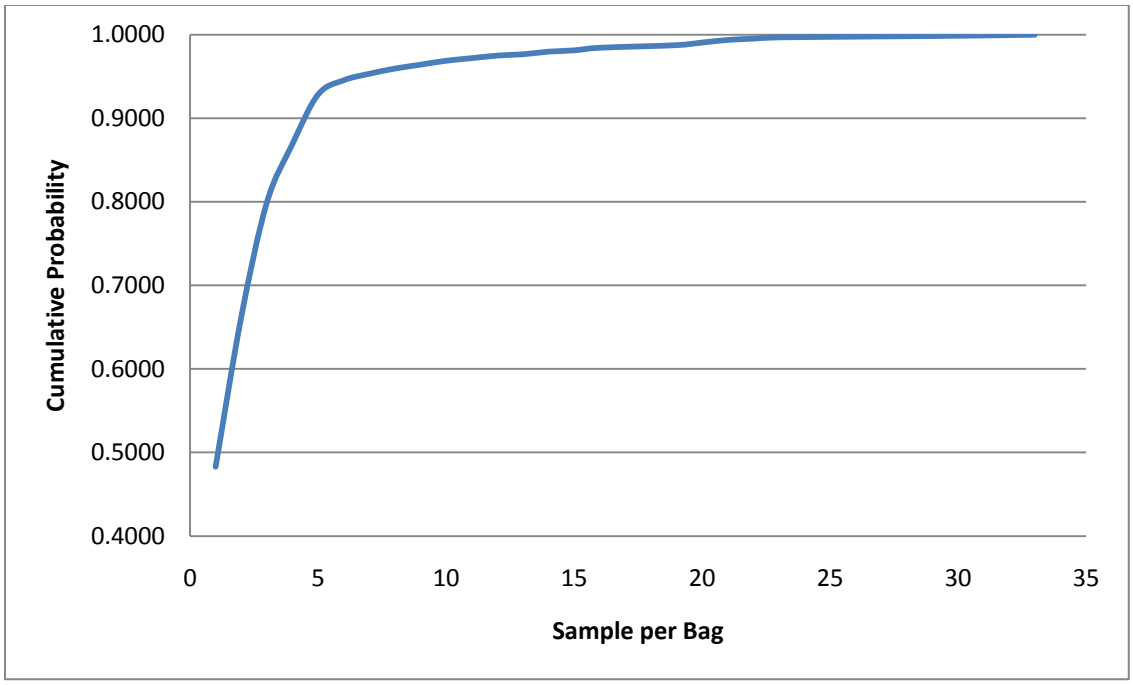

Figure III-7: Specimen Samples per Bag CDF.

3.3 Picking Up Bags – Process Module

Once the bags arrive via the pneumatic delivery system, the processor must recover the bags and remove the bags from the pneumatic carrier or accept them from the person carrying the bag(s). The process module labeled *Picking Up Bags* models the actions of picking up the bags from the tube holding station or person and then separating the actual bags from the pneumatic carrier. The process module allows the user to model any process; the first step is to select the type of action the resource(s) undergo. The type of action used is seize delay release. This indicates that entities seize some number of units of a resource(s) (after a possible wait in queue), then delay for a time representing the service time, and then release unit(s) of the resource so that other entities can seize it (Kelton, et al. 2008). Next resources are added. Each resource added indicates that there are X number of resources needed to perform that task. This

does not mean that there are X number of resources available. The resource for this module requires one processor. This means that it takes one processor to complete the work in this particular module. The final step is to include the expression for the delay (work being performed).

The data observed for the duration of picking up bags does not fit any distribution, so an empirical distribution (CDF) is used. The CDF expression is: CONT (0,.5, 0.0917,6.5, 0.4321,12.5, 0.6755,18.5, 0.7901,24.5, 0.8713,30.5, 0.9030,36.5, 0.9383,42.5, 0.9594,48.5, 0.9753,54.5, 0.9841,60.5, 0.9877,66.5, 1,75.5). Table III-7 depicts the intervals in the CDF. Figure III-8 shows the CDF distribution, while Table III-8 shows the calculations for the duration time CDF. The time units are in seconds and the work is classified as value added.

Table III-7: Picking Up Bags Duration Time CDF Intervals.

```
        Distribution Summary

Distribution:   Empirical
Expression:     CONT or DISC (0.000,  0.500,
                              0.092,  6.500,
                              0.432, 12.500,
                              0.675, 18.500,
                              0.790, 24.500,
                              0.871, 30.500,
                              0.903, 36.500,
                              0.938, 42.500,
                              0.959, 48.500,
                              0.975, 54.500,
                              0.984, 60.500,
                              0.988, 66.500,
                              0.988, 75.500)


        Data Summary

Number of Data Points   = 567
Min Data Value          = 1
Max Data Value          = 75
Sample Mean             = 17.8
Sample Std Dev          = 12.8

        Histogram Summary

Histogram Range         = 0.5 to 75.5
Number of Intervals     = 12
```

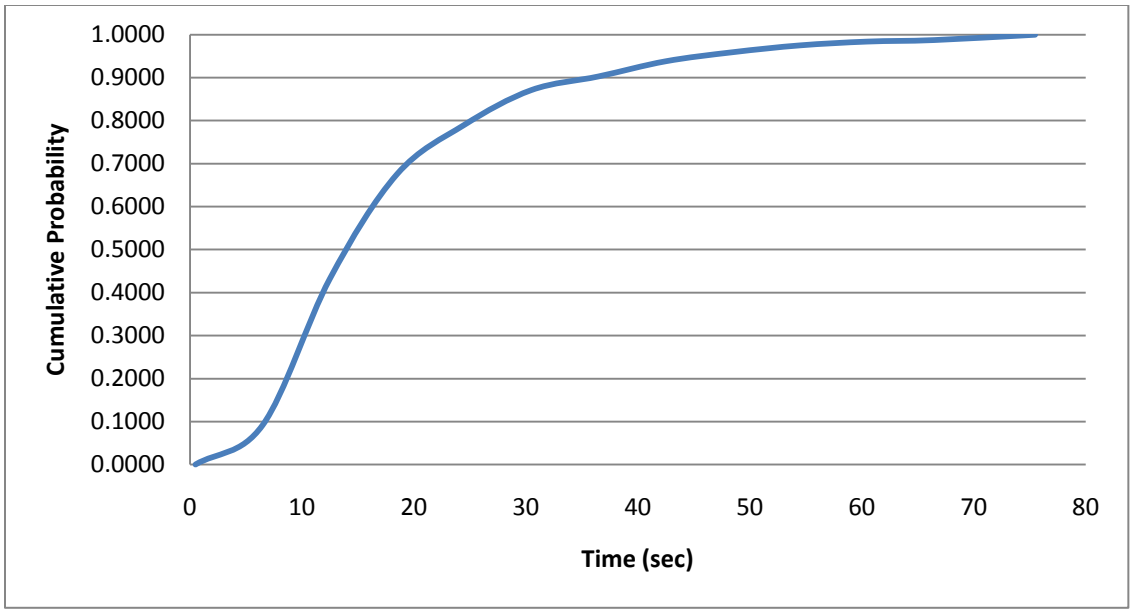

Figure III-8: Picking Up Bags Duration Time CDF.

Table III-8: Picking Up Bags Duration Time CDF Calculations.

Picking Up Bags - Duration Time - CDF			
567	Total Data Points		
Data Points	Time Intervals	Probability	Cumulative Probability
0	0.5	0.0000	0.0000
52	6.5	0.0917	0.0917
193	12.5	0.3404	0.4321
138	18.5	0.2434	0.6755
65	24.5	0.1146	0.7901
46	30.5	0.0811	0.8713
18	36.5	0.0317	0.9030
20	42.5	0.0353	0.9383
12	48.5	0.0212	0.9594
9	54.5	0.0159	0.9753
5	60.5	0.0088	0.9841
2	66.5	0.0035	0.9877
7	75.5	0.0123	1.0000

3.4 Check Sample Type – Process Module

After the bags are placed into the holding bins the bags are emptied while empting the bags the processor checks each patient sample to identify the specific sample type. The five sample types handled in the laboratory is covered later in this thesis. The expression for the duration time is: UNIF (0.5, 2.5), where UNIF allows for the direct input of a uniform distribution function in Arena. There is a total of 617 data points observed for this distribution. The time units are in seconds and the work is classified as value added. Figure III-9 shows the duration time distribution graphically, and Table III-9 shows the distribution results.

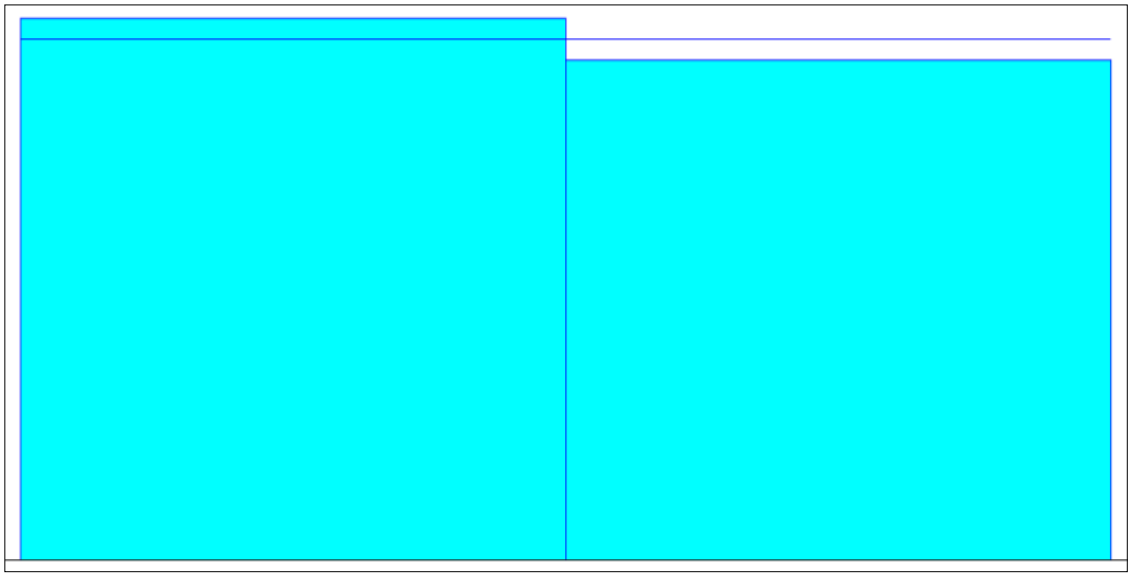

Figure III-9: Checking Sample Type - Duration Distribution.

Table III-9: Checking Sample Type - Duration Dist. Summary.

```
        Distribution Summary

Distribution:   Uniform
Expression:     UNIF(0.5, 2.5)
Square Error:   0.000821

Chi Square Test
  Number of intervals   = 2
  Degrees of freedom    = 1
  Test Statistic        = 1.01
  Corresponding p-value = 0.339

        Data Summary

Number of Data Points   = 617
Min Data Value          = 1
Max Data Value          = 2
Sample Mean             = 1.48
Sample Std Dev          = 0.5

        Histogram Summary

Histogram Range         = 0.5 to 2.5
Number of Intervals     = 2
```

As another group of modules that simulate laboratory activity, the separate, assign, and decide modules represent the removal of specimens from bags. These modules work together to model the removal of specimens from the bags in which those specimens are transported. Essentially, the attribute of number of tubes in the bag is used as a counter, and one tube at a time is removed from the bag until the bag is empty. In the Arena modeling paradigm, the number of tubes in the bag is an attribute for the bag. For these tubes, an entity is duplicated to show tube removal, and the number of tubes in the bag is decremented in an assign module. This removal and decrement process continues until there is only one tube left which is then removed from the bag. The process module represents the processor checking a sample to see if it needs to be labeled or relabeled. The Arena modules for this activity are shown in the second group as Figure III-10.

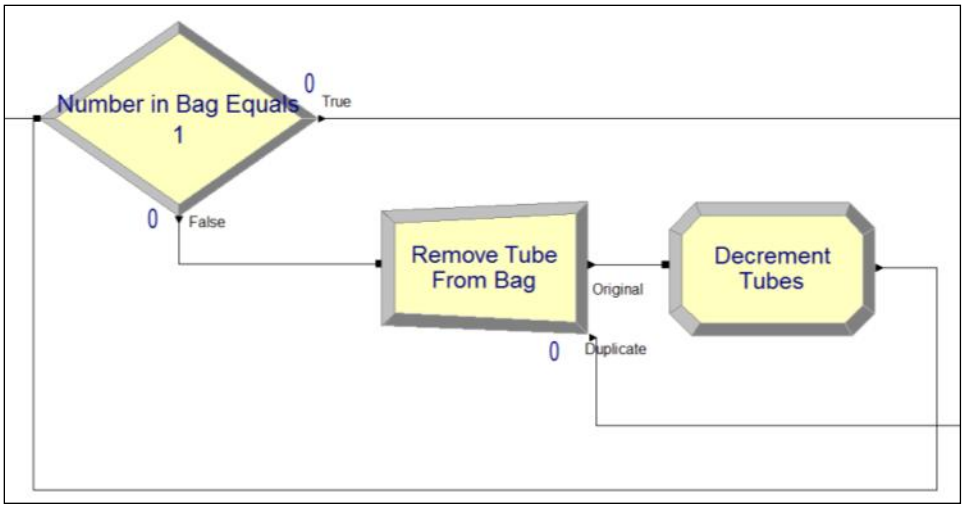

Figure III-10: Second Group of Arena Modules.

3.5 Number In Bag Equals 1 – Decide Module

This particular decide module allows the simulation model to determine when the number of specimen samples in the bag is equal to one. When this lower limit occurs in the model, the decide module terminates the "loop." Once terminated, the process then allows for another bag to enter the separate module where the whole process begins again until there are no more bags arriving into the system.

The decide module is labeled: *Number In Bag Equals1*. The decide type is: 2-way by condition, the condition states that: if the attribute named *Number_In_Bag* is equal to the value of one then it signals a true condition and the loop is terminated, if the condition is not met then the loop continues and another tube is generated by the separate module.

3.6 Remove Tube from Bag – Separate Module

Once the bags are removed from the pneumatic carrier or delivered by an individual to the processors, the bags are emptied to obtain the one or more samples found in the bag. To accomplish this in Arena a separate module is employed. The separate module is used to split a previously batched entity. In the simulation model, separation represents the separating of the bag entities into single specimen sample entities. The separate module also serves as a starting point for a loop created to determine when all of the samples in a bag are taken out and made ready for further processing. The separate module type is: duplicate original. This means when duplicating entities the specified number of copies is made and sent from the module. The original incoming entity also leaves the module. There is also a percent cost to duplicates, this means that percentage of the original entities' time and cost value is allocated evenly to the number of duplicates specified.

The separate module label is: *Remove Tubes from Bag*. The type as specified is duplicate original. The number of duplicates selected for the model is one. So for every entity entering the separate module, one is also created. The percent cost to duplicate is 50%, so both the original and the duplicate entity both share a half of the time and cost value.

3.7 Decrement Tubes – Assign Module

This assign module allows for the model to count down the total number of tubes left in the bag. Every time an entity passes through the assign module the number of specimen samples inside a bag decreases by one The assign module is labeled: *Decrement Tubes*. The assign type is an attribute and the attribute name is: *Number_In_Bag*. Finally, the value given is Number_In_Bag – 1.

As another discrete activity undertaken in the laboratory, the processors must check the samples to see if they are labeled properly. A percentage of bags are not labeled correctly and must be labeled properly. To account for this activity, another group of Arena modules is used as shown in Figure III-11.

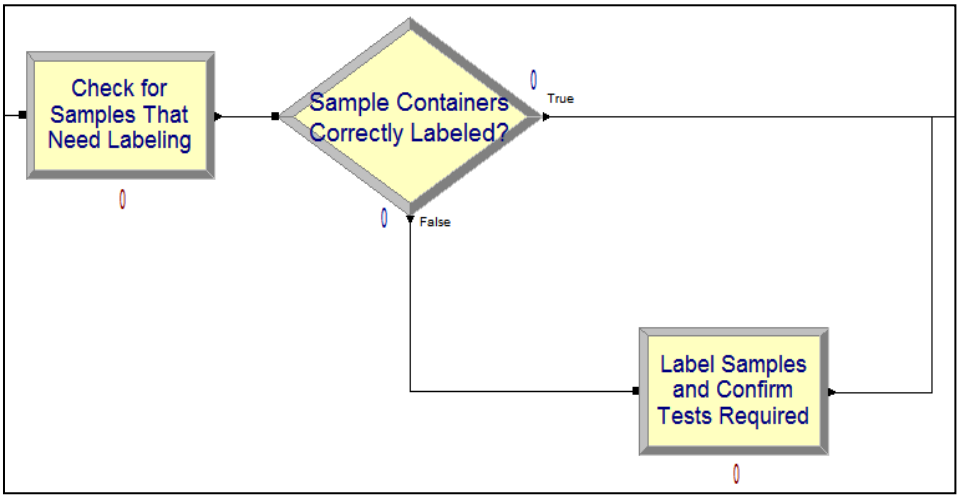

Figure III-11: Third Group of Arena Modules.

3.8 Check for Samples That Need Labeling – Process Module

The process module labeled "*Check for Samples That Need Labeling*" simulates the action of checking the samples to determine which samples need labeling or relabeling. The duration time expression is: UNIF (0.5, 2.5). There is a total of 617 data points observed. The time units are in seconds and the work is classified as value added. Figure III-12 displays the duration time distribution graphically, while Table III-10 shows the duration time distribution results.

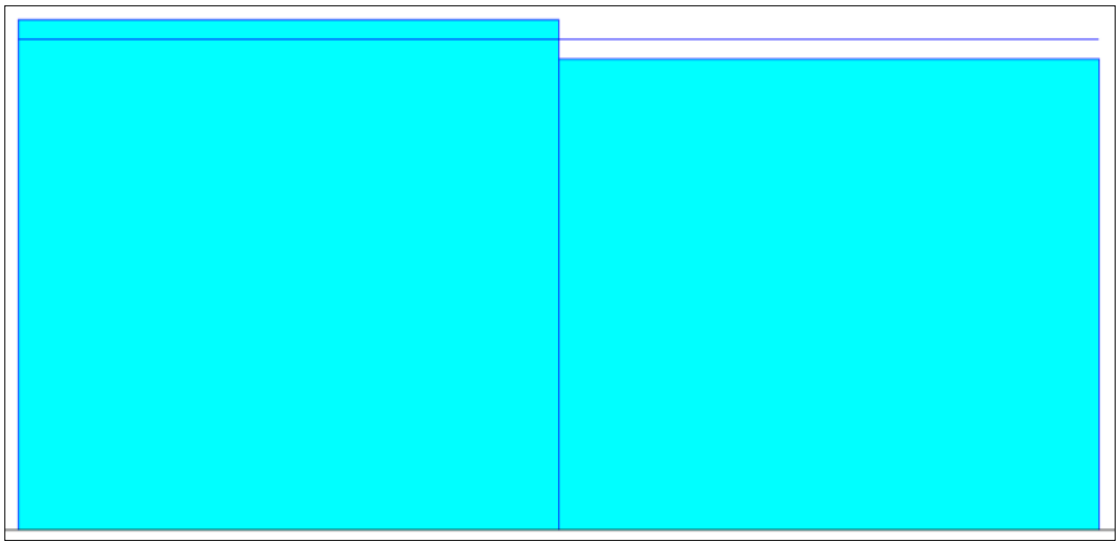

Figure III-12: Checking Samples for Label - Duration Distribution.

Table III-10 : Checking Samples for Label - Duration Dist. Summary.

```
        Distribution Summary

Distribution:   Uniform
Expression:     UNIF(0.5, 2.5)
Square Error:   0.000821

Chi Square Test
  Number of intervals   = 2
  Degrees of freedom    = 1
  Test Statistic        = 1.01
  Corresponding p-value = 0.339

        Data Summary

Number of Data Points   = 617
Min Data Value          = 1
Max Data Value          = 2
Sample Mean             = 1.48
Sample Std Dev          = 0.5

        Histogram Summary

Histogram Range         = 0.5 to 2.5
Number of Intervals     = 2
```

3.9 Sample Containers Correctly Labeled – Decide Module

There is a certain percentage of the total number of specimen samples that arrive in the medical laboratory that need to be labeled or relabeled. The decide module allows for decision making processes in the system. The decision can be made based on one or more conditions, or for modeling purposes, on one or more probabilities. Furthermore, conditions can be based on attribute values, variable values, the entity type or an expression.

The decide type utilized for the *Sample Containers Correctly Labeled* decide module is the "2 Way By Chance" option. The percent true value used in this case is 86.5%. This means that 86.5% of the time the specimens were labeled correctly, while only 13.5% of the time the specimens need to be relabeled. The percentage values are obtained by observing the average daily total of samples processed and by the average daily number of times the samples were relabeled. Table III-11 specifies the numbers used to calculate the percentage values.

Table III-11: Tubes or Test Containers Correctly Labeled - Decide Module Data.

Average Daily Total of Specimens Delivered to Medical Lab	464
Average Daily Total of Specimens Labeled in Medical Lab	62.8
Percentage of Labeled Specimen Samples	13.5%

3.10 Label Samples and Confirm Tests Required – Process Module

Once the processor has identified and sorted which particular samples need to be labeled or relabeled the processor looks up the patient information using the accompanying information sheet and inputs the information into the computer which is networked throughout the hospital. If the proper information cannot be found, the processor calls the department in which the

specimen sample originated to obtain the correct information. Once the correct data has been entered the processor prints out and places the new labels on the specimen sample. Now it is ready to be delivered to its proper destination.

The process module labeled *Label Samples and Confirm Tests Required* models the action of placing a label with the correct data onto the specimen samples. The action chosen for this process module is seize delay release. The resource employed in this module is one or two processor(s). The data observed does not fit any distribution so an empirical distribution (CDF) is used for the duration time. The CDF expression is: CONT (0,1.9, 0.0391,8.3, 0.1418,14.6, 0.2616,20, 0.3667,27.3, 0.4466,33.6, 0.5526,40, 0.6015,46.3, 0.6430,52.6, 0.7074,59, 0.7612,65.3, 0.7995,71.6, 0.8468,78, 0.8720,84.3, 0.9087,90.6, 0.9381,97, 0.9625,103.3, 0.9813,109.6, 1,116). Table III-12 shows the time intervals used for the CDF. There are a total of 1,227 data points observed. Figure III-13 displays the CDF graphically, while Table III-13 depicts the CDF calculations.

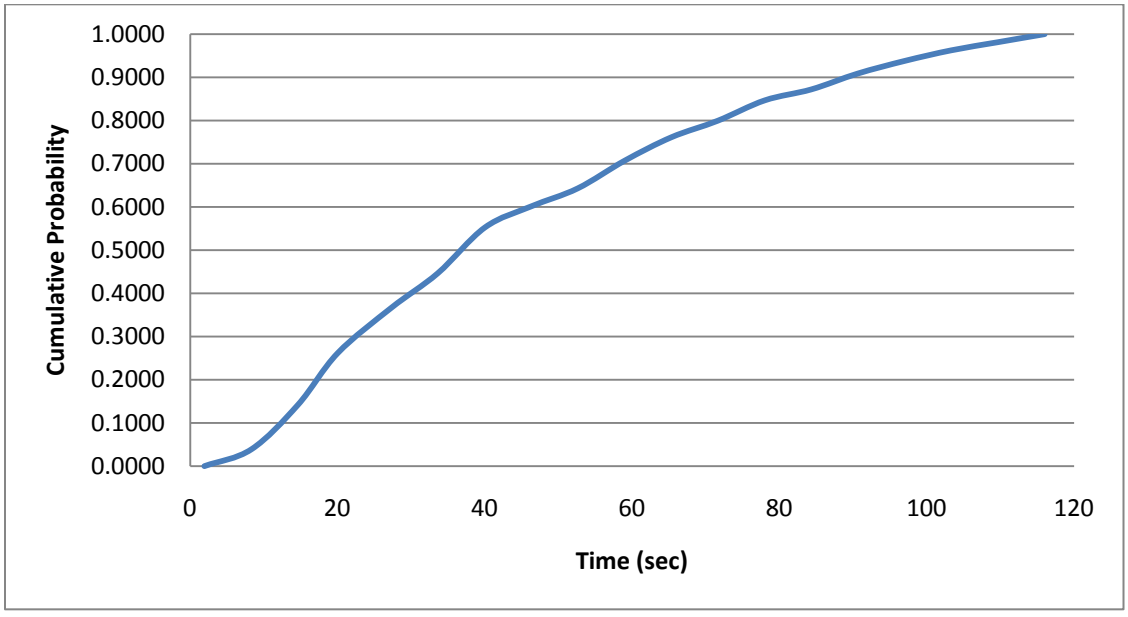

Figure III-13: Labeling Samples Duration Time CDF.

Table III-12: Labeling Samples Duration Time CDF Time Intervals.

```
        Distribution Summary

Distribution:   Empirical
Expression:     CONT or DISC (0.000,  1.999,
                              0.039,  8.332,
                              0.142, 14.666,
                              0.262, 20.999,
                              0.367, 27.333,
                              0.447, 33.666,
                              0.534, 40.000,
                              0.601, 46.333,
                              0.643, 52.667,
                              0.707, 59.000,
                              0.761, 65.333,
                              0.800, 71.667,
                              0.847, 78.000,
                              0.877, 84.334,
                              0.909, 90.667,
                              0.938, 97.001,
                              0.963, 103.334,
                              0.981, 109.668,
                              0.981, 116.001)


        Data Summary

Number of Data Points   = 1227
Min Data Value          = 2
Max Data Value          = 116
Sample Mean             = 44.2
Sample Std Dev          = 28.6

        Histogram Summary

Histogram Range         = 2 to 116
Number of Intervals     = 18
```

Table III-13: Labeling Samples Duration Time CDF Calculations.

Labeling Samples – Duration Time - CDF			
1227	Total Data Points		
Data Points	Time Intervals	Probability	Cumulative Probability
0	1.9	0.0000	0.0000
48	8.3	0.0391	0.0391
126	14.6	0.1027	0.1418
147	20	0.1198	0.2616
129	27.3	0.1051	0.3667
98	33.6	0.0799	0.4466
130	40	0.1059	0.5526
60	46.3	0.0489	0.6015
51	52.6	0.0416	0.6430
79	59	0.0644	0.7074
66	65.3	0.0538	0.7612
47	71.6	0.0383	0.7995
58	78	0.0473	0.8468
31	84.3	0.0253	0.8720
45	90.6	0.0367	0.9087
36	97	0.0293	0.9381
30	103.3	0.0244	0.9625
23	109.6	0.0187	0.9813
23	116	0.0187	1.0000

Once samples are all properly labeled, they must be segregated by sample type. This process is represented by a group of modules that include a decide module in which the type of sample is decided, and a set of assign modules that assign the entity type to the sample. Figure III-14 represents this group of Arena modules. The sorting procedure consists of grouping the specimen samples by type. A specific type of sample is sent to its appropriate area within the lab. For example, the hematology area works with whole blood to do complete blood counts, and blood films as well as many other specialized tests. As another example, the microbiology department receives almost any clinical specimen, including swabs, feces, urine, blood, sputum, cerebrospinal fluid, synovial fluid, as well as possible infected tissue. The work here is mainly concerned with cultures, to look for suspected pathogens which, if found, are further identified based on biochemical tests. There is no standard procedure for the microbiology department. As a result, most blood samples are placed into a open box container while the urine and other samples are grouped on the processors' table. After relabeling and sorting is completed the samples are then delivered to the appropriate areas for testing. It is the job of the processor to deliver the sample to the appropriate area for testing. All samples except the adult blood samples are walked over to the correct testing department, occasionally, a member of another testing department comes and collects the samples. The addition of an automated line allows the processor to place the adult blood samples on a conveyor system which sorts and sends the adult blood samples to the correct testing machine.

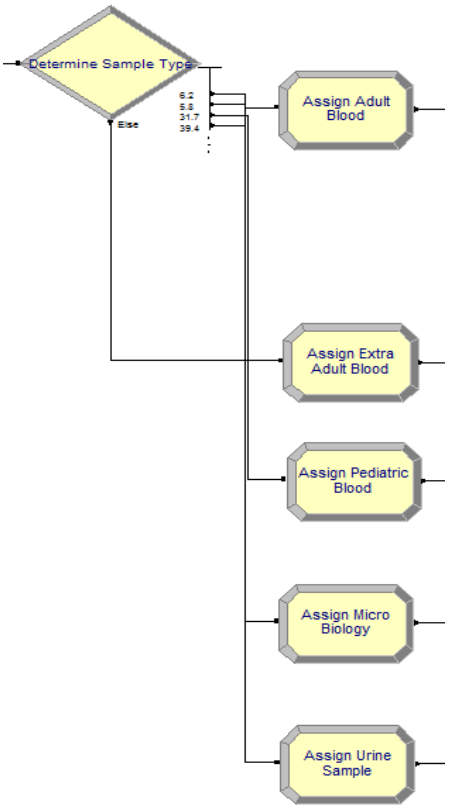

Figure III-14 : Fourth Group of Arena Modules.

3.11 Determine Sample Type – Decide Module

There are five classifications or types given to the specimen samples they are: urine samples, microbiology samples, pediatric blood samples, adult blood samples, and extra adult blood samples. The decide module labeled *Determine Sample Type* decides which specimen sample type is being processed and taken to its next destination within the medical laboratory. The decide type utilized for the *Decide Sample Type* decide module is the "N Way By Chance" option. This option allows for multiple probabilities (although the total probability must equal to 1.0 or 100%). The probabilities that are used can be found in Table III-14. The percentage values were calculated using the following steps:

I. Obtain the 30 day totals for the urine, microbiology, pediatric and adult blood samples from the hospital records. The extra adult blood samples are recorded from direct observation, but only for a period of 19 days.

II. Calculate the daily average of all the specimen sample types. The 30 day totals for the urine, microbiology, pediatric and adult samples are divided by 30. The 19 day total for the extra adult samples are divided by 19.

III. The daily averages for all specimen sample types are totaled (grand total).

IV. The individual daily total for each specimen sample type is divided by the grand total. This yields the daily percentage amount for each specimen sample type that are used in the decide module.

It is important to note that the results shown below are only for the peak hours of sample arrivals, the five hour observation period, from 4am to 9am. Therefore, this model represents a period of maximum activity by the processor(s).

Table III-14: Determine Sample Type – Decide Module Data.

Sample Type	**30 Day Total**	**Daily Average**	**Daily Percentage**
Total Urine Samples	604	20.13	**6.2%**
Total Microbiology Samples	565	18.83	**5.8%**
Total Pedi-Tube Samples	3108	103.60	**31.7%**
Total Adult Tube Samples	3864	128.80	**39.4%**
Total		271.37	
	19 Day Total		
Total Backup Adult Blood Samples	1062	55.89	**17.1%**
Total		55.89	
Grand Total		**327.26**	

3.12 Assigning Specific Patient Sample Type

This next section identifies the assign modules required to individually account for each type of patient sample. There are five types of patient samples that are assigned. They are:

I. Adult Blood Samples

II. Extra Adult Blood Samples

III. Pediatric Blood Samples

IV. Urine Samples

V. Microbiology Samples

3.12.1 Assign Adult Blood – Assign Module

Once a specimen sample entity passes through the *Decide Sample Type* decide module, the specimen type is determined through the associated probability. It is the function of the assign module to assign a new entity characteristic to the incoming specimen samples.

The assign module name is *Assign Adult Blood*, in this assign module there are two assignments defined. The first assignment type is entity picture in which a picture of a red ball is assigned to the adult blood specimen samples. When the simulation is run and an adult blood sample is present in the model it appears as a red ball. The second assignment type is entity type, and is defined as adult blood. This action is what allows the model to identify the specimen sample type that corresponds to the probability from the previously discussed decide module.

3.12.2 Assign Extra Adult Blood – Assign Module

The assign module name is *Assign Extra Adult Blood.* In this assign module there are also two assignments defined. The first assignment type is entity picture in which a picture of a red

ball is assigned to the adult blood specimen samples that are being placed in the backup storage rack. The picture of a red ball is again used for this sample type, because it is still an adult blood sample; however, this sample does not undergo testing and thus is classified as a different sample type in the simulation model. Once again, when the simulation is run and an adult blood sample that is designated to go into the storage rack is present in the model. It appears as a red ball. The second assignment type is entity type, and is also defined as adult blood. The difference here is that this sample is an extra and a different probability has been determined for these types of samples. This assign module is attached to the corresponding probability from the decide module.

3.12.3 Assign Pediatric Blood – Assign Module

The assign module name is *Assign Pediatric Blood*. In this assign module there are also two assignments defined. The first assignment type is entity picture in which a picture of a blue ball is assigned to the pediatric blood specimen. When the simulation is run and a pediatric blood sample is present in the model, it appears as a blue ball. The second assignment type is entity type, and is defined as child blood this is what allows the model to identify the specimen sample type that corresponds to the probability from the decide module named Decide Sample Type.

3.12.4 Assign Urine Sample – Assign Module

The assign module name is *Assign Urine Sample*. In this assign module there are also two assignments defined. The first assignment type is entity picture in which a picture of a green ball is assigned to the urine sample. When the simulation is run and urine sample is present in the model it appears as a green ball. The second assignment type is entity type, and is defined as

urine sample. This assignment is what allows the model to identify the specimen sample type as a urine sample that corresponds to the probability from the decide module.

3.12.5 Assign Micro Biology – Assign Module

The assign module name is *Assign Micro Biology*. In this assign module there are also two assignments defined. The first assignment type is entity picture in which a picture of a yellow ball is assigned to the micro-biology sample. When the simulation is run and micro biology sample is present in the model it appears as a yellow ball. The second assignment type is entity type, and is defined as micro-biology. This assignment allows the model to identify the specimen sample type that corresponds to the micro-biology specimen according to the probability from the decide module.

Following the assignment of the samples to the appropriate processes, the adult blood samples have to be loaded into the automation line. This loading processes is done either manually or using blocks with automation to load the tubes from the blocks into the conveyor system. The Arena modules used for modeling this activity falls into another group which is shown below as Figure III-15.

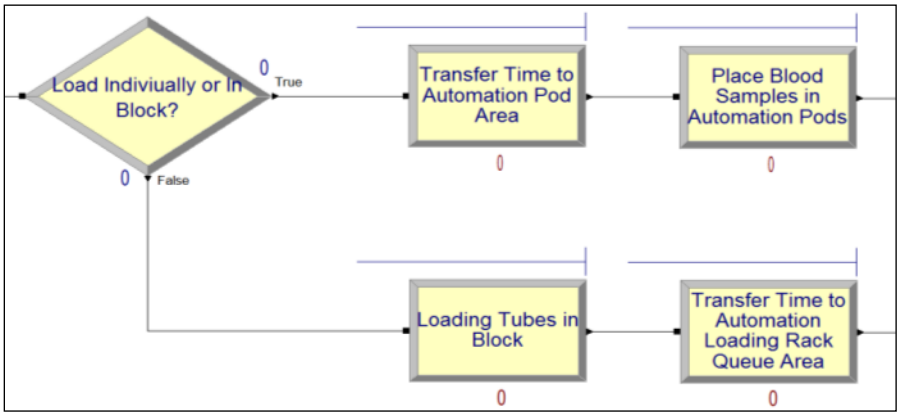

Figure III-15 : The Fifth Group of Arena Modules.

3.13 Load Individually or In Rack – Decide Module

When it comes to placing the adult blood samples onto the automation line, there are two methods. Method one: the adult samples are placed one by one onto the line. With the other method, they are loaded into a blue block which is then placed into the line. The blue blocks are plastic tube racks with tube spacings made for use by the automated system. There is no clear guideline for when to use the block or when to manually insert samples. The decision of which method to use is up to the processors. Generally, when they conclude that there are too many samples to place individually, they use the blue block. When only a small amount of samples arrive (usually between one to five samples), they manually insert the samples into the system.

The decide module labeled *Load Individually or In Rack* allows for the model to decide if the adult blood samples are to be placed into blue block first, then into the automation line or to be placed individually into the automation line. The decide type utilized for the *Decide Sample Type* decide module is "2 Way By Chance." This option allows for two probabilities (although the total probability must equal to 1). It is calculated that 10.7% of the time the processors use the blue blocks to place the adult blood samples onto the automation line. This also means that 89.3% of the time the adult blood samples are individually loaded onto the automation line. The probabilities that are used can be found in Table III-15. The percentage values are calculated using the following steps:

I. Observe the total number of times the processor places adult blood samples in the automation line whether individually or via the loading rack.
II. Observe the number of times the processor places tubes in the automation line via the blue block.

III. Divide the total number of times the processor placed adult blood sample tubes using the blue blocks by the total number of times the processor places adult blood sample manually or by using the blue blocks.

Table III-15: Load individually or in Rack – Decide Module Data.

Date Observed	Total Number of Times at Automation Line	Number of Times That Loading Rack Was Used
January 5, 2010	50	6
January 13, 2010	71	8
January 14, 2010	43	5
January 18, 2010	36	2
January 19, 2010	57	6
January 21, 2010	61	5
January 25, 2010	70	5
January 27, 2010	45	5
January 29, 2010	49	5
February 2, 2010	32	8
Total	514	55
Loading Rack Usage (%)	**10.7%**	

3.14 Transfer Time to Automation Pod Area – Process Module

The transfer time is modeled as a process module because the resources themselves (in this case the processors) are the ones who actually transport the samples from location to location. The transfer time is used here because the processor transports the sample from the processing area to the automation line, and then proceeds to place the sample in the line. The process module is labeled *Transfer Time to Automation Pod Area*. The action chosen for this process module is seize delay release. The resource employed in this module is one processor. The duration time distribution for this module is: 0.5 + WEIB (2.79, 2.54), where WEIB allows

for the direct input of a Weibul distribution in Arena. The distribution data is calculated using seconds for the time units, and the work is classified as value added. Figure III-16 illustrates the graphical representation of the duration time distribution. Table III-16 depicts the results of the distribution. The data is derived by direct observation where there are a total of 388 data points observed.

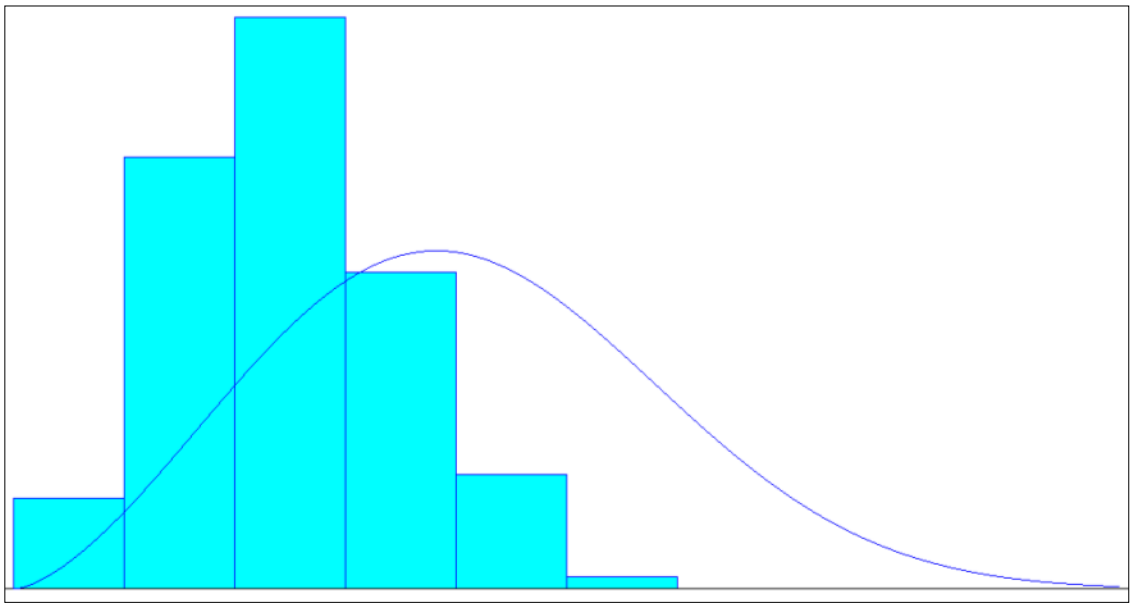

Figure III-16: Transfer Time to Automation Pod Area – Duration Time Distribution.

Table III-16: Transfer Time to Automation Pod Area – Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Weibull
Expression:     0.5 + WEIB(2.79, 2.54)
Square Error:   0.000765

Chi Square Test
  Number of intervals   = 5
  Degrees of freedom    = 2
  Test Statistic        = 1.63
  Corresponding p-value = 0.456

        Data Summary

Number of Data Points   = 388
Min Data Value          = 1
Max Data Value          = 6
Sample Mean             = 2.98
Sample Std Dev          = 1.05

        Histogram Summary

Histogram Range         = 0.5 to 6.5
Number of Intervals     = 10
```

3.15 Place Blood Samples in Automation Pods – Process Module

The automation line is a fully automated delivery/test system. Once a sample has been placed in the line it is scanned and taken to an automated centrifuge machine and then to other machines that automatically test the sample or separate out samples for delivery to the hematology department. Once testing is finished the sample is transported to a refrigerated storage bin where the computer matches the storage location with the sample for easy retrieval/disposal.

If the *Load individually or In Block* decide module determines that an adult blood sample is to be placed individually, the sample is sent to the process module named *Place Blood*

Samples in Automation Pods. These pods hold a single tube upright and allow the barcode to be scanned in order to determine the test(s) to be performed. The automation line is arranged to only accept adult blood samples, which are the majority of test samples received.

The process module labeled *Place Blood Samples in Automation Pods* models the process of individually loading the adult blood samples onto the carrier pods in the automation line. The action chosen for this process module is seize delay release. The resource employed in this module is one processor. The data observed does not fit any distribution properly so an empirical distribution (CDF) is used for the duration time. Table III-17 shows the time intervals for the CDF. Figure III-17 displays the CDF graphically, while Table III-18 depicts the CDF calculations. The distribution data is calculated using seconds for the time units and the work is classified as value added. The data is derived by direct observation where there are a total of 346 data points observed. The CDF expression is: CONT (0, .5, 0.4752, 2.5, 0.6910, 4.5, 0.7901, 6.5, 0.8484, 8.5, 0.8921, 10.5, 0.9213, 12.5, 0.9592, 14.5 , 0.9796, 16.5, 0.9854, 18.5, 1, 20.5).

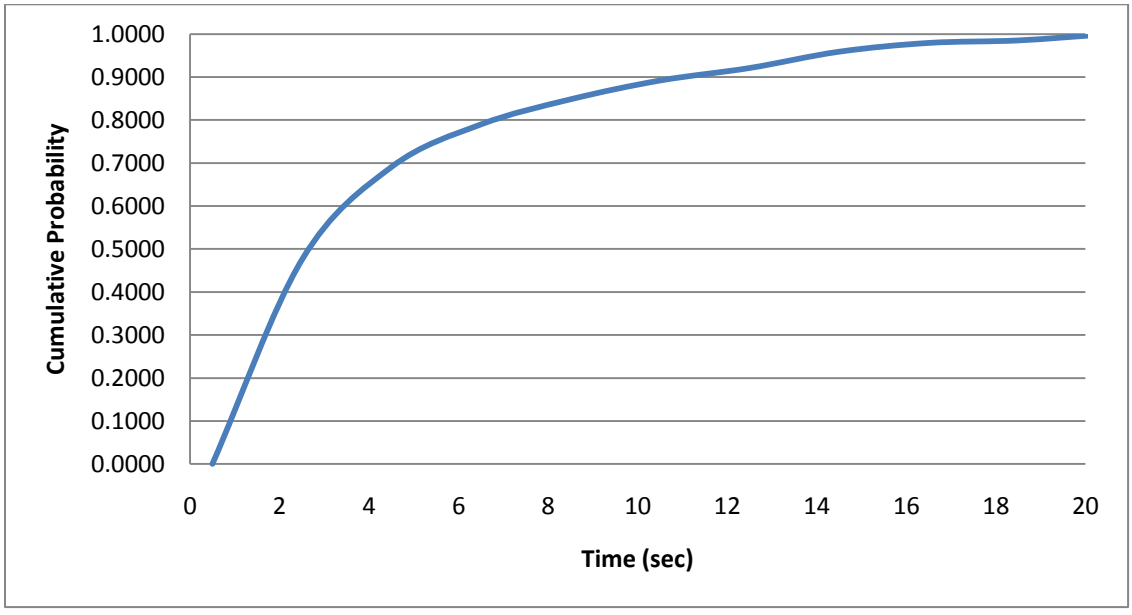

Figure III-17: Placing Blood Sample in Automation Line Duration Time CDF.

Table III-17: Placing Blood Sample in Automation Line Duration Time CDF Time Intervals.

```
        Distribution Summary

Distribution:   Empirical
Expression:     CONT or DISC (0.000,  0.500,
                              0.475,  2.500,
                              0.691,  4.500,
                              0.790,  6.500,
                              0.848,  8.500,
                              0.892, 10.500,
                              0.921, 12.500,
                              0.959, 14.500,
                              0.980, 16.500,
                              0.985, 18.500,
                              0.985, 20.500)


        Data Summary

Number of Data Points   = 343
Min Data Value          = 1
Max Data Value          = 20
Sample Mean             = 4.47
Sample Std Dev          = 4.12

        Histogram Summary

Histogram Range         = 0.5 to 20.5
Number of Intervals     = 10
```

Table III-18: Placing Blood Sample in Automation Line Duration Time CDF Calculations.

Loading Tubes Individually - Duration - CDF			
343	Total Data Points		
Data Points	Time Intervals	Probability	Cumulative Probability
0	0.5	0.0000	0.0000
163	2.5	0.4752	0.4752
74	4.5	0.2157	0.6910
34	6.5	0.0991	0.7901
20	8.5	0.0583	0.8484
15	10.5	0.0437	0.8921
10	12.5	0.0292	0.9213
13	14.5	0.0379	0.9592
7	16.5	0.0204	0.9796
2	18.5	0.0058	0.9854
5	20.5	0.0146	1.0000

3.16 Loading Tubes in Block – Process Module

If the *Load individually or In Block* decide module determines that an adult blood sample is to be loaded into the loading block first then placed into the automation line, the sample is sent to the process module named *Loading Tubes In Block.* The block has enough space to hold multiple samples. However, there is no set number of adult blood samples to place in the block. This is arbitrarily set by the individual processor. The process module labeled *Loading Tubes in Block* models the process of loading the adult blood samples on the loading block. The action chosen for this process module is seize delay release. The resource employed in this module is one processor. The distribution for this module is calculated to be 0.5 + EXPO (3.53). The distribution data is calculated using seconds for the time units and the work is classified as value added. Figure III-18 illustrates the graphical representation of the duration time distribution. Table III-19 depicts the results of the distribution. The data is derived by direct observation there are total of 78 data points observed.

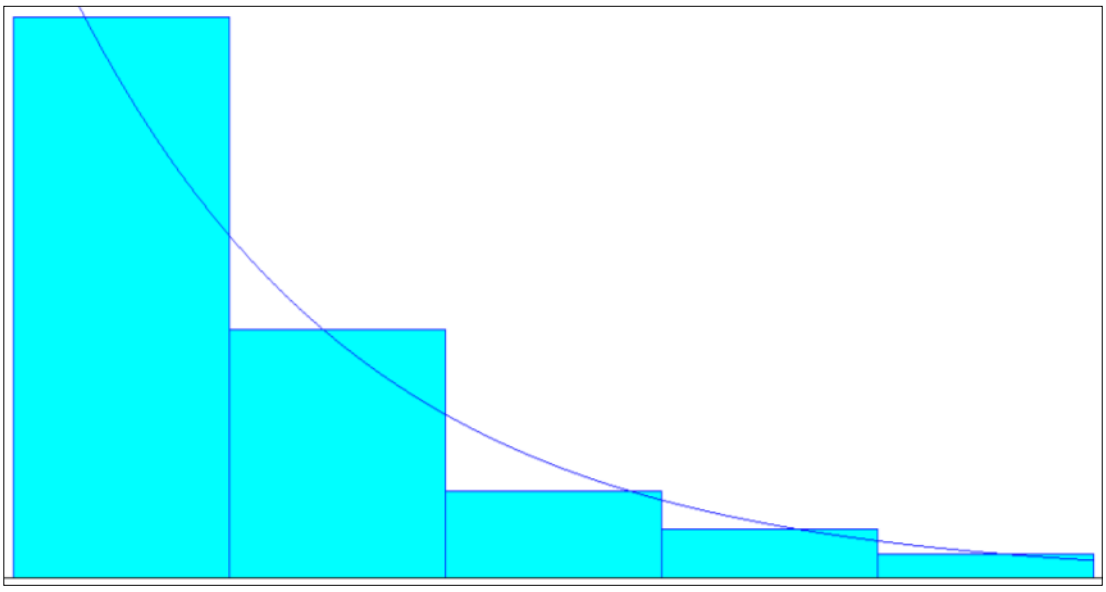

Figure III-18: Loading Tubes in Block - Duration Time Distribution.

Table III-19: Loading Tubes in Block - Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Exponential
Expression:     0.5 + EXPO(3.53)
Square Error:   0.000719

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 1
  Test Statistic        = 0.252
  Corresponding p-value = 0.644

        Data Summary

Number of Data Points   = 78
Min Data Value          = 1
Max Data Value          = 13
Sample Mean             = 4.03
Sample Std Dev          = 2.84

        Histogram Summary

Histogram Range         = 0.5 to 13.5
Number of Intervals     = 5
```

3.17 Transfer Time to Automation Loading Rack Queue Area – Process Module

Once the blood samples are on the rack or block, the block is placed next to the line in a queue area specifically designed for the blocks. The adult blood samples wait until a robotic arm picks up the samples from the loading rack to place the samples into line. The robotic arm pulls five tubes at a time and places them into the pods. Once the loading block is empty, it can be picked up by the processors to be reused.

The process module labeled *Transfer Time to Automation Loading Rack Queue Area* models the process of transferring the loaded block of blood samples from the processing area to the automation line block queue area. The action chosen for this process module is seize delay release. The resource employed in this module is one processor. The duration time expression for

this module is: TRIA (2.5, 6.57, 7.5), where TRIA allows for the direct input of a triangular distribution in Arena. The time units are in seconds and the work is classified as value added. Figure III-19 illustrates the graphical representation of the duration time distribution. Table III-20 depicts the results of the distribution. The data is derived by direct observation. There are a total of 46 data points observed.

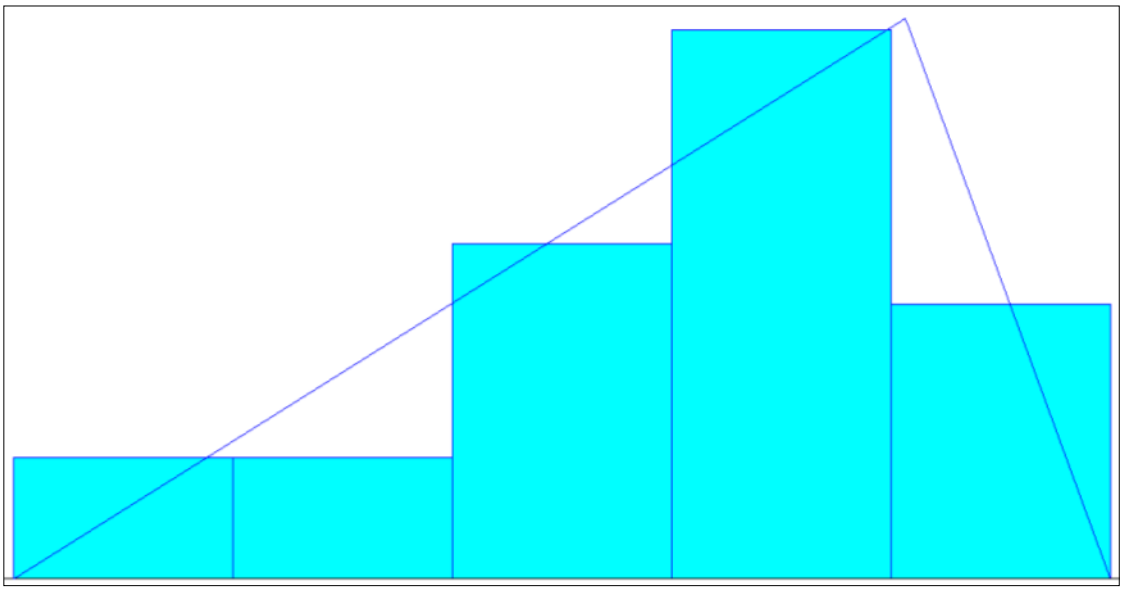

Figure III-19: Transfer Time to Automation Loading Rack Queue Area – Duration Time Distribution.

Table III-20: Transfer Time to Automation Loading Rack Queue Area - Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Triangular
Expression:     TRIA(2.5, 6.57, 7.5)
Square Error:   0.007646

Chi Square Test
  Number of intervals   = 4
  Degrees of freedom    = 2
  Test Statistic        = 0.489
  Corresponding p-value > 0.75

        Data Summary

Number of Data Points   = 46
Min Data Value          = 3
Max Data Value          = 7
Sample Mean             = 5.52
Sample Std Dev          = 1.17

        Histogram Summary

Histogram Range         = 2.5 to 7.5
Number of Intervals     = 5
```

Tubes that are considered pediatric blood samples and those tubes that are additional adult samples that are extra samples must be centrifuged manually and distributed manually. These samples are sent to the centrifuge and the additional adult samples are stored in a white, plastic test tube rack. This arena module is represented as another group of two modules in Figure III-20.

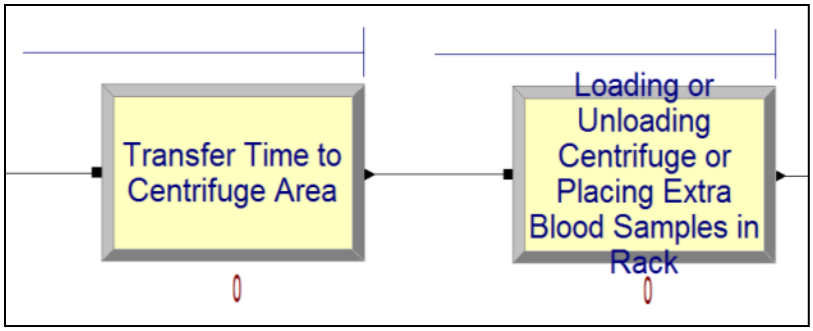

Figure III-20: Sixth Group of Arena Modules.

3.18 Transfer Time to Centrifuge Area

The process module labeled *Transfer Time to Centrifuge Area* simulated the action of taking the pediatric blood samples and the extra adult blood samples to the centrifuge area. The duration time expression is: 0.5 + WEIB (2.79, 2.54). Figure III-21 displays the duration time distribution graphically, while Table III-21 shows the distribution results. There are a total of 388 data points observed.

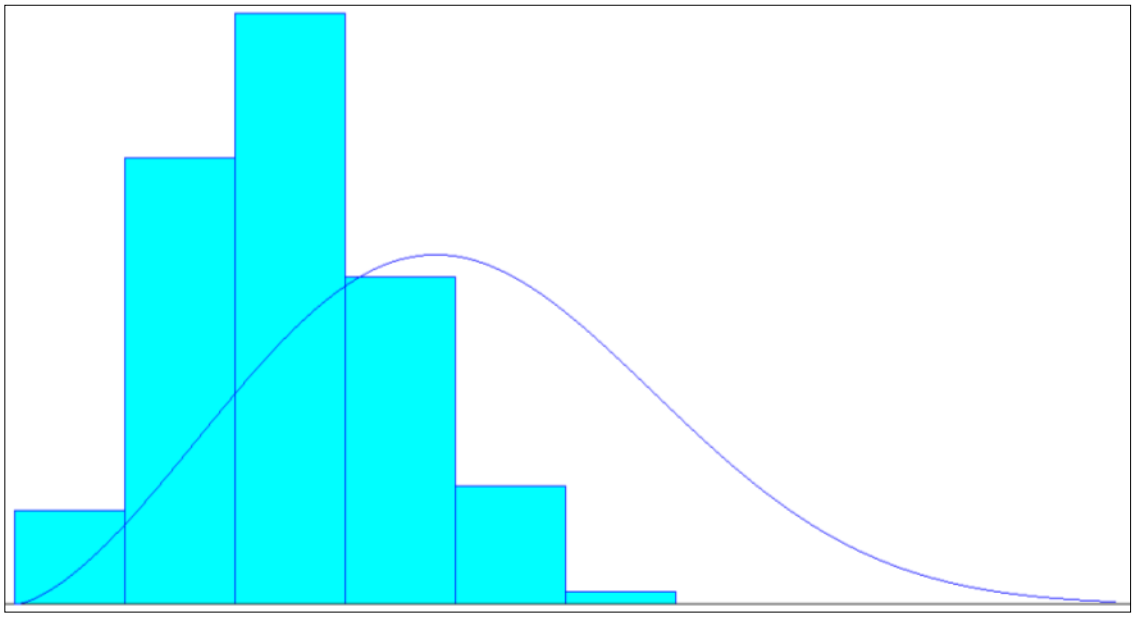

Figure III-21: Transfer Time to Centrifuge Duration Time Distribution.

Table III-21: Transfer Time to Centrifuge Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Weibull
Expression:     0.5 + WEIB(2.79, 2.54)
Square Error:   0.000765

Chi Square Test
  Number of intervals   = 5
  Degrees of freedom    = 2
  Test Statistic        = 1.63
  Corresponding p-value = 0.456

        Data Summary

Number of Data Points   = 388
Min Data Value          = 1
Max Data Value          = 6
Sample Mean             = 2.98
Sample Std Dev          = 1.05

        Histogram Summary

Histogram Range         = 0.5 to 6.5
Number of Intervals     = 10
```

3.19 Loading or Unloading Centrifuge or Placing Extra Blood in Rack – Process Module

There are two centrifuges that are not connected to the automation line and are used by the processors. These centrifuges are used for additional or extra samples and pediatric blood samples. The pediatric blood samples cannot be placed into the automated line due to the small size of the vacutainer. There is not enough space to place the barcode sticker on the pediatric tube, and the laser scanner on the automation line is not in the correct position to read the label. The pediatric blood samples are placed by the processors into the centrifuges manually. When

the samples are ready, they are manually delivered to the hematology or chemistry departments for the appropriate testing.

There is a tray which holds additional adult blood samples that are extras taken from patients. These extras are done as a time saving measure by the phlebotomists in case the doctor orders another series of tests. The phlebotomists do not have to redraw more blood. It also serves to ease the burden on the patient as they do not have to go through the discomfort of having additional blood redrawn. These samples are placed in the centrifuge then placed back into a holding rack. These centrifuges must be loaded and unloaded manually. Each centrifuge cycle lasts five minutes. At the end of the period of study at 9:00 A.M., the extra tubes are sent to a refrigerated storage area.

The process module labeled *Loading or Unloading Centrifuge or Placing Extra Blood in Rack* represents the manual loading and unloading performed by the processors, as well as any work performed in the centrifuge area. The action chosen for this process module is seize delay release. The resource employed in this module is one processor. The distribution expression for the duration time for this module is: 1.5 + GAMM (4.65, 1.62), where GAMM allows for the direct input of a gamma distribution in Arena. The distribution data is calculated in seconds, and the work is classified as value added. Table III-22 depicts the results of the distribution. Figure III-22 illustrates the graphical representation of the duration time distribution. The data is derived by direct observation. There are a total of 105 data points observed.

Table III-22: Loading or Unloading Centrifuge or Placing Extra Blood in Rack - Duration Time Dist. Summary

```
        Distribution Summary

Distribution:   Gamma
Expression:     1.5 + GAMM(4.65, 1.62)
Square Error:   0.000725

Chi Square Test
  Number of intervals   = 4
  Degrees of freedom    = 1
  Test Statistic        = 0.488
  Corresponding p-value = 0.491

        Data Summary

Number of Data Points   = 105
Min Data Value          = 2
Max Data Value          = 25
Sample Mean             = 9.05
Sample Std Dev          = 5.65

        Histogram Summary

Histogram Range         = 1.5 to 25.5
Number of Intervals     = 6
```

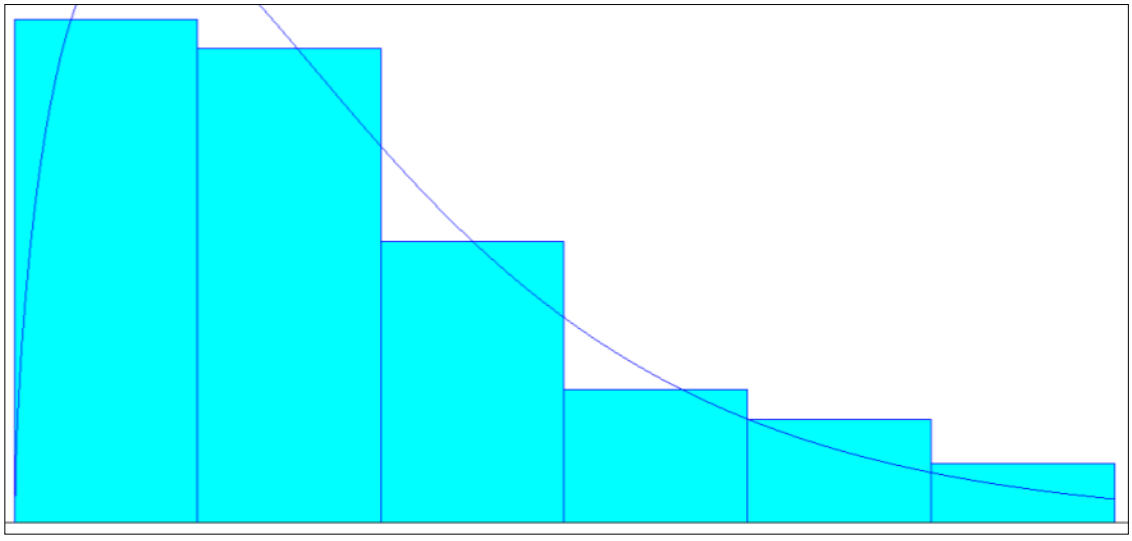

Figure III-22: Loading or Unloading Centrifuge or Placing Extra Blood in Rack – Duration Time Distribution.

3.20 Transfer to Microbiology Bin and Placing in Bin

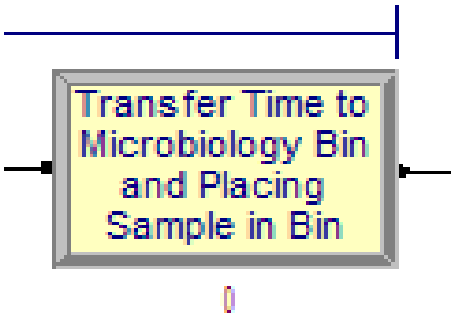

Figure III-23: Microbiology Samples - Process Module.

Figure III-23 depicts the process module labeled *Transfer Time to Microbiology Bin and Placing Sample in Bin*. This process module simulated the processor activity in which the microbiology samples are carried and placed into the bin associated with the microbiology samples. The action type is: seize delay release. The time units are in seconds, and the work is classified as value added. There is a total of 182 data points observed. The duration time expression is: UNIF (1.5, 4.5). Figure III-24 shows the duration time distribution graphically, while Table III-23 shows the distribution results.

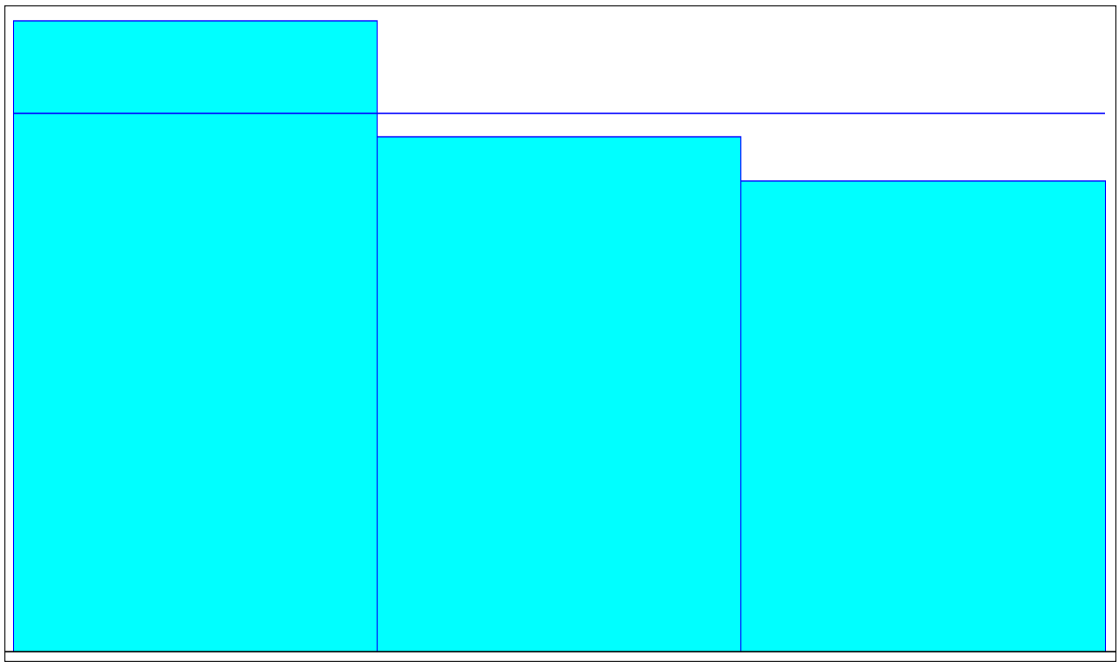

Figure III-24: Transfer Time and Placing Time for Microbiology Samples Duration Time Distribution.

Table III-23: Transfer Time and Placing Time for Microbiology Samples Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Uniform
Expression:     UNIF(1.5, 4.5)
Square Error:   0.005213

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 2
  Test Statistic        = 2.85
  Corresponding p-value = 0.244

        Data Summary

Number of Data Points   = 182
Min Data Value          = 2
Max Data Value          = 4
Sample Mean             = 2.9
Sample Std Dev          = 0.822

        Histogram Summary

Histogram Range         = 1.5 to 4.5
Number of Intervals     = 3
```

As another group of arena modules, the disposal modules allow for the samples to exit the simulation model. In the simulation there are four dispose modules meaning that the samples exit to four different locations. These modules are represented in Figure III-25.

3.21 Dispose Modules

The dispose module is the ending point for the entities in the model. Once entities have reached the dispose module, they effectively exit the simulation system. An option is available to record the entity statistics that leave through the dispose module. This option is checked in order to receive the statistical data. The dispose module only requires a label name.

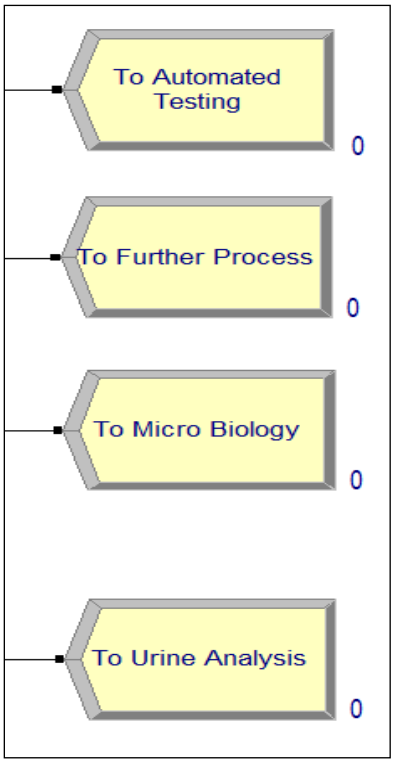

Figure III-25: Seventh Group of Arena Modules.

3.21.1 To Automated Testing – Dispose Module

The dispose module is labeled *To Automated Testing*. In the medical laboratory the adult blood samples that are placed in the automation line by the processors all continue to further testing by automated machines on the line.

3.21.2 To Further Processing – Dispose Module

The dispose module is labeled *To Further Processing*. In the medical laboratory the extra adult blood samples and the pediatric blood samples may go to the hematology department or to the chemistry department or in the case of the extra adult blood samples may stay in the holding rack until needed. Essentially, the processor involvement with the specimen samples is terminated, so the samples may exit the simulation system.

3.21.3 To Micro Biology Department – Dispose Module and To Urine Analysis – Dispose Module

The microbiology samples go to the microbiology department when the processors are done entering them into the computer system. The urine analysis samples go to the urine analysis station when the processors are done. The dispose module labeled *To Microbiology Department* is for the samples going to the Microbiology Department, and the dispose module labeled *To Urine Analysis* is for the samples going to the Urine Analysis station. Once the urine and microbiology entity samples reach their respective dispose modules they exit the simulation system. In the medical laboratory the samples continue to the micro-biology department or to the urine analysis station

3.22 Other Activities

Activities undertaken by the processors that indirectly support their actions as laboratory processors must also be considered. In the medical laboratory, the resources are the processors because they are the equipment that does the work. If they are not available because of other activities, then no work is performed, and so it can be said that there is a need to model these other activities.

The other activities in this model are also set up as processes in the system. This arrangement is done in order to account for processor time committed to these secondary activities. Each other activity is identified with a create module, a processes module, and a dispose module. The create modules are used to simulate the inter arrival time between activities. The inter arrival time expression for the activity is used as the arrival expression in the create module, where one entity (activity) per instance is allowed. The entity identified for all activities is *Activity Instance*. The process module is used to simulate the time of the activities. The activity duration expression is used as the duration expression in the process module. The resources allocated to the activity process modules is one processor. The action type is: seize delay release. The priority level given to the activity is high so that as soon as one activity entity enters the simulation the resource stops what he or she is doing and attend to the activity entity. The time units are in seconds, and the work is classified as value added. The dispose module is only used to dispose of the activity entities. Figure III-26 shows the group of Arena modules that make up the processors' secondary activities.

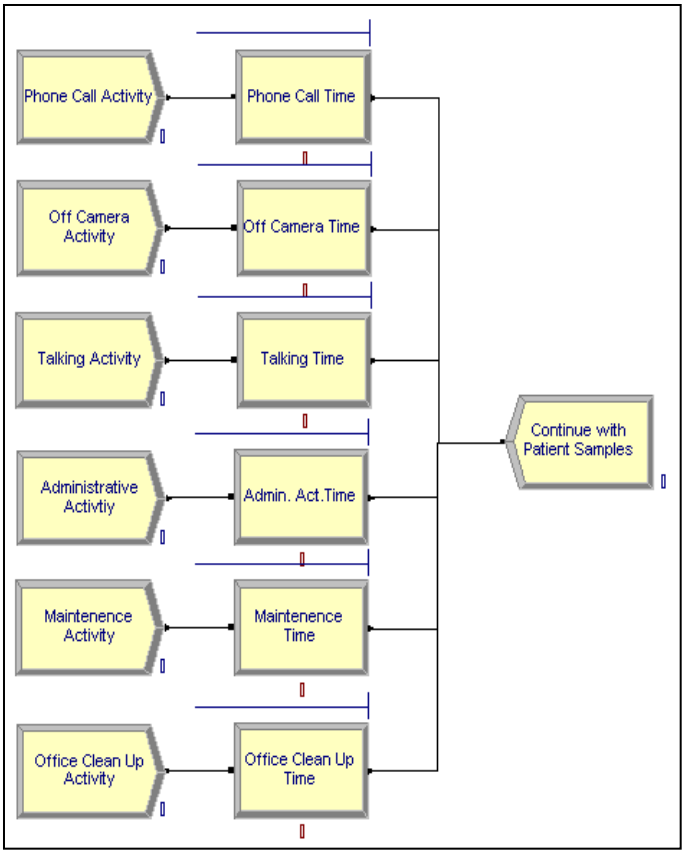

Figure III-26: Eighth Group of Arena Modules.

3.22.1 Phone Call Activity

The phone call activities are an important part of this model, because it is recognized that the number of times a processor must stop to answer the phone greatly influences the amount of time he or she has to complete actual work. Many of the phone calls are not directly related to the work needed to process the specimen samples. However, it is currently the responsibility of the processor to answer phone calls whenever they arrive.

The inter arrival expression for the phone calls is: 5 + LOGN (457, 991), where LOGN allows for the direct input of a lognormal distribution in Arena. The time units are in seconds. There are a total of 640 data points observed. Figure III-27 illustrates the graphical

representation of the up-time distribution. Table III-24 depicts the results of the up-time distribution. The process time expression is: 4 + 110 * BETA (0.582, 2.14), where BETA allows for the direct input of a beta distribution in Arena. There are a total of 622 data points observed for the process time expression. Figure III-28 illustrates the graphical representation of the process time distribution, while Table III-25 depicts the results of the process time distribution.

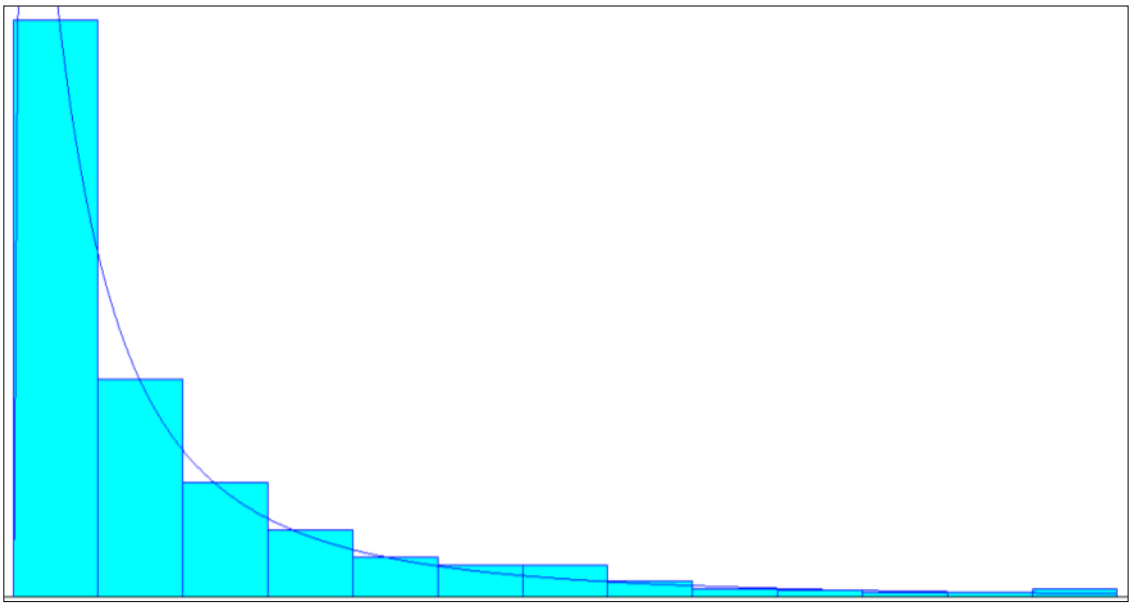

Figure III-27: Phone Call Activity – Inter Arrival Time Distribution.

Table III-24: Phone Call Activity – Inter Arrival Time Dist. Summary.

```
        Distribution Summary

Distribution:   Lognormal
Expression:     5 + LOGN(457, 991)
Square Error:   0.000316

Chi Square Test
  Number of intervals   = 9
  Degrees of freedom    = 6
  Test Statistic        = 7.21
  Corresponding p-value = 0.313

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0364
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 640
Min Data Value          = 5
Max Data Value          = 2.59e+003
Sample Mean             = 382
Sample Std Dev          = 460

        Histogram Summary

Histogram Range         = 5 to 2.59e+003
Number of Intervals     = 13
```

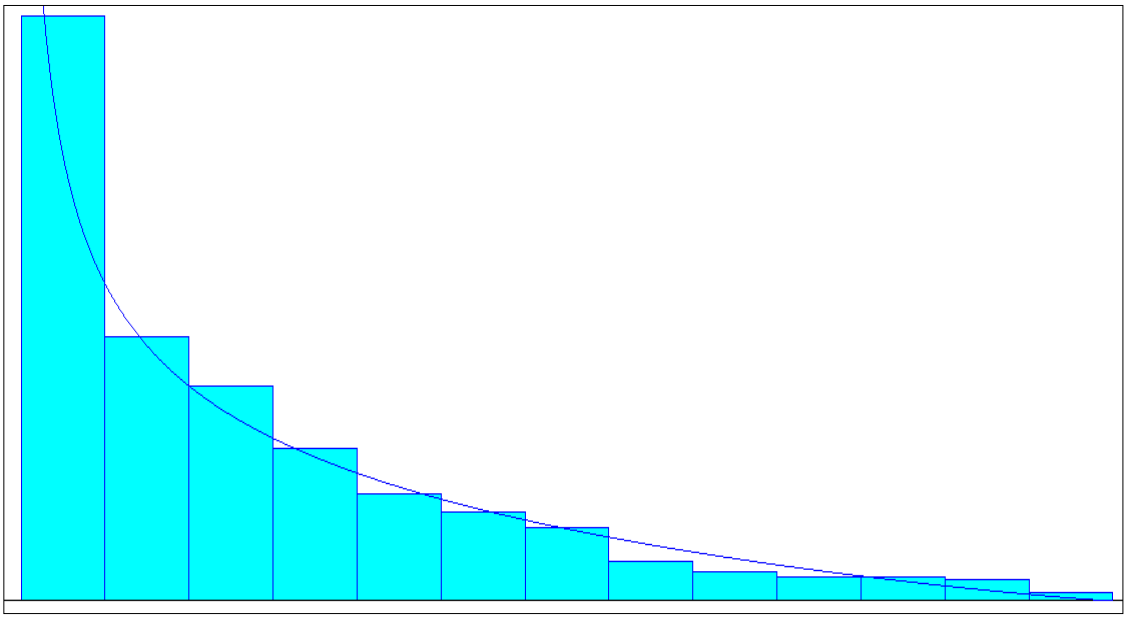

Figure III-28: Phone Call Activity – Duration Time Distribution.

Table III-25: Phone Call Activity – Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Beta
Expression:     4 + 110 * BETA(0.582, 2.14)
Square Error:   0.000867

Chi Square Test
  Number of intervals   = 11
  Degrees of freedom    = 8
  Test Statistic        = 13.1
  Corresponding p-value = 0.113

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0876
  Corresponding p-value < 0.01

        Data Summary

Number of Data Points   = 622
Min Data Value          = 4
Max Data Value          = 114
Sample Mean             = 27.5
Sample Std Dev          = 23.4

        Histogram Summary

Histogram Range         = 4 to 114
Number of Intervals     = 13
```

3.22.2 Off Camera Activity

The off camera activities represent the time that the processor is not in direct view of the two camera recorders. This is the time when the processor is not "on station" and cannot be actively working. This situation represents a variety of circumstances. For instance when the processors are on break or at lunch, the breaks and lunch periods are not represented in the processors' schedule because they are accounted for by the off camera duration distribution. Also represented in the off camera duration distribution is: the time that the processors are delivering samples to the other areas in the laboratory, restroom time, the time they take in stepping out of the lab to gather supplies, or the time spent delivering documents or samples to another part of

the hospital. Although they are performing work related tasks, it is classified as non-value added and is modeled as another activity.

The inter-arrival expression is: 19 + EXPO (410), there are a total of 645 data points observed. Figure III-29 shows the inter arrival time distribution graphically, while Table III-26 displays the distribution results. The process time expression is an empirical distribution (CDF). There are a total of 642 data points observed. The CDF expression is: CONT (0, 4.9, 0.7414, 73.1, 0.8769, 141.6, 0.9159, 209.2, 0.9470, 271.3, 0.9595, 345.4, 0.9642, 413.5, 0.9751, 481.5, 0.9813, 549.6, 0.9844, 617.7, 0.9875, 685.8, 0.9907, 753.8, 0.9938, 821.9, 1, 890). Table III-27 shows the time intervals for the duration time. Figure III-30 illustrates the duration time CDF graphically, and Table III-28 displays the CDF calculations. The distributions are obtained by direct observation. The time units are in seconds.

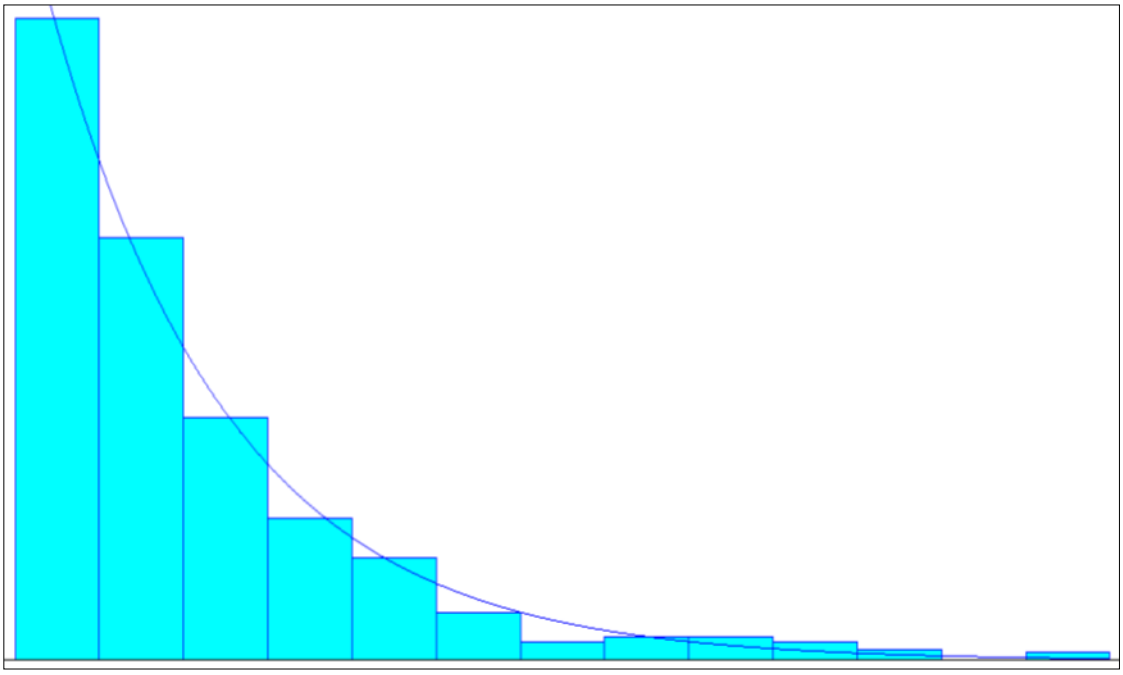

Figure III-29: Off Camera Activity – Inter Arrival Time Distribution.

Table III-26: Off Camera Activity – Inter Arrival Time Dist. Summary.

```
        Distribution Summary

Distribution:   Exponential
Expression:     19 + EXPO(410)
Square Error:   0.000579

Chi Square Test
  Number of intervals   = 8
  Degrees of freedom    = 6
  Test Statistic        = 10.5
  Corresponding p-value = 0.105

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0341
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 645
Min Data Value          = 19
Max Data Value          = 2.51e+003
Sample Mean             = 429
Sample Std Dev          = 419

        Histogram Summary

Histogram Range         = 19 to 2.51e+003
Number of Intervals     = 13
```

Table III-27: Off Camera Duration Time CDF Time Intervals.

```
        Distribution Summary

Distribution:   Empirical
Expression:     CONT or DISC (0.000,  4.999,
                              0.741, 73.076,
                              0.877, 141.153,
                              0.916, 209.230,
                              0.950, 277.307,
                              0.960, 345.384,
                              0.964, 413.461,
                              0.975, 481.539,
                              0.981, 549.616,
                              0.984, 617.693,
                              0.988, 685.770,
                              0.991, 753.847,
                              0.994, 821.924,
                              0.994, 890.001)


        Data Summary

Number of Data Points   = 642
Min Data Value          = 5
Max Data Value          = 890
Sample Mean             = 78.4
Sample Std Dev          = 124

        Histogram Summary

Histogram Range         = 5 to 890
Number of Intervals     = 13
```

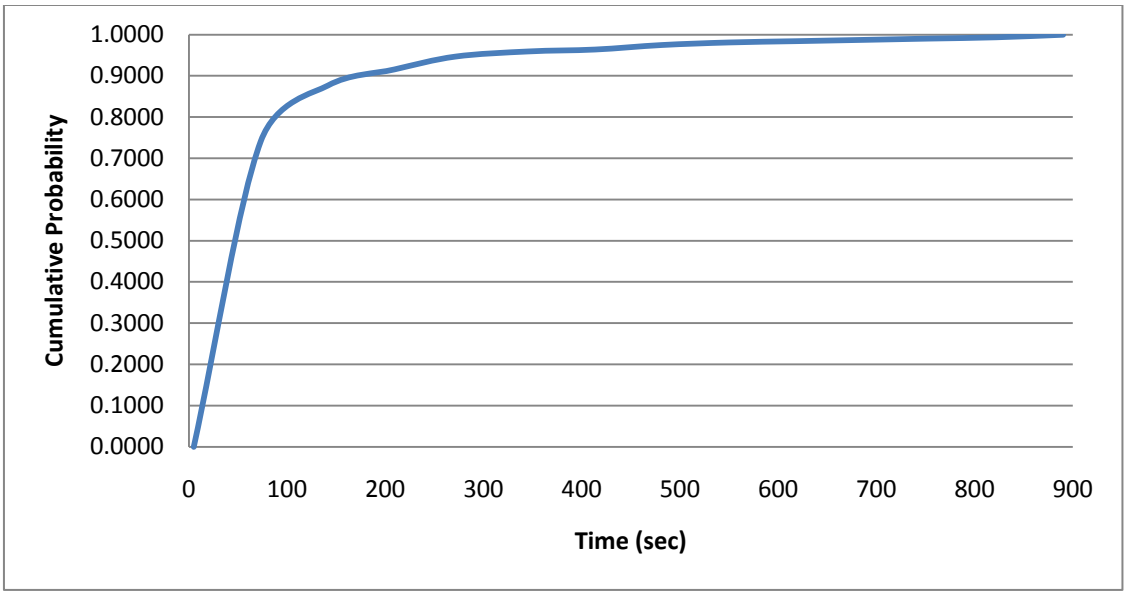

Figure III-30: Off Camera Duration Time CDF.

Table III-28: Off Camera Duration Time CDF Calculations.

Off Camera - Duration Time- CDF			
642	Total Data Points		
Data Points	Time Intervals	Probability	Cumulative Probability
0	4.9	0.0000	0.0000
476	73.1	0.7414	0.7414
87	141.6	0.1355	0.8769
25	209.2	0.0389	0.9159
20	271.3	0.0312	0.9470
8	345.4	0.0125	0.9595
3	413.5	0.0047	0.9642
7	481.5	0.0109	0.9751
4	549.6	0.0062	0.9813
2	617.7	0.0031	0.9844
2	685.8	0.0031	0.9875
2	753.8	0.0031	0.9907
2	821.9	0.0031	0.9938
4	890	0.0062	1.0000

3.22.3 Talking Activities

The talking activities represent the time the processor is engaging in conversation with another member of the medical laboratory. The conversation subject matter is not recorded. It is assumed that a percentage of the conversation is work related and some of the conversation is of a personal nature. Since no direct work is being performed on the specimen samples, this type of activity is classified as non-value added.

The inter-arrival time expression for the talking activities is: 3 + LOGN (671, 2.17e+003). The time units are in seconds. The number of points observed is 343. Figure III-31 illustrates the graphical representation of the inter-arrival distribution, while Table III-29 depicts the results of the inter-arrival distribution. The process time expression for the talking failure is: 4 + WEIB (38.3, 1.11). There are a total of 355 data points observed for the process time expression. Figure III-32 illustrates the graphical representation of the process time distribution, while Table III-30 depicts the results of the process time distribution. The data is derived by direct observation.

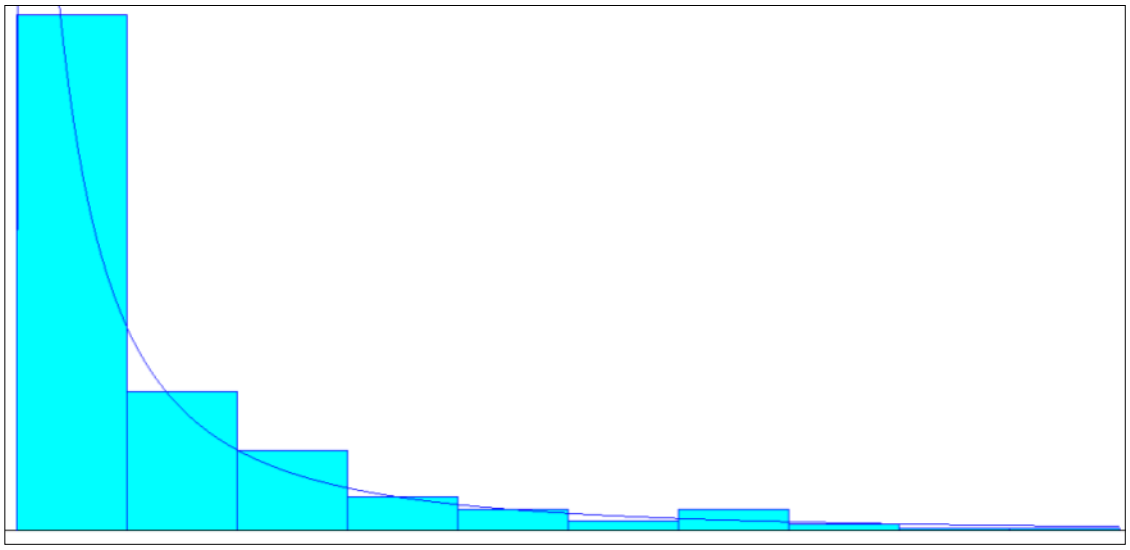

Figure III-31: Talking Activities– Inter Arrival Time Distribution.

Table III-29: Talking Activity – Inter Arrival Time Dist. Summary.

```
        Distribution Summary

Distribution:   Lognormal
Expression:     3 + LOGN(671, 2.17e+003)
Square Error:   0.001109

Chi Square Test
  Number of intervals   = 6
  Degrees of freedom    = 3
  Test Statistic        = 4.72
  Corresponding p-value = 0.207

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0688
  Corresponding p-value = 0.0778

        Data Summary

Number of Data Points   = 343
Min Data Value          = 3
Max Data Value          = 3.16e+003
Sample Mean             = 426
Sample Std Dev          = 529

        Histogram Summary

Histogram Range         = 3 to 3.16e+003
Number of Intervals     = 10
```

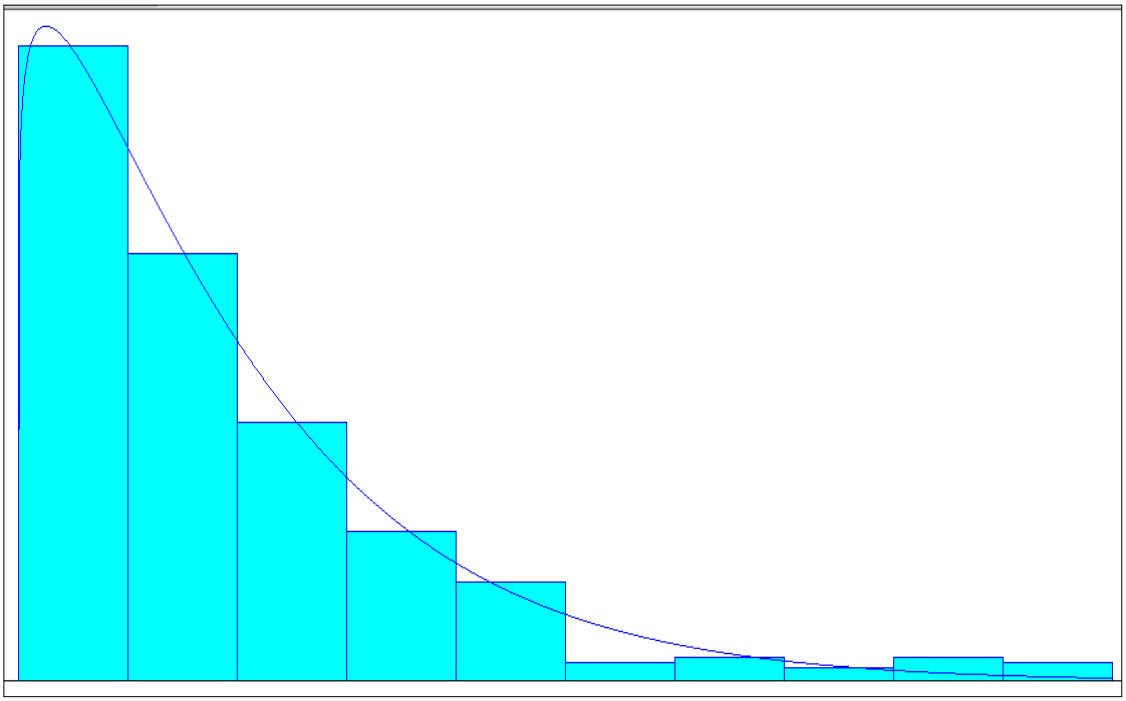

Figure III-32: Talking Activity – Duration Time Distribution.

Table III-30: Talking Activity – Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Weibull
Expression:     4 + WEIB(38.3, 1.11)
Square Error:   0.000852

Chi Square Test
  Number of intervals   = 7
  Degrees of freedom    = 4
  Test Statistic        = 7.36
  Corresponding p-value = 0.126

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0558
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 355
Min Data Value          = 4
Max Data Value          = 192
Sample Mean             = 40.8
Sample Std Dev          = 35.3

        Histogram Summary

Histogram Range         = 4 to 192
Number of Intervals     = 10
```

3.22.4 Administrative Activites

The administrative activities represents the event in which the processor performs administrative duties such as meetings or discussions with management or is working on office tasks such as retrieving label paper and installing the paper into the printer, or other office related duties. This type of work is classified as non-value added

The inter-arrival and process time expressions are: 8 + LOGN (742, 1.68e+003) and 6 + WEIB (45.4, 0.909), respectively. The time units are in seconds, and the distributions are obtained from direct observation. For the up-time expression, there are a total of 347 data points observed, and for the down-time expression, there are a total of 429 data points observed. Figure

III-33 illustrates the graphical representation of the up-time distribution, while Table III-31 depicts the results of the up-time distribution. Figure III-34 illustrates the graphical representation of the downtime distribution, while Table III-32 depicts the results of the downtime distribution.

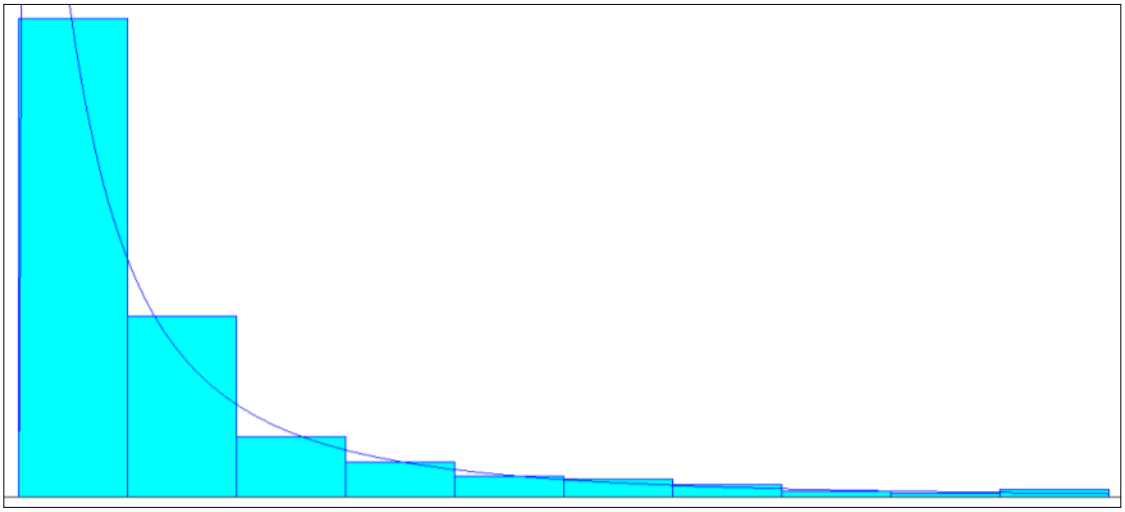

Figure III-33 : Administrative – Inter Arrival Time Distribution.

Table III-31: Administrative Activity – Inter Arrival Time Dist. Summary.

```
        Distribution Summary

Distribution:   Lognormal
Expression:     8 + LOGN(742, 1.68e+003)
Square Error:   0.001685

Chi Square Test
  Number of intervals   = 6
  Degrees of freedom    = 3
  Test Statistic        = 4.99
  Corresponding p-value = 0.188

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0505
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 397
Min Data Value          = 8
Max Data Value          = 4.07e+003
Sample Mean             = 588
Sample Std Dev          = 723

        Histogram Summary

Histogram Range         = 8 to 4.07e+003
Number of Intervals     = 10
```

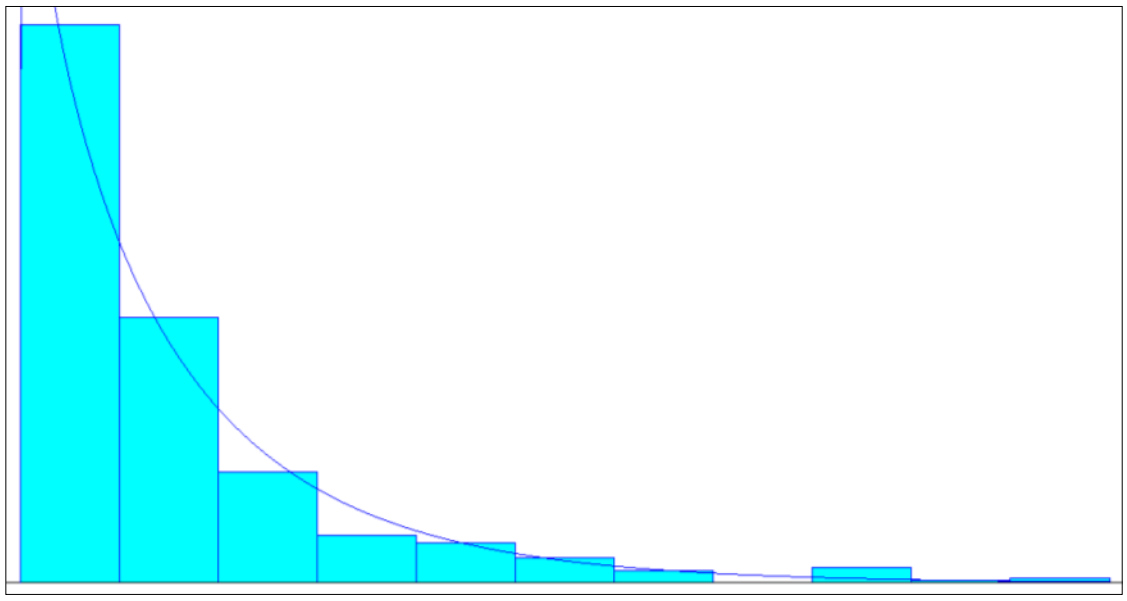

Figure III-34: Administrative Activity – Duration Time Distribution.

Table III-32: Administrative Activity– Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Weibull
Expression:     6 + WEIB(45.4, 0.909)
Square Error:   0.001405

Chi Square Test
  Number of intervals   = 6
  Degrees of freedom    = 3
  Test Statistic        = 5.36
  Corresponding p-value = 0.162

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0552
  Corresponding p-value = 0.142

        Data Summary

Number of Data Points   = 429
Min Data Value          = 6
Max Data Value          = 340
Sample Mean             = 53.5
Sample Std Dev          = 53.9

        Histogram Summary

Histogram Range         = 6 to 340
Number of Intervals     = 11
```

3.22.5 Maintenance Activity

The maintenance activity is the event in which the automation line signals a problem and does not run. The problems usually consist of minor corrective procedures and severe automation line issues are not covered in the model. The minor corrective issues include: correcting a miss-labeled tube that the automation line could not scan, misplaced loading rack in the loading rack queue area, transport pod stuck or damaged, or any other corrective action performed by the processor to the automation equipment.

The inter-arrival expression for the maintenance activity is: 11 + 3.2e+003 * BETA (0.519, 1.23). The number of points observed is 105. Figure III-35 illustrates the graphical representation of the inter-arrival distribution, while Table III-33 depicts the results of the inter-arrival distribution. The process time expression is: 4.5 + EXPO (24.2). There is a total of 124 data points observed. Figure III-36 illustrates the graphical representation of the process time distribution, while Table III-34 depicts the results of the process time distribution. The data is derived by direct observation, and the time units are in seconds.

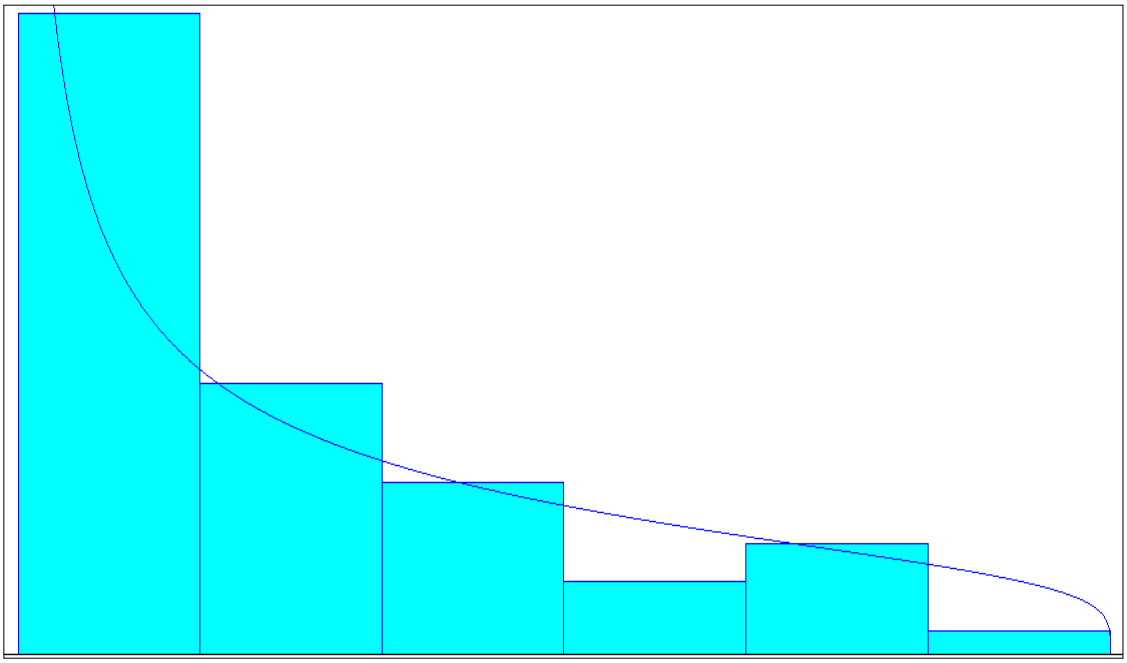

Figure III-35: Maintenance Activity – Inter Arrival Time Distribution.

Table III-33: Maintenance Activity – Inter Arrival Time Dist. Summary.

```
       Distribution Summary

Distribution:   Beta
Expression:     11 + 3.2e+003 * BETA(0.519, 1.23)
Square Error:   0.004694

Chi Square Test
  Number of intervals   = 5
  Degrees of freedom    = 2
  Test Statistic        = 3.49
  Corresponding p-value = 0.191

Kolmogorov-Smirnov Test
  Test Statistic        = 0.114
  Corresponding p-value = 0.126

       Data Summary

Number of Data Points   = 105
Min Data Value          = 11
Max Data Value          = 3.21e+003
Sample Mean             = 814
Sample Std Dev          = 778

       Histogram Summary

Histogram Range         = 11 to 3.21e+003
Number of Intervals     = 6
```

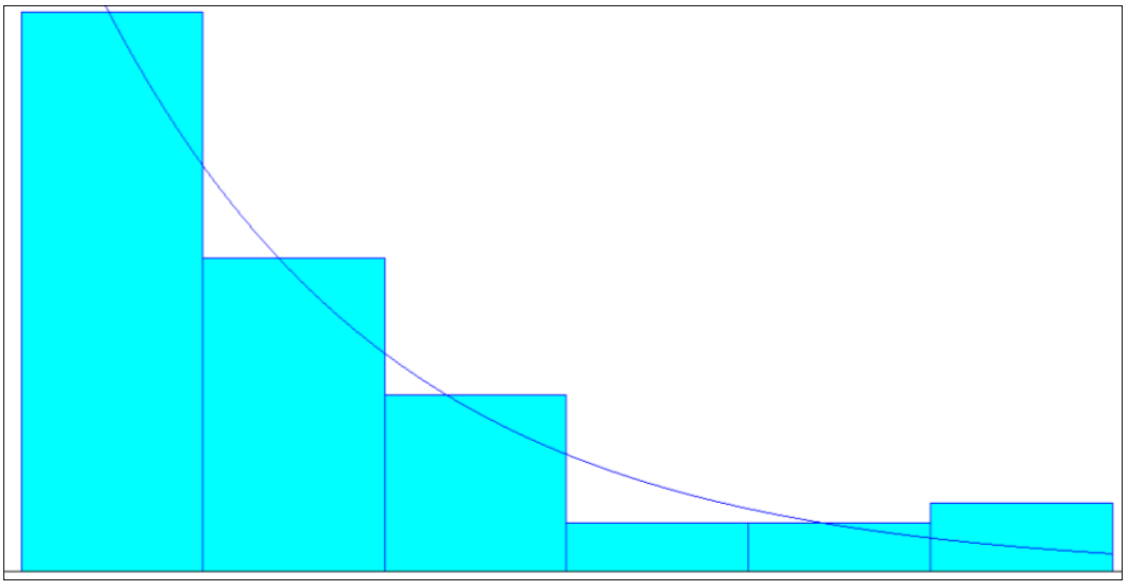

Figure III-36: Maintenance Activity – Duration Time Distribution.

Table III-34: Maintenance Activity – Duration Time Dist. Summary.

```
        Distribution Summary

Distribution:   Exponential
Expression:     4.5 + EXPO(24.2)
Square Error:   0.002499

Chi Square Test
  Number of intervals   = 4
  Degrees of freedom    = 2
  Test Statistic        = 1.2
  Corresponding p-value = 0.556

        Data Summary

Number of Data Points   = 124
Min Data Value          = 5
Max Data Value          = 94
Sample Mean             = 28.7
Sample Std Dev          = 21.3

        Histogram Summary

Histogram Range         = 4.5 to 94.5
Number of Intervals     = 6
```

3.22.6 Office Clean Up Activity

The office clean-up activity is indicative of the the time periods when the processor is caught up with picking up samples, processing samples, placing samples in the automation line, or done with the manual centrifuge. This generally occurs during slower periods when no samples are coming into the laboratory and there is a low volume of phone calls arriving. Essentially, all work is done and the processor or resource is idle and is waiting for samples to arrive. When the processor first becomes “idle” other tasks are performed such as cleaning the computer area, organizing the centrifuge area and overall clean-up of the work areas. This type

of work is necessary in order to keep a clean and efficient work area, but it is considered non-value added and is modeled as a secondary activity in the simulation.

The inter-arrival expression is: 42 + EXPO (1.13e+003). There are a total of 66 data points observed. Figure III-37 illustrates the graphical representation of the inter-arrival distribution, while Table III-35 depicts the results of the inter-arrival distribution. The process time expression used is an empirical distribution (CDF), with 86 data points observed. The CDF expression is: CONT (0, 10.9, 0.6512, 57.9, 0.7791, 105, 0.8953, 152, 0.9535, 199, 1, 246). Table III-36 shows the Time intervals used in the CDF. Figure III-38 illustrates the duration time CDF, while Table III-37 depicts the CDF calculations. The time units are in seconds, and the distributions are obtained from direct observation.

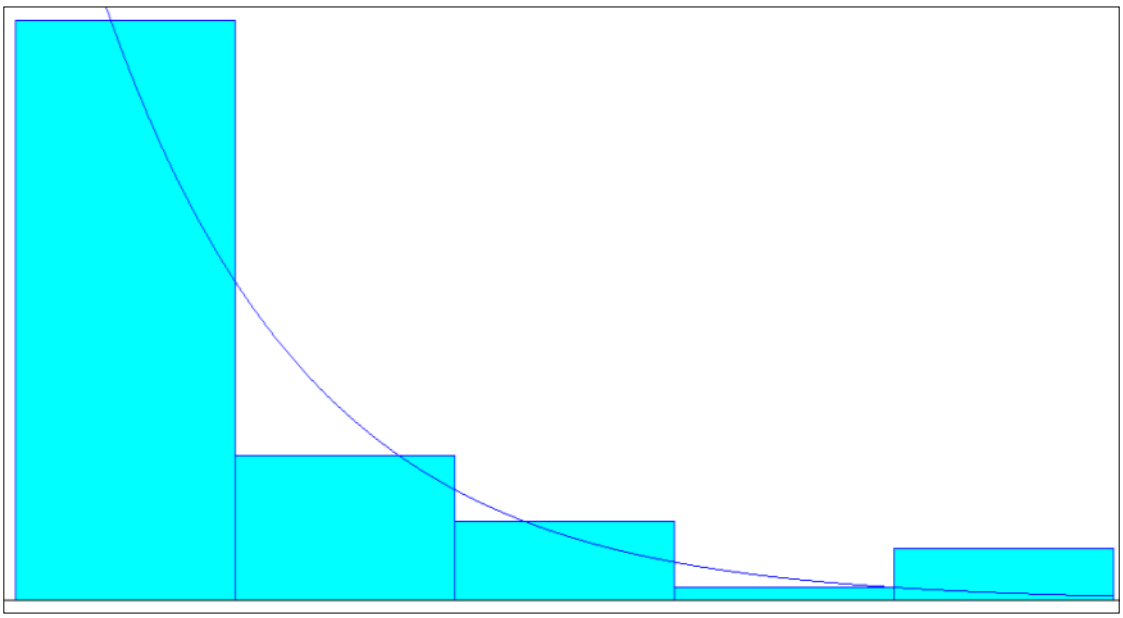

Figure III-37: Clean Up Activities - Inter Arrival Time Distribution.

Table III-35: Clean Up Activities – Inter Arrival Time Dist. Summary.

```
        Distribution Summary

Distribution:   Exponential
Expression:     42 + EXPO(1.13e+003)
Square Error:   0.006739

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 1
  Test Statistic        = 2.54
  Corresponding p-value = 0.118

Kolmogorov-Smirnov Test
  Test Statistic        = 0.186
  Corresponding p-value = 0.019

        Data Summary

Number of Data Points   = 66
Min Data Value          = 42
Max Data Value          = 6.02e+003
Sample Mean             = 1.17e+003
Sample Std Dev          = 1.46e+003

        Histogram Summary

Histogram Range         = 42 to 6.02e+003
Number of Intervals     = 5
```

Table III-36: Clean Up Activities – Duration Time CDF Time Intervals.

```
        Distribution Summary

Distribution:   Empirical
Expression:     CONT or DISC (0.000, 10.999,
                              0.651, 57.999,
                              0.779, 105.000,
                              0.895, 152.000,
                              0.953, 199.001,
                              0.953, 246.001)


        Data Summary

Number of Data Points   = 86
Min Data Value          = 11
Max Data Value          = 246
Sample Mean             = 63.4
Sample Std Dev          = 60.4

        Histogram Summary

Histogram Range         = 11 to 246
Number of Intervals     = 5
```

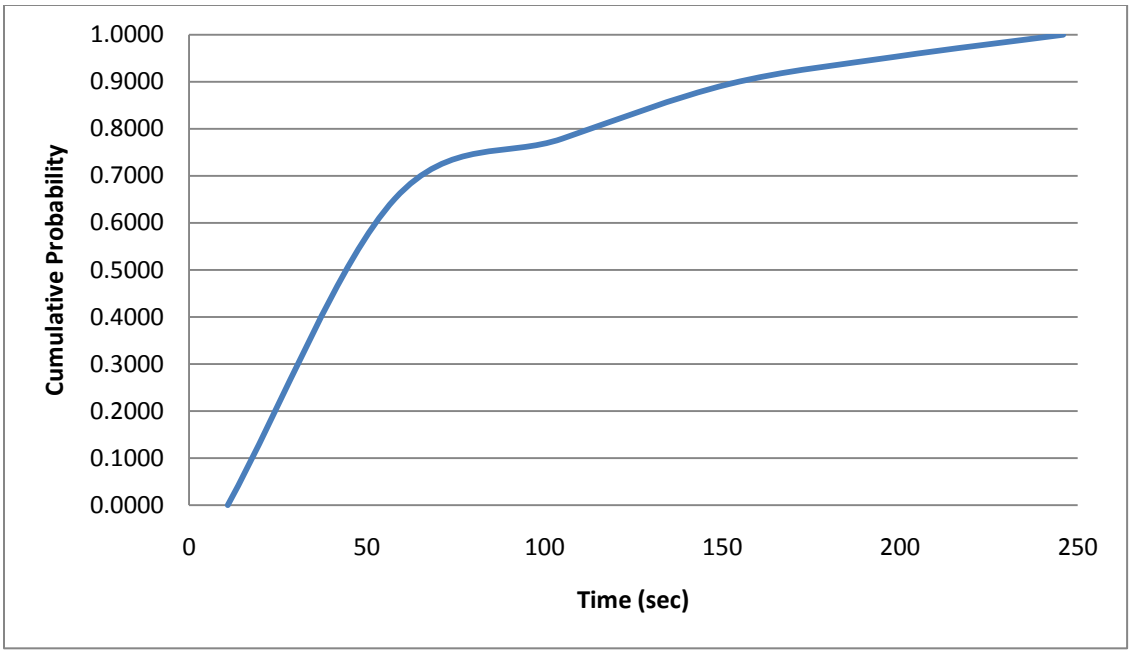

Figure III-38: Clean Up Activities - Duration Time CDF.

Table III-37: Clean Up – Duration Time CDF Calculations.

Office Clean Up - Duration Time- CDF			
86	Total Data Points		
Data Points	Time Intervals	Probability	Cumulative Probability
0	10.9	0.0000	0.0000
56	57.9	0.6512	0.6512
11	105	0.1279	0.7791
10	152	0.1163	0.8953
5	199	0.0581	0.9535
4	246	0.0465	1.0000

3.23 Processors Schedule – Schedule Basic Process

The scheduling scheme used in the model is for a 5 hour period, the time frame when the observers were present and the two camera recorders were filming. The schedule name is *Processor Schedule.* The type is capacity, which allows the input of a resource schedule. The time units are in minutes. The processor schedule is constant meaning that for the duration of the

observations and as well as in the simulation model the processor works consistently without any rest or lunch breaks. Recall that the break periods are accounted for in the *Off Camera* activity module and do not need to be accounted for in the processors schedule. There is a lot of traffic in the medical laboratory. Throughout the shift the phlebotomists enter and leave lab. As the phlebotomist enters the laboratory, they bring with them the specimen samples they have collected. Many times they process the samples themselves. If they are waiting for their next assignment, they help out the processor by placing samples onto the automation line, placing samples into the centrifuge area, and answering phones. Essentially they become an extra processor for the amount of time that they are there.

There is two schedules utilized in the model, the first schedule is applied when only one processor is on duty. It is observed that when only one processor is on duty, the phlebotomists tend to be present for longer periods of time as opposed to when there are two processors on duty. Table III-38 displays the schedule for one processor on duty. In the schedule there is a variable named *Processors_On_Duty* that is used as the schedule value that represents the number of processors on duty. The variable named *Processors_On_Duty + 1,* represents the number of processor on duty plus one (the extra help from the phlebotomists).

Table III-38: Schedule for One Processor on Duty.

Resource(s)	Time (Min)
Processors_on_Duty	27
Processors_on_Duty + 1	33
Processors_on_Duty	27
Processors_on_Duty + 1	33
Processors_on_Duty	27
Processors_on_Duty + 1	33
Processors_on_Duty	28
Processors_on_Duty + 1	32
Processors_on_Duty	28
Processors_on_Duty + 1	32
Processors_on_Duty	60

The duration of the phlebotomists at work is obtained by direct observation. It is observed that the phlebotomists help out for an average of 2.7 hours for the 5 hours when there is only one processor on duty. The extra 60 minutes in the schedule is to account for the one hour warm up period in the simulation.

Table III-39 displays the schedule for two processors on duty. It is observed that when there are two processors on duty the phlebotomist help out only an average of 50 minutes for the five hours of observation. In both schedules the time is distributed evenly over the five hours.

Table III-39: Schedule for Two Processors on Duty.

Resource(s)	Time (Min)
Processors_on_Duty	50
Processors_on_Duty + 1	10
Processors_on_Duty	50
Processors_on_Duty + 1	10
Processors_on_Duty	50
Processors_on_Duty + 1	10
Processors_on_Duty	50
Processors_on_Duty + 1	10
Processors_on_Duty	50
Processors_on_Duty + 1	10
Processors_on_Duty	60

3.24 Phone Call Factor – Variable Basic Process

The phone call factor is a variable added to the model, it is observed that when the processors answer the incoming phone calls they are also engaged in polyphasic activity. This means that they are engaged in two types of work simultaneously. Firstly they are attending to the phone call, and secondly they are also processing samples. Since the incoming phone calls are modeled as activities the Phone Call Factor variable is added to offset the activity time to account for the actual work that the processor is doing while answering the phone calls.

Chapter IV

Results and Discussion

The validation procedure is an important step. It allows the medical laboratory administration to check the simulation results and compare them to the available data and check for accuracy. If the model cannot be validated to certain degree then careful consideration must be given on the weight placed on the simulation results.

4.1 Model Validation

The simulation model is validated using the average number of specimen samples that exit from the model. There are a total of four different simulation cases that are studied for the primary study: analyzing the throughput with varying resource capacities. The average number out for all four cases is 326 samples. There is a daily average of 327 samples for the five hour period that the medical laboratory processed for the dates that the video camera recorders were in use. These findings suggest that the percentage in error for the average number of samples out is only 0.23%. The percent error for the individual cases is shown below in Table IV-1. As can be seen, the percentage in error for each individual case run is still less than 3% from the actual process data.

Table IV-1: Individual Case Percent Error.

Case	Average Number Out	% Error
Case 1	324	0.92
Case 2	322	1.53
Case 3	325	0.61
Case 4	334	2.14
Average	**326.25**	**0.23**

The resources utilization is another approach for model validation. In the model all of the processors actions are taken into account and modeled. As such, the utilization should be close to 100%. Table IV-2 shows the utilization results for all four cases. The utilization results suggest that the processor utilization is on average 56.91%. This result is lower than expected.

Table IV-2: Individual Case Utilization Data.

Case	Resource Instantaneous Utilization (Average)
Case 1	68.54%
Case 2	64.96%
Case 3	47.35%
Case 4	46.78%
Average	**56.91%**

4.2 Primary Study - Simulation Results

The primary study is focused on two factors, first to see if the number of phone calls causes significant delays in the processors' primary duty (the processing of the patient samples). Second, this study is useful to find the effect of having one or two processors on duty at all times. This situation being the case, four different scenarios are executed.

4.2.1 Case One

Case one consists of one processor on duty with a phone call factor of 0.8. Recall from the chapter 3 section 3-22-1, the phone call activity duration time equation was derived from the statistical distribution of the observed instances followed by a variable "Phone Call Factor." This "Phone Call Factor" variable is used, because it is observed that when the processors answer the incoming phone calls they are also engaged in polyphasic activity. In other words, they are engaged in two types of work simultaneously. Firstly they are attending to the phone call, and secondly they are also processing samples. The Phone Call Factor variable is added to offset the duration time to account for the actual work that the processor is doing while answering the phone calls.

Since there is only one processor on duty, the schedule used in this simulation run is found in chapter 3, section 3-23. Recall that when one processor is on duty the phlebotomists "help out" for an average of 2.7 hours for the five hour observation period. The extra help time is distributed evenly throughout the five hours.

The results shown below are only the results that are the most pertinent to the thesis objectives, for the full Category Overview report see Appendix A. Table IV-3 shows the selected results from the case one analysis. Notice that the total time for the adult blood sample is 7.22 minutes this means that when one processor is on duty the samples are left in the system for that period of time. In section 4-3 Discussion the four cases are compared to one another. This allows for recommendations based on the findings.

Table IV-3: Case One Selected Results.

Case One	
Processors on Duty	1
Phone Call Factor	0.8
Number Out (Average)	324
Adult Blood Total Time (min)	7.22
Extra Adult Blood Total Time (min)	7.16
Pediatric Blood Total Time (min)	7.32
Processor Instantaneous Utilization	68.54%

4.2.2 Case Two

Case two consists of one processor on duty with a phone call factor of 0. In this scenario the effect of having no phone calls in the system is investigated. It is believed by the medical laboratory manager that this may cause a high level of interruptions, so the results may prove useful in deciding to hire a phone operator to handle all incoming phone calls. There is only one processor on duty being modeled so the schedule is the same as in case one. See chapter 3, section 3-23 for the schedule. Table IV-4 displays the key results for the case two simulation. For the full report please refer to Appendix B. Now that the phone calls have been eliminated from the system, the total time for the adult blood sample is now 6.64 minutes. There is an improvement in the time when compared to the results from case one. In section 4-3 of this chapter a full comparison is discussed.

Table IV-4: Case Two Selected Results.

Case Two	
Processors on Duty	1
Phone Call Factor	0
Number Out (Average)	322
Adult Blood Total Time (min)	6.64
Extra Adult Blood Total Time (min)	6.72
Pediatric Blood Total Time (min)	6.56
Processor Number Instantaneous Utilization	64.96%

4.2.3 Case Three

Case three consists of two processors on duty with a phone call factor of 0.8. In this scenario the effect of scheduling two processors with the phone call activity present in the simulation is analyzed. When there are two processors on duty the phlebotomists do not help out as much as when there is only one processor on duty. Refer to chapter 3, section 3-23 for the schedule when two processors are on duty. Recall that when two processors are on duty the phlebotomists "help out" for an average of 50 minutes for the five hour observation period. The extra help time is distributed evenly throughout the five hours. Table IV-5 shows the selected results for the case three simulation. The table indicates that the average number of samples out is 325 and the total time for the adult blood samples is 2.89 minutes. For the complete category overview report refer to Appendix C.

Table IV-5: Case Three Selected Results.

Case Three	
Processors on Duty	2
Phone Call Factor	0.8
Number Out (Average)	325
Adult Blood Total Time (min)	2.89
Extra Adult Blood Total Time (min)	2.95
Pediatric Blood Total Time (min)	2.89
Processor Number Instantaneous Utilization	47.35%

4.2.4 Case Four

Case four consists of two processors on duty with a phone call factor of 0. In this scenario the effect of scheduling two processors with the phone call activity taken out of the simulation is analyzed. As with case three, the phlebotomists are not present in the system for a long period of time and do not assist the processor as much as when there is only one processor on duty. For the schedule refer to chapter 3, section 3-23. Table IV-6 shows the selected results for the case three simulation. The table indicates that the average number of samples out is 334 and the total time for the adult blood samples is 2.97 minutes. For the complete Category Overview report refer to Appendix D.

Table IV-6: Case Four Selected Results.

Case Four	
Processors on Duty	2
Phone Call Factor	0
Number Out (Average)	334
Adult Blood Total Time (min)	2.97
Extra Adult Blood Total Time (min)	2.99
Pediatric Blood Total Time (min)	3.00
Processor Number Instantaneous Utilization	46.78%

4.2.5 Primary Study Discussion

In this section, the results are analyzed and compared to each other, and a discussion is presented based on these findings. Table IV-7 combines the results from the previous section in order to make the comparison of the results easier.

Table IV-7: Selected Results for All Four Cases.

Selected Simulation Results				
Data	**Case**			
	Case 1 (1 Processor, 0.8 Phone Call Factor)	**Case 2 (1 Processor, 0 Phone Call Factor)**	**Case 3 (2 Processors, 0.8 Phone Call Factor)**	**Case 4 (2 Processors, 0 Phone Call Factor)**
Average Out	324	322	325	334
Adult Blood Total Time	7.22	6.64	2.89	2.97
Extra Adult Blood Total Time	7.16	6.72	2.95	2.99
Pediatric Blood Total Time	7.32	6.56	2.89	3.00
Processor Instantaneous Utilization	68.54%	64.96%	47.35%	46.78%

Table IV-8 shows the times for adult blood samples, extra adult blood samples, and pediatric blood samples with regard to total time in process. These three categories of patient samples represent a majority of the laboratory processes and a key parameter in timely throughput.

Table IV-8: Blood Type Patient Sample Average Total Time.

Data	Cases 1 & 2		Cases 3 & 4	
	Average	Standard Deviation	Average	Standard Deviation
Adult Blood Total Time	6.93	0.410	2.93	0.057
Extra Adult Blood Total Time	6.94	0.311	2.97	0.028
Pediatric Blood Total Time	6.94	0.537	2.95	0.078

Clearly having two processors on duty yields the lowest average time that the blood samples are in the system, about 2.9 minutes compared with only one processor on duty which has the blood samples in the system between 6.9 minutes. Obviously there is a tradeoff to be made. If only one processor on duty the important samples in the laboratory take about double the amount of time to be processed. The laboratory can save on the labor cost of one processor; however, it is important to recall that when there is only one processor on duty the phlebotomists are helping the processor on average a total of 2.7 hours just for the 5 hour period of observation.

Table IV-9 takes Case 1 as the base case and analyzes the percent improvement in time of process. The results from the table indicate that when one processor is on duty the phone calls effect the total time the samples are in the system by about 6% to 10% depending on the sample type. Although there is significant improvement in the total time the samples are in the system when there are two processors on duty (between 58% and 60% improvement) the difference between the cases in which the phone calls are allowed not allowed and shows only a minor change in the total time the samples are in the system.

Table IV-9: Percent Change with Regard to Adult, Extra Adult, and Pediatric Blood Samples Total Time in System.

Case	Adult Blood Total time	Percentage Change
Case 1	7.22	-
Case 2	6.64	8.03%
Case 3	2.89	59.97%
Case 4	2.97	58.86%
Case	**Extra Adult Blood Total Time**	**Percentage Change**
Case 1	7.16	-
Case 2	6.72	6.15%
Case 3	2.95	58.80%
Case 4	2.99	58.24%
Case	**Pediatric Blood Total Time**	**Percentage Change**
Case 1	7.32	-
Case 2	6.56	10.38%
Case 3	2.89	60.52%
Case 4	3.00	59.02%

4.3 Sensitivity Analysis Study – Simulation Results

This section covers the two sensitivity analyses performed. In the first sensitivity analysis the effects of changing the percentage of samples not correctly labeled is investigated. In the second sensitivity analysis the increase at different intervals to the number of patient samples arriving into the laboratory is examined.

4.3.1 Change in the Percentage of Samples Not Correctly Labeled

Another issue concerning the medical laboratory manager is the number of patient samples that are entering the laboratory that are not labeled correctly or are missing a label. This sensitivity analysis examines the effects of varying the percentage of patient samples that are not correctly labeled on hospital laboratory performance.

The sensitivity analysis is performed using 0%, 6%, 20% and 25% for the percentage of patient samples not labeled correctly. The current percentage of samples not labeled correctly is 13.5% and is used as the base case. Table IV-10 shows the results for the sensitivity analysis. Figure IV-1 displays the sensitivity results graphically for one processor on duty. Figure IV-2 depicts the sensitivity results graphically for two processors on duty. The graphical representations indicate a strong sensitivity between the time and the percentage of samples not labeled correctly.

Table IV-10: Change in Samples Not Correctly Labeled - Sensitivity Analysis Results.

Percentage Change	Average Total Time (min) - One Processor		
	Adult Blood Samples	Extra Adult Blood Samples	Pediatric Blood Samples
0.0%	4.63	4.63	4.79
6.0%	5.74	5.78	5.86
13.5%	7.23	7.16	7.32
20.0%	9.2	9.57	9.42
25.0%	11.21	11.1	11.11
Percentage Change	Average Total Time (min) - Two Processors		
	Adult Blood Samples	Extra Adult Blood Samples	Pediatric Blood Samples
0.0%	1.85	1.95	1.94
6.0%	2.29	2.33	2.33
13.5%	2.89	2.95	2.89
20.0%	3.46	3.48	3.55
25.0%	3.87	3.92	3.92

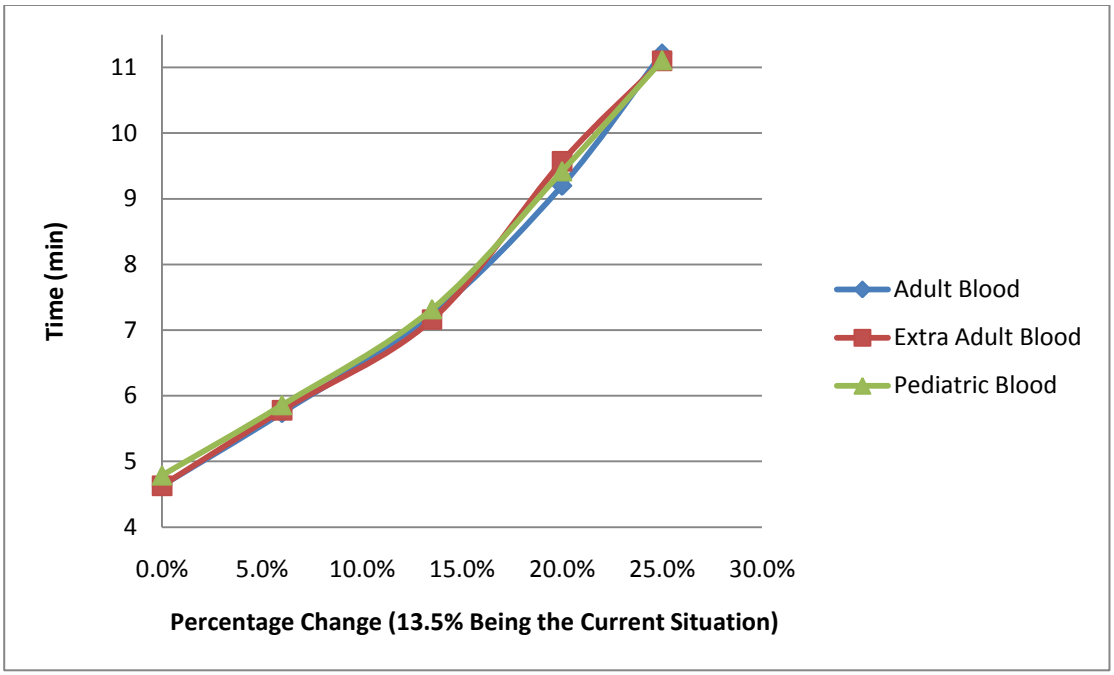

Figure IV-1: 1 Processor on Duty - Change in Samples Not Labeled Correctly.

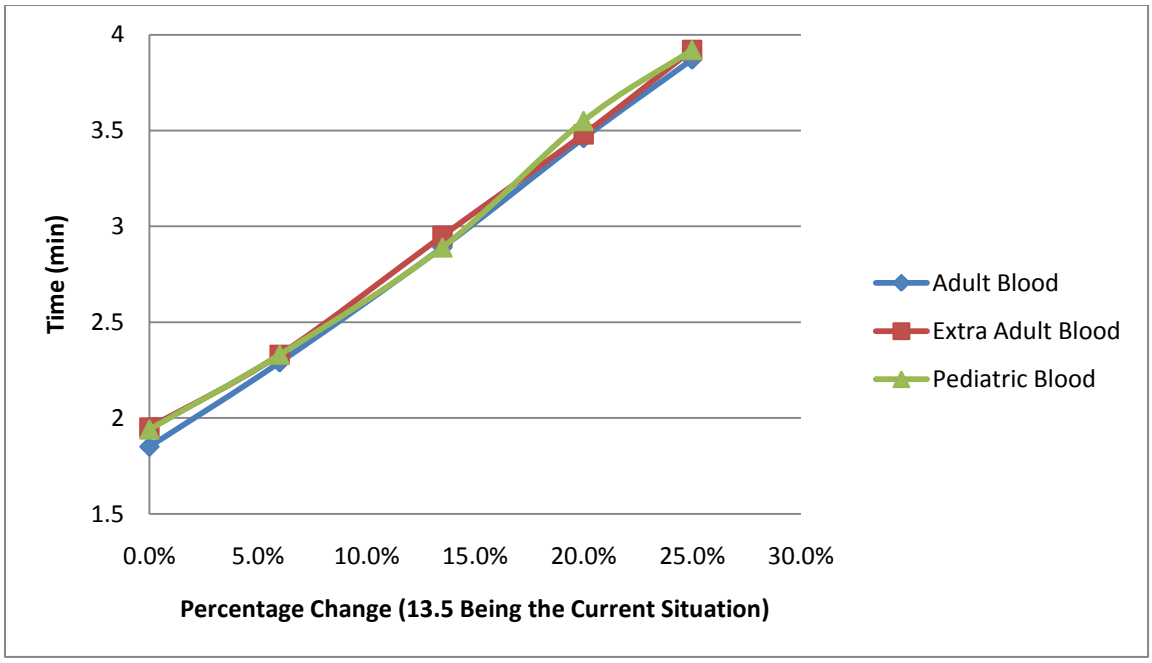

Figure IV-2: 2 Processors on Duty - Change in Samples Not Labeled Correctly.

4.3.2 Change in the Magnitude of Sample Arrivals

The medical laboratory is considering expanding its services. Also, the hospital services one of the fastest growing areas in the country. As such a study detailing the effects of hospital performance in light of an increase to the number of patient samples processed is beneficial to DHR and also other similar hospitals.

The sensitivity analysis is performed using an increase of 10%, 20%, 30%, 40%, and 50% to the time between arrivals for the two create modules in order to increase the arrival instances. A variable labeled *Var X* is created and multiplied to the two respective expressions in the create modules. Values are chosen to obtain the desired percentage increase in patient sample arrival into the simulation. Table IV-11 shows the results from the sensitivity analysis performed. Figure IV-3 displays the results for one processor on duty, while Figure IV-4 shows the results for two processors on duty. The results show that the total time for the samples is sensitive to the percentage increases to the number of arriving samples. When there are two processors on duty the total time for the samples is less sensitive to the increasing the number of arrival samples, this is evident by examining the slope of the two graphs. In Figure IV-3 the slope is at about a 45 degree angle indicating a steady increase. In Figure IV-4 the slope is almost nonexistent for the 20% and 30% increases, the slope then rises sharply for the 40% and 50% increases in sample arrivals.

Table IV-11: Change in Sample Arrivals - Sensitivity Analysis Results.

Percentage Increase	Average Total Time (min) - One Processor		
	Adult Blood Samples	Extra Adult Blood Samples	Pediatric Blood Samples
0%	7.23	7.16	7.32
10%	7.64	7.75	7.72
20%	8.74	8.97	8.80
30%	9.67	9.91	9.63
40%	11.67	12.00	11.64
50%	13.74	13.54	13.66
Percentage Increase	Average Total Time (min) - Two Processors		
	Adult Blood Samples	Extra Adult Blood Samples	Pediatric Blood Samples
0%	2.89	2.95	2.89
10%	3.10	3.30	3.21
20%	3.18	3.25	3.23
30%	3.19	3.26	3.27
40%	3.52	3.61	3.61
50%	3.76	3.80	3.85

4.4 Summary of Results

Results from these sensitivity studies help to highlight the effects of increases and decreases in the mis-labeling of patient samples and the effect of increasing sample volume on the processor functions. Further, the case studies show the effects of using one or two processors combined with the effects of telephone interruptions. Although the model was validated to sample throughput, the model could not be validated on the basis of utilization, and this distinctly limits the usefulness of the Arena model.

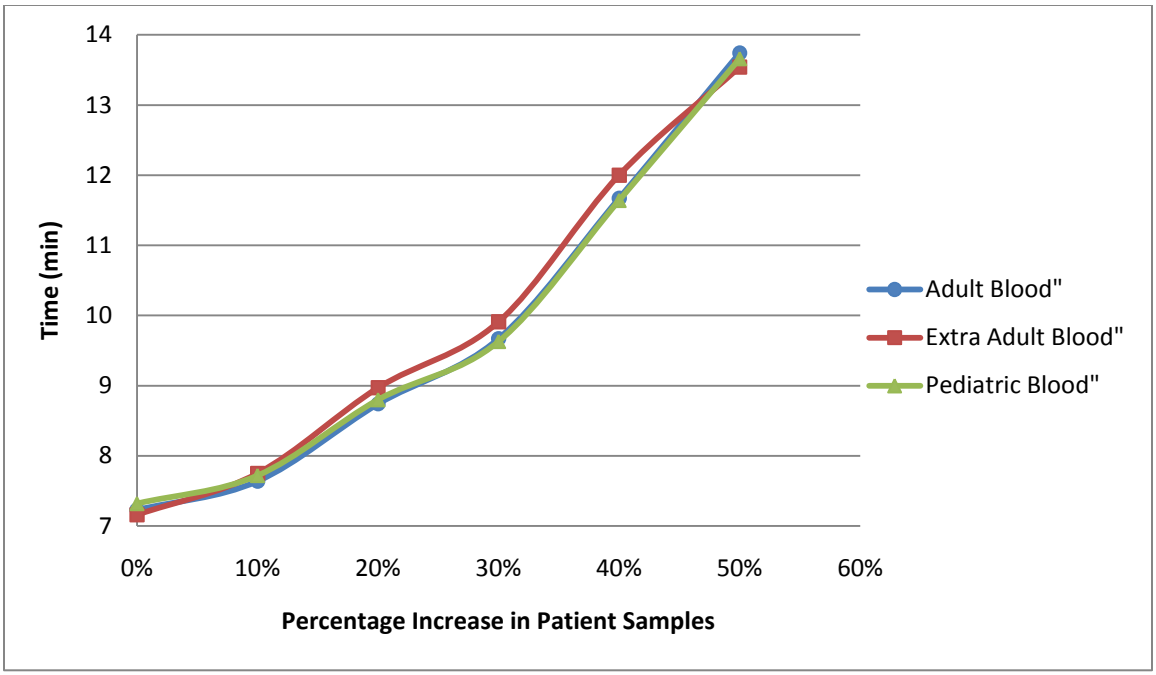

Figure IV-3: 1 Processor on Duty - Change in Sample Arrivals.

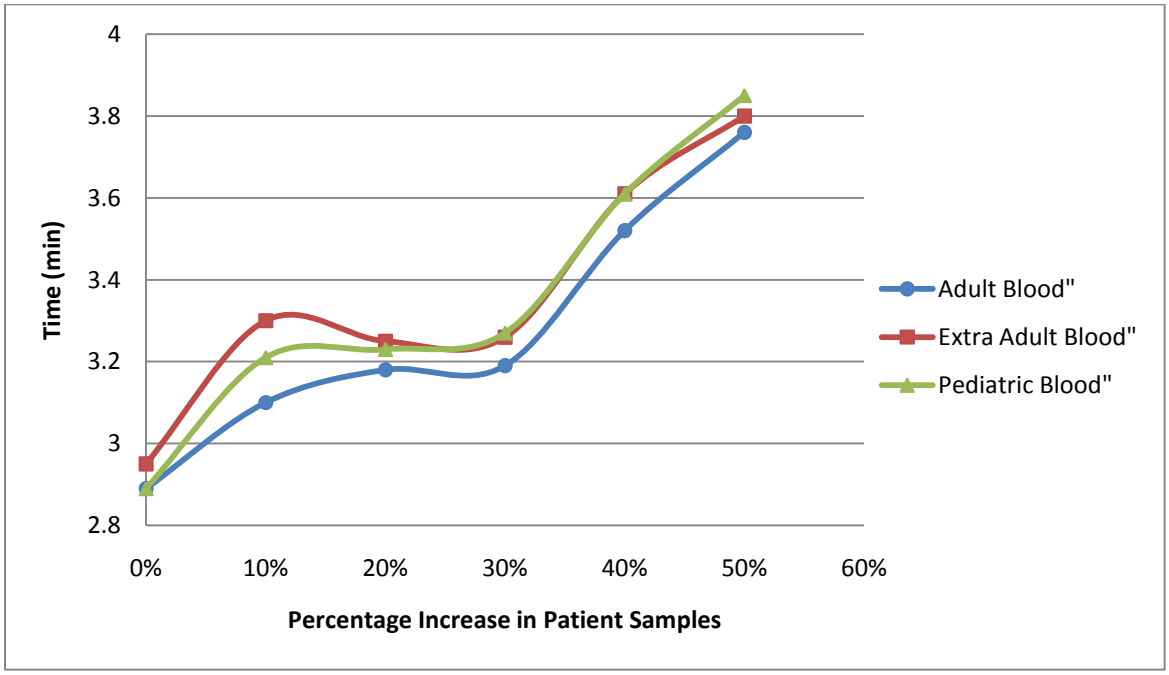

Figure IV-4: 2 Processors on Duty - Change in Sample Arrivals.

Chapter V

Conclusions

5.1 Thesis Objective

In the last quarter of the twentieth century the medical industry began to realize the importance of using manufacturing techniques in order to improve the overall efficiency and level of care in medical hospitals. Discrete event simulation is a powerful tool and has been used widely in the medical industry since its potential was realized in the mid 80's. However, the majority of studies using discrete event simulation focus on patient queuing and the reduction of wait times. Most studies model the triage and examination departments. While this is an important step to ensuring patient satisfaction and maximizing hospital resources, it is not the only area that can benefit from simulation. The medical laboratories are an important part of the hospital. They receive all types of patient samples that undergo a series of type specific tests that are used to diagnose the patient's medical condition. The patient's primary care provider in many cases cannot prescribe the proper treatment for their patients until the results are delivered from the medical laboratory. A delay in receiving the results can have a significant impact on the duration of stay or discomfort to the patient. Therefore, the optimization of a hospital medical laboratory should be a high priority in the eyes of hospital administrators.

This thesis investigates the planned changes to an area of the medical laboratory at Doctors Hospital at Renaissance. The study is focused on the processing area of the medical laboratory. When samples arrive it is up to the processing department to label and confirm the arrival of the patient samples. Then, they must be expedited to the correct area of the medical laboratory for the proper testing of the samples. The processing area receives a high level of phone calls that may have a considerable effect on the processors' workflow. One option available for the laboratory is the hiring of a phone call operator to manage the high level of calls. Additionally, the effects of having one versus two processors on duty are examined in this thesis. As a secondary study, two sensitivity analyses are also performed. In the first analysis the effects of changing the percentage of patient samples that are not correctly labeled is studied. In the second analysis the effect of increasing the number of patient samples arriving into the medical laboratory is evaluated.

5.2 Method and Results

The thesis explained in detail the methods used to build the simulation model. First the processing area was observed by a series of researchers, and two video camera recorders were also used to capture the processor(s) movements within their work area. The videos were then used to determine the inter-arrival and duration times of the defined work motions. The times were then converted into statistical distributions using the statistical software, Input Analyzer, which is part of the Arena package. The distribution equations were used in the actual simulation model. The software used a series of modules that allow for the input of the collected statistical data. The data which was based on the real system allowed for an accurate representation of the real system being modeled.

After the construction of the model was complete the model was validated using the number of patient samples that were processed in the system. These results came to within less than a 1% error from the medical data available from the medical laboratory. Validation of processor utilization was less successful at approximately 50%. Once the model was confirmed to be a reasonable representation of the system, the model was exercised with the proposed changes.

The results for the primary study suggested that when one processor was on duty the average time that a patient sample is in the system is nearly doubled when compared to the time when there are two processors on duty. Also when one processor is on duty the phlebotomists must help with the workload taking up an average of 2.7 hours of their work time to assist the processor handle the workload. It was also concluded that the phone calls entering the system do not pose a significant delay in the processors work flow.

In the secondary study, the two sensitivity analyses performed indicated that the total time the samples are in the system is indeed sensitive to the increase in the number of arriving patient samples. As the number of samples increases so does the amount of time each patient sample spends in the medical laboratory. The same can be said for increasing the percentage of patient samples that are not labeled correctly.

5.3 Implications and Recommendations

Based on the results it is recommended that two processors be kept on duty in order to minimize the total time the blood samples are in the system. Also, this strategy allows the phlebotomists more time to focus on their primary duties instead of helping out the medical laboratory processors. Also, acquiring a phone operator to handle the incoming calls in medical

laboratory may not make a significant difference. It is recommended that two hands-free sets for the telephones be acquired. These hands free sets can help free the processor from being tied to the desk where the telephone is located, so that he or she may perform other tasks and not have to stop loading the centrifuge or the automation system just because a call must be answered.

The sensitivity analyses may be useful to the laboratory staff to aid in determining the resource capacities in light of increasing the total number of samples handled, or to promote the tendency to mislabel the patient samples in order to improve the efficiency of the laboratory

This study may be useful as a guide for other hospitals to follow. The methods used in this thesis conform to accepted standards and procedures used in industry and are valid methods that can be followed for any type of discrete event simulation.

It is important to note that this thesis was performed on only a section the medical laboratory, and for the peak period of arriving patient samples. For future investigations it would be beneficial to include the whole medical laboratory in the simulation. Also, there are several machines that test the sample specimens that were not included in the simulation model. It would also be insightful to analyze the equipment capacity.

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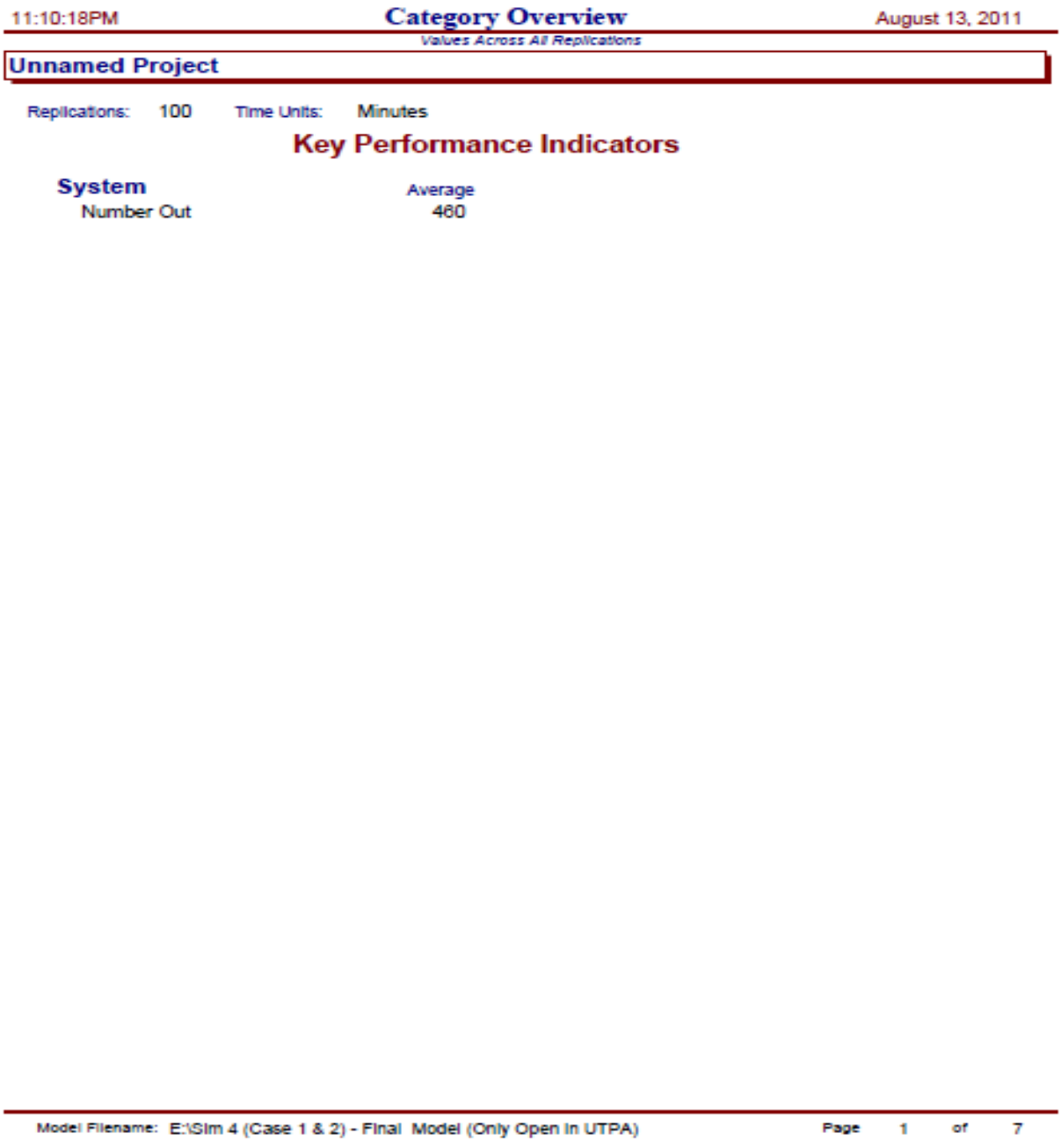
APPENDIX A

APPENDIX A

CASE 1 RESULTS



11:10:18PM **Category Overview** August 13, 2011

Values Across All Replications

Unnamed Project

Replications: 100 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	460

Model Filename: E:\Sim 4 (Case 1 & 2) - Final Model (Only Open In UTPA) Page 1 of 7

Unnamed Project

Replications: 100 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.8355	0.02	0.5952	1.1043	0.05334206	14.8322
Adult Blood	0.3689	0.01	0.2965	0.4827	0.04043600	3.2348
Adult Blood Extra	0.4488	0.01	0.3228	0.6608	0.07322060	2.9206
Child Blood	0.4458	0.01	0.3482	0.5405	0.06289793	2.7881
Micro Biology	0.3045	0.02	0.1132	0.6195	0.03420525	2.6254
Urine Sample	0.2538	0.02	0.08281652	0.5265	0.00837750	2.4817

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.5946	0.08	0.1260	2.1769	0.00	14.7972
Adult Blood	6.8584	0.58	1.9417	16.2646	0.00	74.8873
Adult Blood Extra	6.7100	0.62	1.6079	18.9237	0.00	76.6341
Child Blood	6.8718	0.63	1.7008	17.9598	0.00	57.2203
Micro Biology	4.7805	0.61	0.8102	15.1969	0.00	54.3228
Urine Sample	2.9497	0.45	0.2113	13.0763	0.00	42.7850

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Unnamed Project

Replications: 100 Time Units: Minutes

Entity

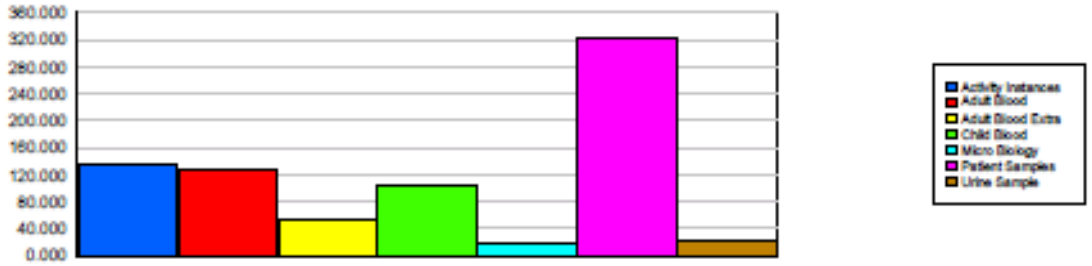
Time

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	1.4300	0.09	0.8399	3.1110	0.05335174	19.1459
Adult Blood	7.2273	0.58	2.3047	16.5831	0.04688732	76.5405
Adult Blood Extra	7.1588	0.62	2.1064	19.4508	0.0952	78.4980
Child Blood	7.3176	0.63	2.1301	18.4453	0.08838348	58.1141
Micro Biology	5.0850	0.62	0.9871	15.5598	0.04465242	54.7769
Urine Sample	3.2035	0.45	0.4042	13.3329	0.01128074	43.1552

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Activity Instances	136.27	4.19	90.0000	186.00
Adult Blood	127.78	5.43	81.0000	224.00
Adult Blood Extra	54.6000	2.44	29.0000	93.0000
Child Blood	103.39	4.45	52.0000	173.00
Micro Biology	18.1900	1.10	5.0000	31.0000
Patient Samples	324.14	13.15	187.00	532.00
Urine Sample	20.2100	1.27	9.0000	39.0000



Unnamed Project

Replications: 100 Time Units: Minutes

Entity

Other

Number Out	Average	Half Width	Minimum Average	Maximum Average
Activity Instances	136.30	4.16	91.0000	189.00
Adult Blood	127.53	5.31	79.0000	211.00
Adult Blood Extra	54.5900	2.45	29.0000	93.0000
Child Blood	102.85	4.41	52.0000	175.00
Micro Biology	18.1500	1.09	5.0000	31.0000
Patient Samples	324.17	12.83	187.00	527.00
Urine Sample	20.2100	1.27	9.0000	39.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.8186	0.06	0.3285	2.0221	0.00	15.0000
Adult Blood	2.3275	0.26	0.5275	7.7849	0.00	42.0000
Adult Blood Extra	0.9866	0.11	0.1704	3.2771	0.00	18.0000
Child Blood	1.9076	0.22	0.4269	6.1592	0.00	38.0000
Micro Biology	0.1441	0.02	0.02270622	0.6126	0.00	8.0000
Patient Samples	4.2683	0.52	0.7544	13.4929	0.00	108.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	1.0000

Unnamed Project

Replications: 100 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Admin.Act.Dow Time.Queue	0.6413	0.12	0.00	3.2271	0.00	14.7396
Check for Samples That Need Labeling.Queue	1.0025	0.14	0.1813	3.8938	0.00	38.7762
Check Sample Type.Queue	1.5458	0.17	0.2962	4.3586	0.00	38.3079
Label Samples and Confirm Tests Required.Queue	1.7618	0.20	0.1801	4.9527	0.00	37.6558
Loading or Unloading Centrifuge or Placing Extra Blood Samples in Rack.Queue	2.1705	0.19	0.6075	5.9044	0.00	38.7678
Loading Tubes in Block.Queue	1.8800	0.23	0.3840	5.6554	0.00	38.5583
Maintenence Down Time.Queue	0.5480	0.09	0.01393977	2.0193	0.00	14.7188
Off Camera Down Time.Queue	0.5634	0.09	0.05344234	2.2294	0.00	14.7972
Office Clean Up Down Time.Queue	0.5932	0.09	0.00833047	2.2984	0.00	11.8676
Phone Call Down Time.Queue	0.5957	0.11	0.06814705	2.9160	0.00	13.4825
Picking Up Bags.Queue	2.5958	0.27	0.4528	6.9364	0.00	36.7590
Place Blood Samples in Automation Pods.Queue	2.2018	0.19	0.7911	6.2241	0.00	34.8732
Talking Down Time.Queue	0.7313	0.19	0.00	7.1418	0.00	13.2295
Transfer Time to Automation Loading Rack Queue Area.Queue	2.2126	0.24	0.4624	7.4581	0.00	34.5619
Transfer Time to Automation Pod Area.Queue	1.8810	0.19	0.5517	5.0301	0.00	38.5000
Transfer Time to Centrifuge Area.Queue	1.8675	0.19	0.5224	5.1653	0.00	38.6284
Transfer Time to Microbiology Bin and Placing Sample in Bin.Queue	1.7697	0.22	0.4110	5.8525	0.00	23.7378

Other

Unnamed Project

Replications: 100 Time Units: Minutes

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Add Labels To Tubes and Test Containers or Processing.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Admin.Act.Dow Time.Queue	0.05417697	0.01	0.00	0.3227	0.00	6.0000
Automation.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Centrifuge.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Check for Samples That Need Labeling.Queue	1.4453	0.24	0.1617	7.3105	0.00	93.0000
Check Sample Type.Queue	0.8150	0.11	0.1259	2.5981	0.00	29.0000
House Keeping.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Label Samples and Confirm Tests Required.Queue	0.3367	0.05	0.01650925	1.3056	0.00	20.0000
Loading or Unloading Centrifuge or Placing Extra Blood Samples In Rack.Queue	1.4762	0.16	0.2810	4.5759	0.00	38.0000
Loading Tubes In Block.Queue	0.1075	0.02	0.01335444	0.4562	0.00	6.0000
Maintenece on Automation Line.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Maintenence Down Time.Queue	0.03433941	0.01	0.00063891	0.1178	0.00	3.0000
Off Camera Down Time.Queue	0.08105552	0.01	0.00757100	0.4180	0.00	6.0000
Office Clean Up Down Time.Queue	0.03158793	0.01	0.00024297	0.1226	0.00	3.0000
Phone Call Down Time.Queue	0.08338313	0.01	0.00465860	0.4900	0.00	5.0000
Picking Up Bags.Queue	1.3422	0.16	0.1962	4.2197	0.00	31.0000
Picking Up Samples.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Place Blood Samples In Automation Pods.Queue	1.0866	0.12	0.2495	3.6244	0.00	27.0000
Placing Block Into Automation Line.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Talking Down Time.Queue	0.06209915	0.01	0.00	0.3182	0.00	7.0000
Transfer Time to Automation Loading Rack Queue Area.Queue	0.1276	0.02	0.00663845	0.5594	0.00	6.0000
Transfer Time to Automation Pod Area.Queue	0.9381	0.12	0.1732	3.1857	0.00	27.0000
Transfer Time to Centrifuge Area.Queue	1.2859	0.17	0.2145	4.5152	0.00	38.0000
Transfer Time to Microbiology Bin and Placing Sample In Bin.Queue	0.1403	0.02	0.02059160	0.6068	0.00	8.0000

Unnamed Project

Replications: 100 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	0.6854	0.01	0.5087	0.8559	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	1.0046	0.02	0.7411	1.2778	0.00	2.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	1.5406	0.00	1.5333	1.5417	1.0000	2.0000

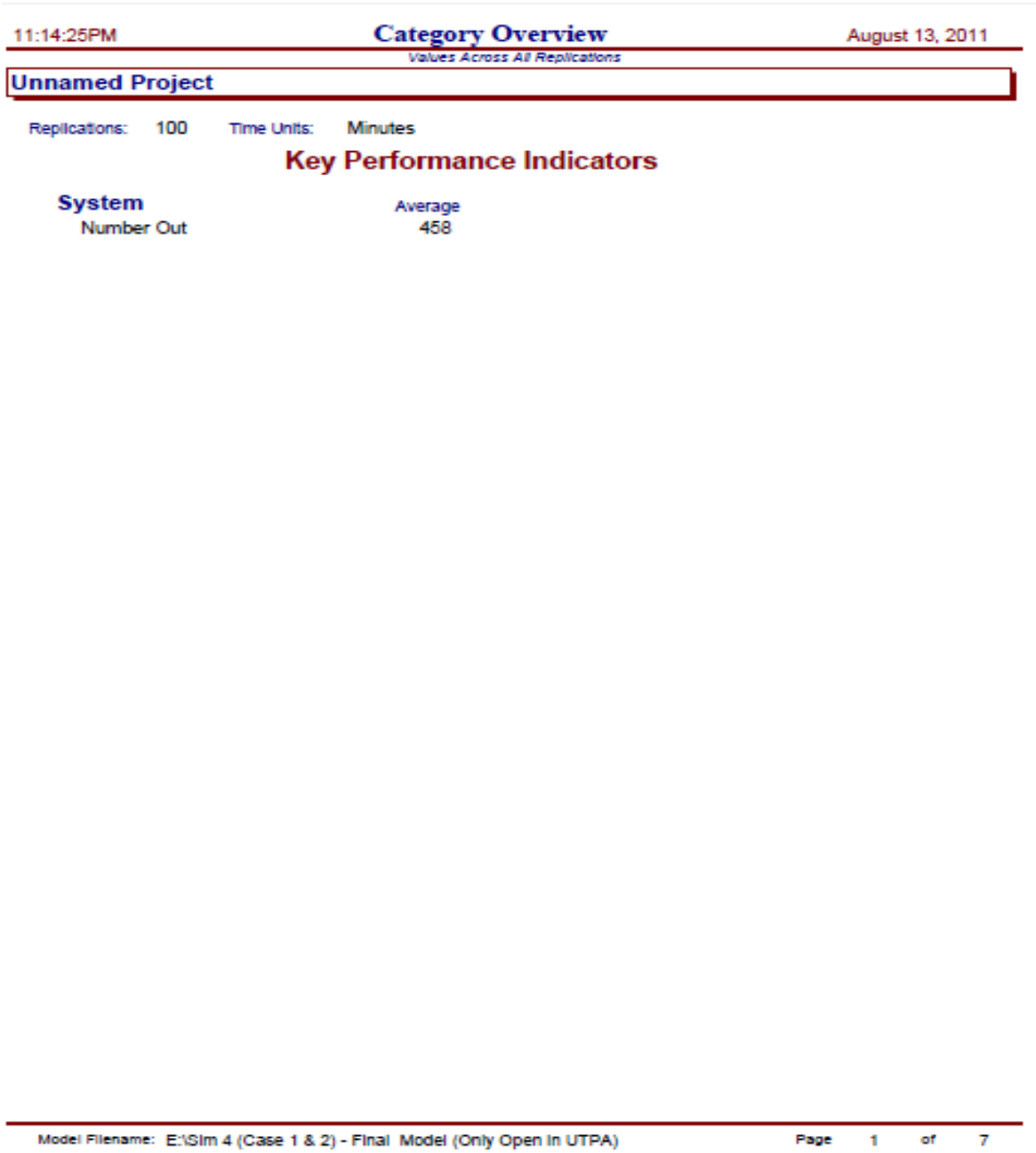
Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Processor	0.6521	0.01	0.4808	0.8291

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Processor	1333.29	43.08	895.00	1980.00

APPENDIX B

APPENDIX B

CASE TWO RESULTS



11:14:25PM **Category Overview** August 13, 2011

Values Across All Replications

Unnamed Project

Replications: 100 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	458

Model Filename: E:\Sim 4 (Case 1 & 2) - Final Model (Only Open In UTPA) Page 1 of 7

Unnamed Project

Replications: 100 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.7636	0.02	0.4855	1.1748	0.00	14.8107
Adult Blood	0.3688	0.01	0.2964	0.4712	0.03822399	3.2115
Adult Blood Extra	0.4380	0.01	0.3328	0.6422	0.06105764	2.8285
Child Blood	0.4395	0.01	0.3437	0.5314	0.06639683	2.8818
Micro Biology	0.3051	0.02	0.08895531	0.5960	0.03560534	2.1060
Urine Sample	0.2350	0.02	0.05576517	0.4801	0.00839005	2.2554

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.5236	0.08	0.1263	2.3063	0.00	16.9293
Adult Blood	6.2729	0.75	2.0267	28.4830	0.00	97.0221
Adult Blood Extra	6.2792	0.76	1.8915	29.0771	0.00	83.1675
Child Blood	6.1181	0.66	1.9877	21.8061	0.00	91.3303
Micro Biology	4.4264	0.61	0.8483	18.9333	0.00	84.4653
Urine Sample	2.4637	0.40	0.4744	14.4413	0.00	57.9766

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Unnamed Project

Replications: 100 Time Units: Minutes

Entity

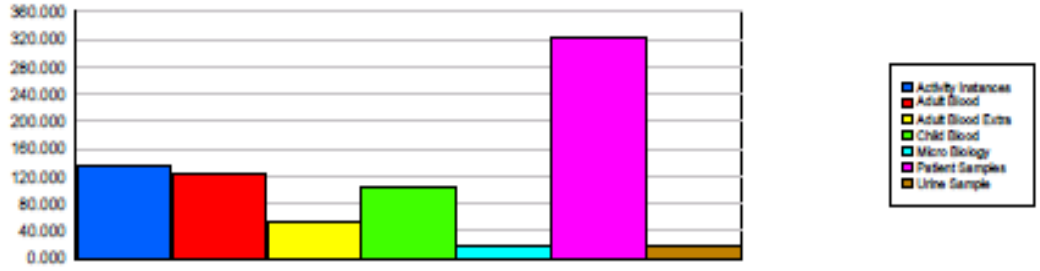
Time

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	1.2873	0.10	0.6543	3.2137	0.00	21.0848
Adult Blood	6.6416	0.75	2.3827	28.8600	0.05904831	98.4933
Adult Blood Extra	6.7172	0.76	2.3327	29.5364	0.1176	83.4361
Child Blood	6.5576	0.66	2.3314	22.1986	0.08766208	91.8634
Micro Biology	4.7316	0.61	0.9936	19.1822	0.04581393	84.9688
Urine Sample	2.6988	0.40	0.7238	14.7630	0.00988444	58.8502

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Activity Instances	134.04	3.54	91.0000	183.00
Adult Blood	124.91	5.81	66.0000	204.00
Adult Blood Extra	54.3400	2.74	21.0000	93.0000
Child Blood	104.10	5.00	48.0000	186.00
Micro Biology	18.4000	1.05	10.0000	34.0000
Patient Samples	320.73	14.16	165.00	549.00
Urine Sample	20.0700	1.31	7.0000	38.0000



Unnamed Project

Replications: 100 Time Units: Minutes

Entity

Other

Number Out	Average	Half Width	Minimum Average	Maximum Average
Activity Instances	134.03	3.54	91.0000	182.00
Adult Blood	125.90	5.96	77.0000	213.00
Adult Blood Extra	54.7800	2.80	21.0000	93.0000
Child Blood	104.87	5.03	49.0000	179.00
Micro Biology	18.4600	1.04	10.0000	34.0000
Patient Samples	321.82	14.20	167.00	542.00
Urine Sample	20.0700	1.31	7.0000	38.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.7230	0.06	0.3576	1.8613	0.00	19.0000
Adult Blood	2.1603	0.33	0.3422	12.6817	0.00	55.0000
Adult Blood Extra	0.9505	0.14	0.06303023	5.4297	0.00	22.0000
Child Blood	1.7843	0.25	0.2116	7.7786	0.00	36.0000
Micro Biology	0.1504	0.03	0.01554789	0.8288	0.00	9.0000
Patient Samples	3.7872	0.59	0.8721	21.4686	0.00	112.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	1.0000

Unnamed Project

Replications: 100 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Admin.Act.Dow Time.Queue	0.5670	0.13	0.00719890	3.4297	0.00	16.8966
Check for Samples That Need Labeling.Queue	0.8955	0.17	0.1447	7.1939	0.00	36.5082
Check Sample Type.Queue	1.3334	0.18	0.3162	5.9310	0.00	34.5650
Label Samples and Confirm Tests Required.Queue	1.5781	0.18	0.3447	5.8285	0.00	34.3696
Loading or Unloading Centrifuge or Placing Extra Blood Samples in Rack.Queue	2.0292	0.22	0.4397	8.0050	0.00	34.8224
Loading Tubes in Block.Queue	1.5941	0.23	0.1120	6.8534	0.00	36.6355
Maintenence Down Time.Queue	0.4813	0.12	0.01110100	3.5303	0.00	16.3571
Off Camera Down Time.Queue	0.4715	0.08	0.08097109	2.0943	0.00	14.1701
Office Clean Up Down Time.Queue	0.5336	0.11	0.00981892	2.6192	0.00	16.2434
Phone Call Down Time.Queue	0.5198	0.11	0.03617786	4.2852	0.00	16.9293
Picking Up Bags.Queue	2.3037	0.28	0.4620	7.2938	0.00	33.5838
Place Blood Samples in Automation Pods.Queue	2.0591	0.24	0.3938	9.4004	0.00	36.4901
Talking Down Time.Queue	0.5734	0.12	0.00	3.3340	0.00	16.7067
Transfer Time to Automation Loading Rack Queue Area.Queue	1.9713	0.26	0.2693	8.4869	0.00	34.1808
Transfer Time to Automation Pod Area.Queue	1.7193	0.19	0.4600	6.5199	0.00	36.6175
Transfer Time to Centrifuge Area.Queue	1.6577	0.18	0.3701	5.7080	0.00	36.6381
Transfer Time to Microbiology Bin and Placing Sample in Bin.Queue	1.7811	0.22	0.2921	7.0135	0.00	36.6402

Other

Unnamed Project

Replications: 100 Time Units: Minutes

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Add Labels To Tubes and Test Containers or Processing.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Admin.Act.Dow Time.Queue	0.04938592	0.01	0.00016021	0.3001	0.00	5.0000
Automation.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Centrifuge.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Check for Samples That Need Labeling.Queue	1.3228	0.32	0.1689	13.3101	0.00	93.0000
Check Sample Type.Queue	0.6877	0.11	0.1357	3.2191	0.00	31.0000
House Keeping.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Label Samples and Confirm Tests Required.Queue	0.3046	0.05	0.03590404	1.4086	0.00	15.0000
Loading or Unloading Centrifuge or Placing Extra Blood Samples In Rack.Queue	1.4360	0.22	0.1301	7.8610	0.00	39.0000
Loading Tubes In Block.Queue	0.0937	0.02	0.00186613	0.3875	0.00	8.0000
Maintenece on Automation Line.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Maintenence Down Time.Queue	0.02831811	0.01	0.00050880	0.1912	0.00	3.0000
Off Camera Down Time.Queue	0.06517744	0.01	0.00809711	0.2967	0.00	5.0000
Office Clean Up Down Time.Queue	0.02722990	0.01	0.00040912	0.1355	0.00	3.0000
Phone Call Down Time.Queue	0.06899240	0.01	0.00172404	0.3750	0.00	6.0000
Picking Up Bags.Queue	1.1518	0.16	0.2080	3.4119	0.00	31.0000
Picking Up Samples.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Place Blood Samples In Automation Pods.Queue	1.0305	0.17	0.1083	7.1794	0.00	33.0000
Placing Block Into Automation Line.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Talking Down Time.Queue	0.05844805	0.01	0.00	0.4029	0.00	7.0000
Transfer Time to Automation Loading Rack Queue Area.Queue	0.1151	0.02	0.00448870	0.5679	0.00	8.0000
Transfer Time to Automation Pod Area.Queue	0.8548	0.13	0.1265	4.4378	0.00	33.0000
Transfer Time to Centrifuge Area.Queue	1.1664	0.17	0.1095	5.1515	0.00	39.0000
Transfer Time to Microbiology Bin and Placing Sample In Bin.Queue	0.1465	0.02	0.01338995	0.8232	0.00	9.0000

Unnamed Project

Replications: 100 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	0.6496	0.02	0.4626	0.8182	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	0.9481	0.03	0.6777	1.2312	0.00	2.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	1.5405	0.00	1.5299	1.5417	1.0000	2.0000

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Processor	0.6155	0.02	0.4397	0.7991

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Processor	1321.40	48.75	804.00	2028.00

APPENDIX C

APPENDIX C

CASE 3 RESULTS

11:17:27PM **Category Overview** August 13, 2011

Values Across All Replications

Unnamed Project

Replications: 100 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	460

Model Filename: E:\Sim 4 (Case 3 & 4) - Final Model (Only Open In UTPA) Page 1 of 7

Unnamed Project

Replications: 100 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.8423	0.03	0.6304	1.2402	0.05333356	14.8315
Adult Blood	0.3770	0.01	0.3135	0.4973	0.03743321	3.0143
Adult Blood Extra	0.4536	0.01	0.3187	0.6421	0.06161673	3.1374
Child Blood	0.4453	0.01	0.3501	0.5626	0.05964792	3.1326
Micro Biology	0.2787	0.02	0.1159	0.5362	0.03503569	2.3687
Urine Sample	0.2434	0.02	0.07376650	0.4898	0.00847714	2.7605

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.0956	0.01	0.02772432	0.3999	0.00	12.3853
Adult Blood	2.5141	0.24	0.7791	7.0892	0.00	29.3752
Adult Blood Extra	2.4944	0.24	0.8662	6.4547	0.00	28.6570
Child Blood	2.4408	0.22	0.9825	6.0332	0.00	27.6189
Micro Biology	1.5573	0.20	0.3420	6.1494	0.00	27.8822
Urine Sample	0.7726	0.09	0.1409	3.3512	0.00	23.2975

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Unnamed Project

Replications: 100 Time Units: Minutes

Entity

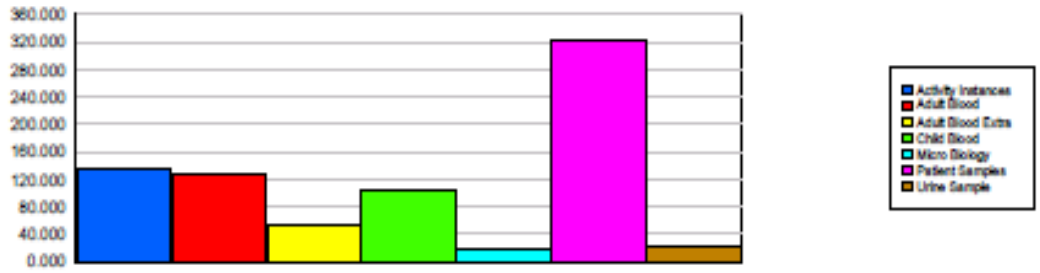
Time

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.9379	0.03	0.7133	1.6400	0.05333356	22.9137
Adult Blood	2.8911	0.24	1.1575	7.4648	0.06536198	30.3380
Adult Blood Extra	2.9480	0.24	1.2133	6.9028	0.08310389	29.0679
Child Blood	2.8861	0.22	1.3808	6.4551	0.07813781	28.2716
Micro Biology	1.8360	0.20	0.4834	6.4837	0.04124450	30.0222
Urine Sample	1.0160	0.10	0.2519	3.6483	0.00847714	24.2337

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Activity Instances	134.48	4.11	84.0000	199.00
Adult Blood	128.11	5.49	75.0000	199.00
Adult Blood Extra	54.0900	2.93	29.0000	110.00
Child Blood	104.03	4.13	62.0000	166.00
Micro Biology	18.9200	1.13	7.0000	34.0000
Patient Samples	324.45	13.18	197.00	519.00
Urine Sample	20.2700	1.27	8.0000	37.0000



Unnamed Project

Replications: 100 Time Units: Minutes

Entity

Other

Number Out	Average	Half Width	Minimum Average	Maximum Average
Activity Instances	134.44	4.09	85.0000	199.00
Adult Blood	128.18	5.55	75.0000	199.00
Adult Blood Extra	54.1500	2.95	29.0000	110.00
Child Blood	104.16	4.18	62.0000	166.00
Micro Biology	18.9200	1.14	7.0000	34.0000
Patient Samples	325.42	13.23	197.00	532.00
Urine Sample	20.2700	1.27	8.0000	37.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.5228	0.02	0.3409	0.8570	0.00	8.0000
Adult Blood	1.0144	0.11	0.2363	3.0563	0.00	34.0000
Adult Blood Extra	0.4459	0.06	0.1052	1.6853	0.00	20.0000
Child Blood	0.8429	0.09	0.2808	2.5640	0.00	28.0000
Micro Biology	0.06957961	0.01	0.01017903	0.3823	0.00	8.0000
Patient Samples	1.4422	0.14	0.5335	4.0905	0.00	78.0000
Urine Sample	0.00	0.00	0.00	0.00	0.00	1.0000

Unnamed Project

Replications: 100 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Admin.Act.Dow Time.Queue	0.1096	0.02	0.00	0.8003	0.00	4.5007
Check for Samples That Need Labeling.Queue	0.3091	0.03	0.08653494	0.9767	0.00	11.3083
Check Sample Type.Queue	0.4457	0.04	0.1288	1.3372	0.00	11.8201
Label Samples and Confirm Tests Required.Queue	0.6943	0.09	0.1758	2.4555	0.00	12.9540
Loading or Unloading Centrifuge or Placing Extra Blood Samples in Rack.Queue	0.9344	0.08	0.3605	2.2450	0.00	12.8507
Loading Tubes in Block.Queue	0.7559	0.10	0.05827730	3.4296	0.00	9.0481
Maintenence Down Time.Queue	0.08083972	0.01	0.00204818	0.3786	0.00	2.2966
Off Camera Down Time.Queue	0.0931	0.02	0.00879804	0.7561	0.00	12.3853
Office Clean Up Down Time.Queue	0.0953	0.03	0.00	1.4154	0.00	10.5678
Phone Call Down Time.Queue	0.0958	0.01	0.00	0.4340	0.00	5.4374
Picking Up Bags.Queue	0.5790	0.08	0.1431	2.7380	0.00	19.2709
Place Blood Samples in Automation Pods.Queue	0.9547	0.08	0.2843	2.5583	0.00	12.7963
Talking Down Time.Queue	0.1008	0.02	0.00	0.6318	0.00	11.1138
Transfer Time to Automation Loading Rack Queue Area.Queue	0.9911	0.11	0.1518	3.1963	0.00	9.5881
Transfer Time to Automation Pod Area.Queue	0.7439	0.08	0.1900	2.4664	0.00	13.4458
Transfer Time to Centrifuge Area.Queue	0.7449	0.08	0.2498	2.1725	0.00	13.5162
Transfer Time to Microbiology Bin and Placing Sample in Bin.Queue	0.7798	0.11	0.1353	3.4533	0.00	13.4052

Other

Unnamed Project

Replications: 100 Time Units: Minutes

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Add Labels To Tubes and Test Containers or Processing.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Admin.Act.Dow Time.Queue	0.00850465	0.00	0.00	0.05307455	0.00	2.0000
Automation.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Centrifuge.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Check for Samples That Need Labeling.Queue	0.4416	0.06	0.0919	1.8815	0.00	75.0000
Check Sample Type.Queue	0.2321	0.03	0.05675277	0.6808	0.00	19.0000
House Keeping.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Label Samples and Confirm Tests Required.Queue	0.1349	0.02	0.02088359	0.5141	0.00	14.0000
Loading or Unloading Centrifuge or Placing Extra Blood Samples in Rack.Queue	0.6432	0.07	0.1885	2.0971	0.00	35.0000
Loading Tubes in Block.Queue	0.04399702	0.01	0.00097129	0.2613	0.00	6.0000
Maintenece on Automation Line.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Maintenence Down Time.Queue	0.00483738	0.00	0.00010530	0.01835753	0.00	2.0000
Off Camera Down Time.Queue	0.01309907	0.00	0.00104222	0.1103	0.00	2.0000
Office Clean Up Down Time.Queue	0.00486522	0.00	0.00	0.04717874	0.00	1.0000
Phone Call Down Time.Queue	0.01239390	0.00	0.00	0.04183724	0.00	3.0000
Picking Up Bags.Queue	0.3008	0.04	0.06381054	1.3462	0.00	19.0000
Picking Up Samples.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Place Blood Samples in Automation Pods.Queue	0.4759	0.05	0.1018	1.4840	0.00	26.0000
Placing Block into Automation Line.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Talking Down Time.Queue	0.01020246	0.00	0.00	0.0948	0.00	5.0000
Transfer Time to Automation Loading Rack Queue Area.Queue	0.05613405	0.01	0.00442839	0.2404	0.00	6.0000
Transfer Time to Automation Pod Area.Queue	0.3706	0.05	0.06571735	1.2898	0.00	25.0000
Transfer Time to Centrifuge Area.Queue	0.5138	0.07	0.1085	1.8560	0.00	35.0000
Transfer Time to Microbiology Bin and Placing Sample in Bin.Queue	0.06570644	0.01	0.00850249	0.3771	0.00	8.0000

Unnamed Project

Replications: 100 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	0.4735	0.01	0.3395	0.6245	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	1.0054	0.02	0.7079	1.3456	0.00	3.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	2.1663	0.00	2.1614	2.1667	2.0000	3.0000

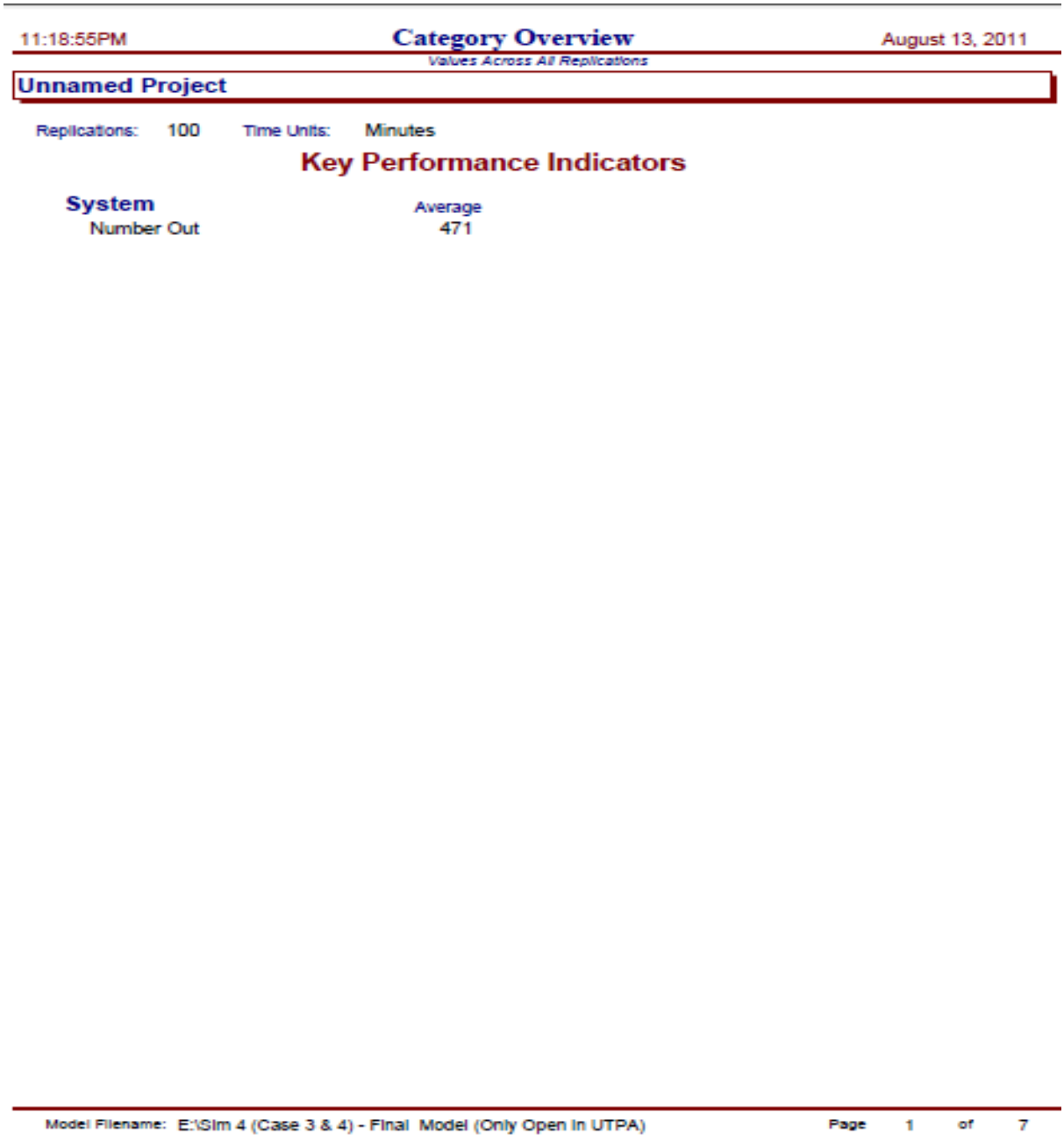
Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Processor	0.4641	0.01	0.3267	0.6212

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Processor	1339.10	45.01	888.00	2070.00

APPENDIX D

APPENDIX D

CASE FOUR RESULTS



11:18:55PM **Category Overview** August 13, 2011

Values Across All Replications

Unnamed Project

Replications: 100 Time Units: Minutes

Key Performance Indicators

System	Average
Number Out	471

Model Filename: E:\Sim 4 (Case 3 & 4) - Final Model (Only Open In UTPA) Page 1 of 7

Unnamed Project

Replications: 100 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.7924	0.03	0.4904	1.3599	0.00	14.8315
Adult Blood	0.3737	0.01	0.2999	0.4546	0.02836416	3.1762
Adult Blood Extra	0.4419	0.01	0.3160	0.5579	0.06041322	2.8305
Child Blood	0.4482	0.01	0.3733	0.5355	0.06572950	2.8412
Micro Biology	0.2849	0.02	0.1376	0.6782	0.03477123	2.4835
Urine Sample	0.2344	0.02	0.04979614	0.4992	0.00839041	2.1242

NVA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.08884631	0.01	0.02040220	0.2764	0.00	7.2254
Adult Blood	2.6011	0.23	0.9311	6.0834	0.00	22.5967
Adult Blood Extra	2.5431	0.22	0.7627	6.3028	0.00	20.7834
Child Blood	2.5586	0.21	0.8343	5.5506	0.00	21.6034
Micro Biology	1.5965	0.17	0.3152	4.8448	0.00	18.0692
Urine Sample	0.8613	0.11	0.1078	2.9110	0.00	15.6346

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Unnamed Project

Replications: 100 Time Units: Minutes

Entity

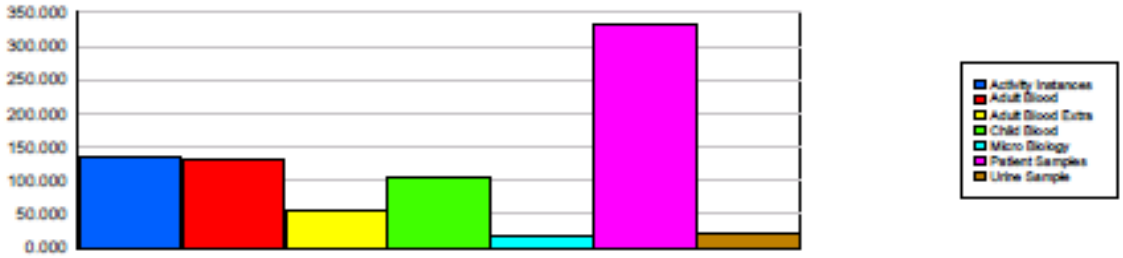
Time

Other Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood	0.00	0.00	0.00	0.00	0.00	0.00
Adult Blood Extra	0.00	0.00	0.00	0.00	0.00	0.00
Child Blood	0.00	0.00	0.00	0.00	0.00	0.00
Micro Biology	0.00	0.00	0.00	0.00	0.00	0.00
Urine Sample	0.00	0.00	0.00	0.00	0.00	0.00

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.8812	0.03	0.5121	1.4061	0.00	16.6126
Adult Blood	2.9748	0.23	1.2391	6.4877	0.05143685	24.0003
Adult Blood Extra	2.9851	0.22	1.1902	6.7523	0.08887616	22.1941
Child Blood	3.0069	0.21	1.2881	6.0183	0.08950955	22.9076
Micro Biology	1.8813	0.17	0.4725	5.0946	0.04914222	19.0944
Urine Sample	1.0957	0.11	0.2338	3.1641	0.00854811	15.7801

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Activity Instances	135.70	3.60	76.0000	182.00
Adult Blood	132.41	5.18	69.0000	197.00
Adult Blood Extra	56.0600	2.36	27.0000	86.0000
Child Blood	105.71	4.12	69.0000	154.00
Micro Biology	18.7900	0.91	10.0000	32.0000
Patient Samples	334.30	11.86	212.00	479.00
Urine Sample	21.2700	1.24	8.0000	35.0000



Unnamed Project

Replications: 100 Time Units: Minutes

Entity

Other

Number Out	Average	Half Width	Minimum Average	Maximum Average
Activity Instances	135.71	3.57	77.0000	183.00
Adult Blood	132.83	5.28	69.0000	197.00
Adult Blood Extra	56.2400	2.40	27.0000	91.0000
Child Blood	105.95	4.16	69.0000	157.00
Micro Biology	18.8200	0.91	10.0000	32.0000
Patient Samples	334.24	11.89	212.00	479.00
Urine Sample	21.2700	1.24	8.0000	35.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Activity Instances	0.4951	0.02	0.2996	0.7724	0.00	8.0000
Adult Blood	1.0617	0.11	0.2570	3.1878	0.00	38.0000
Adult Blood Extra	0.4612	0.05	0.1140	1.4412	0.00	18.0000
Child Blood	0.8810	0.09	0.1922	2.5462	0.00	34.0000
Micro Biology	0.06451971	0.01	0.00962119	0.1892	0.00	7.0000
Patient Samples	1.5503	0.15	0.5221	3.9345	0.00	88.0000
Urine Sample	0.00	0.00	0.00	0.00	0.00	1.0000

Unnamed Project

Replications: 100 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Admin.Act.Dow Time.Queue	0.1040	0.03	0.00	0.6328	0.00	6.0906
Check for Samples That Need Labeling.Queue	0.3432	0.05	0.0922	1.4898	0.00	11.7790
Check Sample Type.Queue	0.4793	0.05	0.1308	1.1579	0.00	11.7815
Label Samples and Confirm Tests Required.Queue	0.6797	0.07	0.1401	1.7845	0.00	10.3173
Loading or Unloading Centrifuge or Placing Extra Blood Samples In Rack.Queue	0.9766	0.08	0.2727	2.2343	0.00	11.5474
Loading Tubes In Block.Queue	0.7578	0.08	0.07716475	2.2068	0.00	11.0720
Maintenence Down Time.Queue	0.0915	0.02	0.00	0.6408	0.00	6.6726
Off Camera Down Time.Queue	0.07925362	0.01	0.00481376	0.3480	0.00	6.1964
Office Clean Up Down Time.Queue	0.07929646	0.02	0.00	0.5351	0.00	3.4175
Phone Call Down Time.Queue	0.08825758	0.01	0.01417595	0.4560	0.00	7.2254
Picking Up Bags.Queue	0.6157	0.06	0.1592	1.5861	0.00	11.1641
Place Blood Samples In Automation Pods.Queue	0.9795	0.09	0.2930	2.3652	0.00	11.4472
Talking Down Time.Queue	0.0920	0.02	0.00	0.4801	0.00	5.0932
Transfer Time to Automation Loading Rack Queue Area.Queue	1.0255	0.11	0.07355911	2.6130	0.00	9.7846
Transfer Time to Automation Pod Area.Queue	0.7501	0.07	0.2486	2.0688	0.00	12.9529
Transfer Time to Centrifuge Area.Queue	0.7461	0.06	0.1931	1.7395	0.00	11.5937
Transfer Time to Microbiology Bin and Placing Sample In Bin.Queue	0.7600	0.08	0.1582	2.3401	0.00	9.0871

Other

Unnamed Project

Replications: 100 Time Units: Minutes

Queue

Other

Number Waiting	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Add Labels To Tubes and Test Containers or Processing.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Admin.Act.Dow Time.Queue	0.00827321	0.00	0.00	0.07383032	0.00	3.0000
Automation.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Centrifuge.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Check for Samples That Need Labeling.Queue	0.4950	0.07	0.0937	1.9492	0.00	80.0000
Check Sample Type.Queue	0.2555	0.03	0.05940917	0.6783	0.00	20.0000
House Keeping.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Label Samples and Confirm Tests Required.Queue	0.1338	0.02	0.01400887	0.5271	0.00	14.0000
Loading or Unloading Centrifuge or Placing Extra Blood Samples In Rack.Queue	0.6853	0.08	0.1284	2.2565	0.00	40.0000
Loading Tubes In Block.Queue	0.04465406	0.01	0.00289368	0.1287	0.00	5.0000
Maintenece on Automation Line.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Maintenence Down Time.Queue	0.00551242	0.00	0.00	0.04004917	0.00	2.0000
Off Camera Down Time.Queue	0.01133631	0.00	0.00062178	0.04910558	0.00	3.0000
Office Clean Up Down Time.Queue	0.00426441	0.00	0.00	0.03121155	0.00	2.0000
Phone Call Down Time.Queue	0.01125673	0.00	0.00096845	0.04559625	0.00	3.0000
Picking Up Bags.Queue	0.3270	0.04	0.07231958	1.0376	0.00	21.0000
Picking Up Samples.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Place Blood Samples In Automation Pods.Queue	0.5019	0.06	0.07325594	1.5078	0.00	27.0000
Placing Block Into Automation Line.Queue	0.00	0.00	0.00	0.00	0.00	0.00
Talking Down Time.Queue	0.00983660	0.00	0.00	0.07600976	0.00	3.0000
Transfer Time to Automation Loading Rack Queue Area.Queue	0.06202098	0.01	0.00275847	0.1851	0.00	5.0000
Transfer Time to Automation Pod Area.Queue	0.3822	0.04	0.08296200	1.3189	0.00	27.0000
Transfer Time to Centrifuge Area.Queue	0.5210	0.06	0.0909	1.4452	0.00	40.0000
Transfer Time to Microbiology Bin and Placing Sample In Bin.Queue	0.06060668	0.01	0.00725004	0.1853	0.00	7.0000

Unnamed Project

Replications: 100 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	0.4676	0.01	0.3344	0.6446	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	0.9942	0.02	0.6990	1.3809	0.00	3.0000

Number Scheduled	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Processor	2.1664	0.00	2.1629	2.1667	2.0000	3.0000

Scheduled Utilization	Average	Half Width	Minimum Average	Maximum Average
Processor	0.4589	0.01	0.3226	0.6375

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Processor	1371.43	41.50	975.00	1867.00

BIOGRAPHICAL SKETCH

Gerardo Morales was born in McAllen, Texas in 1984. Gerardo received his B.S. in Mechanical Engineering from the University of Texas Pan American in 2007, and M.S. in Engineering Management from the University of Texas Pan American in 2011. He was a Teachers' Assistant for the Manufacturing Engineering Department in the University of Texas Pan American from 2009 to 2011 where he instructed the Manufacturing Processes Laboratory Class. His research includes investigating improvements to molten salt bath cleaning methods, installation of a virtual environment laboratory, and design of a water filtration system. He has worked in the automotive industry as an engineering specialist in a manufacturing plant. Gerardo Morales can be reached at P.O. Box 801 Edinburg, Texas 78540.