



AMERICAN UNIVERSITY OF BEIRUT

APPLYING OPERATIONS RESEARCH AT AUBMC: TWO  
PILOT STUDIES ON MATERIAL  
MANAGEMENT AND FAMILY MEDICINE PATIENT FLOW

by  
HISHAM FOUAD ARNAOUT

A thesis  
submitted in partial fulfillment of the requirements  
for the degree of Master in Engineering Management  
to the Engineering Management Program  
of the Faculty of Engineering and Architecture  
at the American University of Beirut

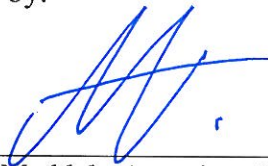
Beirut, Lebanon  
January 2014

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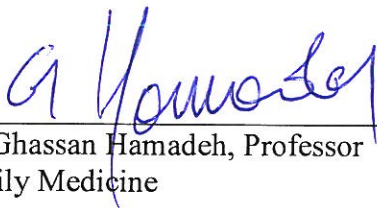
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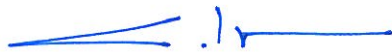
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## ACKNOWLEDGMENTS

This thesis would have not been possible without the support of many people. Henceforth, I would like to extend my appreciation to the following.

Singular thanks to God for the perseverance, wisdom, and patience that he has bestowed upon me, without which I would not have been able to accomplish such a project.

Thanks to my family, beloved ones, and friends who have showed their continuous support and tolerance throughout the project, in addition to their credence in my capabilities to finish the thesis. Specifically, thanks to my Father and Mother for their tremendous emotional and financial support, without which I would not have been able to accomplish such an endeavor.

Special thanks to Dr. Bacel Maddah, for making this research conceivable. His guidance, support, advice, brilliance, and tremendous effort are greatly appreciated.

Thanks to Dr. Walid Nasr and Dr. Joe Naoum Sawaya for their contribution and provision during the course of accomplishing the first pilot study.

Thanks to Dr. Ghassan Hamadeh and Mr. Hrayr Aprahamian, for their major role, contribution, and say in the second pilot study.

Thanks to Dr. Dania Baba, Ms. Anna Maria Abi Rashed, Mr. Ashraf Saleh, and Mr. Yaman Skheita for their influence, input, and endurance in the first pilot study.

Finally, thanks to AUB for providing me with adequate knowledge and foresight that I had used to complete the project.

# AN ABSTRACT OF THE THESIS OF

Hisham Fouad Arnaout for Master of Engineering Management  
Major: Engineering Management

Title: Applying Operations Research At AUBMC: Two Pilot Studies On Material Management And Family Medicine Patient Flow

This thesis is on applying Operations Research (OR) techniques to managing the operations of the American University of Beirut Medical Center (AUBMC). It is divided to two parts, of applying OR to (i) material management, and (ii) family medicine clinics patient flow modeling and analysis. Such OR applications are now common practices in the US with notable success in performance improvement. We aim on replicating this success at AUBMC, taking into account the distinctive features of the healthcare environment in Lebanon and the region.

We first provide an overview of the current status of material management and patient flow at the family medicine clinics at AUBMC. We then provide a literature review on OR applications in healthcare, in specific, inventory management and patient flow. We then describe our preliminary results of the first pilot study, which is on applying OR to material management, where we propose a new base-stock policy that takes into account demand variability and the extended lead times AUBMC is faced with in Lebanon. This base-stock policy is shown to outperform an existing policy based on time series forecasting of the mean demand, and setting the stock level accordingly. AUBMC management validated our findings and is in the process of instituting the new Base Stock policy.

We then discuss the second pilot study, on modeling and analyzing the patient flow at the family medicine clinics with the objective of reducing patient delay, improving appointment scheduling, and increasing employee utilization using a combination of discrete-event computer simulation and queueing theory. After successfully validating the model, i.e. being able to replicate the real performance system, we propose several improvements and perform useful analysis. In particular, we investigate the effect of appointment scheduling on waiting time and clinic revenue.

## CONTENTS

ACKNOWLEDGMENTS .....	v
AN ABSTRACT OF THE THESIS OF .....	vi
LIST OF ILLUSTRATIONS .....	x
LIST OF TABLES .....	1
Chapter	
1. INTRODUCTION AND MOTIVATION .....	2
1.1 Motivation.....	2
1.2 Material Management at AUBMC .....	8
1.3 Patient flow at the Family Medicine Department.....	10
1.4 Thesis Plan .....	8
2. LITERATURE REVIEW .....	9
2.1 Background.....	9
2.2 Healthcare Inventory Management.....	10
2.2.1 Empirical Surveys .....	12
2.2.2 Inventory Control Policies .....	12
2.3 Patient flow and Appointment Scheduling .....	13
3. IMPROVING MATERIAL MANAGEMENT AT AUBMC .....	15
3.1 Introduction.....	15
3.2 Data Analysis .....	16
3.2.1 Runs Test .....	16
3.2.2 ABC Analysis .....	18
3.2.3 Demand Distribution.....	24
3.3 Base Stock Policy .....	25
3.4 Policy Comparison via Simulation .....	26

3.4.1 Comparison Set-up.....	27
3.4.2 Base Stock vs. Actual Min-Max vs. Theoretical Min-Max .....	28
3.4.4.1 Frequency of Order Comparison .....	28
3.4.4.2 Number of Shortages .....	30
3.4.4.3 Average on-hand Stock.....	31
3.5 Policy Comparison via Real Time Testing .....	33
3.5.1 Procedure .....	33
3.5.3 Real-time Testing Results .....	35
3.5.3.1 Shortages Comparison .....	35
3.5.3.2 Weekly Average on-Hand Comparison.....	35
3.5.3.3 Frequency of Order Comparison .....	36
3.6 Accounting for Fixed Ordering Cost .....	37
3.6.1 Estimating the Fixed Ordering Cost.....	37
3.6.2 (s, S) Policy with Ordering Cost .....	38
4. ANALYZING & IMPROVING PATIENT FLOW AT FMD .....	40
4.1 Introduction.....	40
4.2 Process flow diagram.....	42
4.3 Data Analysis .....	43
4.3.1 Physicians' Statistics.....	46
4.3.2 Inter-arrival Time .....	47
4.3.2.1 Scheduled Patients .....	47
4.3.2.2 Random Walk-in Patients .....	52
4.3.3 Service Times.....	55
4.3.3.1 Physician Service Times.....	55
4.3.3.2 Assessment Nurse Service Times .....	57
4.3.3.3 Check-in Service Times.....	58
4.3.3.4 Cashier's Service Times .....	59
4.3.4 Data Validation .....	60
4.4 Simulation Model .....	67
4.4.1 Patients Arrival .....	67
4.4.2 Check-in Station.....	69
4.4.3 Cashier Station .....	70
4.4.4 Assessment Nurse Station.....	71
4.4.5 Physician Station.....	73
4.5 Results.....	75
4.6 Suggestions for Improvement.....	79



4.6.1 Check-in Station.....	79
4.6.2 Appointment Time Slot.....	81
5. CONCLUSION.....	85
5.1 Inventory Control at MMD.....	85
5.2 Patient Flow at FMD.....	85
6. FUTURE WORK.....	87
BIBLIOGRAPHY.....	88
APPENDIX A: LATENESS DISTRIBUTIONS PER PHYSICIAN.....	91
APPENDIX B: SERVICE TIME DISTRIBUTIONS PER PHYSICIAN.....	101
APPENDIX C: INTER-ARRIVAL TIME DISTRIBUTION FOR RANDOM WALK- IN PATIENTS .....	111
APPENDIX D: ASSESSMENT NURSE DISTRIBUTIONS.....	113

## ILLUSTRATIONS

Figure	Page
1. Material Management Warehouse (A1 Store: Bottom Right) .....	9
2. Sawwaf Building.....	11
3. High Variability Item's Monthly Demand .....	17
4. Medium Variability Items' Monthly Demand.....	17
5. Low Variability Items' Monthly Demand.....	17
6. Monthly Demand x Cost Histogram.....	19
7. Cumulative Percentage of Items vs. Cumulative Percentage of Sum Cost .....	20
8. Demand Distribution For Item 50786 (High Variability).....	24
9. Demand Distribution For Item 52225 (Medium Variability).....	24
10. Demand Distribution For Item 59019 (Low Variability) .....	25
11. Frequency of Orders Comparison Between The Different Policies .....	29
12. Number of Shortages Comparison Between The Different Policies .....	30
13. Weekly Average On-hand Comparison between the Different.....	31
14. Frequency of Order Comparison .....	37
15. FM Clinic Current Flow Diagram .....	43
16. Inter-arrival Time Distribution of walk-in patients to the clinic from Arena Input Analyzer; Beta distribution having a Beta of 0.267, alpha of 7.44, a constant of -0.001 distribution mean of 16.7, and distribution standard deviation of 30 (minutes).....	45
17. Service Time Distribution of walk-in patients to the clinic from Arena Input Analyzer; Weibull distribution a Beta of 15.7, an alpha of 1.23, a constant of 5, a distribution mean of 19.7, and a distribution standard deviation of 12.9 (minutes).....	45
18. Patient Count per Physician.....	46
19. Patient Percentage per Physician .....	47
20. Lateness Distribution of scheduled patients from Arena Input Analyzer; Weibull distribution with a Beta of 9.98, an alpha of 0.903, distribution mean 10.5, and a distribution standard deviation of 11.62 .....	49
21. Graph Showing The Percentage Of Late Patients Per Physician.....	50
22. Graph Showing The Patients' Average Lateness Per Physician .....	51
23. Patients' Percentage No-show Per Physician (Population with Random Walk-in Patients) .....	52
24. Inter-arrival Time Distribution of walk-in patients to the clinic from Arena Input Analyzer; Beta distribution having a Beta of 0.273, an alpha of 7.48, a multiplier of 484, a distribution mean of 17.04, and distribution standard deviation of 30.15 (minutes)...	54
25. Inter-arrival Time Distribution of walk-in patients to the clinic from Arena Input Analyzer; Beta distribution having a Beta of 0.267, an alpha of 7.44, a multiplier of 484, a constant of -0.001, a distribution mean of 16.7, and distribution standard deviation of 30 (minutes) .....	54
26. Physician Service Time Distribution of patients to the clinic from Arena Input Analyzer; Weibull distribution having a Beta of 7.88, an alpha of 1.46, a constant of 5, a distribution mean 16.5, and a distribution standard deviation of 9.8 (minutes) .....	56
27. Assessment Nurse Service Time Distribution of patients to the clinic from Arena Input Analyzer; Gamma distribution with a Beta of 1.93, an alpha of 1.59, a constant of 0.999, a distribution mean 4.08, and a distribution standard deviation of 2.63 (minutes) .....	58

28. Lateness Mean Validation Graph .....	63
29. Lateness Standard Deviation Graph .....	63
30. Lateness Validation Difference Percentage Graph .....	63
31. Physician Service Time Mean Validation .....	64
32. Physician Service Time Standard Deviation .....	64
33. Physician Service Time Validation Difference Percentage Graph .....	64
34. Assessment Nurse Service Time Mean Validation .....	65
35. Assessment Nurse Service Time Standard Deviation Validation .....	65
36. Assessment Nurse Service Time Validation Difference Percentage Graph .....	65
37. Inter-arrival Time Standard Deviation Validation .....	66
38. Inter-arrival Time Mean Validation .....	66
39. Inter-arrival Time Validation Difference Percentage Graph .....	66
40. Cashier Process Model Blocks .....	71
41. Checking For Prescription Model Blocks .....	71
42. Assessment Nurse Model Blocks .....	72
43. Assessment Nurse Procedure Model Blocks .....	73
44. Physician Station Flow Diagram .....	73
45. Average Waiting and Service Times Spent at Physician's Queues .....	76
46. Pie Chart Showing The Waiting Times At The Different Stations .....	77
47. Number of Patients Waiting In the Different Stations' Queues .....	77
48. Utilization Of The FM Clinic Employees Over 100 Simulated Days .....	78
49. Patient's Lateness and Waiting Time Percentage .....	79
50. Time Spent in System with 2 Check-in Employees .....	80
52. Pie Chart Showing The Waiting Times At The Different Stations with 2 Check-in Employees .....	81
52. Average Patient System and Waiting Time vs. Time Slot .....	82
53. Number of Patients Served vs. Time Slot .....	83
54. Average Number of Patients in Physician's Queue vs. Time Slot .....	83
55. Average Physician Utilization vs. Time Slot .....	84

## TABLES

Table	Page
1. The Run's Test Results.....	18
2. The Monthly Demand x Cost.....	19
3. The Items Having High Demand x Cost and High Variability.....	21
4. Items having High Demand x Cost and Medium Variability .....	22
5. Items Having High Demand x Cost and Low Variability .....	23
6. The Order Frequencies between the Different Policies .....	29
7. The Comparison Between The Different Policies .....	32
8. The Rush Orders To Be Received .....	34
9. The Rush Orders To Be Received .....	34
10. The Real-time Testing Results.....	36
11. The Difference Between The (s,S) Policy With Ordering Cost and The Base Stock Policy .....	39
12. Patient Lateness Distributions per Physician.....	48
13. The Probability Of Late Patients Per Physician.....	50
14. The No-show Probability Analysis.....	52
15. The Inter-arrival Distributions For The Two Groups .....	54
16. The Service Time Distributions per Physician .....	56
17. The Assessment Nurse Service Time Distributions .....	58
18. The Tasks At The Check-in Station With Service Time Statistics.....	59
19. The Tasks at The Check-in Station With Service Time Statistics.....	60
20. The Data Validation Done on The Different Fitted Distributions .....	62
21. The Model Validation Calculations.....	74
22. The Model Validation Probability Calculations .....	75
23. The Random Patient Validation Calculation .....	75
24. The Average Time Waiting and Average Queue Size at The Different Stations .....	77
25. The Average Time Waiting and Average Queue Size at The Different Stations .....	81

# CHAPTER 1

## INTRODUCTION AND MOTIVATION

In this chapter, we introduce our research problem and motivation. In section 1.1, we discuss the motivation of taking the projects at AUBMC. In Section 1.2, we introduce the problem that the Material Management Department at AUBMC is facing. In section 1.3, we introduce the problem that the Family Medicine clinic is facing. Finally, in Section 1.4, we introduce the thesis plan.

### **1.1 Motivation**

The American University of Beirut Medical Center (AUBMC) is the largest university hospital in Lebanon. With an expansion plan determined to be complete in 2020, the hospital's management is determined on improving its operations to add efficiency and reduce cost.

One motivation for the AUBMC's management is the upswing of complicated medical decision-making in several healthcare institutions in Western countries during the last decade. This utilizes data-driven decisions, i.e., analytics. A pressing challenge, however, in healthcare and other services, is on leveraging the data into tactical/operational decisions. These challenges are not easily addressed by the conventional wisdom of healthcare providers. A remedy in the US has been to utilize the expertise of Industrial Engineering (IE) and Operations Research (OR) professionals.

IE/OR has been at the forefront of resolving challenging industry problems via analytics starting with military, to manufacturing and logistics, and more recently, in

healthcare, humanitarian logistics, and combating terrorism. In healthcare, in particular, IE/OR has seen tremendous advancements with significant improvements in reducing cost and patient access to services. Hence, utilizing the advancement of IE/OR in healthcare and tackling AUBMC's need seems like a perfect opportunity to implement IE/OR in Lebanon.

## **1.2 Material Management at AUBMC**

The first project taken was with the Material Management Department. MMD is responsible of ordering, storing, and keeping track of items. The MMD gives great care to the operation room items, which are stored at a dedicated warehouse (A1 store), because of their variable demand and large lead-time. However, keeping safety stock to cover the demand is constrained by the limited size of the A1 store and the holding costs. In addition, with the application of a Min-Max policy independent from demand variability, the MMD was facing shortages and overages based on AUBMC's administration feedback. Figure 1 presents a picture of the MMD warehouse, showing the different stores, including the A1 store. Also, Figure 1 testifies to the limited space of the MMD facilities.



Figure 1: Material Management Warehouse (A1 Store: Bottom Right)

### **1.3 Patient flow at the Family Medicine Department**

The second project is with the Family Medicine Department (FMD). FMD provides medical services for AUB employees, students, and non-AUBians. In addition to the treatment of physical and mental illnesses, the FMD also provides adolescent and adult medicine, chronic disease management, and other healthcare services. With the current AUBMC expansion plan, the opening of the new Family Medicine building, the Sawwaf Building, is currently underway. AUBMC's management decided to utilize this expansion and to develop new processes that might improve the patient flow. Figure 2 presents a pictorial view of the new FMD building.

In this thesis, we develop a simulation model of the entire future FMD at Sawwaf building. We verify that the new facility will perform adequately as planned, with some minor changes (adding one employee at the cashier). We then analyze the effect of scheduling policy, in terms of appointment time slot duration, on the service level of patients, measured in mean waiting time. This could allow FMD to improve its scheduling policy upon the opening of the new Sawwaf building. As such, this second research project is timely and can be a role model for analyzing the operations of prospective buildings in AUBMC expansion plan and elsewhere at AUB. This allows for anticipating problems before they occur.





Figure 2: Sawwaf Building

## **1.4 Thesis Plan**

The remainder of the thesis is divided as follows: Chapter 2 offers a literature review on OR in healthcare background, healthcare inventory management, and patient flow and appointment scheduling. Chapter 3 discusses pilot study 1, on improving material management at AUBMC. As for Chapter 4, it discusses pilot study 2 on analyzing and improving patient flow at the Family Medicine Department. Finally, Chapter 5 presents conclusions for both pilot studies and Chapter 6 discusses the future work.

## CHAPTER 2

### LITERATURE REVIEW

This chapter presents a literature review on three main topics. In Section 2.1, we present a background literature review on analytics and its utilization in the healthcare industry. Then, in Section 2.2, we present a literature inventory management at hospitals. Finally, in Section 2.3, we present a literature on patient flow and scheduling in hospitals.

#### **2.1 Background**

The last decade has seen the rise of sophisticated (quantitative) medical decision making tools in the US and other western countries with an increase in life expectancy, tight budgets, and an economic shift toward services in the “post-industrial age”. Surveys of quantitative approaches to medical decision-making can be found in Pierskalla and Brailer (1994), Rais and Viana (2010) and Royston (2009). These tools emphasize data-driven decisions, i.e., analytics. A pre-requisite for analytics is effective data collection schemes. This can be achieved with Electronic Medical Records (EMR) and Health Information Technology (HIT) tools (e.g., Gupta and Denton 2008). However, a pressing challenge, in healthcare and other services, is on leveraging the data collected by EMR and HIT systems into tactical/operational decisions. Examples of these decisions include, how many physicians and nurses to schedule in a given clinical time block, and how many appointments per hour should be given in that block, in addition to setting a policy for walk-in patients who request service without an appointment.

These challenging questions are not easy to address by the conventional wisdom of health care providers. A remedy in the US and other Western countries has been to utilize the expertise of Industrial Engineering (IE) and Operations Research (OR) professionals and academicians. This is evidenced by an enormous body of literature on academic and practical IE/OR studies; for surveys of this literature see Cayirli and Veral (2003), Gupta and Denton (2008), Mondschein and Weintraub (2003), Pierskalla and Brailer (1994), Rais and Viana (2010) and Royston (2009). Being a relatively young science, with inception post WWII, IE/OR, “efficiency engineering”, or the science of the better, has been at the forefront of resolving challenging industry problems via analytics starting with military ones, to manufacturing and logistics, and services (airlines, hotels, finance, retailing, e-commerce, etc. See INFORMS<sup>1</sup> and IIE<sup>2</sup> websites for further background). More recently, with motivation from the US and other governments, IE/OR has shifted interest to healthcare, humanitarian logistics (disaster response), and combating terrorism.

Unfortunately, Lebanon and the MENA region seem to be late in catching up with the healthcare analytics paradigm, despite sincere efforts, at AUBMC in particular. One critical factor in this, we believe, is the lack of the IE/OR important component for translating data into decisions. This thesis aims at offering one of the steps in bridging this gap in healthcare practices in our region

## **2.2 Healthcare Inventory Management**

Supply chain management is the process of proficiently integrating stores, suppliers, warehouses, and manufacturers so that products are manufactured at the right quantity and delivered at the right time and place (Rossetti, 2008). Supply chain can be

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<sup>1</sup>The Institute for Operations Research and the Management Sciences, [www.informs.org](http://www.informs.org)

<sup>2</sup>Institute of Industrial Engineers, [www.iienet2.org](http://www.iienet2.org)

divided into two areas, inventory management and distribution. Inventory cost comprises a large portion of the hospital's total budget; hence managing it is a must. Inventory management is the control of the ordering, storage, and use of components in the production of items and delivery of services. According to Rossetti (2008), a hospital could reduce its total budget by at least 2% if there was proper inventory management. However, health care providers have been reluctant in changing the model of business they follow, simply because they are satisfied with it.

According to Schneider et al. (1990), estimating holding costs (being linear most of the time) and ordering costs, are easier to estimate than shortage cost. In addition, managers find it quite difficult to estimate the shortage cost. Therefore, specifying a service level is easier for managers and is a suitable alternative for estimating shortage costs. There are two types of service levels, Type-1 and Type-2. Type-1 service level states that demand will be met over lead-time and review period with a given probability. Type-2 service level states that the demand will be met by a fraction of the on-hand inventory with a certain probability. In this thesis, we use a Type I service level in view of the difficulty of estimating the hospital's shortage cost.

The literature on inventory management in hospitals is somewhat scarce. It can be divided into two streams (i) empirical surveys of business practices, and (ii) development and application of control policies based on inventory theory. In the following we briefly review these two streams.

### ***2.2.1 Empirical Surveys***

According to Stark and Mangione (2004), inventory management at hospitals can exceed 35% of the hospitals' operating budget, 20% to 25% of which are supply costs.

In regard to the holding cost at hospitals, Corman (1988) observed that on average, according to a survey he had conducted, the carrying cost (holding cost) comprised a minimum of 0%, an average of 13%, and a maximum of 31% of the total cost. In addition, 51% of the people who answered continue to rely on visual or judgmental methods to determine how much and when to order inventory, exhibiting the lag of science and the dominance of judgment in preparing inventory policies. This might justify the answer of another question regarding the actual stock out rates, where 74% of further respondents answered that the actual stock out rates are less than 4%, and 26% answered that the actual stock out rates are between 5% and 10%.

### ***2.2.2 Inventory Control Policies***

According to Ruud et al. (2010), ABC classifications with demand value and volume criteria are widely used nowadays. Reid (1987) discussed an ABC policy for items in the respiratory therapy unit. The ABC policy was applied to 47 disposable Stock Keeping Units (SKU's) in the respiratory therapy unit, 10 of which composed 70% of the cost. It was shown that there was a relationship between the cumulative number of SKU units and the cumulative value of the units.

The goal of Reid's (1987) research was to establish a policy for each of the classes. Starting with the policy for class A items, stock replenishment was done when the stock level reached the re-order point. In addition, minimum stock levels were put

relative to lead times, availability of alternative units, and criticality. The re-order point was reviewed twice every year and physical inventory count was done weekly. As for the policy of class B items, replenishment occurred on a biweekly period while reconsidering a reduction in the minimum safety stock. As for class C items, items were replenished every two or three months to a defined maximum. It is important to note that coordination between the purchases of the class C items should take place to deal with the space constraint.

Several papers have been written discussing demand variability (i.e. standard deviation) in coming up with the policies, such as Callahan et al. (2004) who discussed the benefits of good demand forecasts.

Little and Coughlan (2008) introduced a new constraint-based model for determining optimal stock level for all products at a storage area taking into consideration the restriction on space, constraints on deliveries, and criticality of items. They develop a mathematical program with the objective of maximizing the minimum and the average service level under certain inventory constraints

### **2.3 Patient flow and Appointment Scheduling**

In this literature, many researchers use the classical queuing theory with typically exponential inter-arrival and service times, and minor variation of these, and stylized assumptions aimed at simplifying the math. Examples of these works in chronological order include Bailey (1952), Birchall et al. (1983), Brahim and Worthington (1991), Green and Savin (2008), Hassin and Mendel (2008), and Jouini and Benjaafar (2011). Many other researchers use simulation, where there is no need for the exponential distribution and other simplifying assumptions. Examples of these works in

chronological order include Fetter and Thompson (1966), Vissers (1979), Marshall, (1986), Babas and Sarma (1991), Paul (1995), Taylor and Kuljis (1998), Zilm et al. (2002), Harper and Gamlin (2003), Guo et al. (2004) and Gunal and Pidd (2007).

However, simulation studies are time-consuming to develop, require a computer to run, and require extensive care fitting input data in analyzing the results (e.g., Law 2007). In particular, long CPU times remain a hurdle for “simulation-optimization”, i.e., looking for a good system configuration by restarting the simulation (e.g. Fu 2002). Our simulation has the distinctive features of modeling the whole FMD clinic with great detail and of performing simulation optimization.

Finally, the medical literature on analyzing appointment scheduling and patient waiting at clinics is empirical in nature and utilizes statistical methods of hypothesis testing and inference, e.g., Chung (2002), Heaney et al., 1991, and Penneys (2000).



## CHAPTER 3

### IMPROVING MATERIAL MANAGEMENT AT AUBMC

In this chapter, we discuss the first pilot study of improving material management at AUBMC. In Section 3.1, we introduce the research problem at MMD in detail. Section 3.2 is on data analysis. In Section 3.2.1, we discuss the runs test that was done on selected items to check for independence and randomness of the demand. In Section 3.2.2, items are classified using an ABC analysis on total cost and further stratified based on variability that is measured by the coefficient of variation. In Section 3.2.3, we discuss demand modeling. Then, in Section 3.3, we present our base stock policy. Then, in Section 3.4, we compare the current min-max inventory management policy to our proposed base stock policy via simulation. Finally, in Section 3.5, we report on a similar comparison based on a real case study on 17 class A items selected to cover the demand variability spectrum.

#### **3.1 Introduction**

The MMD department at the AUBMC had been adopting a Min-Max policy for the operating room items replenishment assuming that demand is only variable and not random. The minimum and maximum values were calculated using a forecast based on exponential smoothing, with  $\alpha = 0.25$  (giving more weight to recent demand). How the policy works is that when the inventory position (on-hand + on order) level reaches the minimum, the MMD orders to the maximum level. However, according to the AUBMC administration, the hospital had been facing some shortages, especially for OR items,

which caused serious issues because of the long lead-time of the items (9 weeks for local items and 22 weeks for imported items).

It is clear that the current forecast does not cover the variability of the demand, which suggests the need of a new policy that would cover the variability over the lead-time.

## **3.2 Data Analysis**

In this section, we discuss the data analysis performed for the first pilot study. Specifically, we discuss the runs test in Section 3.2.1, the ABC classification in Section 3.2.2, and the demand distribution in Section 3.3.3. Also, we will discuss the Base Stock policy derivation and policies comparisons.

### **3.2.1 Runs Test**

The runs test is a test that shows whether or not a series is independent. The logic is that for a truly random and independent series, the number of runs  $R$  should not be too small or too large. If  $R$  is not too large or too small and the numbers are independent, then it can be shown that the number of runs  $R$  is normally distributed, Law (2007). The graphs in Figures 3, 4, and 5 show the monthly demand for items having high cost and high variability (coefficient of variation  $>1$ ), medium variability (coefficient of variation between 0.5 and 1), and low variability (coefficient of variation  $<0.5$ ) respectively. These figures clearly show that demand is different months is independent. In addition, Table 1 shows the results of the test performed on the items (designated by the item IDs in the legend), having number of points  $n$  and number of runs  $R$ .

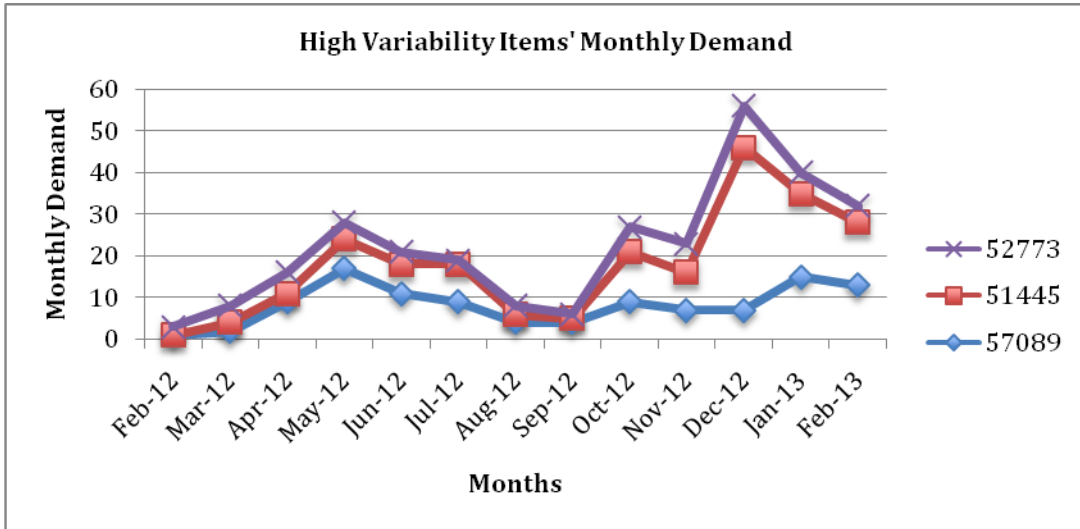


Figure 3: High Variability Item's Monthly Demand

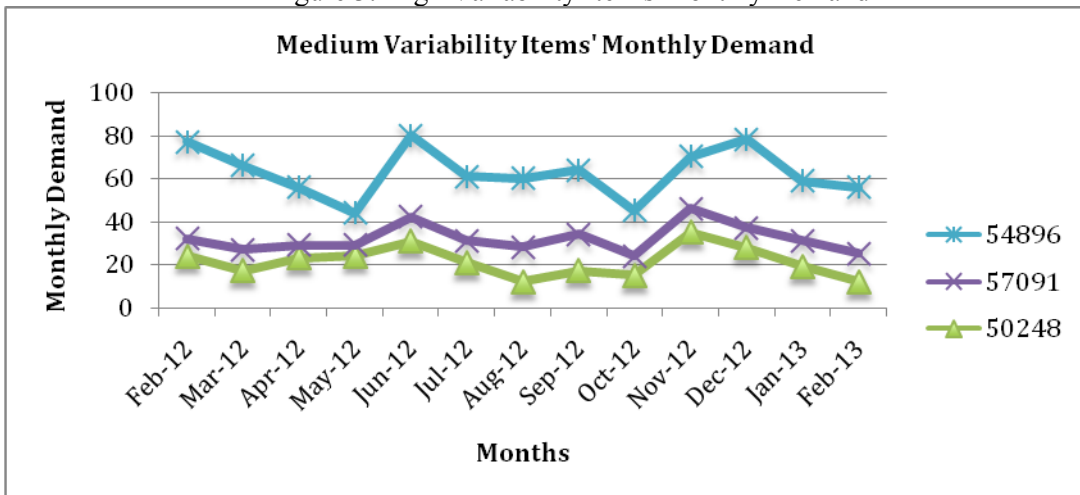


Figure 4: Medium Variability Items' Monthly Demand

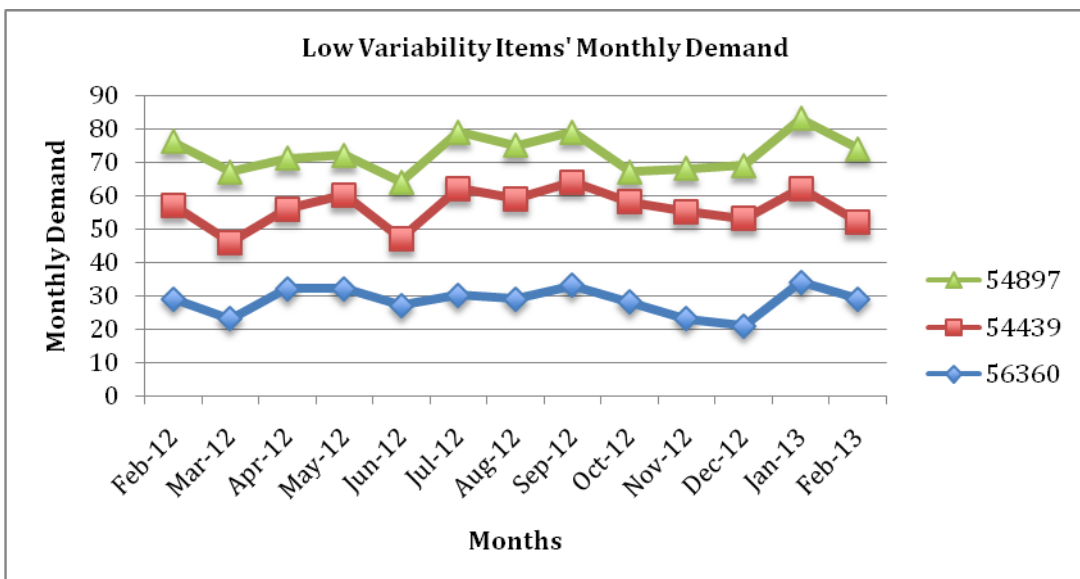


Figure 5: Low Variability Items' Monthly Demand

Variability	Item ID	Description	n	R	$E[R] = \frac{2n-1}{3}$	$\sigma_r^2 = \frac{16n-29}{90}$	$Z = \frac{r-E[R]}{\sigma}$	Result
High	57089	Orthopedic Dome-Ac3525-01	12	6	7.67	1.81	-1.24	Don't Reject
High	51445	Reticulator Endo Gia 60-3.5	12	6	7.67	1.81	-1.24	Don't Reject
High	52773	LigasureHandswitch Atlas Ls1037	12	6	7.67	1.81	-1.24	Don't Reject
Medium	50248	Trocar Bladeless W/Sleeve 12mm Versaport Plus Covidien Nb12s	12	7	7.67	1.81	-0.50	Don't Reject
Medium	57091	Orthopedic Super Asc4250-01	12	7	7.67	1.81	-0.50	Don't Reject
Medium	54896	Reload Stapler Linear 75mm Blue Tcr75	12	7	7.67	1.81	-0.50	Don't Reject
Low	56360	Pump Tube For Coblator	12	9	7.67	1.81	0.99	Don't Reject
Low	54439	Clip Applier Medium-Large Er320	12	9	7.67	1.81	0.99	Don't Reject
Low	54897	Stapler Linear 75mm Tlc75	12	9	7.67	1.81	0.99	Don't Reject

Table 1: The Run's Test Results

From the above test, we hypothesize that at a 0.1% significance level, there was insufficient evidence that the points are not independent; hence, there was no correlation (no proof of existence of a trend) between the demand series for an item. Thus, this justifies the assumption that the demand is independent and identically distributed (iid), hence random and not only variable, which permitted the use of the simply average instead of the forecast.

### 3.2.2 ABC Analysis

ABC analysis was conducted for the 935 operating room items based on total cost, where  $Total\ Cost = Monthly\ Average\ Demand \times Cost$ . Figure 6 shows the monthly Demand x Cost histogram and Table 2 shows the percentage of items versus the monthly cost.

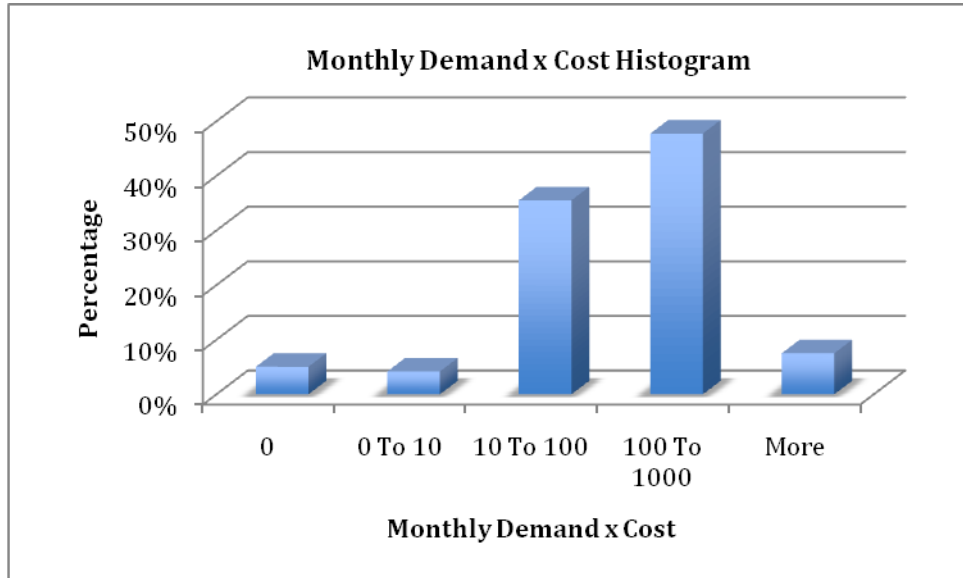


Figure 6: Monthly Demand x Cost Histogram

The next step was to determine which items comprise class A. In order to do that, the items were sorted based on decreasing total cost and grouped together as shown in Table 2. The curve in Figure 7 shows the cumulative sum of cost versus the cumulative number of items. As shown, around 20% of the items account for 60% of the total cost, 70 of which have a total cost greater than \$1000.

Monthly DxC	Count	% Count	Cum. % Count	Cost	% Cost	Cum. % Cost
More than 1000	70	7.5%	7.5%	157,310	48.5%	48.5%
100 to 1000	459	49.2%	56.8%	149,841	46.2%	94.7%
0 to 100	356	38.2%	95.0%	17,033	5.3%	100.0%
0	47	5.0%	100.0%	0	0.0%	100.0%

Table 2: The Monthly Demand x Cost

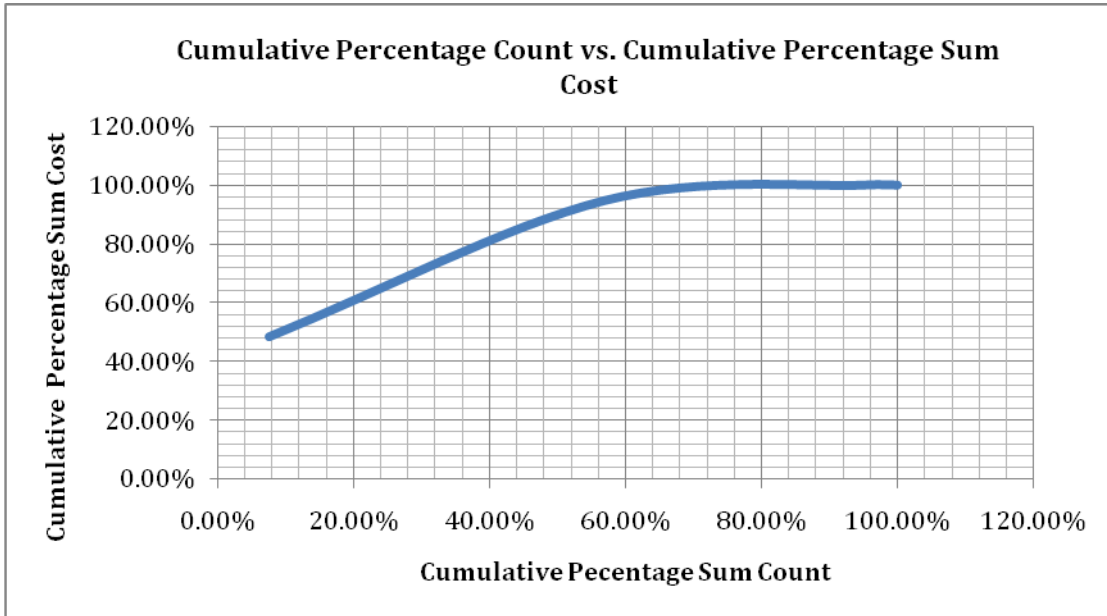


Figure 7: Cumulative Percentage of Items vs. Cumulative Percentage of Sum Cost

In addition, class A items were categorized into three categories: High, Medium and Low Variability. High variability items had a weekly demand coefficient of variation<sup>3</sup> greater than 1 and accounted for 31 items (shown in Table 3), medium variability items had a weekly coefficient of variation between 0.5 and 1 and accounted for 21 items (shown in Table 4), and low variability items had a weekly coefficient of variation less than 0.5 and accounted for 18 items (shown in Table 5).

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<sup>3</sup> The coefficient of variation is the ratio of the standard deviation over the mean

Item ID	Item Description	Average Cost (\$)	Lead Time	Monthly Average	Weekly Average	Monthly Standard Deviation	Weekly Standard Deviation	Monthly Coeff. of Variation	Weekly Coeff. of Variation	Total Cost
51638	Bone Graft Human Bo4	1100	2	8.083	2.021	4.142	2.071	0.512	1.025	8892
51858	Allomatrix InjecTable 10cc 8600	1570	1	2.000	0.500	1.113	0.556	0.556	1.113	3140
57089	Orthopedic Dome- Ac3525-01	375	1	7.917	1.979	4.663	2.331	0.589	1.178	2969
56367	Filter VenacavaTrapease	1219	2	2.043	0.511	1.160	0.580	0.568	1.135	2491
51924	Oxygenator Open Membrane Pediatric + Pack Terumo	660	2	3.652	0.913	1.832	0.916	0.502	1.003	2410
56059	Phathaphoenix Calcium Sulphate Pam36	1100	2	2.154	0.538	1.791	0.895	0.831	1.663	2369
50219	Rotulator Endo Gia 60 4.8	326	1	6.625	1.656	3.462	1.731	0.523	1.045	2160
56281	Reload Endo Gia 35mm/White-Ethicon	120	2	16.880	4.220	9.746	4.873	0.577	1.155	2026
53472	Oxygenator W.Tubing Pack, Infant	660	2	3.048	0.762	2.126	1.063	0.698	1.395	2011
54109	Reload Endo Gia 60mm, White	160	2	12.400	3.100	9.347	4.673	0.754	1.508	1984
54807	Ligasure Impact Lf4200	850	1	2.333	0.583	1.724	0.862	0.739	1.478	1983
57090	Multivac Ortho- Asc4830-01	450	1	4.400	1.100	2.417	1.208	0.549	1.098	1980
51445	Rotulator Endo Gia 60-3.5	220	1	8.087	2.022	7.879	3.940	0.974	1.949	1779
52182	Catheter Ash Split Set 28cm	480	1	3.625	0.906	2.118	1.059	0.584	1.168	1740
52773	LigasureHandswitch Atlas Ls1037	500	1	3.480	0.870	2.317	1.159	0.666	1.332	1740
52116	Band Gastric Sweedish AdjusTable	2215	2	0.750	0.188	0.433	0.217	0.577	1.155	1661
55813	20ga Posterior Procedural Pack W/Afi	455	2	3.526	0.882	2.087	1.043	0.592	1.184	1604
50393	Duraseal Spinal 20-4003-1	600	1	2.650	0.663	1.711	0.855	0.646	1.291	1590
51432	Gel Sp/Oxiplex, Spg03	540	1	2.760	0.690	1.861	0.930	0.674	1.348	1490
54853	Tip &Flu Cusa Excel 36khz, C4614s	425	2	3.476	0.869	2.822	1.411	0.812	1.624	1477
56298	Filter VenacavaOptease Ret.	1325	2	1.000	0.250	0.707	0.354	0.707	1.414	1325
54818	Reload /Gia 45mm Rot Blue	180	1	7.080	1.770	4.039	2.020	0.570	1.141	1274
52651	Graft Aortic RotaTable 23mm	1692.52	1	0.750	0.188	0.433	0.217	0.577	1.155	1269
51583	J-Vac Res 100ml 2160	23.754	2	53.250	13.313	28.927	14.464	0.543	1.086	1265
53920	Mesh Parietex 15x10cm Tet1510	196	1	6.261	1.565	3.492	1.746	0.558	1.115	1227
51248	Ligasure V Instrument Vessel Sealing Ls1500	600	1	1.800	0.450	1.108	0.554	0.615	1.231	1080
51643	Allomatrix InjecTable 1cc 8600-	500	1	2.125	0.531	1.333	0.666	0.627	1.254	1063
54111	Reload Endo Gia 60mm, Blue	160	2	6.583	1.646	3.316	1.658	0.504	1.007	1053
57092	Orthopedic Dome A3625-01	320	1	3.222	0.806	2.973	1.487	0.923	1.845	1031
57088	Pack Vitrectomy Anterior High Speed Ref Bl 5612	365	2	2.800	0.700	2.227	1.114	0.795	1.591	1022
51174	Bur Legend 10ba30	121	2	8.304	2.076	4.398	2.199	0.530	1.059	1005

Table 3: The Items Having High Demand x Cost and High Variability

Item ID	Item Description	Average Cost (\$)	Lead Time	Monthly Average	Weekly Average	Monthly Standard Deviation	Weekly Standard Deviation	Monthly Coeff. of Variation	Weekly Coeff. of Variation	Total Cost
52225	Vavd System For Minimal Invasive	390	1	16.000	4.000	5.052	2.526	0.316	0.631	6240
57091	Orthopedic Super Asc4250-01	450	1	10.416	2.604	3.427	1.713	0.329	0.658	4688
56198	Shears Harmonic Ace 36p	530	2	8.800	2.200	3.250	1.625	0.369	0.739	4664
57487	Endo Shears 5mm Scissors 176643	120	1	37.320	9.330	11.668	5.834	0.313	0.625	4478
57032	Stapler Tacker 5mm Origin Oms-Ttsd	450	1	9.840	2.460	3.343	1.671	0.340	0.679	4428
56282	Stapler Endo Gia 35mm,Tsb35 Ethicon	225	2	13.880	3.470	5.465	2.732	0.394	0.787	3123
50248	Trocar Bladeless W/Sleeve 12mm Versaport Plus Covidien Nb12s	135	1	22.640	5.660	9.951	4.976	0.440	0.879	3056
55812	Pack PhacoStellaris STable Chamber Vacuum BI5112	70	2	42.500	10.625	18.509	9.255	0.436	0.871	2975
52538	Set Implanted Port 8 Fr	180	2	13.760	3.440	3.570	1.785	0.259	0.519	2477
50392	DurasealCraniotomy Ds-D-5005-1	600	1	4.120	1.030	2.046	1.023	0.497	0.993	2472
54896	Reload Stapler Linear 75mm Blue Tcr75	75	1	32.000	8.000	9.822	4.911	0.307	0.614	2400
51587	Allomatrix InjecTable 5cc 8600-	968	1	2.320	0.580	1.157	0.578	0.499	0.997	2246
55814	Pack 25ga Posterior Procedural W/Afi BI5425	475	2	4.313	1.078	1.828	0.914	0.424	0.848	2048
50786	Endo Clip Iii Applier 5mm 176630	363	1	5.160	1.290	2.541	1.270	0.492	0.985	1873
50280	Vitreotomy Pack 20g MveCx 6920	329	1	5.000	1.250	2.121	1.061	0.424	0.849	1645
52548	Drill Perforator Adult 26-1221	126	2	11.040	2.760	4.331	2.166	0.392	0.785	1391
52382	Endocatch Pouch 10mm/Obgyn As173050	64	2	20.120	5.030	5.559	2.780	0.276	0.553	1288
57485	Endo Retract 10mm As176613	202	1	6.240	1.560	3.010	1.505	0.482	0.965	1261
51584	Blake Drain 15fr 2233	36	2	32.200	8.050	8.773	4.386	0.272	0.545	1159
51440	Blake Drain 2234 24fr	36.062	2	29.480	7.370	8.584	4.292	0.291	0.582	1063
55430	Clip Applier Medium Ethicon	36	2	29.000	7.250	8.874	4.437	0.306	0.612	1044

Table 4: Items having High Demand x Cost and Medium Variability



<b>OR Item</b>	<b>Item Description</b>	<b>Average Cost (\$)</b>	<b>Lead Time</b>	<b>Monthly Average</b>	<b>Weekly Average</b>	<b>Monthly Standard Deviation</b>	<b>Weekly Standard Deviation</b>	<b>Monthly Coeff. of Variation</b>	<b>Weekly Coeff. of Variation</b>	<b>Total Cost</b>
52676	Trocar W/Sleeve 5mm Xcel Ethicon D5lt	45	2	113.280	28.320	19.566	9.783	0.173	0.345	5098
51134	Drape Universal	14.519	1	246.960	61.740	17.981	8.991	0.073	0.146	3586
52699	Trocar W/ Sleeve 11mm Xcel Ethicon D11lt	45	2	76.240	19.060	13.892	6.946	0.182	0.364	3431
54975	Plate Rem Vallelab E7507	5	1	588.240	147.060	28.272	14.136	0.048	0.096	2941
56360	Pump Tube For Coblator	100	1	28.240	7.060	3.953	1.976	0.140	0.280	2824
54439	Clip Applier Medium-Large Er320	92.97	1	24.480	6.120	5.247	2.623	0.214	0.429	2276
53939	Surgi Cell 4"X8"	42.59	2	52.920	13.230	9.988	4.994	0.189	0.377	2254
54897	Stapler Linear 75mm Tlc75	130	1	16.680	4.170	3.518	1.759	0.211	0.422	2168
59145	Cautery Electrosurgical Disp Hand Control V1	5.017	1	399.080	99.770	28.389	14.194	0.071	0.142	2002
51815	Drape Set T.U.R	22.9	1	86.400	21.600	11.049	5.524	0.128	0.256	1979
52021	Sheet Split Adhesive Large 200 X 260 Cm	12	1	149.560	37.390	15.034	7.517	0.101	0.201	1795
51586	Blake Drain 19fr 2232	36	2	49.640	12.410	9.121	4.560	0.184	0.367	1787
51162	Bur Legend F2/8ta23	102	2	16.840	4.210	4.192	2.096	0.249	0.498	1718
55572	Catheter AngiogetXpeedior 105040-002	1700	2	1.000	0.250	0.000	0.000	0.000	0.000	1700
52653	Graft Aortic RotaTable 27mm	1544.4	1	1.000	0.250	0.000	0.000	0.000	0.000	1544
52652	Graft Aortic RotaTable 25mm	1520.495	1	1.000	0.250	0.000	0.000	0.000	0.000	1520
59019	Suture Monocryl 4-0 16mm Rc W3205	3.4	1	389.360	97.340	36.842	18.421	0.095	0.189	1324
53964	Stapler Skin 35 Wide Pmw35	5.4	1	228.080	57.020	23.269	11.634	0.102	0.204	1232

Table 5: Items Having High Demand x Cost and Low Variability

### 3.2.3 Demand Distribution

In order to understand the demand data and to properly develop a suitable inventory control policy, the demand distributions for the different items were to be found. To fit the distributions, Arena Input Analyzer was used (Arena, 2014). It was concluded that there was no common distribution that fits the demand of all the items. Figures 8, 9, and 10 show the distributions for several items belonging to Class A, having different variability.

Item 50786 (High Variability): Endo Clip Iii 176630

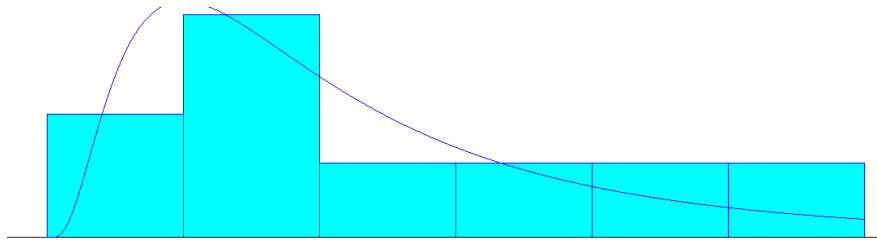


Figure 8: Demand Distribution For Item 50786 (High Variability)

Distribution Summary:

Distribution: Lognormal  
Expression:  $-0.5 + \text{LOGN}(2.57, 2.4)$

Item 52225 (Medium Variability): Vavd System For Minima

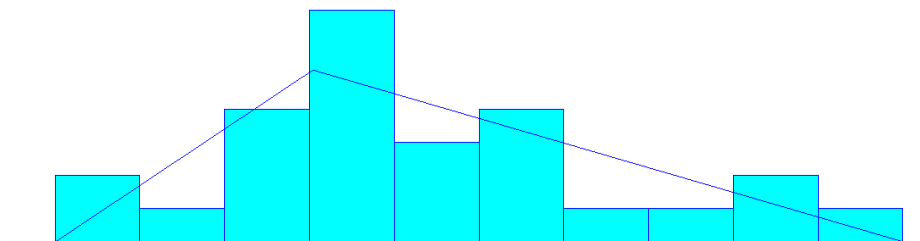


Figure 9: Demand Distribution For Item 52225 (Medium Variability)

Distribution Summary:

Distribution: Triangular  
Expression:  $\text{TRIA}(-0.5, 2.54, 9.5)$

Item 59019 (Low Variability): Sut.Mono.16mm, 4-0cp

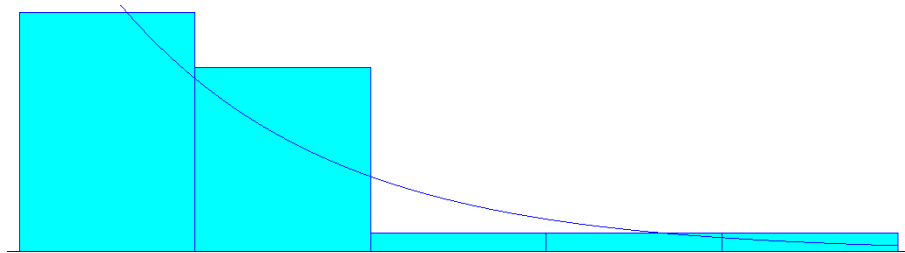


Figure 10: Demand Distribution For Item 59019 (Low Variability)

Distribution Summary:

Distribution: Exponential

Expression:  $65 + \text{EXPO}(47.7)$

### 3.3 Base Stock Policy

Based on the hospital's feedback, there is no fixed and ordering cost; hence, there is no need for an (s,S) policy. Accordingly, a base stock policy is derived, with weekly and bi-weekly review (depending on bulkiness of the items, e.g. weekly for bulky and bi-weekly for non-bulky items), assuming a normal distribution for the items' demand over the lead-time a review period. This is justified based on the central limit theory, adding a large number of random variables will almost be normal. The derivation of the policy with a 99.9% service level is as follows:

$$P(D_{L+1} > S) < 0.001 \Rightarrow P(D_{L+1} < S) < 0.999 \Rightarrow P\left(Z < \frac{S - \mu}{\sigma}\right) < 0.999$$

Therefore,

$$S_{99.9\%} = \mu_{L+1} + Z_{0.999} \times \sigma_{L+1}$$

where,

- $D_{L+1}$  is the demand over the lead time and review period

- $S_{99.9\%}$  is the base stock based on a service level of 0.1% (there is a 0.1% probability of wanting an item and not finding it during the lead time and review period)
- $Z_{0.999}$  is the 99.9% fractile of the standard normal distribution;  $Z_{0.999} = 3.09$
- $\mu_{L+1}$  is the average demand over the lead time and review period
- $\sigma_{L+1}$  is the standard deviation over the lead time and review period
- $\mu_{L+1} = \mu_{\text{weekly/bi-weekly}} \times (L + 1)$ , where  $\mu_{\text{weekly/bi-weekly}}$  is the mean of the weekly/bi-weekly demand
- $\sigma_{L+1} = \sigma_{\text{weekly/bi-weekly}} \times \sqrt{L + 1}$ , where  $\sigma_{\text{weekly/bi-weekly}}$  is the standard deviation of the weekly/bi-weekly demand
- $L$  is the lead time and it's as follows:
  - Local Bulky Items: 9.2 weeks
  - Local Non-Bulky Items: 4.5 bi-weeks
  - Imported Bulky Items: 22 weeks
  - Imported Non-Bulky Items: 11 bi-weeks

### 3.4 Policy Comparison via Simulation

In order to reveal the benefits of the Base Stock policy, a comparison between its performance and the Min-Max policy performance is carried out. The comparison is done over three criteria.

1. The weekly average on-hand inventory held at the warehouse between the two policies, which allows the comparison between holding costs.

2. The number of shortages between the two policies, which allows for a shortage cost and a service level comparison.
3. The order frequency and the order quantity, which allows for an ordering cost comparison.

### ***3.4.1 Comparison Set-up***

In order to compare the two policies, it was first necessary to check whether or not the MMD is actually following the Min-Max policy. To do that, we define the following.

- Actual Data: they are actual daily on-hand, frequency of orders, demand, and values of the maximum and minimum data for a six months period from September 1st 2012 to February 28th 2013 prior to the testing period.
- Theoretical Data: using the exponential smoothing forecast method used by the MMD to find the minimum and the maximum values, the theoretical data are the theoretical (i.e. replicated) values. The minimum and maximum values are calculated as follows (based on MMD input):

- For Local Items:

$$\textit{Minimum} = (\textit{Forecast} \times 1.1) \times 3.3$$

$$\textit{Maximum} = (\textit{Forecast} \times 1.05) \times 6$$

- For Imported Items:

$$\textit{Minimum} = (\textit{Forecast} \times 1.1) \times 6.5$$

$$\textit{Minimum} = (\textit{Forecast} \times 1.05) \times 12$$

### 3.4.2 Base Stock vs. Actual Min-Max vs. Theoretical Min-Max

The actual Min-Max policy is the policy that the MMD was adopting. As for the theoretical policy, it is the replicated Min-Max policy that we derived after taking the minimum and maximum calculation method from the MMD.

A simulation was done using the Base Stock policy. However, an issue was faced regarding at what level should the simulation initiate when using the Base Stock Policy. If the policy starts at the base stock  $S$  level, we would be holding too much. If the policy would start at 0, then shortages will be faced. So, it was decided to start at the average base stock, which is calculated as follows:

$$\text{Average } S = S - \mu_{L+1} \text{ (in weeks)}$$

#### 3.4.4.1 Frequency of Order Comparison

The MMD at AUBMC adopt the partial deliveries concept, where they buy a specific amount from the supplier, on condition that the supplier delivers the amount split into specific quantities at specific dates. The motivation behind this practice is space limitations. Table 8 and Figure 12 show the frequency of orders provided over the study period. Partial deliveries were detected by the request number and deliveries for the same item having the same request number. If we consider the partial deliveries to be one order, then the frequency of orders will be lower than that of the Base Stock. However, if we consider each partial delivery as a separate order, then the frequency orders of the Actual Min-Max will be very close to the Base Stock policy as shown in Figure 11 and Table 6.

When comparing the frequency of orders, it was shown that with the actual Min-Max policy, when considering the partial deliveries to be as separate orders, the number of orders is very close to the Base Stock policy, especially for bulky items. According to

Table 6, on average, the Base Stock policy has a 61.7% higher ordering cost, however, with a standard deviation of 51.9%, which is very high.

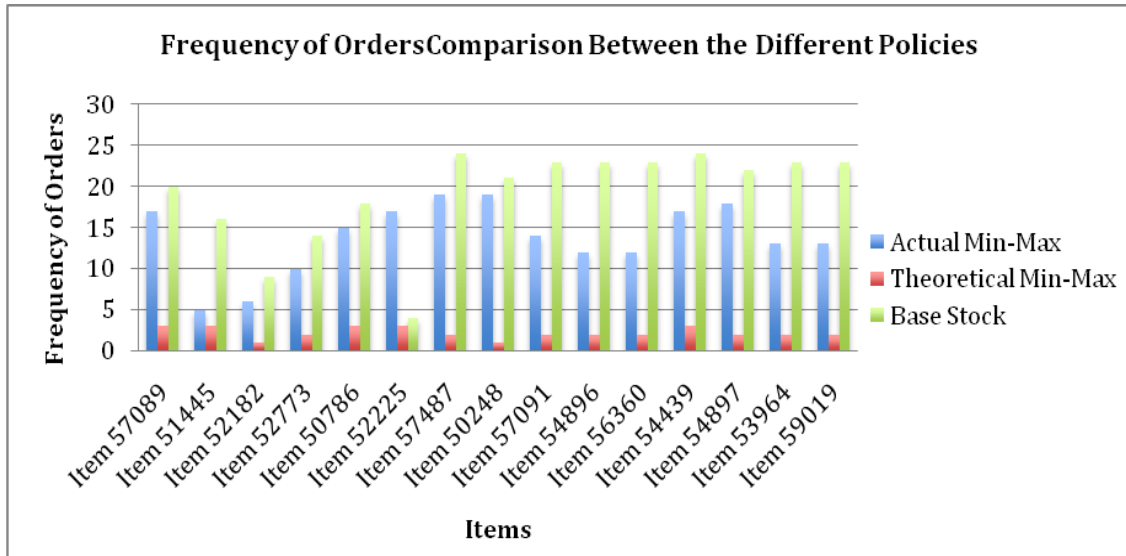


Figure 11: Frequency of Orders Comparison Between The Different Policies

Frequency of Orders				
Variability	Actual Min-Max (Partial)	Actual Min-Max(Partial As Separate)	Base Stock (with rush)	Difference (Base Stock Vs. Separate)
High	8	17	20	17.6%
High	5	5	16	220.0%
High	1	6	9	50.0%
High	3	10	14	40.0%
High	5	15	18	20.0%
Average				69.5%
Standard Deviation				85.2%
Medium	4	17	4	76.5%
Medium	9	19	24	26.3%
Medium	5	19	21	10.5%
Medium	5	14	23	64.3%
Medium	4	12	23	91.7%
Average				53.9%
Standard Deviation				34.2%
Low	3	12	23	91.7%
Low	5	17	24	41.2%
Low	7	18	22	22.2%
Low	3	13	23	76.9%
Low	4	13	23	76.9%
Average				61.8%
Standard Deviation				28.9%
Total Average				61.7%
Total Standard Deviation				51.87 %

Table 6: The Order Frequencies between the Different Policies

### 3.4.4.2 Number of Shortages

In regard to the number of shortages, the actual Min-Max, theoretical Min-Max, and the base stock policy do have shortages, however, the Base Stock and actual Min-Max perform better than the theoretical Min-Max (refer to Figure 12). The theoretical policy does not have frequent shortages, but when they occur, the amount of shortages is high. As for the actual Min-Max policy, when the MMD detects the possibility of a shortage, they immediately ask for a rush order from the supplier, which arrives quickly. Hence, shortages are present, but occur at a lower frequency and amount. As for the Base Stock, it maintains a 99.9% service level, which greatly decreases the chance of shortages happening. Even though there are shortages when using the Base Stock, but their frequency and amount are comparable to the actual Min-Max policy. The advantage of the Base Stock over the Actual Min-Max is that the Base Stock is able to achieve in comparable results with the actual Min-Max policy without any type of human intervention, which is not the case for the actual Min-Max that greatly depends on human intervention as stated earlier.

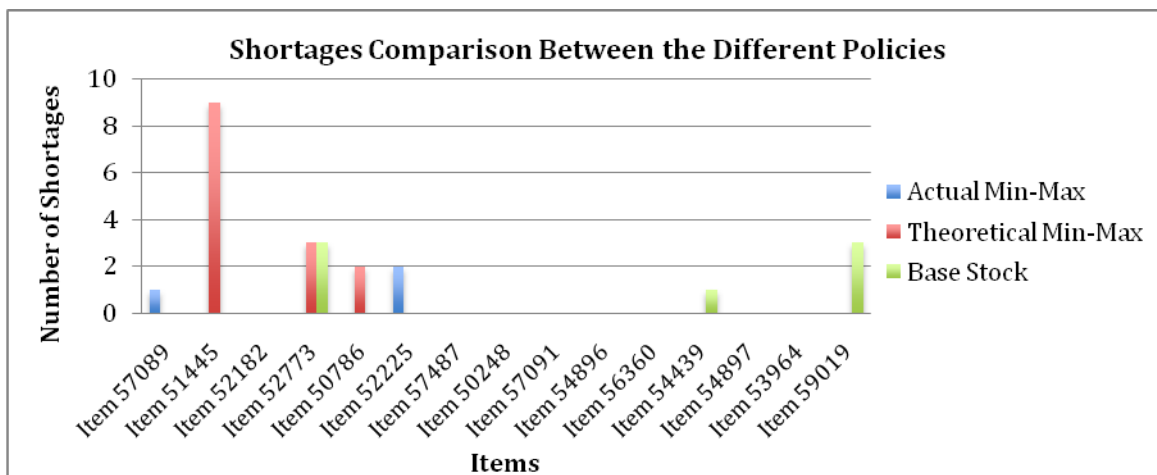


Figure 12: Number of Shortages Comparison Between The Different Policies



### 3.4.4.3 Average on-hand Stock

The actual Min-Max and base stock weekly average on-hand stock seem similar; however, the base stock requires no human interference. These results perfectly reflect the results found in the literature by Gallego et al. (2006). Figure 13 and Table 7 summarize the simulation results.

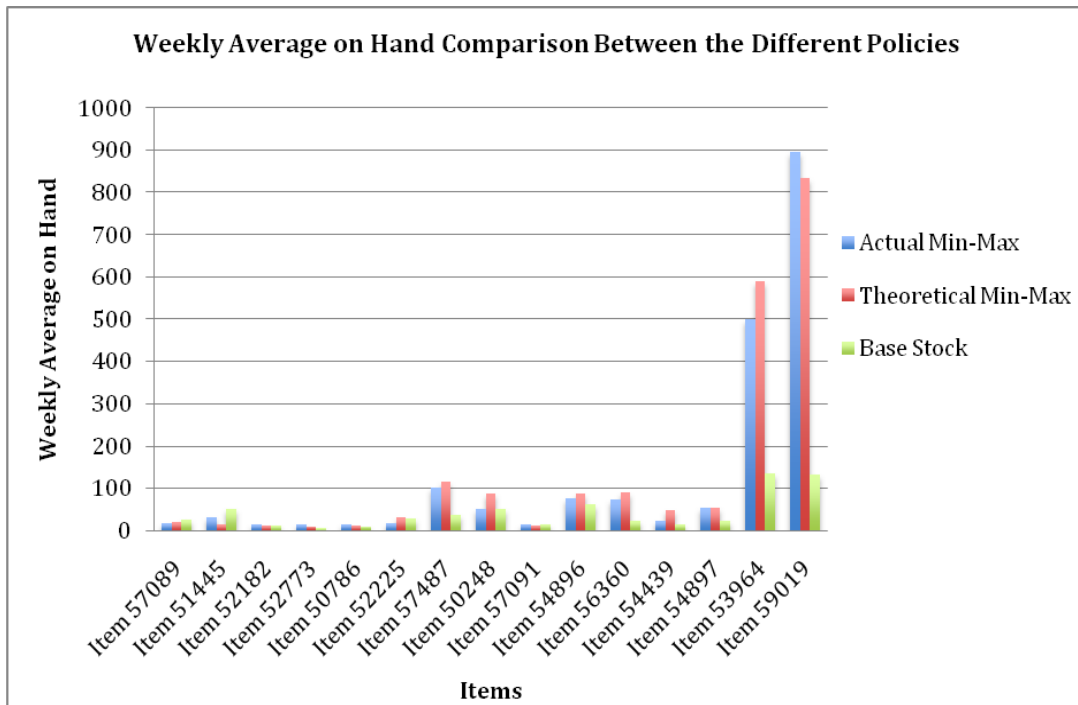


Figure 13: Weekly Average On-hand Comparison between the Different

Variability	Bulkiness	Item ID	Weekly Average On-hand			Number of Shortages			Frequency of Orders		
			Actual Min-Max	Theoretical Min-Max (2 year)	Base Stock	Actual Min-Max	Theoretical Min-Max (2 year)	Base Stock	Actual Min-Max	Theoretical Min-Max (2 year)	Base Stock
High	Non-Bulky	57089	18.4	20.8	26.5	1	0	0	17	3	20
High	Non-Bulky	51445	31	15	51.5	0	9	0	5	3	16
High	Non-Bulky	52182	15	11	12	0	0	0	6	1	9
High	Non-Bulky	52773	13	10	7	0	3	3	10	2	14
High	Non-Bulky	50786	13	12	9	0	2	0	15	3	18
Medium	Bulky	52225	17	31	29	2	0	0	17	3	4
Medium	Bulky	57487	100	114.5	36	0	0	0	19	2	24
Medium	Bulky	50248	50	86.2	50	0	0	0	19	1	21
Medium	Non-Bulky	57091	14	12.1	14	0	0	0	14	2	23
Medium	Non-Bulky	54896	77	86.5	62	0	0	0	12	2	23
Low	Bulky	56360	74	90	24	0	0	0	12	2	23
Low	Bulky	54439	24	49	13	0	0	1	17	3	24
Low	Bulky	54897	54	53	24	0	0	0	18	2	22
Low	Bulky	53964	500	591	135	0	0	0	13	2	23
Low	Non-Bulky	59019	896	833	131	0	0	3	13	2	23

Table 7: The Comparison Between The Different Policies

### **3.5 Policy Comparison via Real Time Testing**

After the simulation showed that the base stock policy would lead to a performance comparable to the currently adopted policy, but with much less human interference, real time testing was carried out according to a 99.9% service level Base Stock policy, where 17 local, class A items, belonging to the different variability categories, were selected for testing because their lead time is short (9.2 taken as 10 weeks) compared to imported items (22 weeks) for a period of six months from March 1st 2013 to August 16th 2013.

#### ***3.5.1 Procedure***

The policy testing procedure was as follows. The MMD canceled all orders not yet received. An initialization period for bulky items would be ten weeks, and that for non-bulky items would be twelve weeks.

Several issues were faced before initiating the testing. The first issue faced was revising the review period based on bulkiness of items due to space constraints. In case of bulky items, review would be done weekly in order to save space. In case of non-bulky items, review would be done bi-weekly.

The second issue faced was the starting stock level for the testing. The average on-hand stock was calculated as discussed in the previous section. The actual on-hand was compared to it. In case the actual stock is less than the average, then a rush order had to be placed and to arrive on the day of initiating testing. In addition, a rush order must arrive every week (2 weeks) for bulky (non-bulky) items, so that after 10 weeks (12 weeks) (lead time +1), to maintain an inventory position equal to the base stock level  $S$ . An example would be bulky item 52225, which is the Vavd System For

Minimal Invasive having  $\mu_{weekly} = 4$ ,  $\sigma_{weekly} = 2.52$ ,  $\mu_{L+1} = 40.8$ , and  $\sigma_{L+1} = 8.067$ .

Table 8 illustrates how much and when rush orders must be received for the first four weeks.

S	Total On-Hand	Comparison	AV. S On-hand	Rush Order	Week 0 (Rush order)	Week 1	Week 2	Week 3	Week 4
66	7	<	26	19	Receive 19	Receive 4 & Order S-On-hand-On Order	Receive 4 & Order S-On-hand-On Order	Receive 4 & Order S-On-hand-On Order	Receive 4 & Order S-On-hand-On Order

Table 8: The Rush Orders To Be Received

In case the actual on-hand stock is greater, then no rush order would be required before the actual on-hand decreases to the average level, after which a rush order would be received every week till the end of the lead time. An example would be bulky item 56360, which is the Pump Tube for Coblator having  $\mu_{weekly} = 7.06$ ,  $\sigma_{weekly} = 1.976$ ,  $\mu_{L+1} = 72.012$ , and  $\sigma_{L+1} = 6.312$ . Table 9 illustrates how much and when rush orders must be received for the first four weeks. Since the on-hand is greater than the average on-hand by  $35 - 22 = 13$ , then we need to wait  $\frac{13}{weekly\ demand = 7.06} \approx 2$  weeks in order to reach average on-hand, hence we should receive a rush order at the end of week 2.

The same procedure would be applied for non-bulky items.

S	Total On-Hand	Comparison	AV. S On-hand	Rush Order	Week 0 (Rush order)	Week 1	Week 2	Week 3	Week 4
92	35	>	22	0	0	Order S-On-hand-On Order	Receive 7 & Order S-On-hand-On Order	Receive 7 & Order S-On-hand-On Order	Receive 7 & Order S-On-hand-On Order

Table 9: The Rush Orders To Be Received

### ***3.5.3 Real-time Testing Results***

In this section, we compare the weekly average on-hand stock, frequency of orders and shortages when applying the Min-Max by the MMD for the period between September 2012 and February 2013 and the Base Stock policy in real time for the period between March 2013 and August 2013. The results are in-line with the simulation comparison, where the Base Stock policy produces competitive results to the (manually altered) min-max policy, saving a great deal of labor time and hassle.

#### **3.5.3.1 Shortages Comparison**

When applying the Base Stock policy, no shortages were faced. However, as presented in Section 3.4.4.2, the Actual Min-Max does actually have shortages, despite the rush order act conducted based on human intervention.

#### **3.5.3.2 Weekly Average on-Hand Comparison**

As shown in Table 10, the Base Stock results in higher on-hand inventory by 15%, but with a standard deviation of 45 %. Statistically speaking, we can't infer any results in that regard because the standard deviation is very high when compared to the average.

Variability	Bulkiness	Item ID	Weekly Average On-hand		Difference
			Actual Min-Max (Sept-Feb)	Base Stock (Mar-Aug)	
High	Non-Bulky	57089	18.4	31.45	71%
High	Non-Bulky	51445	31	41.36	33%
High	Non-Bulky	52182	15	18.36	22%
High	Non-Bulky	52773	13	10.27	-21%
High	Non-Bulky	50786	13	14	8%
Medium	Bulky	52225	17	31.5	85%
Medium	Bulky	57487	100	76	-24%
Medium	Non-Bulky	57091	14	22	57%
Medium	Non-Bulky	54896	77	128	66%
Low	Bulky	56360	74	75	1%
Low	Bulky	54897	54	25	-54%
Low	Bulky	53964	500	535	7%
Low	Non-Bulky	59019	896	330	-63%
				Average	15%
				Standard Deviation	45%

Table 10: The Real-time Testing Results

### 3.5.3.3 Frequency of Order Comparison

As shown in Figure 14, the frequency of orders between the actual Min-Max and the base stock are almost the same, hence, the ordering cost, if any, should be the same for the Base Stock or the actual Min-Max. This also demonstrates that the base stock delivers competitive results without any human intervention.

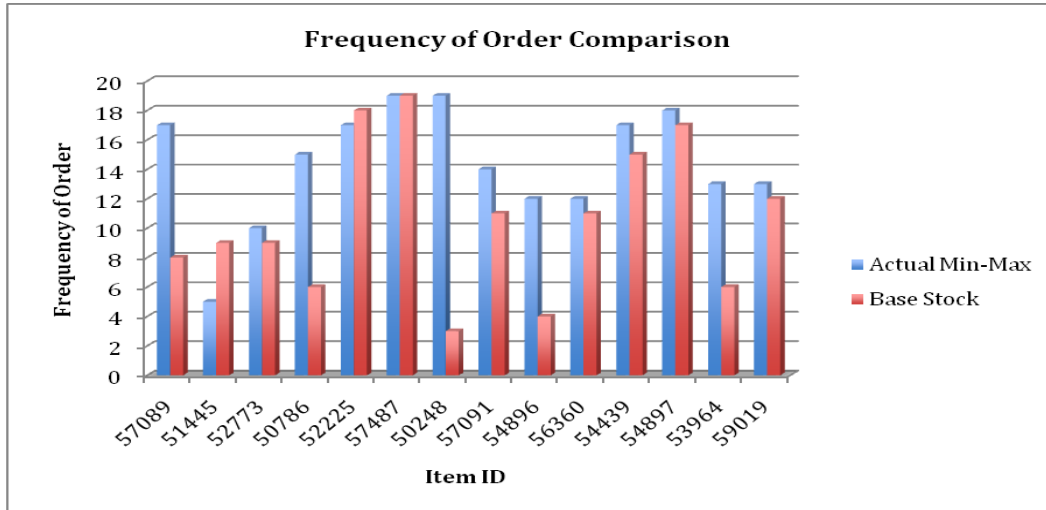


Figure 14: Frequency of Order Comparison

### 3.6 Accounting for Fixed Ordering Cost

So far, we have assumed that the setup and ordering cost,  $K$ , to be 0, simply because AUBMC does not recognize such a cost. However, such a cost does exist. Even if the setup and ordering cost is small, considering it over the number of items that the MMD at AUBMC manages (more 13,000 items in total), this setup and ordering cost could become significant. In the following, we estimate the fixed ordering cost.

#### 3.6.1 Estimating the Fixed Ordering Cost

After interviewing several storekeepers at the MMD, it was recognized that the process of ordering and receiving is made up of three important phases:

- Placing the order and approving it at the MMD
- Approval and purchasing by the Purchasing Department
- Physical entry and system entry at the MMD

Upon accounting for the labor cost at each of these three stages, the fixed cost was estimated to be \$10.

### 3.6.2 (s, S) Policy with Ordering Cost

In order to study the effect of the calculated ordering cost on the policy, an (s, S) policy taking into consideration the consideration the ordering cost  $K$  should be calculated and compared against the Base Stock Order up to S policy. The Table shows the different values for the policies for the fifteen (15) items under study.

According to Ravindran and Warsing (2013), an (s, S) Period-Review, Reorder-Point-Order-up to Model can be calculated as follows:

$$s = \mu_{L+1} + Z_{0.999} \times \sigma_{L+1}, S = s + EOQ = s + \sqrt{\frac{2KD}{h}}, \text{ where}$$

- $\mu_{L+1}$  is the average demand over the lead time and review period
- $\sigma_{L+1}$  is the standard deviation over the lead time and review period
- $D$  is the demand per year
- $h$  is the holding cost per item, considered to be 13% according the survey presented by Corman (1998)



			Ordering Cost K = 10\$			Base Stock Policy (S Level)	(s, S) Policy		Difference	
Variability	Bulkiness	Item ID	Unit Price	Holding Cost	Demand		s	S	S-s	Percentage
High	Non-Bulky	57089	375	48.75	8	49	49	51	2	3.7%
High	Non-Bulky	51445	220	28.6	12.25	92	92	95	3	3.2%
High	Non-Bulky	52182	480	62.4	3.625	22	22	23	1	4.9%
High	Non-Bulky	52773	500	65	3.5	23	23	24	1	4.5%
High	Non-Bulky	50786	363	47.19	5.16	29	29	30	1	5.1%
Medium	Bulky	52225	390	50.7	16	66	66	69	3	3.8%
Medium	Bulky	57487	120	15.6	37.32	153	153	160	7	4.5%
Medium	Bulky	50248	135	17.55	22.64	107	107	112	5	4.7%
Medium	Non-Bulky	57091	450	58.5	10.4	50	50	52	2	3.8%
Medium	Non-Bulky	54896	75	9.75	32	149	149	157	8	5.4%
Low	Bulky	56360	100	13	28.24	92	92	99	7	7.2%
Low	Bulky	54439	93	12.09	24.48	88	88	94	6	7.2%
Low	Bulky	54897	130	16.9	16.68	60	60	64	4	7.4%
Low	Bulky	53964	5.4	0.702	222.08	696	696	776	80	11.4%
Low	Non-Bulky	59019	3.4	0.442	390	1365	1365	1498	133	9.7%

Table 11: The Difference Between The (s,S) Policy With Ordering Cost and The Base Stock Policy

As shown in Table 11, the (s, S) policy and Order up to Policy slightly differ in the values, which show that the decision taken at the beginning to ignore the ordering cost in calculating the Order up to Level S is acceptable.

## CHAPTER 4

### ANALYZING & IMPROVING PATIENT FLOW AT FMD

In this chapter, we discuss data collection, model building, and model simulation of the FM patient flow. We had been provided with a year old data for all the patients that had visited the FM clinic. The data included physician details, appointment details, patient type, and entry and exit times from each station in the system (check-in, cashier, assessment nurse, physician, etc.). Section 4.1, introduces FMD research problem in detail. Then, Section 4.2 discusses the patient process flow in the FMD. Next, Section 4.3, we will discuss the data analysis. In Section 4.4, we will discuss the simulation model and its validation. In Section 4.5, we will present the results of the simulation. Finally, in Section 4.6, we will present the suggested improvements.

#### **4.1 Introduction**

Our research methodology is unique in that it blends a paradigm of practical (modern) queuing theory, and cutting-edge discrete-event simulation and simulation-optimization in Arena.

The objectives of the family medicine simulation are (i) to reduce the patient delay at AUBMC FM clinics at minimum cost, (ii) to increase employee utilization, and (iii) to develop new analytical (queuing) models, which can be applied in any primary care facility. Specifically, we aim at:

1. Developing a discrete-event simulation model for the patient flow of FM, allowing assessing the performance. The main measures of performance (key performance indicator, KPI) we have in mind relate to patient total waiting

time, i.e., the sum of times a patient spends waiting at different sub-systems (e.g., at the check-in, assessment nurse, and the FM physician). Specific KPIs that we will target include the mean delay, the average number of patients in FM, and the fraction of patients waiting more than some threshold (e.g., 1.5 hours). Another important KPIs are the fraction of walk-ins denied service and employee utilization. Arena software will be used, e.g., Kelton et al. (2009).

2. Performing “simulation-optimization”, (Fu, 2002). The improved approximations in (3) would serve as a good starting point for “optimizing” the FM medicine, which will ultimately improve the performance such as reducing patient waiting time within reasonable cost and profitability. We envision two sets of “decision variables” for this optimization, (i) the number of physicians and nurses throughout the day, and (ii) the duration of appointment slots (which should range between 15 and 30 minutes, e.g., Gupta and Denton 2008) at each physician, in addition to a budget constraint limiting the payroll and overhead costs and a profitability constraint setting a minimum number of expected consultations per day for each physician.
3. Analyze the structure of the optimal schedule and resource allocations. This allows gaining managerial insights that all healthcare providers can benefit from.

## 4.2 Process flow diagram

The process flow diagram, shown in Figure 15, dictates how patient move around the FM system. In “queuing speaks”, this will give a “routing matrix” defining the likelihood of a patient going from one subsystem (e.g. cashier) to another (e.g., assessment nurse). The family medicine center will be relocating into a new facility (the Sawwaf Building) soon and this flow will change. Our queuing and simulation models are currently being used by FM to help in improving the process flow in the Sawwaf building and estimating the mean patient delay, before it opens. The flow is as follows, the patient arrives and checks in for his appointment. The patient is then directed to the cashier to pay fees if applied. Afterward the patient will proceed to the assessment waiting area (waiting area 1) until a nurse is available to perform the assessment procedure. Next the patient will be lead to the physicians waiting area (waiting area 2) until a physician becomes available after which he will proceed to the physician for the examination to occur. After the examination ends the patients will either need a procedure performed or not. In the latter case, the patient will directly leave the system. Otherwise, if a procedure is required the patient will proceed to the check-in to fill in the necessary documentations and then go to the cashier to pay any additional fees. Afterwards, the patient will proceed to the procedure room and then exits the system.

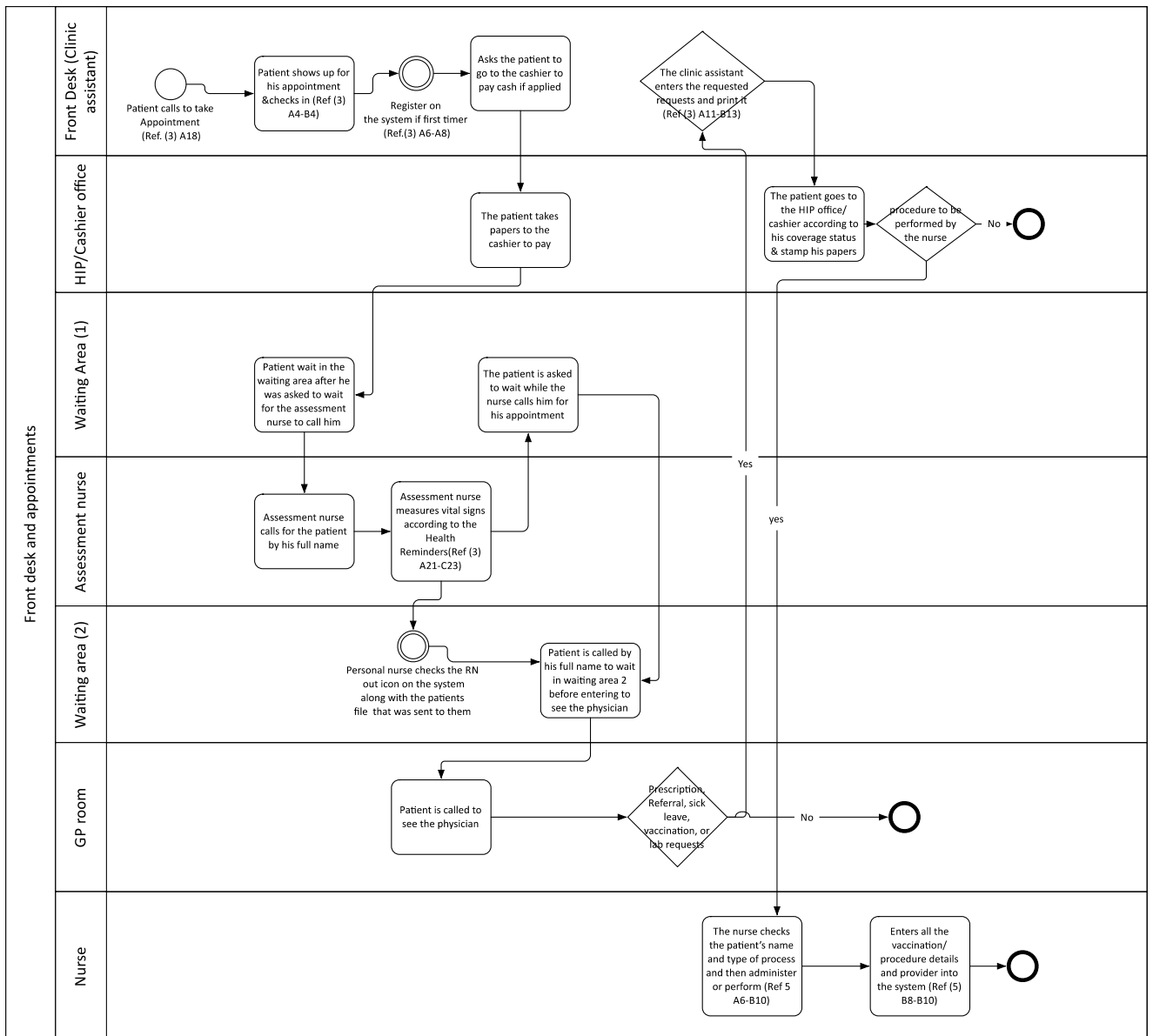


Figure 15: FM Clinic Current Flow Diagram

### 4.3 Data Analysis

To properly model the Family Medicine patient flow, we need the following data:

1. Physicians' Statistics: these statistics were needed to detect which physicians are the most active in the system, or in other words, serve the largest number of patients when compared to other physicians. The list of physicians having the largest number of patients will be the ones under study.

2. Inter-arrival times to each physician, based on two streams of arrivals:
  - a. “Scheduled,” who arrive based on a pre-set appointment with the physician. While this stream of arrival may seem straightforward. It is common that some patients will (i) call and cancel their appointments the last minute, (ii) not show-up for their appointment, or (iii) arrive late for their appointment. In our ongoing data collection, we are accounting for this by estimating the fraction of cancelations and no-shows for every FM physician, as well as late. The current schedule of a physician at FM is set to receive appointments in slots of 20 minutes per patient.
  - b. “Walk-ins”, who arrive without an appointment. These arrivals have a high variability, as evidenced by the histogram in Figure 16 for the inter-arrival time of walk-ins to the clinic. To this histogram, a probability distribution is fit using a handy package, which is bundled with Arena, the Input Analyzer. Arena’s Input Analyzer indicates a Beta distribution for the inter-arrival of walk-ins to the clinic having a distribution mean of 16.7, and a distribution standard deviation of 30 (minutes). Data on arrival times was obtained from the FM staff that collects data electronically through an effective bookkeeping system, which was very rich and versatile. It captures the arrival times and service times of more than 60,000 patients at FM over the past year.
3. Service Times: this refers to the time patients spend at different subsystems of the FM clinic; the longer of which is typically at the physician clinic. While some literature (e.g. Gupta and Denton 2008) suggests deterministic service times in ambulatory care, our experience has been different. For example, Figure

17 shows the histogram and the fitted distribution (from Input Analyzer) to the clinic over the past year of a certain physician. The service time at the clinic has a Weibull distribution with a distribution mean of 19.7, and a distribution standard deviation of 12.9 (minutes). This implies some significant variability with a coefficient of variation,  $CV = \frac{\sigma}{\mu}$ , of 65.4%. (A typical approach in

Operations Research is to assume a deterministic process when  $CV < 20\%$ , e.g. Taha (2007).



Figure 16: Inter-arrival Time Distribution of walk-in patients to the clinic from Arena Input Analyzer; Beta distribution having a Beta of 0.267, alpha of 7.44, a constant of -0.001 distribution mean of 16.7, and distribution standard deviation of 30 (minutes)

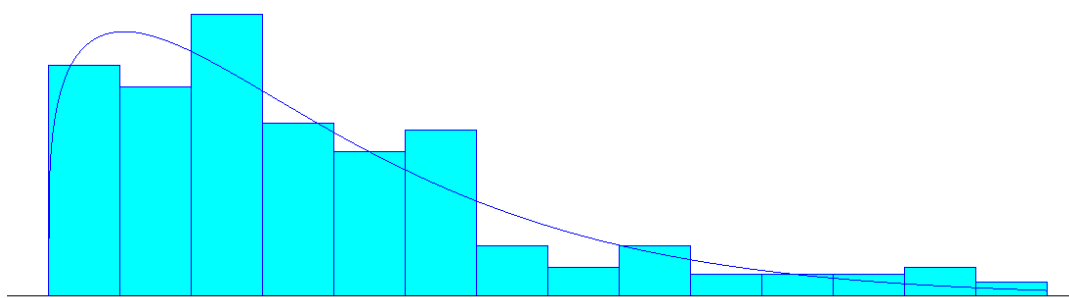


Figure 17: Service Time Distribution of walk-in patients to the clinic from Arena Input Analyzer; Weibull distribution a Beta of 15.7, an alpha of 1.23, a constant of 5, a distribution mean of 19.7, and a distribution standard deviation of 12.9 (minutes)

### 4.3.1 Physicians' Statistics

As stated earlier, the aim of the research was to properly model the current FM clinic operations, with a final goal of developing a schedule for physicians that would lower patient waiting time, in addition to increasing FM clinic employees' utilization.

An important starting point to reach the above goals was to decide on which physicians shall the study be carried on. To do that, we had considered the data given to us by the FM clinic administration, and analyzed patients who have checked in the system (having a time in record) and checked in the physician's station, which sum up to 29,188 patients for the past year. The reason behind that is that we wanted to study the number of patients actually being served by the doctor. Figures 18 and 19 show the number and percentage of patients served by the top ten physicians when compared to the total number of served patients, who serve around 81% of the total number of patients admitted to the FM clinic. The analysis and research was done on the top ten physicians.

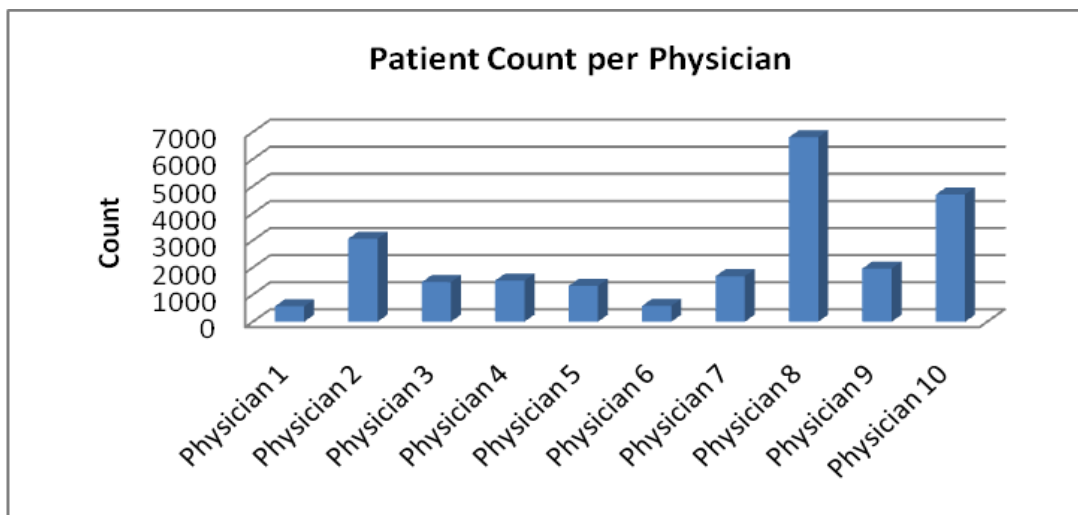


Figure 18: Patient Count per Physician



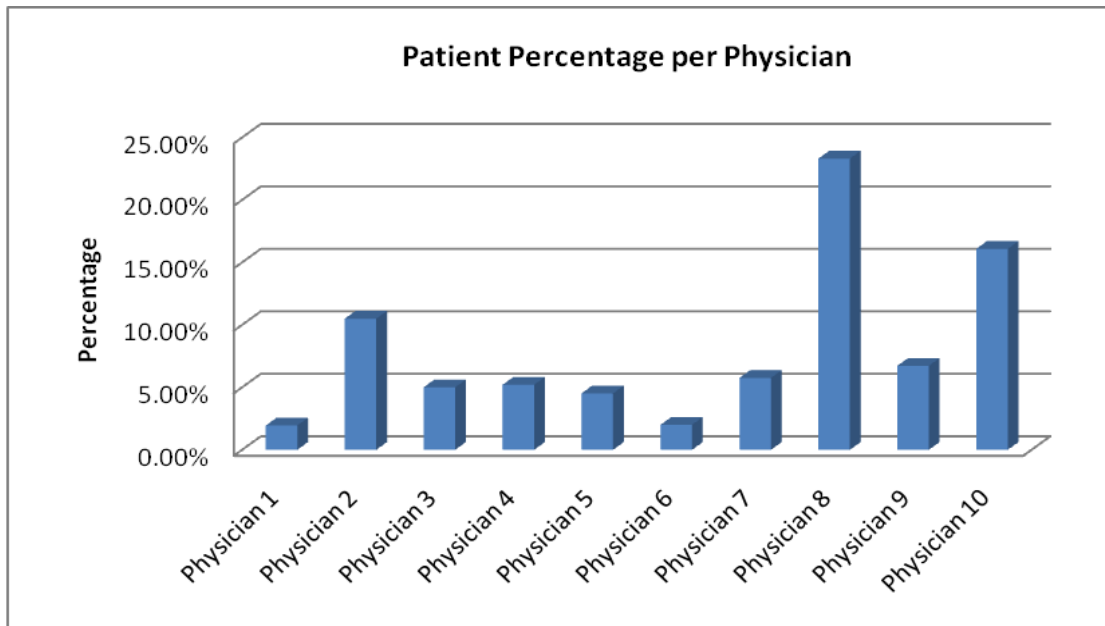


Figure 19: Patient Percentage per Physician

### 4.3.2 Inter-arrival Time

#### 4.3.2.1 Scheduled Patients

The current schedule of a physician at FM is set to receive appointments in slots of twenty minutes per patient. However, what effects the inter-arrival time of a schedule patient is his arrival status, whether he arrives early or on time, which are treated in the same way, or late.

As defined earlier, scheduled patients are those who arrive based on a pre-set appointment with the physician. Scheduled patients would either arrive early, or on time, or late, or call and cancel their appointment, or not show up for the appointment. In our model, we had assumed that patients who arrive early and on time to their appointment to be on time patients, because they will be treated the same manner, meaning that they will be admitted at their appointment time or after, but not before.

Hence, given that we need the lateness of the patient to his appointment, we had to extract from the data provided the appropriate patient lateness data per physician so

that we could fit proper distributions and model the system. In that regard, we had cleaned the data, applied several filters, and took several assumptions, which are:

1. Only consider patients that are being treated by the physicians under study
2. Only consider patients who are only labeled as patients with appointments
3. Remove patient entries that have no time in, i.e. the system did not recorded their entrance
4. In order to estimate the lateness per patient, we had taken the difference between the time the patient arrived in the system and his scheduled appointment. Early and on time patients had a value of 0, and weren't considered late.
5. Patients who had lateness greater than 120 minutes were not considered

After acquiring the data, cleaning it, and applying the filters and our assumptions, we had fitted lateness distributions for each physician (refer to appendix A for the distributions). Table 12 shows the lateness distributions for the different physicians under study. In addition, a sample distribution is found in Figure 20, where the lateness has a Weibull distribution with a distribution mean 10.5, and a distribution standard deviation of 11.62 (minutes).

<b>Physician Name</b>	<b>Lateness Distribution</b>	<b>Distribution Mean (minutes)</b>	<b>Distribution Standard deviation (minutes)</b>
Physician 1	WEIB(9.98, 0.903)	10.5	11.6
Physician 2	WEIB(15.8, 0.888)	17	18.9
Physician 3	WEIB(9.2, 0.936)	9.48	10.1
Physician 4	WEIB(9.51, 0.827)	10.53	12.8
Physician 5	115 * BETA(0.546, 2.68)	19.46	21
Physician 6	WEIB(10.7, 0.933)	11.047	11.9
Physician 7	WEIB(11.7, 0.881)	12.459	17.3
Physician 8	WEIB(12, 0.793)	13.68	17.4
Physician 9	WEIB(9.48, 0.859)	10.25	12
Physician 10	WEIB(10.5, 0.857)	11.36	13.3

Table 12: Patient Lateness Distributions per Physician

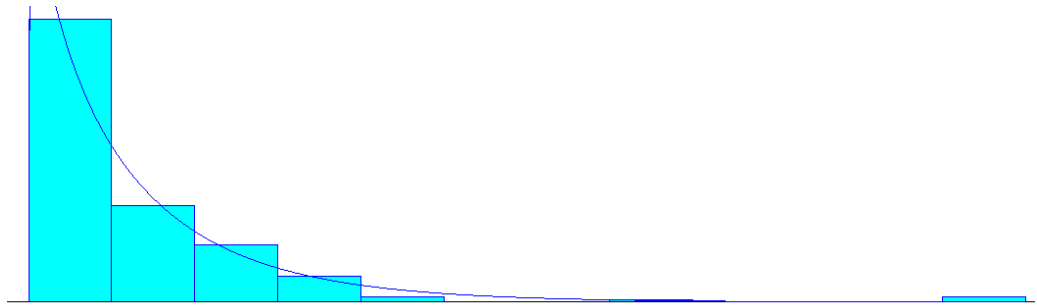


Figure 20: Lateness Distribution of scheduled patients from Arena Input Analyzer; Weibull distribution with a Beta of 9.98, an alpha of 0.903, distribution mean 10.5, and a distribution standard deviation of 11.62

In addition, we needed the probability of patients who are actually late to their appointment, so that they would be modeled by the lateness distribution. In order to do that, we had cleaned the data, applied several filters, and took several assumptions that are the same as the ones applied to get the data in order to fit the lateness distributions.

According to the data analysis, it turned out that in total, when considering early and on time patients, they account for 67% of the total number patients visiting the FM clinic, whereas the late patients account for 33% of the total number of patients visiting the FM clinic, with mean lateness of 12.6 minutes and standard deviation of 3.3 minutes. However, we needed per physician in the model, which have been estimated and are found in the Table 13 and explained by graphs 21 and 22:

Physician	Total (without WI+XI)	Number Late	Percentage Late (without WI+XI)	Average Late (minutes)
Physician 1	430	168	39%	10.5
Physician 2	2499	801	32%	17
Physician 3	825	250	30%	9.5
Physician 4	667	202	30%	10.6
Physician 5	964	288	30%	19.5
Physician 6	391	143	37%	11.1
Physician 7	935	286	31%	12.5
Physician 8	1111	339	31%	13.9
Physician 9	1177	287	24%	10.3
Physician 10	1727	667	39%	11.3
Average			33%	12.6
Standard Deviation			5%	3.3

Table 13: The Probability Of Late Patients Per Physician

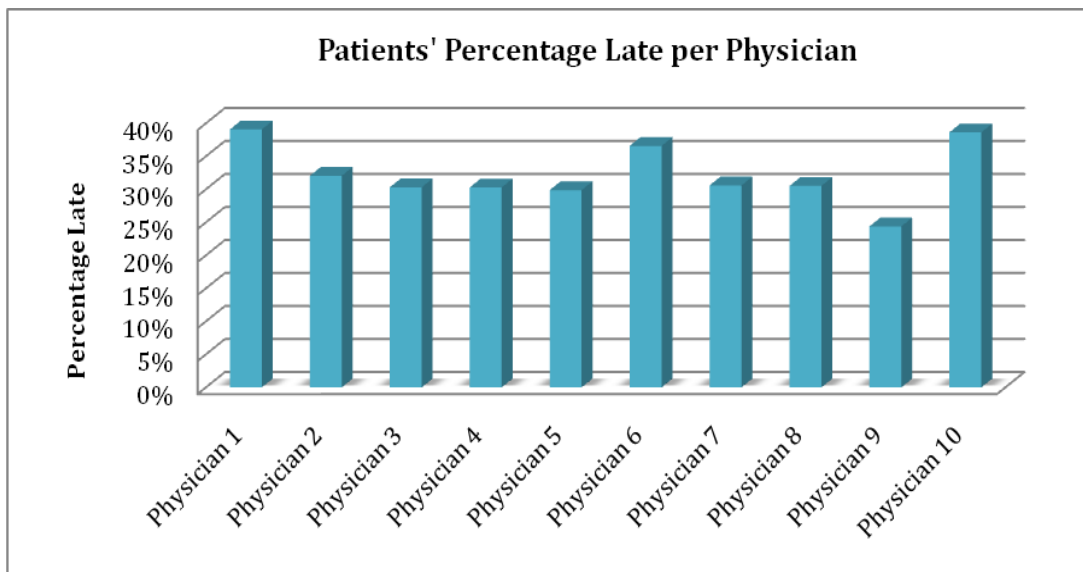


Figure 21: Graph Showing The Percentage Of Late Patients Per Physician

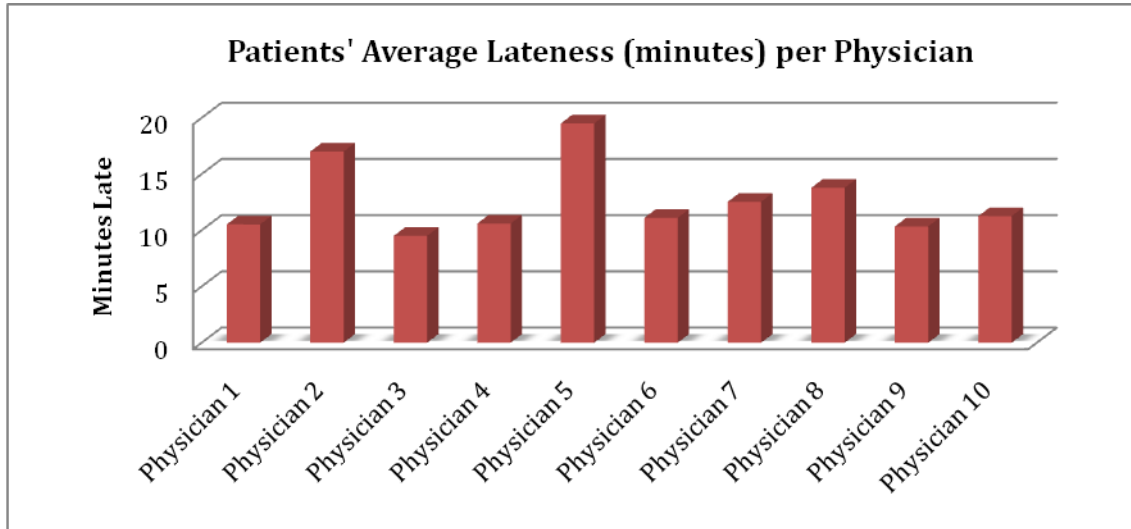


Figure 22: Graph Showing The Patients' Average Lateness Per Physician

In addition, we have assumed patients, those who call and cancel and those who do not show to be no-show patients, because they affect the system in the same manner, meaning that there will be empty time slot in the physician's schedule. In order to extract no-show probability data from the provided data, we had cleaned the data, applied several filters, and took several assumptions, which are:

1. Considered patients that are being treated by the 10 physicians under study
2. Considered patients who are only labeled as:
  - a. Patients with appointments
  - b. Patients who are random walk in with a assigned appointment later on to be canceled
3. Patients who are labeled with No-show or Canceled were considered as no-show patients

According to the data analysis, we had recorded two types of results, based on whether or not we consider the random walk-in patients as a part of the population. In that sense, we had recorded both results, as shown in Table 14 and Figure 23, and

discussed them with FM clinic administration. Based on their feedback, the patients' no-show probability ranges between 10 and 20%, which aligns with our results when we consider the random walk-in patients as part of the population, hence, we had used the associated results in the model, which have an average of 15% and a standard deviation of 4%, as shown in the Table 14 .

Physician	Total (without WI+XI)	Number of No-show	Percentage No-show (without WI+XI)	Total (with WI+XI)	Number Nb No-show	Percentage No-show (with WI+XI)	Average
Physician 1	614	141	23%	896	156	17%	20%
Physician 2	2877	621	22%	4922	688	14%	18%
Physician 3	1251	337	27%	2120	458	22%	24%
Physician 4	906	158	17%	1921	260	14%	15%
Physician 5	1718	298	17%	3042	330	11%	14%
Physician 6	574	151	26%	829	166	20%	23%
Physician 7	1899	475	25%	3301	634	19%	22%
Physician 8	1985	343	17%	9371	735	8%	13%
Physician 9	1973	350	18%	2987	430	14%	16%
Physician 10	2594	698	27%	5843	890	15%	21%
<b>Average</b>			<b>22%</b>			<b>15%</b>	<b>19%</b>
<b>Standard Deviation</b>			<b>4%</b>			<b>4%</b>	<b>4%</b>

Table 14: The No-show Probability Analysis

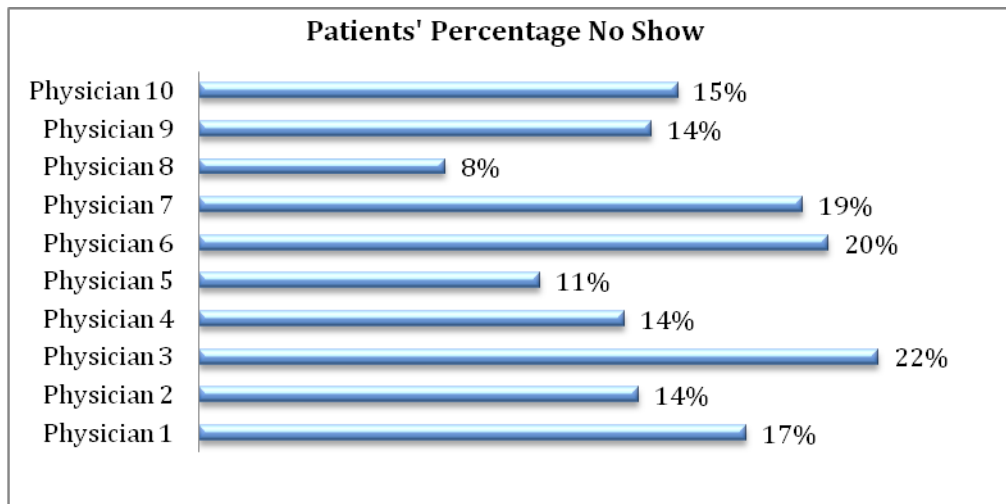


Figure 23: Patients' Percentage No-show Per Physician (Population with Random Walk-in Patients)

#### 4.3.2.2 Random Walk-in Patients

As defined earlier, random walk-in patients are those who arrive at the FM clinic without prior appointment. It was pointed out by the FM clinic staff that these random

walk-in patients comprise around 20% (35% based on the data) of the total number of patients being admitted to the clinic; hence, adding random walk-in patient data to the model was a must. Hence, we had to derive random walk-in inter-arrival times distribution to imbed them in the model in order to properly model the real performance system. In order to do that, we had cleaned the data, applied several filters, and took several assumptions:

1. Considered patients that have registered system entry time (entered the system)
2. The data was sorted in a dual manner, in decreasing priority of sorting:
  - 2.1. Data sorted according to visit date
  - 2.2. Data sorted according to the time the patients was admitted in the system
3. Considered patients that were only treated by the 10 physicians under analysis

After applying the above filers and assumptions, we were left with one more assumption to take, which regarded 0 and negative valued inter-arrival times. The 0 valued inter-arrival time meant that the patient randomly arrived and was recorded in the system at 8 am sharp, whereas the negative valued inter-arrival times meant that the randomly arrived patient was recorded in the system prior to 8 am. Hence, distributions were fitted for two groups of data found. However, since the distributions were not significantly different (appendix C), using any was safe. Table 25 shows the distributions for the two groups. In addition, the distributions are shown in graphs 24 and 25:

Description	Inter-arrival Data distribution for Random Walk-in with (without 0)	Inter-arrival Data distribution for Random Walk-in with (with 0)
Distribution Function	484 * BETA(0.273, 7.48)	-0.001 + 484 * BETA(0.267, 7.44)
Distribution Mean (minutes)	17	16.7
Distribution Standard Deviation (minutes)	30.15	30

Table 15: The Inter-arrival Distributions For The Two Groups

1. Data without 0 and negative values, where the fitted distribution is found in

Figure 24 :



Figure 24: Inter-arrival Time Distribution of walk-in patients to the clinic from Arena Input Analyzer; Beta distribution having a Beta of 0.273, an alpha of 7.48, a multiplier of 484, a distribution mean of 17.04, and distribution standard deviation of 30.15 (minutes)

2. Data with 0 and negative values, where the fitted distribution is found in Figure

25:

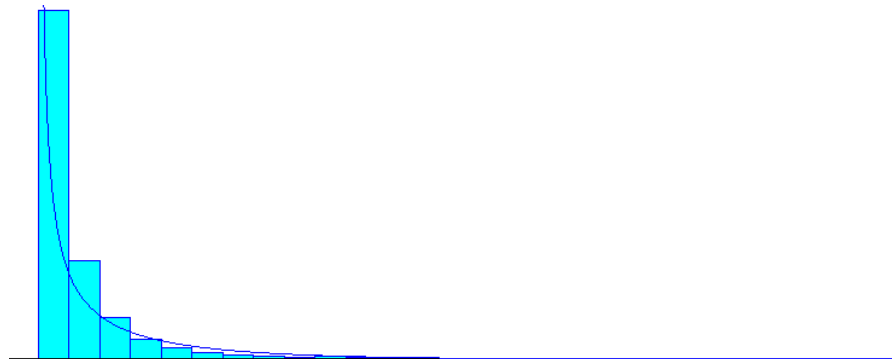


Figure 25: Inter-arrival Time Distribution of walk-in patients to the clinic from Arena Input Analyzer; Beta distribution having a Beta of 0.267, an alpha of 7.44, a multiplier of 484, a constant of -0.001, a distribution mean of 16.7, and distribution standard deviation of 30 (minutes)



### ***4.3.3 Service Times***

As defined earlier, services times represent the duration that a patient spends at every station in the FM clinic. As described earlier, the patient passes through several stations: the check-in station, the cashier station, the assessment nurse station, and the physician station. Each of the stations needs to be imbedded in our model in order to properly simulate the real performance system. In order to do that, and using the data provided by the FM clinic administration, distribution functions were fitted to the service times at different stations, as we will describe.

#### **4.3.3.1 Physician Service Times**

The physician's service time is the time it took the physician to check the patient. In other words, it is the time the patient had spent in the physician's station. As explained earlier, we needed the service time distribution for each physician in order to accurately model the real time operations. In order to do that, we had cleaned the data, applied several filters, and took several assumptions, which are:

1. Considered patients that have registered system entry time (i.e. admitted to the system)
2. Removed empty entries in any of the stations specified above (check-in, cashier, assessment nurse, and physician stations)
3. Considered patients who have consistent data, i.e. time into station is less than time out of station for each station and in the correct order (check-in, followed by cashier, nurse assessment, and finally the physician station)
4. Calculated the physicians' service times by subtracting the time the patient enters the physician's station from the time he leaves the station

5. Considered only entries that are between 5 and 60 minutes based on the feedback of the FM administration, which based their feedback on the fact that patient records not falling in that range are suspected to numerous data entry errors.

After acquiring the data, cleaning it, and applying the filters and our assumptions, we had fitted the service time distributions for each physician (refer to appendix B for the distributions and details). Table 16 shows the physician service time distributions. In addition, a sample distribution is found Figure 26 , where the service time has a Weibull distribution, a distribution mean 16.5, and a distribution standard deviation of 9.8 (minutes):

Physician	Service Time Distribution	Distribution Mean (minutes)	Distribution Standard deviation (minutes)
Physician 1	5 + WEIB(15.7, 1.23)	19.7	12.2
Physician 2	5 + WEIB(14.1, 1.23)	18.2	11
Physician 3	5 + GAMM(5.49, 1.64)	14	7.4
Physician 4	5 + ERLA(6.07, 2)	17.1	8.9
Physician 5	5 + WEIB(13.4, 1.33)	17.3	9.6
Physician 6	5 + WEIB(20.3, 1.69)	23.1	11.2
Physician 7	5 + GAMM(7.88, 1.46)	16.5	9.8
Physician 8	5 + GAMM(5.9, 0.867)	10.1	5.9
Physician 9	5 + ERLA(5.31, 2)	15.6	7.8
Physician 10	5 + GAMM(3.2, 1.09)	8.5	4

Table 16: The Service Time Distributions per Physician

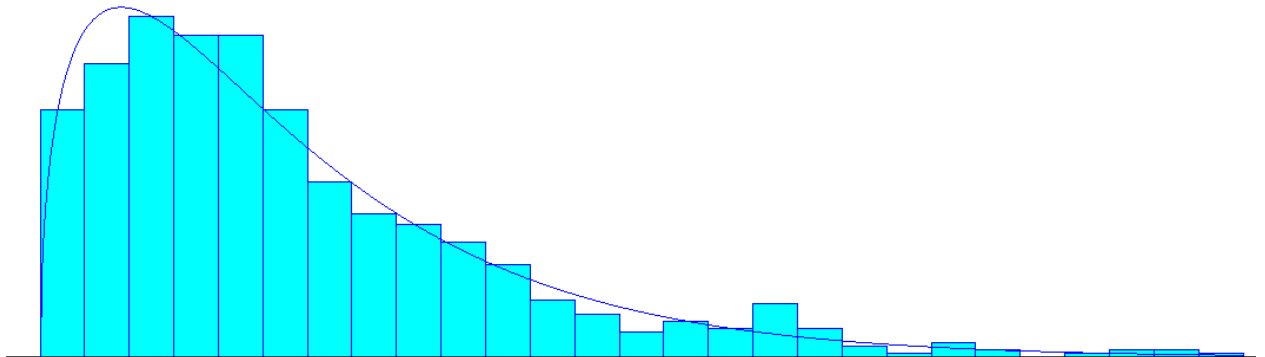


Figure 26: Physician Service Time Distribution of patients to the clinic from Arena Input Analyzer; Weibull distribution having a Beta of 7.88, an alpha of 1.46, a constant of 5, a distribution mean 16.5, and a distribution standard deviation of 9.8 (minutes)

#### 4.3.3.2 Assessment Nurse Service Times

The assessment nurse's service time is the time it took the assessment nurse to check the patient. In other words, it is the time the patient had spent in the assessment nurse station. As explained earlier, we need the service time distribution for service nurse in order to accurately model the real time operations. In order to do that, we had cleaned the data, applied several filters, and took several assumptions, which are:

1. Removed empty entries in any of the stations specified above (check-in, cashier, assessment nurse, and physician stations)
2. Considered patients who have consistent data, i.e. time into station is less than time out of station for each station and in the correct order (check-in, followed by cashier, nurse assessment, and finally the physician station)
3. Calculated the nurse's service times by subtracting the time the patient enters the nurse's station from the time he leaves the station
4. Removed service times greater than 15 minutes based on the feedback of FM clinic administration, who based their feedback on the fact that patient records greater than the previous number are suspected to numerous data entry errors.

After acquiring the data, cleaning it, and applying the filters and our assumptions, we had fitted the service time distributions for three groups of data: service times between 0 and 15 minutes, service times between 0.5 and 15 minutes, and service times between 1 and 15 minutes (refer to appendix D for the distributions and details). However, given the fact the distribution slightly varied from each other, taking any of them was safe. However, we had decided to take the group having service times between 1 and 15 minutes in the model after taking the feedback of the FM clinic administration, with the justification that a nurse can't possibly check the patient in less

than 1 minute. Table 17 shows the distributions for the different groups. In addition, the distribution for the group having service times between 1 and 15 minutes is found in Figure 27 (details and remaining distributions are found in appendix B), where the service time has a Gamma distribution with a distribution mean 4.08, and a distribution standard deviation of 2.63 (minutes):

Description	Nurse Assessment (entries between 0 and 15minutes):	Nurse Assessment (entries between 0.5 and 15minutes):	Nurse Assessment (entries between 1 and 15minutes):
Distribution Function	15 * BETA (0.48, 2.22)	GAMM (1.4, 2.79)	0.999 + GAMM (1.93, 1.59)
Distribution Mean	2.7	3.9	4
Distribution Standard Deviation	3	5.5	2.6

Table 17: The Assessment Nurse Service Time Distributions

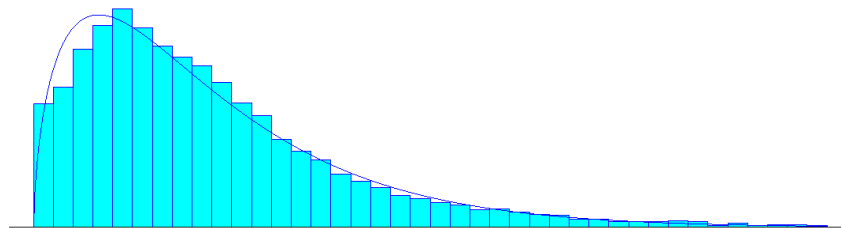


Figure 27: Assessment Nurse Service Time Distribution of patients to the clinic from Arena Input Analyzer; Gamma distribution with a Beta of 1.93, an alpha of 1.59, a constant of 0.999, a distribution mean 4.08, and a distribution standard deviation of 2.63 (minutes)

#### 4.3.3.3 Check-in Service Times

In regard to the check-in service times, no data was provided in order to fit a probability distribution. However, it turned out that the FM clinic administration had already conducted a study for the check-in service times. They had organized the different tasks at the Check-in station, which had one employee, and recorded the minimum and maximum time required to accomplish each task, as shown in Table 18. After discussing the data with them, we had fitted an empirical distribution that has a

Beta form with a distribution mean of 1.75, and a distribution standard deviation of 1.75 (minutes).

<b>Tasks</b>	<b>Minimum Time (Minutes)</b>	<b>Maximum Time (Minutes)</b>
Receiving patients and directing them to other stations	0.5	1
Check- in on the system	0.5	1
Data entry of all patients' medical requests after appointments for all clinic/issuing new encounters	0.5	1
Answering patient-related phone calls	0.5	3
Scheduling appointments for patients showing up in person	0.5	3
Rescheduling appointments by phone or in person	5	10
Calling patients and transfer to doctors	0.5	0.5
Handling new patients' registration File Maker and MPI	1	5
Calling medical records to update/correct duplicate Hospital patient numbers	5	10

Table 18: The Tasks At The Check-in Station With Service Time Statistics

#### 4.3.3.4 Cashier's Service Times

As for the case of the cashier's service times, it was similar to that of the check-in, where no data was provided and the FM clinic administration had already conducted a study for the cashier service times, where one employee is located. They had organized the different tasks at the Check-in station, and recorded the minimum and maximum time required to accomplish each task, as shown in Table 19. After discussing the data with them, we had fitted an empirical distribution that has a Beta form with a distribution mean of 1.54, and a distribution standard deviation of 1.04 (minutes).

<b>Tasks</b>	<b>Minimum Time (Minutes)</b>	<b>Maximum Time (Minutes)</b>
Charging HIP patients' visit fee on payroll	0.25	0.5
Stamping papers	1	0.5
Handling the stamping of non-chronic prescriptions	1	2
Handing in ready requests for all clinics (referral, prescription, x-rays...)	1	5

Table 19: The Tasks at The Check-in Station With Service Time Statistics

#### **4.3.4 Data Validation**

After acquiring the data from the FM clinic, and fitting distributions to the different types of service times (i.e. for the check-in, cashier, nurse assessment, and the physician stations), we had to validate the accuracy of the distributions, and how well it describes the data, in other words, whether the distributions are a good fit or not. In order to do that, we had compared the distributions' sample data points' mean and standard deviation from the acquired data, and compared it to the mean and standard deviation of the distribution itself. It is important to note that each distribution function has a formula for the mean and standard deviation as described by Kelton et al. (2009). Table 20 describes this.

As shown in the Table and Figures 28, 29, and 30, the maximum mean difference for the lateness distribution was 0.9%, with an average of 0.4%. As for the standard deviation, the maximum value was 16.4%, with an average of 9.7%. Moving on to the physician service time distribution. As shown in the Table and Figures 31, 32, and 33, the maximum mean difference was 3.9%, with an average of 0.5%. As for the standard deviation, the maximum standard deviation difference was 14.9%, with an average of 7.7%. Moreover, for the nurse assessment service time, as shown in Figures 34, 35, and 36, and for distribution of data belonging to the range of 1-15minutes, the

mean difference was 0.3%, and the standard deviation difference was 11.4%. Finally, for the inter-arrival time distribution, for the group having the early and on time patients, the mean difference and the standard deviation were both 0% as shown in Figures 37, 38, and 39.

The above analysis had proven that since the sample data mean and standard deviation are close, if not equal in a lot of cases, to the distribution mean and standard deviation, then the data is valid, or in other words, the distributions are a good fit for the data.

Data	Physician Name	Distributions	Square Error	Chi Square Test P-Value	KS Test P-Value	Sample Mean	Calculated Mean	Difference	Sample Standard Deviation	Calculated Standard Deviation	Difference	Valid
Lateness	Physician 1	WEIB(9.98, 0.903)	0.001957	> 0.15	> 0.15	10.5	10.5	0%	13.5	11.62	14%	Yes
	Physician 2	WEIB(15.8, 0.888)	0.00272	< 0.005	> 0.15	17	17	0%	20.4	18.9	7%	Yes
	Physician 3	WEIB(9.2, 0.936)	0.001986	0.0901	> 0.15	9.51	9.48	0%	11.7	10.14	13%	Yes
	Physician 4	WEIB(9.51, 0.827)	0.002765	0.0347	> 0.15	10.6	10.53	1%	14.5	12.8	12%	Yes
	Physician 5	115 * BETA(0.546, 2.68)	0.002108	0.197	< 0.01	19.5	19.46	0%	21	20.97	0%	Yes
	Physician 6	WEIB(10.7, 0.933)	0.000945	0.453	> 0.15	11.1	11.047	0%	12.4	11.85	4%	Yes
	Physician 7	WEIB(11.7, 0.881)	0.001286	0.431	> 0.15	12.5	12.459	0%	15.3	17.3	13%	Yes
	Physician 8	WEIB(12, 0.793)	0.001212	0.0708	> 0.15	13.8	13.68	1%	17.8	17.4	2%	Yes
	Physician 9	WEIB(9.48, 0.859)	0.002673	0.313	> 0.15	10.3	10.25	0%	14.3	11.96	16%	Yes
	Physician 10	WEIB(10.5, 0.857)	0.002182	0.0308	0.0282	11.3	11.36	1%	15.5	13.3	14%	Yes
Service Time	Physician 1	5 + WEIB(15.7, 1.23)	0.005404	0.0931	> 0.15	19.7	19.69	0%	11.6	12.19	5%	Yes
	Physician 2	5 + WEIB(14.1, 1.23)	0.00095	0.0244	0.142	17.5	18.19	4%	9.67	11	14%	Yes
	Physician 3	5 + GAMM(5.49, 1.64)	0.00141	0.246	> 0.15	14	14	0%	6.84	7.37	8%	Yes
	Physician 4	5 + ERLA(6.07, 2)	0.003957	< 0.005	0.0456	17.1	17.14	0%	9.96	8.87	11%	Yes
	Physician 5	5 + WEIB(13.4, 1.33)	0.000773	0.557	> 0.15	17.3	17.34	0%	9.3	9.59	3%	Yes
	Physician 6	5 + WEIB(20.3, 1.69)	0.00358	0.497	> 0.15	23.1	23.12	0%	11.1	11.24	1%	Yes
	Physician 7	5 + GAMM(7.88, 1.46)	0.00113	0.383	> 0.15	16.5	16.5	0%	9.28	9.78	5%	Yes
	Physician 8	5 + GAMM(5.9, 0.867)	0.002852	< 0.005	< 0.01	10.1	10.1153	0%	6.66	5.93	11%	Yes
	Physician 9	5 + ERLA(5.31, 2)	0.001228	0.0259	> 0.15	15.6	15.62	0%	8.14	7.83	4%	Yes
	Physician 10	5 + GAMM(3.2, 1.09)	0.000713	0.346	> 0.15	8.47	8.488	0%	3.5	4.02	15%	Yes
Assessment Nurse	0-15min	15 * BETA(0.48, 2.22)	0.010722	< 0.005	NA	2.8	2.667	5%	2.68	2.98	11%	Yes
	0.5-15min	GAMM(1.4, 2.79)	0.000309	< 0.005	NA	3.9	3.9	0%	2.41	2.338	3%	Yes
	1-15min	0.999 + GAMM(1.93, 1.59)	0.000634	< 0.005	NA	4.08	4.067	0%	2.36	2.63	11%	Yes
Inter-arrival	With 0	-0.001 + 484 * BETA(0.267, 7.44)	0.006909	< 0.005	NA	16.7	16.7	0%	30	29.99	0%	Yes
	Without 0	484 * BETA(0.273, 7.48)	0.006712	< 0.005	NA	17.2	17.04	1%	30.2	30.15	0%	Yes

Table 20: The Data Validation Done on The Different Fitted Distributions



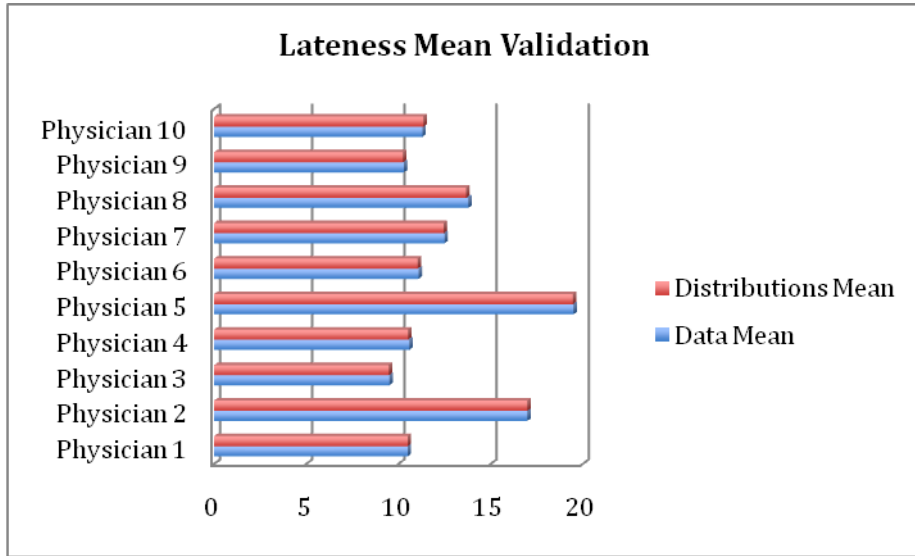


Figure 28: Lateness Mean Validation Graph

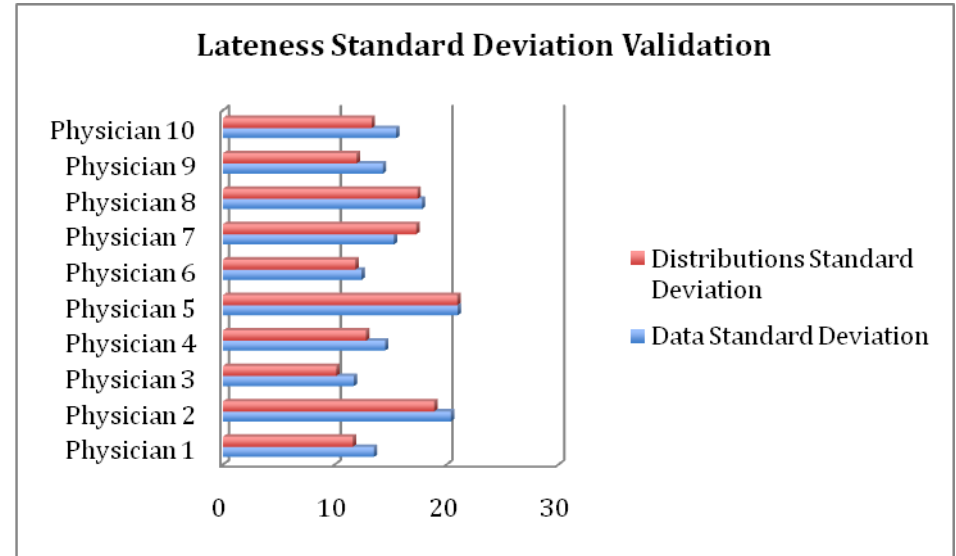


Figure 29: Lateness Standard Deviation Graph

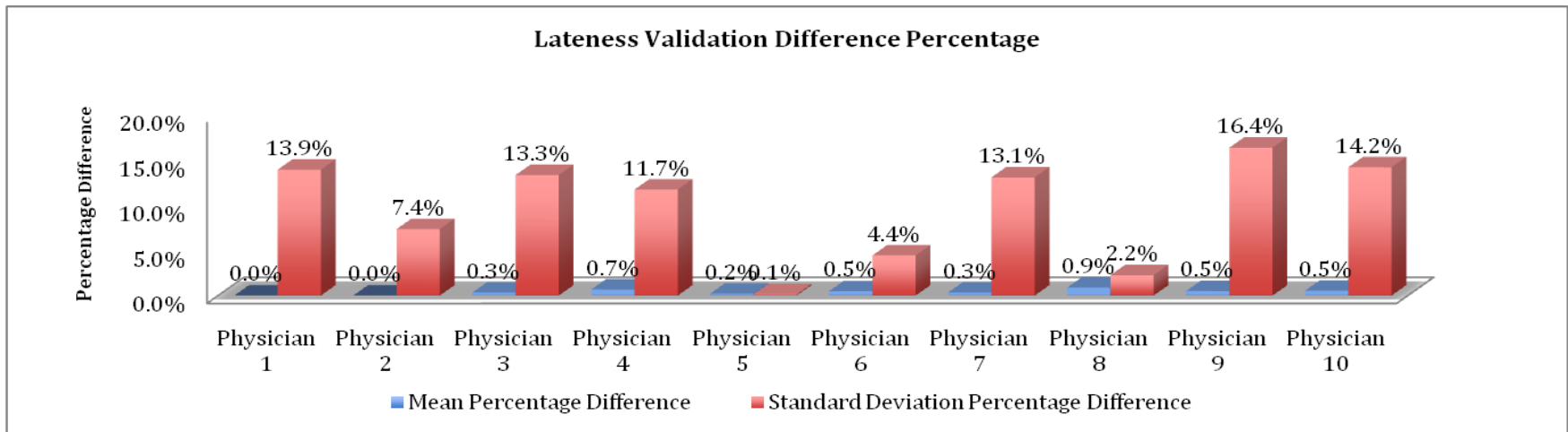


Figure 30: Lateness Validation Difference Percentage Graph

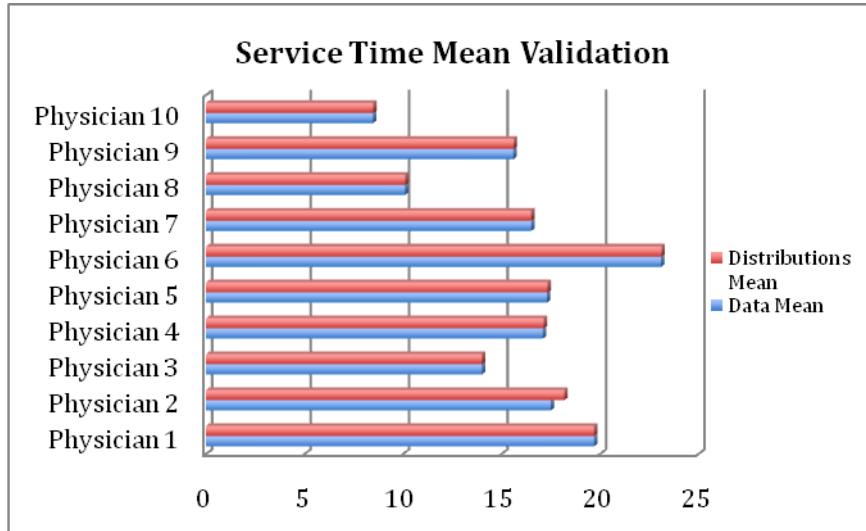


Figure 31: Physician Service Time Mean Validation

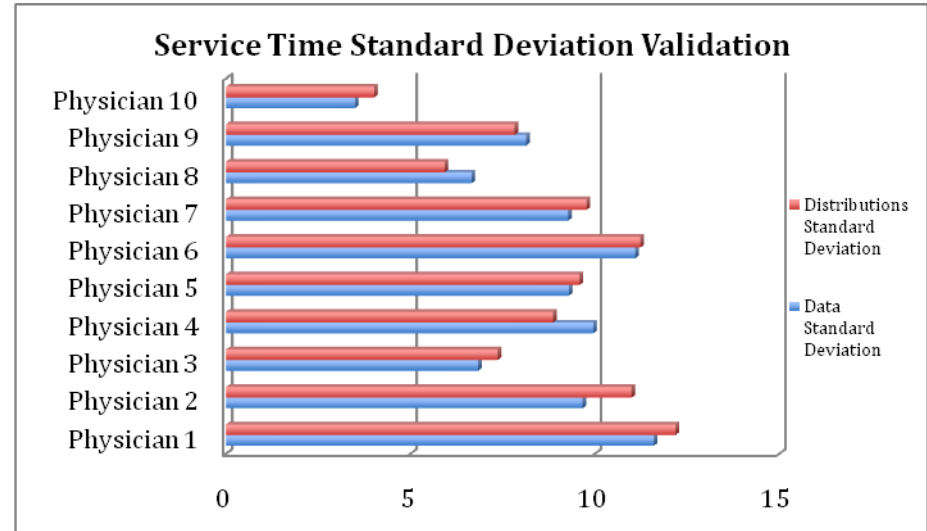


Figure 32: Physician Service Time Standard Deviation

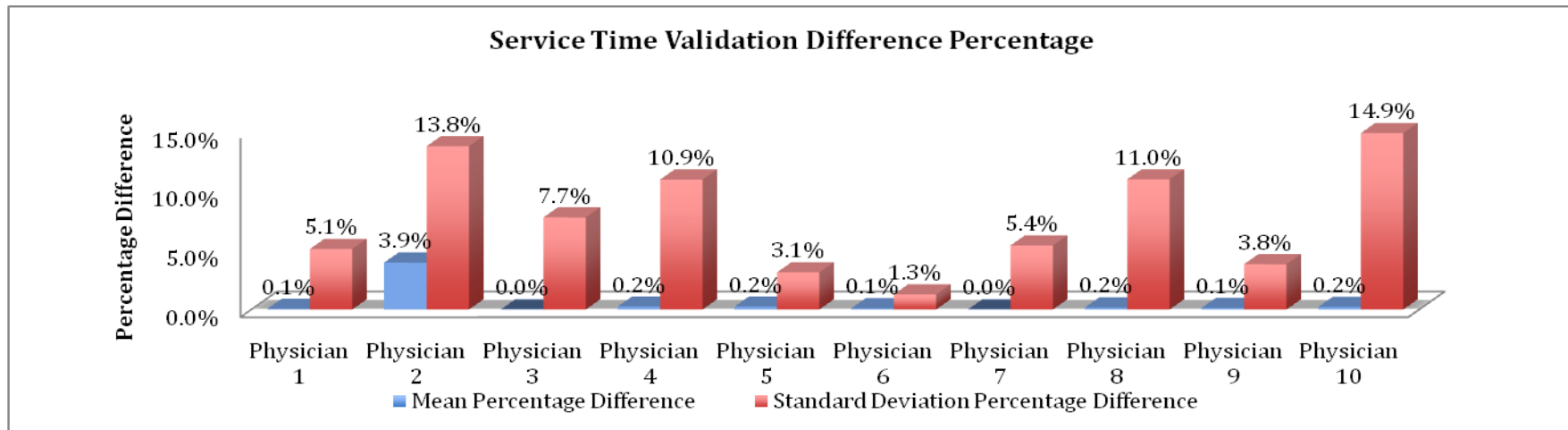


Figure 33: Physician Service Time Validation Difference Percentage Graph

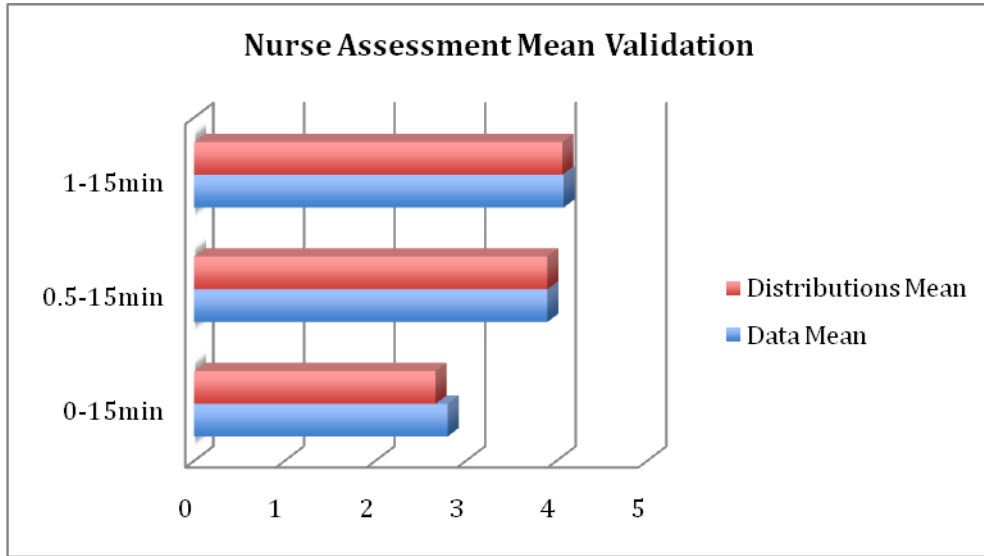


Figure 34: Assessment Nurse Service Time Mean Validation

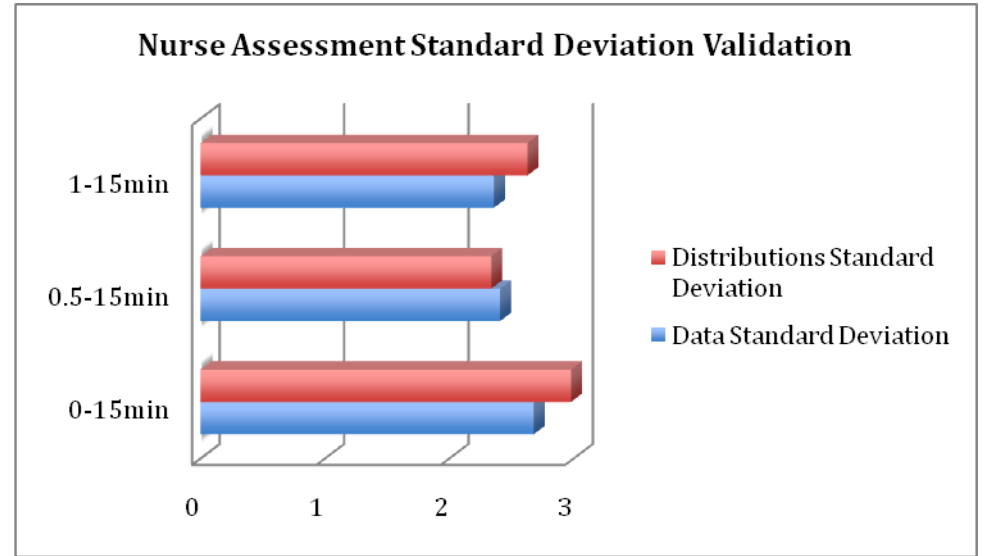


Figure 35: Assessment Nurse Service Time Standard Deviation Validation

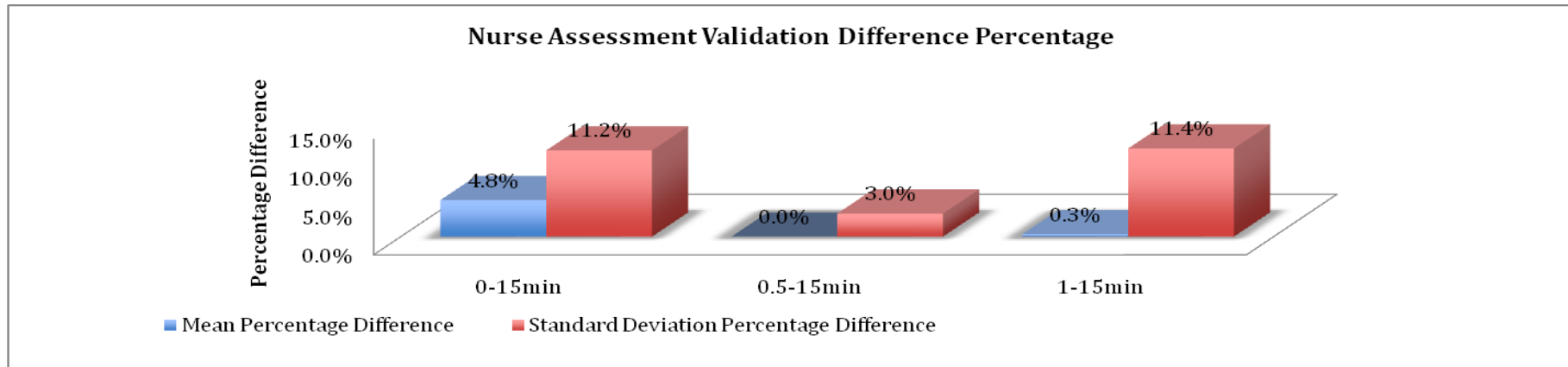


Figure 36: Assessment Nurse Service Time Validation Difference Percentage Graph

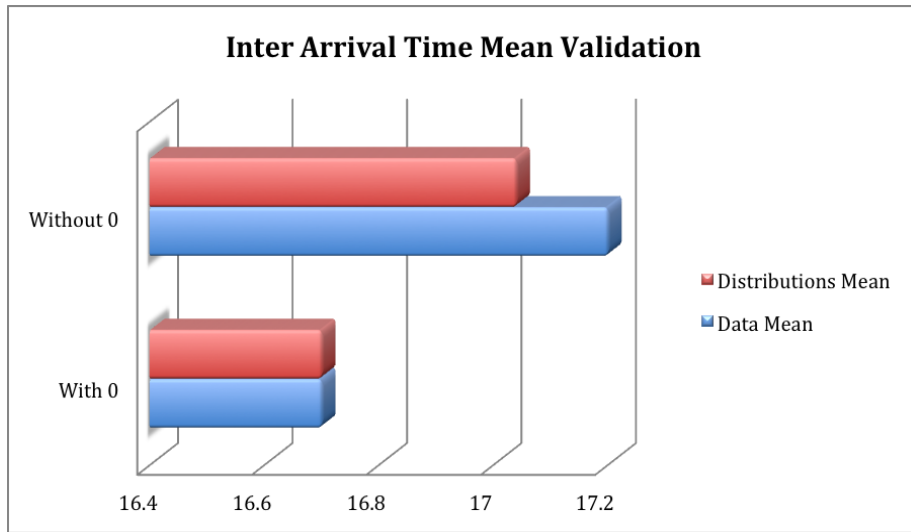


Figure 38: Inter-arrival Time Mean Validation

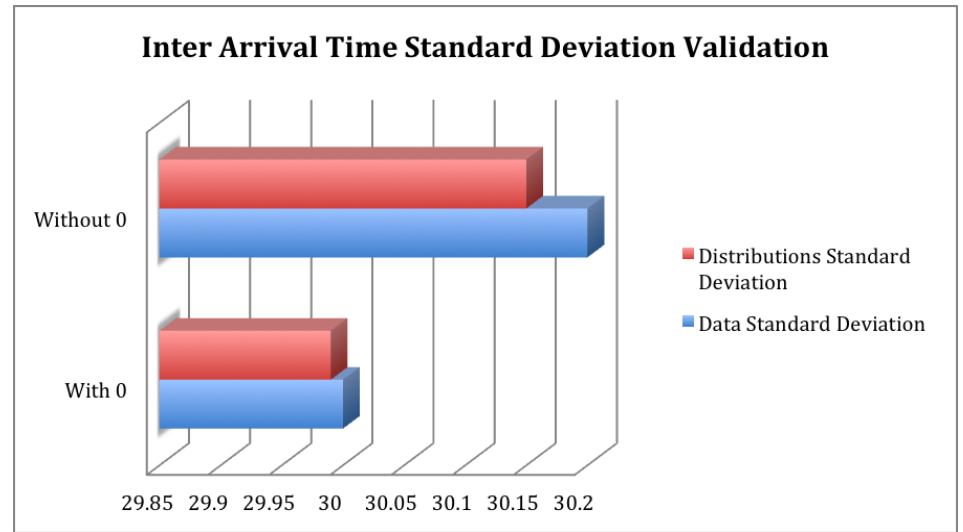


Figure 37: Inter-arrival Time Standard Deviation Validation

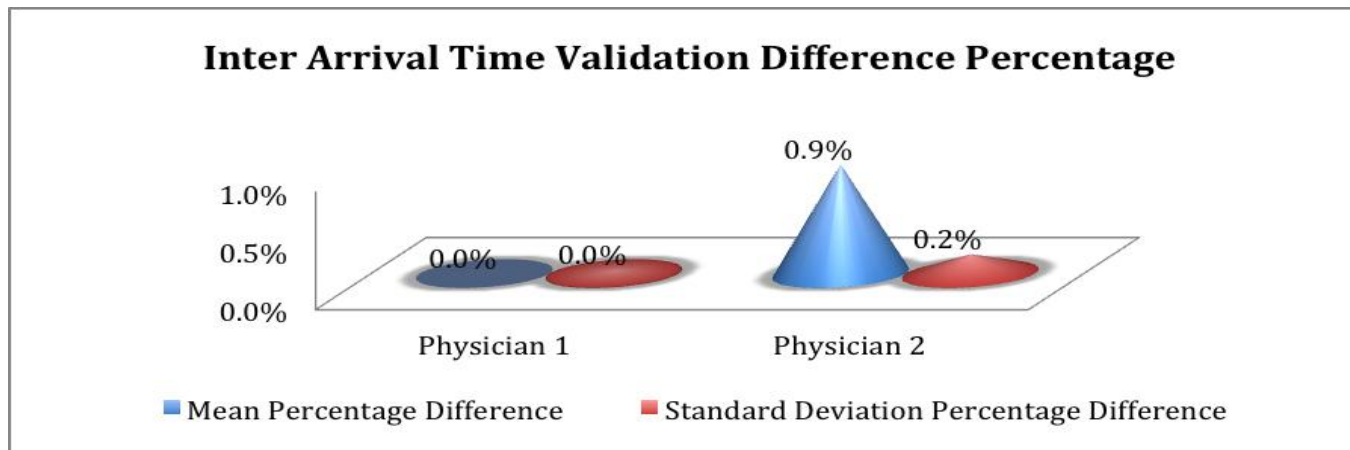


Figure 39: Inter-arrival Time Validation Difference Percentage Graph

#### **4.4 Simulation Model**

As discussed in Section 4.1, the primary goal of the research was to design a simulation model that correctly replicates operations of the FM clinic. As a first step, we had fitted distributions for data at every station in the FM clinic in order to be able to simulate the behavior at the different stations. However, in order to replicate the real performance behavior, we needed to imbed all these distributions together in order to replicate the real system. In that regard, we had developed a simulation model using the Arena Simulation software. In the following sections, we will elaborate on the model design, model validation, and the results attained.

The simulation model was made up of four main stations: the check-in station, the cashier station, the assessment nurse station, and the physician station. We will elaborate on each station in the following sections.

##### ***4.4.1 Patients Arrival***

As explained earlier, patients arriving to the FM clinic could be of two types, scheduled patients who have pre-scheduled appointments and random walk-in patients who arrive to the clinic without a pre-set appointment. As for scheduled patients, they are treated on per physician basis, because each patient is associated with an appointment with a specified physician. In order to simulate patient arrival, the model uses the specified schedule time slots (the FM clinic follows a 20 minute time slot) in addition to the patient lateness associated to each physician, which were explained earlier. As for the random walk-in patients, they are modeled with the inter-arrival distribution functions derived earlier.

To elaborate, scheduled patients are, ideally, supposed to arrive twenty minutes from each other, given that the appointment time slot is twenty minutes in duration. It is important to note that in the model, this is referred to as “doctime”. Basically, “doctime” is the main decision variable used to set the schedule of the physicians. However, given that some patients arrive late, imbedding the lateness is a must. The patient’s arrival is modeled with several checks that he has to pass through before he enters the system. First, the patient passes through the no-show check, where the model adds a no-show tag which describes if the patient arrives or not, based on the physician no-show probability discussed earlier. If the patient is tagged a no-show, then he will not enter the system. If he is not tagged with a no-show tag, then he will pass to the next check, which is the lateness check.

As shown earlier, 33% of the patients arrive late 12.6 minutes on average. Hence, patients, after passing through the no-show check, will pass through the lateness check, where the system models their arrival by giving them a late attribute associate them with the lateness distribution for the physician. In case the patient is not tagged with a late tag, then he will enter the system normally. On the other hand, if the patient is tagged with a late tag, then the lateness distribution will be added to his arrival to model his lateness. If the patient is tagged as late, he will then pass through another check-in the system, which is related to the availability limits of the physicians, to check whether or not the patient can be admitted to the clinic.

Availability limits is a term used to describe day times when the physician is not available, such as the coffee break, lunch time, and the end of day. It is important to note that in the model, it has adopted that no appointments will be scheduled when the doctor is not available. In case the patients are not tagged with the availability limits

tag, they will be allowed in the system. However, if they are tagged with the availability limits tag, then they might not enter the system, depending on the patient arrival and availability of physician scenario. This check also depends on the nature of the patient, whether he is a patient with a pre-set appointment, or a random walk-in patient. In summary, if a patient is too late for his appointment and arrives to the system at a point in time where the physician is not available, then he will not enter the system.

#### ***4.4.2 Check-in Station***

When a patient arrives at check-in, which has one employee, he can be of two types, either a new entry in the system, or an old arriving entry returning from the physician station with a prescription. In case the patient was a random walk-in patient entering the check-in station, he will pass through the process if being assigned to a physician. Starting first with the random walk-in patient. If the patient has a prescription, then he will be directed to the cashier station. In case he doesn't have a prescription, he will then go through the process of assigning him to a free physician. The assignment starts by checking whether or not there is at least one available physician in the clinic. Next, the model check whether or not there is at least one idle physician in the system, in other words, whether or not a physician has a free time slot not occupied by an appointment. In case the physician was available and idle (free), then the random patient will be assigned to the time slot, and will be directed to the cashier station. In case the physician is available and does not have a free time slot (i.e. is not idle), the severity of the random walk-in patient is checked. In case the patient's case is severe, then he will be assigned to a random free and available physician and

will be given a higher priority than other patients in the physician's queue. If the case is not severe, then the random walk-in patient will be rejected.

In case the patient was a pre-scheduled patient with or without a prescription, he will be directed to the cashier station, which we discuss next.

#### ***4.4.3 Cashier Station***

The patients entering the cashier station, which has one employee, could be of two types, either new patients arriving from the check-in station who have just entered the system, or old returning patients coming from the check-in station that have been already in the system and were directed from the physician station to the check-in station with a prescription. In case the patient was a new patient in the system without any prescription, he will be directed to the nurse assessment station, where the assessment nurse, which we will discuss later on, will serve him, if needed. On the other hand, in case the patient was already in the system and has a prescription, he will pay the required fees at the cashier station and will then be directed to the assessment nurse station, where he will be either served by the nurse, or will leave the system, which we will discuss in the assessment nurse station next. Figure 40 shows the cashier flow diagram of the simulation model.



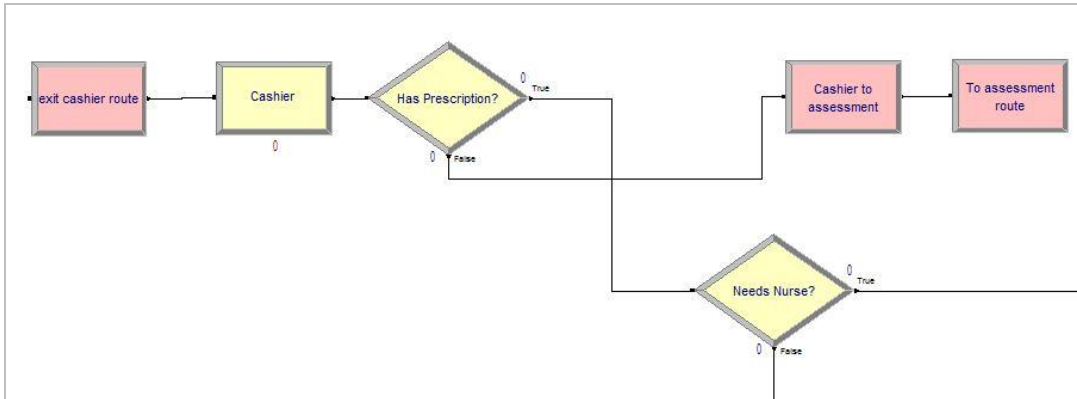


Figure 40: Cashier Process Model Blocks

#### 4.4.4 Assessment Nurse Station

Patients arriving to the assessment nurse station could be of two types, either new patients coming from the cashier and previously from check-in without any prescription, or patients who are already in the system and have a prescription from the doctor. After arriving at the nurse assessment station, which has an assessment nurse dedicated to perform certain tasks for new patient in the system, or a nurse dedicated to perform procedures for patients who are already present in the system, the patient waits in Waiting Area 1 until the nurse is available. The nurse checks whether or not the patient has a prescription. If so, the patient will be directed to the procedure nurse as shown in Figure 41.

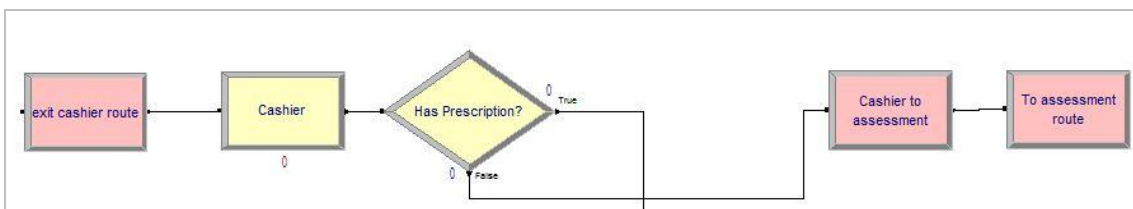


Figure 41: Checking For Prescription Model Blocks

In case the patient does not have a prescription, the nurse will perform the specified assessment tasks, which are mainly taking vital sign measurements and assessing patient's health status. After which, the patient is directed to the specified physician queue, which is located in Waiting Area 2. This process is shown in Figure 42.

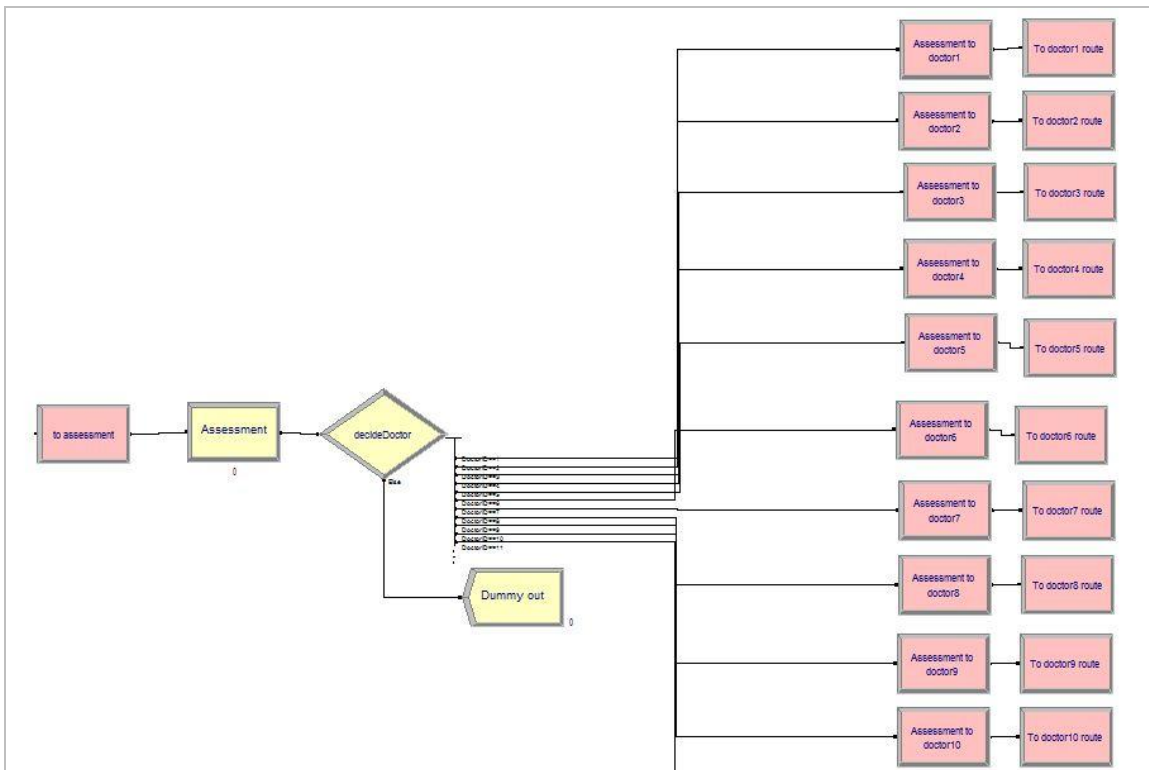


Figure 42: Assessment Nurse Model Blocks

In case the patient has a prescription, the nurse will then check whether or not he is need of a certain medical operation. In case he does not need a procedure, then the patient will be directed to the exit. In case the patient needs a procedure, then the nurse will perform the required procedure, after which, the patient will be directed to the exit. This process is shown in Figure 43:

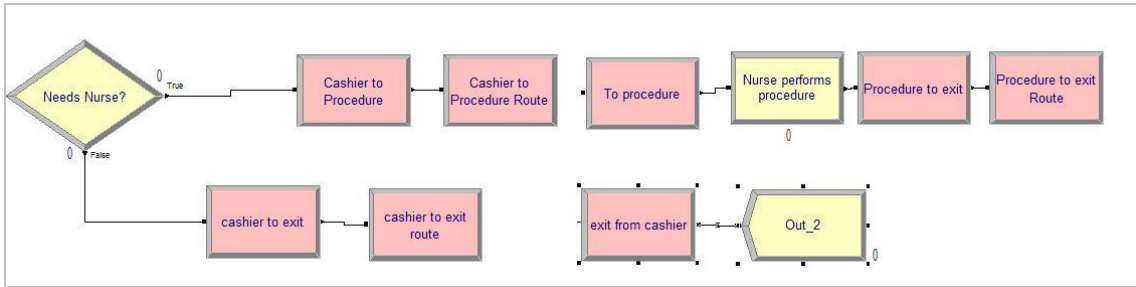


Figure 43: Assessment Nurse Procedure Model Blocks

#### 4.4.5 Physician Station

Only new entering patients in the system will pass through the physician station. After being served by the assessment nurse (i.e. vital sign taken and health status recorded), and have been waiting in the associated physician’s queue in Waiting Area 2, the patient then enters the specified physician’s clinic. The patient is then examined by the physician, who specifies whether or not the patient needs a prescription. In case the patient needs a prescription, he is directed to the check-in station and goes through the process as explained earlier. In case no prescription is needed, the patient is directed to exit the system. Figure 48 describes the physician station process. It is important to note that there is a unique model blocks for each one of the ten physicians similar to the one seen in figure 44.

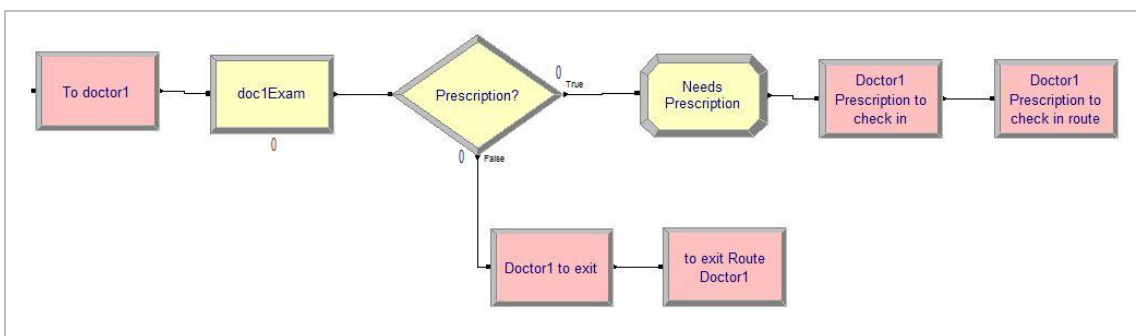


Figure 44: Physician Station Flow Diagram

#### 4.4.6 Simulation Model Validation

As stated earlier, the primary goal of the simulation was to replicate the real performance process of the FM clinic. An important part of the validation was the number of patients entering the system. In that sense, we had done some calculation using the data provided, especially, physician-related data.

After performing the proper calculations shown above in Tables 21, 22, and 23, it turned out that the total number of scheduled patients that should have been served by the system in a day is 209. As for the number of random patients served, it should be 35; hence, the total number of patients to be served per day should be 244. As we run the simulation model for 100 days, the analysis report of the model showed that there were on average, 245 patients, in total, in the system per day, 8 of which have been rejected, over 100 days. These results attest to the models validity.

<b>Model Validation</b>							
<b>Physicians</b>	<b>No-show</b>	<b>Hours Working</b>	<b>Total Patients</b>	<b>Percent Late</b>	<b>Lateness</b>	<b>Alpha</b>	<b>Beta</b>
Physician 1	17.41	7.75	14	50%	WEIB(9.98, 0.903)	0.903	9.98
Physician 2	14	7.75	15	50%	WEIB(15.8, 0.888)	0.888	15.8
Physician 3	21.6	7.75	16	50%	WEIB(9.2, 0.936)	0.936	9.2
Physician 4	14	7.75	15	50%	WEIB(9.51, 0.827)	0.827	9.51
Physician 5	10.85	7.75	15	50%	115 * BETA(0.546, 2.68)	2.68	0.546
Physician 6	15.32	7.75	15	50%	WEIB(10.7, 0.933)	0.933	10.7
Physician 7	19.21	7.75	14	50%	WEIB(11.7, 0.881)	0.881	11.7
Physician 8	7.84	9.75	24	50%	WEIB(12, 0.793)	0.793	12
Physician 9	14.4	9.75	22	50%	WEIB(9.48, 0.859)	0.859	9.48
Physician 10	15.23	9.75	22	50%	WEIB(10.5, 0.857)	0.857	10.5

Table 21: The Model Validation Calculations

<b>Probability of Being Greater Than X Minutes</b>							
<b>X= 20</b>	<b>X= 40</b>	<b>X= 60</b>	<b>X= 80</b>	<b>X= 100</b>	<b>X= 120</b>	<b>X= 140</b>	<b>X= 160</b>
15%	3%	1%	0%	0%	0%	0%	0%
29%	10%	4%	1%	1%	0%	0%	0%
13%	2%	0%	0%	0%	0%	0%	0%
16%	4%	1%	0%	0%	0%	0%	0%
38%	15%	6%	2%	0%	0%	0%	0%
17%	3%	1%	0%	0%	0%	0%	0%
20%	5%	1%	0%	0%	0%	0%	0%
22%	7%	3%	1%	0%	0%	0%	0%
15%	3%	1%	0%	0%	0%	0%	0%
18%	4%	1%	0%	0%	0%	0%	0%

Table 22: The Model Validation Probability Calculations

<b>Random Walk-in Patients</b>	
Mean	16.7
Patients per Hour	3.6
Hours Available	9.75
Total Random	35

Table 23: The Random Patient Validation Calculation

#### 4.5 Results

We had run the model for 100 days to study the behavior of the simulated FM clinic. We then analyzed the results of the simulation and studied how we can improve the process. To elaborate, Figure 45 shows the average time spent over the 100 days in the system for patients of a specific doctor, which is made up of the waiting time and the service time. As shown, the patient spends around 70 minutes in the system, 36.5 minutes of which he spends waiting, and the remaining being served. The average waiting time ratio was shown to be 52.22%, which means that the patient spends half of his time waiting to be served. Figure 45 shows the patient average waiting time per physician.

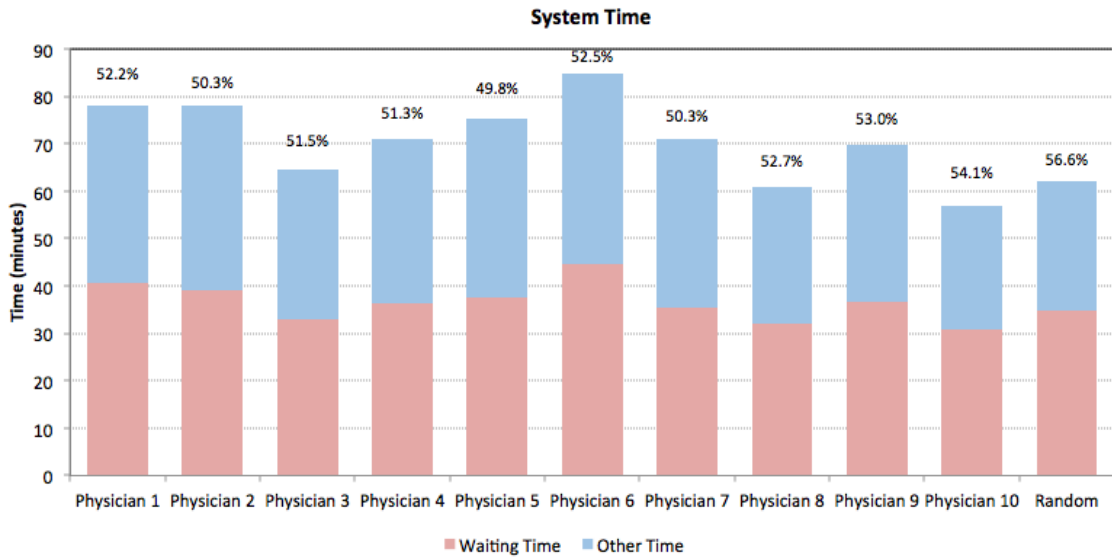


Figure 45: Average Waiting and Service Times Spent at Physician’s Queues

Moreover, the model results show that the average number of patients, either scheduled or random walk-in, served per day over 100 days by the physicians is 237, in addition to 8 patients being rejected for any of the reasons stated earlier. These results were discussed in Section 4.4.6 where we validated the model.

After deriving the results related to the patient time spent in the system and the number of patients served and rejected, we then targeted our result analysis to the waiting time of the patients. We wanted to detect which part of the FM clinic is contributing the most to the patient waiting time, signaling a need of improvement. The pie chart in Figure 46 shows the patient waiting times at the different stations in the FM clinic over 100 simulated days. As shown in Figure 46, the patient spends almost 53% of his waiting time at the check-in station, which is almost 16 minutes on average for 100 days according to Table 24. In addition, Table 24 and Figure 47 show that the largest queues are at the check-in and the physician’s queues, being 8 and 3 respectively, meaning that improvements need to be done at those stations.

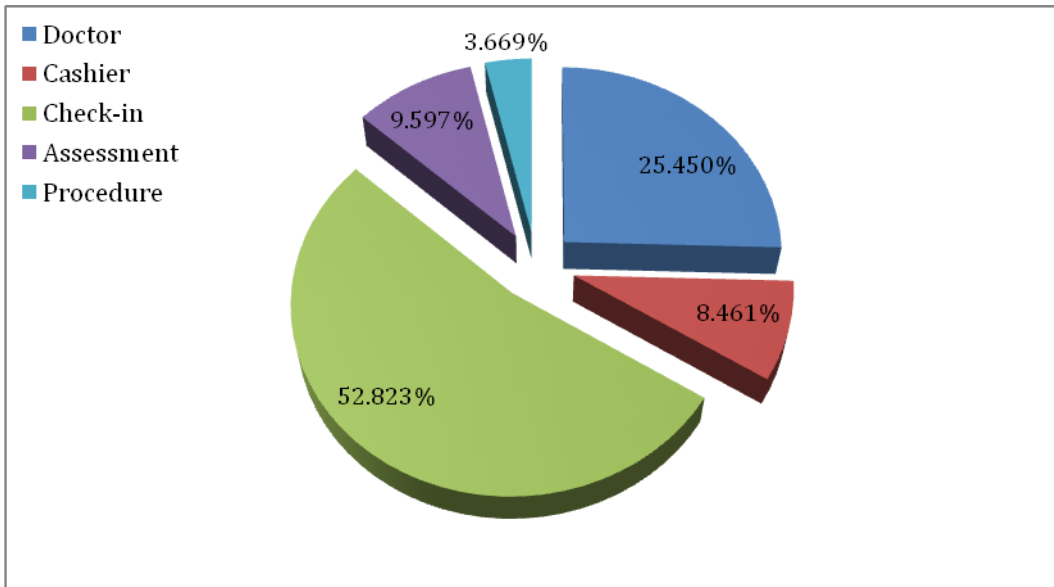


Figure 46: Pie Chart Showing The Waiting Times At The Different Stations

	Average Waiting Time (minutes)	Average Queue Size
Physician	7.7	3
Assessment Nurse	2.9	1
Procedure	1.1	1
Cashier	2.6	2
Check-in	16	8

Table 24: The Average Time Waiting and Average Queue Size at The Different Stations

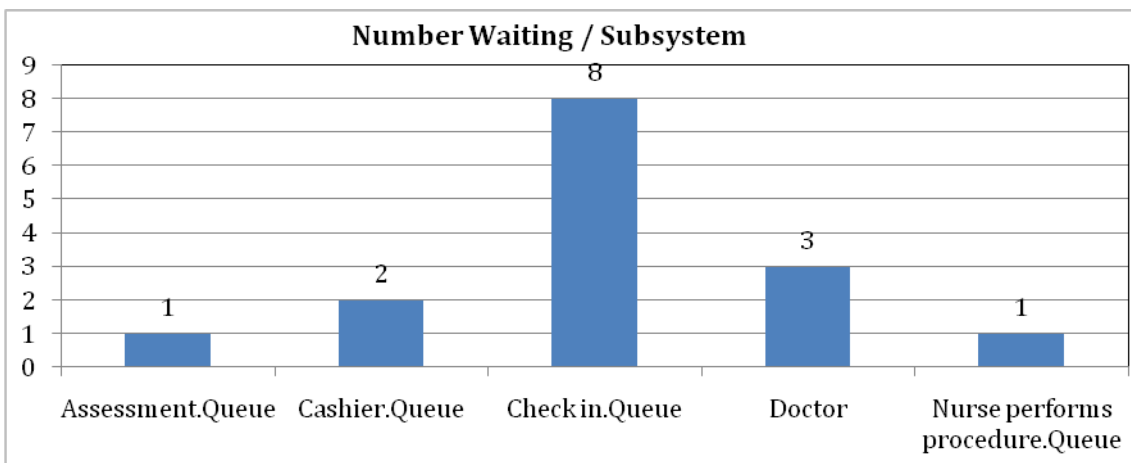


Figure 47: Number of Patients Waiting In the Different Stations' Queues

Another result we analyzed was the FM clinic employees' utilization. Figure 48 summarizes the utilization of the physicians over 100 simulated days. As shown, the average physician utilization is about 70%, which is considered low according to the FMD administration, and which also aligns with what the FM administration noted that physicians spend a noticeable part of their day not serving patients. In addition, the physician utilization standard deviation is 15.5%, with a minimum utilization of 41% and a maximum utilization of 94%, showing that there is a significant difference in physician performance.

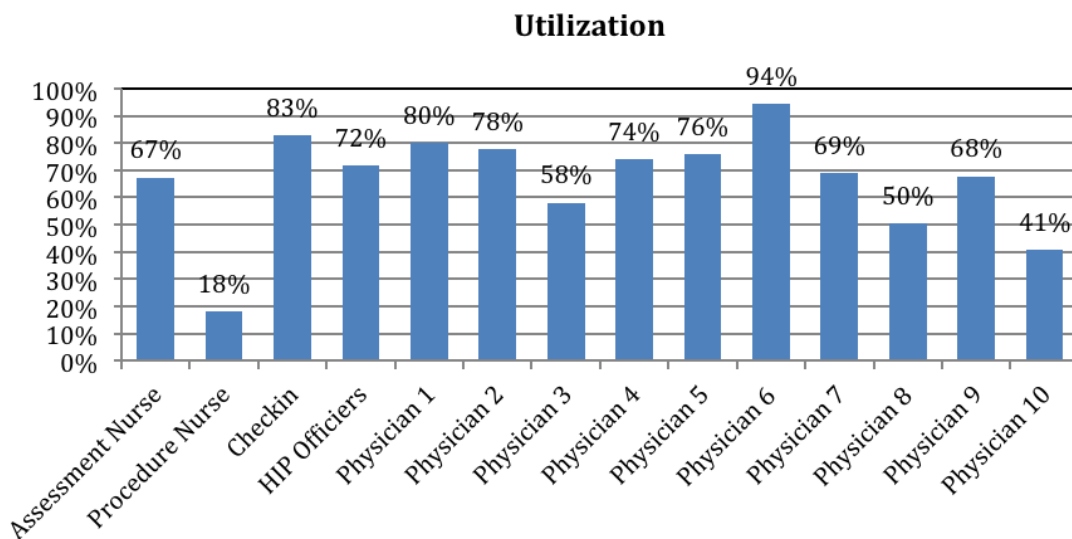


Figure 48: Utilization Of The FM Clinic Employees Over 100 Simulated Days

In addition, Figure 49 shows the patients' percentage lateness and that of the waiting time they spend at each physician station. In order to justify the patient's delay, it was suspected that it might be due to the time that the patients spend at the physician's queue waiting to be seen by the doctor. In other word, a patient would know that he will spend a lot of time waiting for his turn at the physician, so he would come late, however, this is not reflected in the graph, where the patients' percentage waiting



time is almost equal at all the physicians, which is around 25.45% of the total waiting time and 13% of the patient's total time in the clinic.

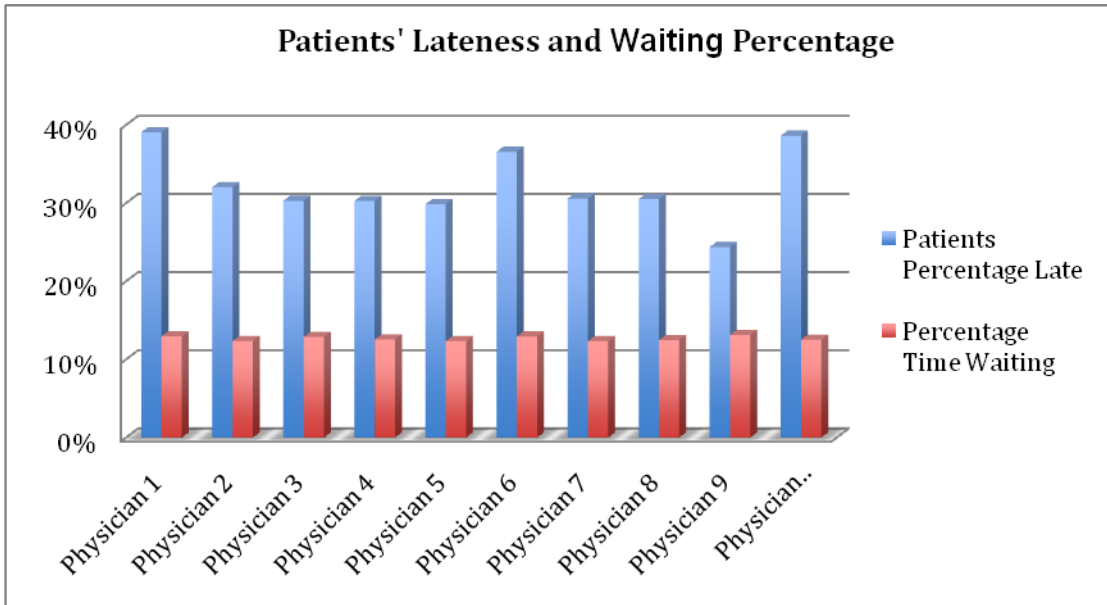


Figure 49: Patient's Lateness and Waiting Time Percentage

## 4.6 Suggestions for Improvement

### 4.6.1 Check-in Station

As stated earlier, the main goal of the FM research, after developing a valid model, was to lower patient waiting time and to increase employee efficiency. As shown in the results section 4.5, a big part of patient waiting time is at the check-in station, which is around 16 minutes accounting for 53% of the total patient waiting time, with a check-in employee utilization of 83%, the highest in the system. In that sense, a simulation was done having two check-in employees. As shown in Figure 50, the average total time spent in the system by the patient is 57.38 minutes, out of which he spends 23.87 minutes waiting, which is around 41% of the total system time. Hence, adding a second check-in employee reduced the patient average total system time by 18% and the total waiting time by 34%, a recommendation that the FM administration decided to apply.

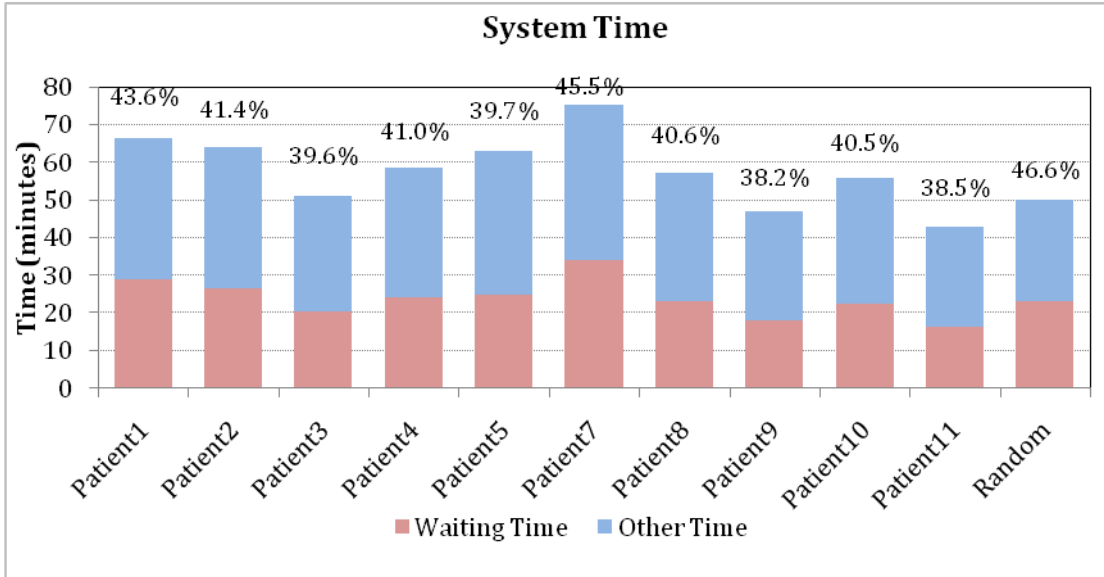


Figure 50: Time Spent in System with 2 Check-in Employees

Moving on to the patient average total waiting time that has been reduced by 34%. As shown in the pie chart in Figure 51, the check-in station is now the station at which the waiting time, which is now 1.1 minutes on average and comprises 5% of the total patient waiting time. However, the physician station now has the greatest share of the patient waiting time of 40% (8.5 minutes on average according to Table 32), followed by the cashier station, which is 31% (6.7 minutes on average according to Table 32). In addition, the average queue size has decreased to 1 at the check-in station after being 8, which is a reduction by 87.5% according to Table 25.

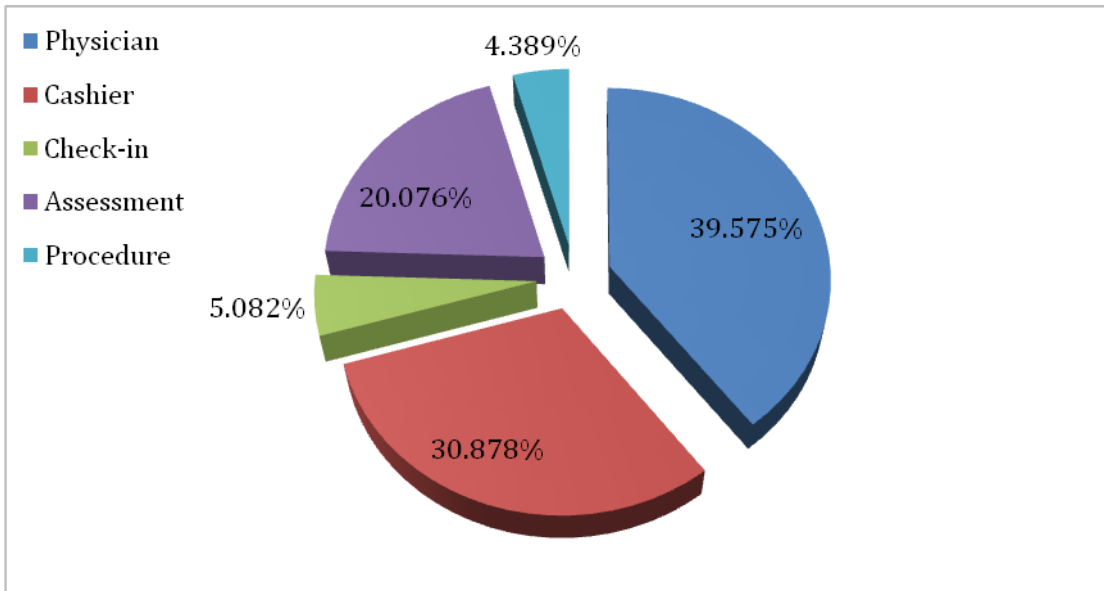


Figure 51: Pie Chart Showing The Waiting Times At The Different Stations with 2 Check-in Employees

	<b>Average Waiting Time (minutes)</b>	<b>Average Queue Size</b>
Doctor	8.5	3
Assessment Nurse	4.3	2
Procedure	1	1
Cashier	6.7	4
Check-in	1.1	1

Table 25: The Average Time Waiting and Average Queue Size at The Different Stations

#### 4.6.2 Appointment Time Slot

In addition, as shown in the section 4.5, the physician utilization is low, being 70% on average. This shows that physicians spend a big part of their day not serving patients. Hence, in order to increase physician utilization and increase number of patients served, a comparison was performed between the different simulations done on different appointment slots length with a fixed number of check-in employees of 2.

As shown in Figure 52, both the average system time and the average waiting time decrease as the time slot increase. Moreover, as shown in Figure 53, the number patients served increases as the time slot decreases. Also, as shown in Figure 54, as the time slot increases, the average number of patients in the physicians' queues decrease,

which is due to the lower number of patients being served, with a fixed physicians' service time. Finally, as shown in Figure 55, the physician utilization decreases as the time slot increases. That is justified by the fact that as the time slot increases, the number of patients served decreases, hence, decreasing the physician utilization.

Therefore, there exists a tradeoff between the system revenue, which is proportional to the number of patients served, and the waiting time. Having said that, and having a given waiting time, the associated time slot, revenue, utilization and queue size could be found. For instance, suppose it is required to have a system average waiting time of 24 minutes. So graph 52 is used to get the associated time slot, which is 20 (minutes) that would give the required waiting time, in addition to using Figure 53 to getting the number of patients served (i.e. revenue), which is around 236 patients, Figure 54 for the queue size, which is around 3, and Figure 55 for the resource utilization, which is around 70%.

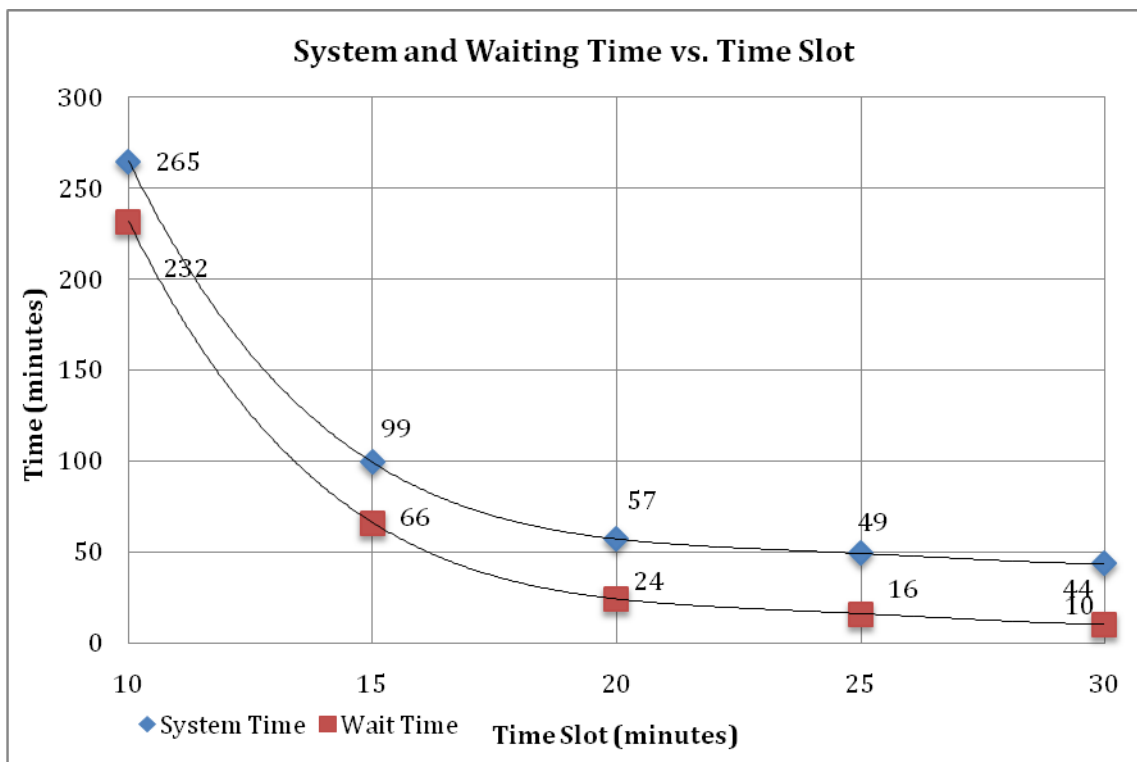


Figure 52: Average Patient System and Waiting Time vs. Time Slot

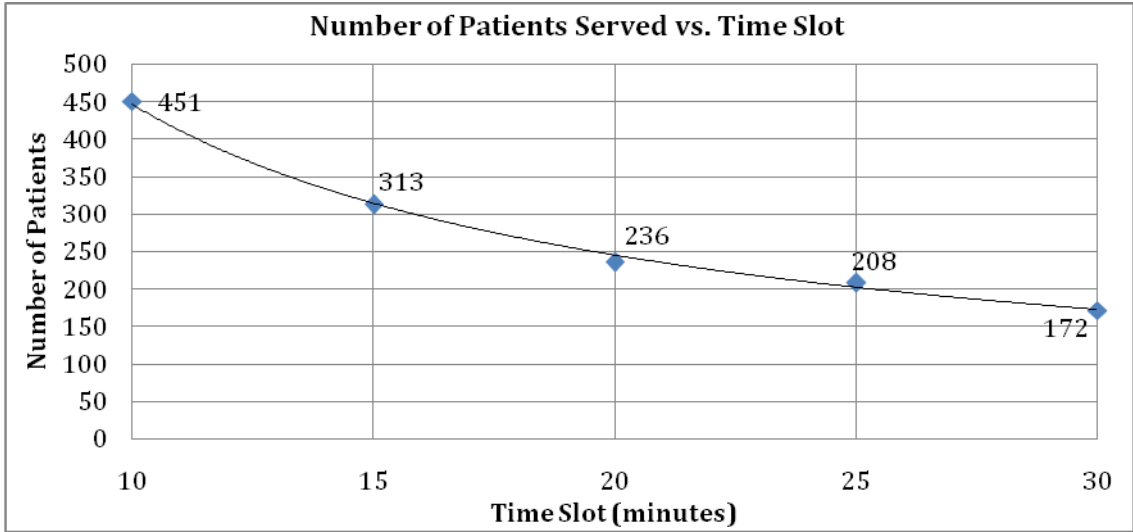


Figure 53: Number of Patients Served vs. Time Slot

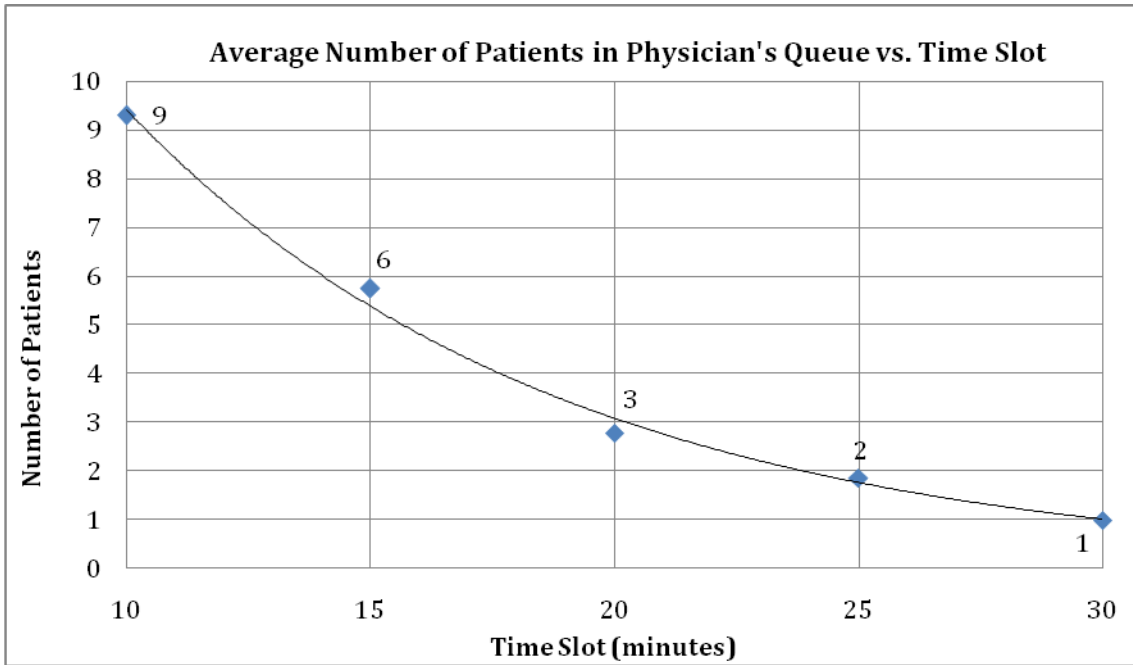


Figure 54: Average Number of Patients in Physician's Queue vs. Time Slot

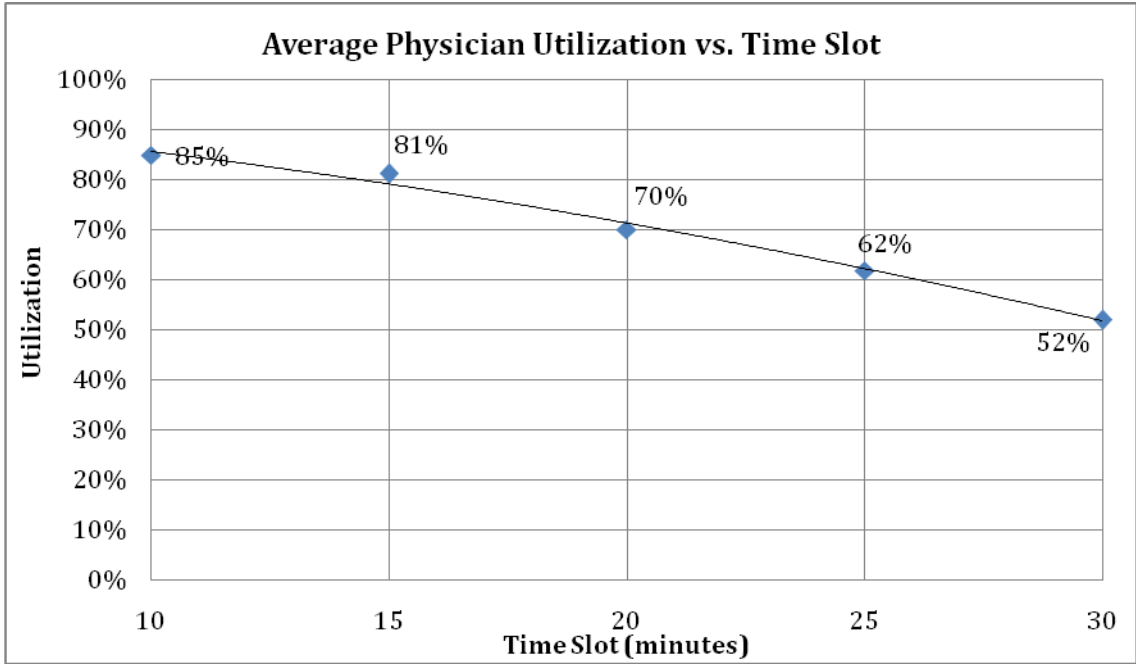


Figure 55: Average Physician Utilization vs. Time Slot

## CHAPTER 5

### CONCLUSION

In this chapter we provide our conclusions. Section 5.1 concludes on our material management research and Section 5.2 concludes on our patient flow research.

#### **5.1 Inventory Control at MMD**

Several arguments can be raised that argue with the Base Stock policy against the Min-Max policy adopted by the MMD at AUBMC. First, the real time testing shows the easiness of implementing such a policy, in addition to its practicality. The Base Stock policy only needs the average and standard deviation, given the required service level and its coefficient, to calculate the order up to levels. In addition, the weekly review that took place during the six months testing period takes no more than fifteen minutes per review.

Second, based on the simulation and real-time testing, the Base Stock policy performs similar to the Min-Max policy based on the three criteria, the average on-hand, the order frequency, and the shortages. However, base stock requires much less human intervention than the actual Min-Max. This allows saving labor cost.

#### **5.2 Patient Flow at FMD**

To conclude, we can confirm, based on our results, that the goals of our study have been reached. To start with the simulation model, we have been successfully able to develop a model that replicates the real performance FM clinic operations. In addition, we were able to identify, via simulation, the different areas that need

improvement, and provided recommendation to improve the system, which have been confirmed by the FM clinic administration. In particular, we have developed charts via simulation that depict the tradeoff between patient waiting time and clinic revenue as the appointment time slot varies. These charts are useful in practice, as they will help the FMD in selecting the appropriate appointment scheduling policy.



## CHAPTER 6

### FUTURE WORK

Starting with the Base Stock policy in the material management pilot study, a future work might be to apply a similar policy to the Base Stock policy on Class B and Class C Operation Room items.

As for the patient flow simulation in the FM clinic, it is clear that applying simulation to improve systems at hospitals is within reach. In addition, some improvements were suggested at specific areas in the FM clinic and in the appointment policy. Future work could be to design customized schedules per physician, based on physician efficiency.

In addition, the success in applying simulation techniques in the Family Medicine Department at AUBMC can be a gateway to increase system efficiency at the different departments of AUBMC. This will allow the AUBMC administration to predict problems before they happen and solve them at a lower cost.

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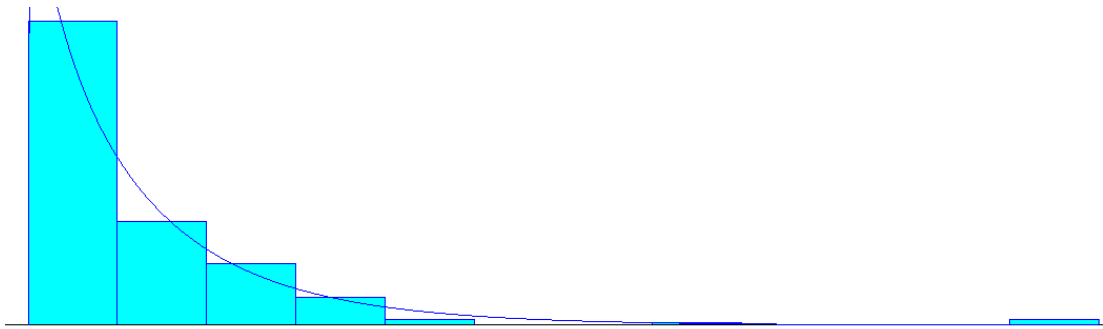
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# APPENDIX A: LATENESS DISTRIBUTIONS PER PHYSICIAN

## Physician 1:



### Distribution Summary:

Distribution: Weibull  
Expression: WEIB(9.98, 0.903)  
Square Error: 0.001957

### Chi Square Test:

Number of intervals = 4  
Degrees of freedom = 1  
Test Statistic = 1.89  
Corresponding p-value = 0.189

### Kolmogorov-Smirnov Test

Test Statistic = 0.0469  
Corresponding p-value > 0.15

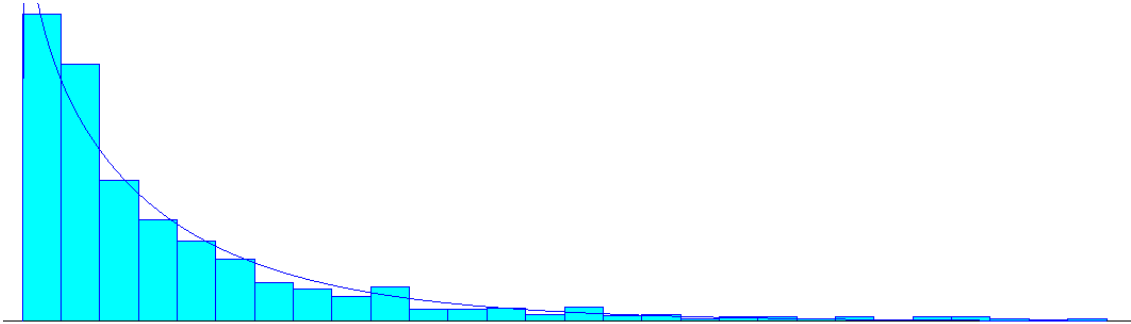
### Data Summary:

Number of Data Points = 167  
Min Data Value = 0.117  
Max Data Value = 97.7  
Sample Mean = 10.5  
Sample Standard Deviation = 13.5

### Histogram Summary:

Histogram Range = 0 to 98  
Number of Intervals = 12

## Physician 2:



### Distribution Summary:

Distribution: Weibull  
Expression: WEIB(15.8, 0.888)  
Square Error: 0.002720

### Chi Square Test:

Number of intervals = 15  
Degrees of freedom = 12  
Test Statistic = 29.3  
Corresponding p-value < 0.005

### Kolmogorov-Smirnov Test

Test Statistic = 0.0397  
Corresponding p-value > 0.15

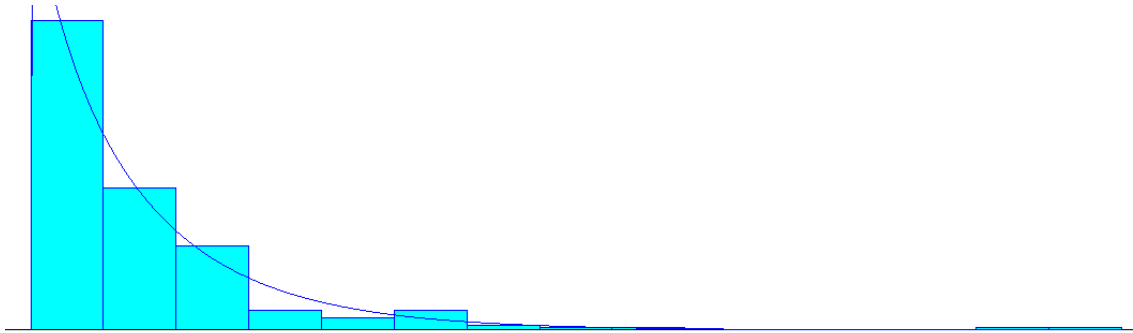
### Data Summary:

Number of Data Points = 800  
Min Data Value = 0.0333  
Max Data Value = 119  
Sample Mean = 17  
Sample Standard Deviation = 20.4

### Histogram Summary:

Histogram Range = 0 to 119  
Number of Intervals = 28

### Physician 3:



#### Distribution Summary

Distribution: Weibull  
Expression: WEIB(9.2, 0.936)  
Square Error: 0.001986

#### Chi Square Test

Number of intervals = 5  
Degrees of freedom = 2  
Test Statistic = 4.88  
Corresponding p-value = 0.0901

#### Kolmogorov-Smirnov Test

Test Statistic = 0.0461  
Corresponding p-value > 0.15

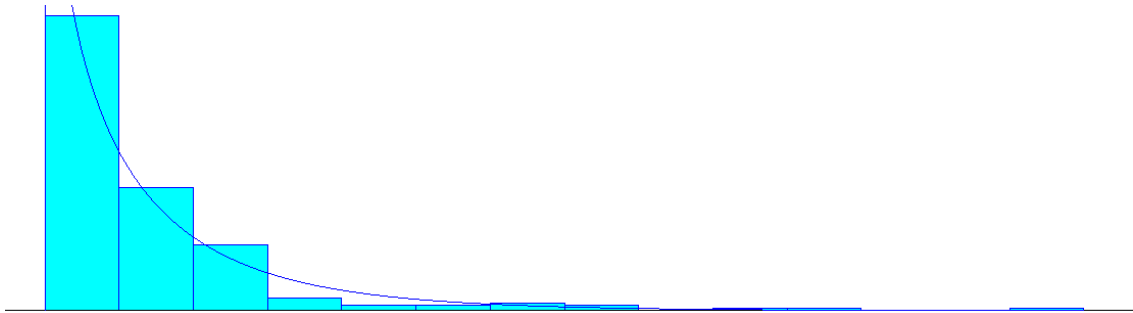
#### Data Summary

Number of Data Points = 249  
Min Data Value = 0.0333  
Max Data Value = 93.3  
Sample Mean = 9.51  
Sample Standard Deviation = 11.7

#### Histogram Summary

Histogram Range = 0 to 94  
Number of Intervals = 15

## Physician 4:



### Distribution Summary

Distribution: Weibull  
Expression: WEIB(9.51, 0.827)  
Square Error: 0.002765

### Chi Square Test

Number of intervals = 5  
Degrees of freedom = 2  
Test Statistic = 6.84  
Corresponding p-value = 0.0347

### Kolmogorov-Smirnov Test

Test Statistic = 0.0425  
Corresponding p-value > 0.15

### Data Summary

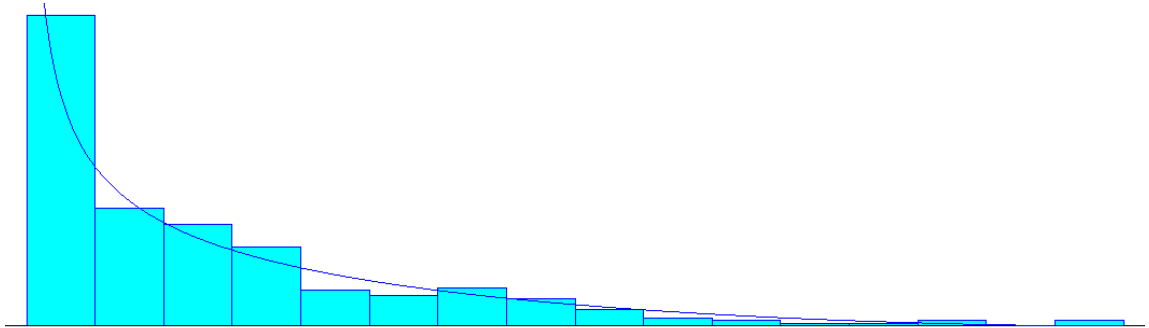
Number of Data Points = 201  
Min Data Value = 0.0333  
Max Data Value = 108  
Sample Mean = 10.6  
Sample Standard Deviation = 14.5

### Histogram Summary

Histogram Range = 0 to 108  
Number of Intervals = 14



## Physician 5:



### Distribution Summary

Distribution: Beta  
Expression:  $115 * \text{BETA}(0.546, 2.68)$   
Square Error: 0.002108

### Chi Square Test

Number of intervals = 9  
Degrees of freedom = 6  
Test Statistic = 8.83  
Corresponding p-value = 0.197

### Kolmogorov-Smirnov Test

Test Statistic = 0.0987  
Corresponding p-value < 0.01

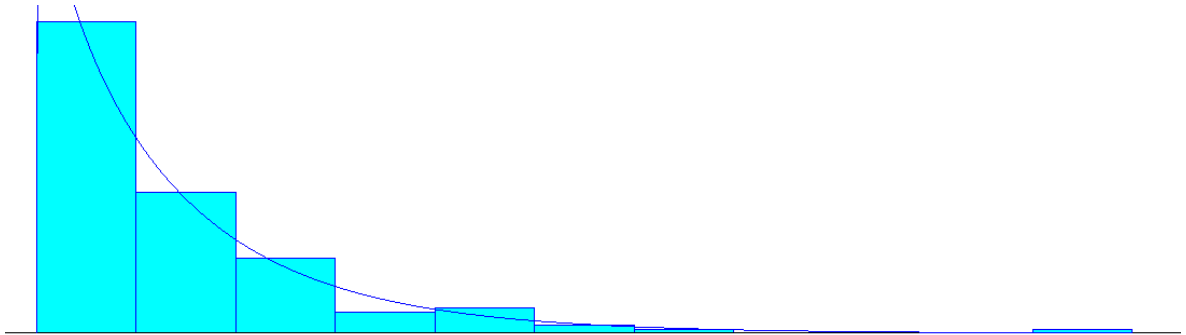
### Data Summary

Number of Data Points = 287  
Min Data Value = 0.0333  
Max Data Value = 115  
Sample Mean = 19.5  
Sample Standard Deviation = 21

### Histogram Summary

Histogram Range = 0 to 115  
Number of Intervals = 16

## Physician 6:



### Distribution Summary

Distribution: Weibull  
Expression: WEIB(10.7, 0.933)  
Square Error: 0.000945

### Chi Square Test

Number of intervals = 4  
Degrees of freedom = 1  
Test Statistic = 0.618  
Corresponding p-value = 0.453

### Kolmogorov-Smirnov Test

Test Statistic = 0.0437  
Corresponding p-value > 0.15

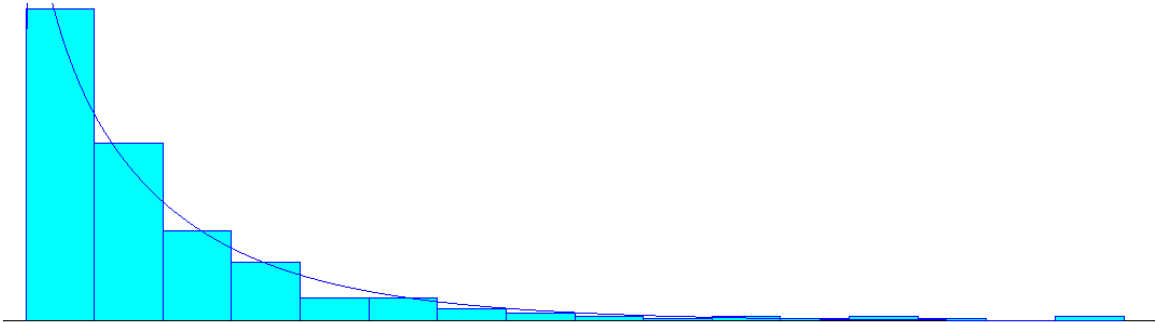
### Data Summary

Number of Data Points = 142  
Min Data Value = 0.1  
Max Data Value = 87.8  
Sample Mean = 11.1  
Sample Standard Deviation = 12.4

### Histogram Summary

Histogram Range = 0 to 88  
Number of Intervals = 11

## Physician 7:



### Distribution Summary

Distribution: Weibull  
Expression: WEIB(11.7, 0.881)  
Square Error: 0.001286

### Chi Square Test

Number of intervals = 7  
Degrees of freedom = 4  
Test Statistic = 3.92  
Corresponding p-value = 0.431

### Kolmogorov-Smirnov Test

Test Statistic = 0.0306  
Corresponding p-value > 0.15

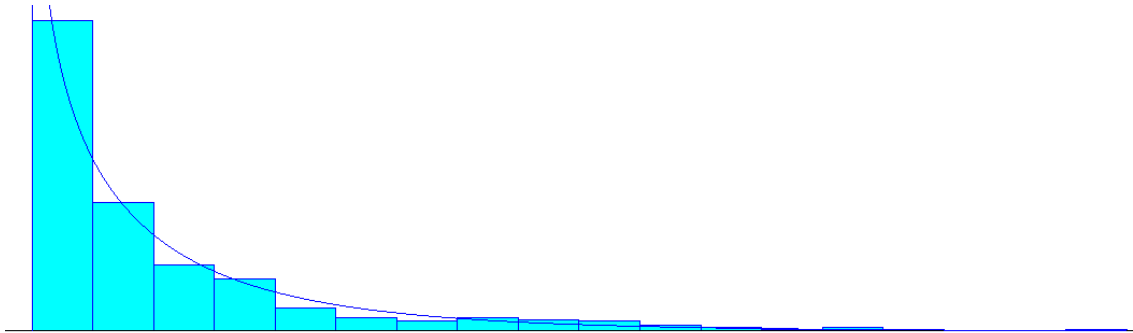
### Data Summary

Number of Data Points = 285  
Min Data Value = 0.0833  
Max Data Value = 96.6  
Sample Mean = 12.5  
Sample Standard Deviation = 15.3

### Histogram Summary

Histogram Range = 0 to 97  
Number of Intervals = 16

## Physician 8:



### Distribution Summary

Distribution: Weibull  
Expression: WEIB(12, 0.793)  
Square Error: 0.001212

### Chi Square Test

Number of intervals = 8  
Degrees of freedom = 5  
Test Statistic = 10.3  
Corresponding p-value = 0.0708

### Kolmogorov-Smirnov Test

Test Statistic = 0.0426  
Corresponding p-value > 0.15

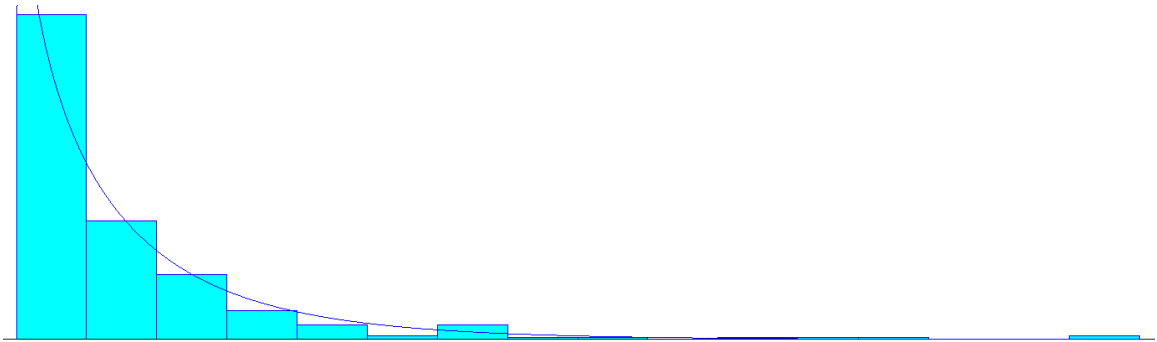
### Data Summary

Number of Data Points = 338  
Min Data Value = 0.05  
Max Data Value = 113  
Sample Mean = 13.8  
Sample Standard Deviation = 17.8

### Histogram Summary

Histogram Range = 0 to 113  
Number of Intervals = 18

## Physician 9:



### Distribution Summary

Distribution: Weibull  
Expression: WEIB(9.48, 0.859)  
Square Error: 0.002673

### Chi Square Test

Number of intervals = 6  
Degrees of freedom = 3  
Test Statistic = 3.67  
Corresponding p-value = 0.313

### Kolmogorov-Smirnov Test

Test Statistic = 0.0509  
Corresponding p-value > 0.15

### Data Summary

Number of Data Points = 286  
Min Data Value = 0.0667  
Max Data Value = 104  
Sample Mean = 10.3  
Sample Standard Deviation = 14.3

### Histogram Summary

Histogram Range = 0 to 104  
Number of Intervals = 16

## Physician 10:



### Distribution Summary

Distribution: Weibull  
Expression: WEIB(10.5, 0.857)  
Square Error: 0.002182

### Chi Square Test

Number of intervals = 10  
Degrees of freedom = 7  
Test Statistic = 15.6  
Corresponding p-value = 0.0308

### Kolmogorov-Smirnov Test

Test Statistic = 0.0565  
Corresponding p-value = 0.0282

### Data Summary

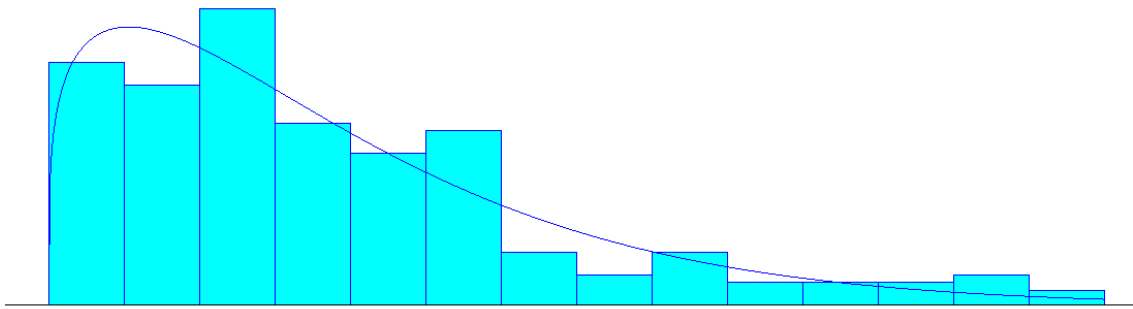
Number of Data Points = 666  
Min Data Value = 0.0167  
Max Data Value = 119  
Sample Mean = 11.3  
Sample Standard Deviation = 15.5

### Histogram Summary

Histogram Range = 0 to 120  
Number of Intervals = 25

## APPENDIX B: SERVICE TIME DISTRIBUTIONS PER PHYSICIAN

### Physician 1:



### Distribution Summary

Distribution: Weibull  
Expression:  $5 + \text{WEIB}(15.7, 1.23)$   
Square Error: 0.005404

### Chi Square Test

Number of intervals = 9  
Degrees of freedom = 6  
Test Statistic = 10.9  
Corresponding p-value = 0.0931

### Kolmogorov-Smirnov Test

Test Statistic = 0.0405  
Corresponding p-value > 0.15

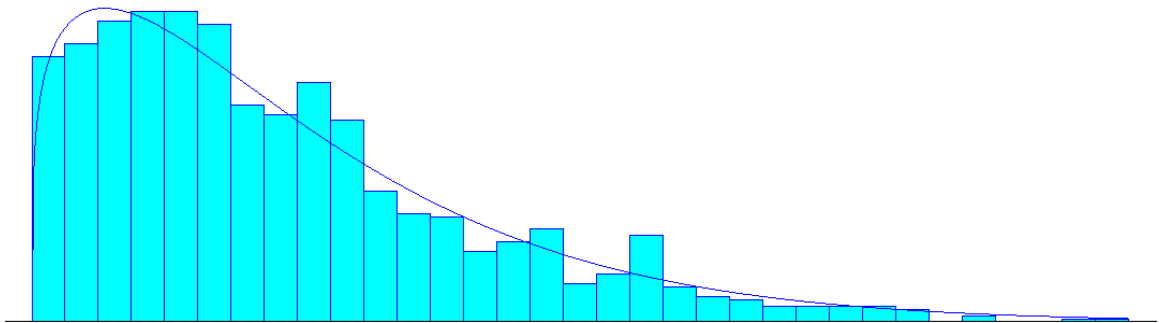
### Data Summary

Number of Data Points = 200  
Min Data Value = 5  
Max Data Value = 58.6  
Sample Mean = 19.7  
Sample Standard Deviation = 11.6

### Histogram Summary

Histogram Range = 5 to 59  
Number of Intervals = 14

## Physician 2:



### Distribution Summary

Distribution: Weibull  
Expression:  $5 + \text{WEIB}(14.1, 1.23)$   
Square Error: 0.000950

### Chi Square Test

Number of intervals = 24  
Degrees of freedom = 21  
Test Statistic = 35.6  
Corresponding p-value = 0.0244

### Kolmogorov-Smirnov Test

Test Statistic = 0.0344  
Corresponding p-value = 0.142

### Data Summary

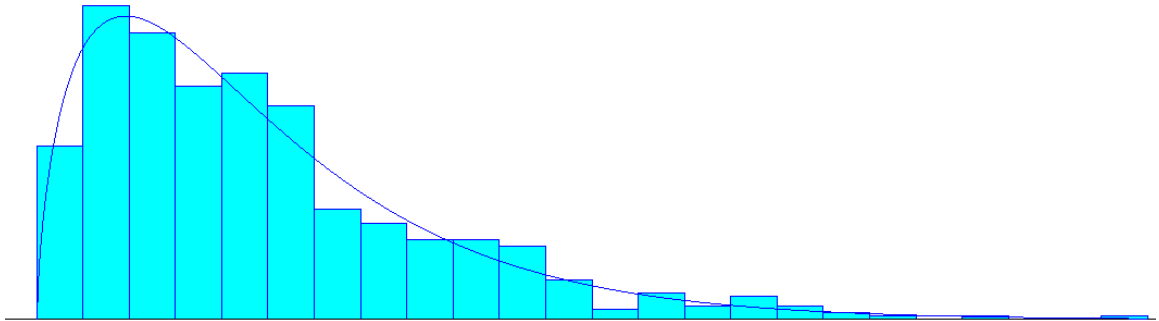
Number of Data Points = 1114  
Min Data Value = 5  
Max Data Value = 59.5  
Sample Mean = 17.5  
Sample Standard Deviation = 9.67

### Histogram Summary

Histogram Range = 5 to 60  
Number of Intervals = 33



### Physician 3:



#### Distribution Summary

Distribution: Gamma  
Expression:  $5 + \text{GAMM}(5.49, 1.64)$   
Square Error: 0.001410

#### Chi Square Test

Number of intervals = 14  
Degrees of freedom = 11  
Test Statistic = 13.8  
Corresponding p-value = 0.246

#### Kolmogorov-Smirnov Test

Test Statistic = 0.0251  
Corresponding p-value > 0.15

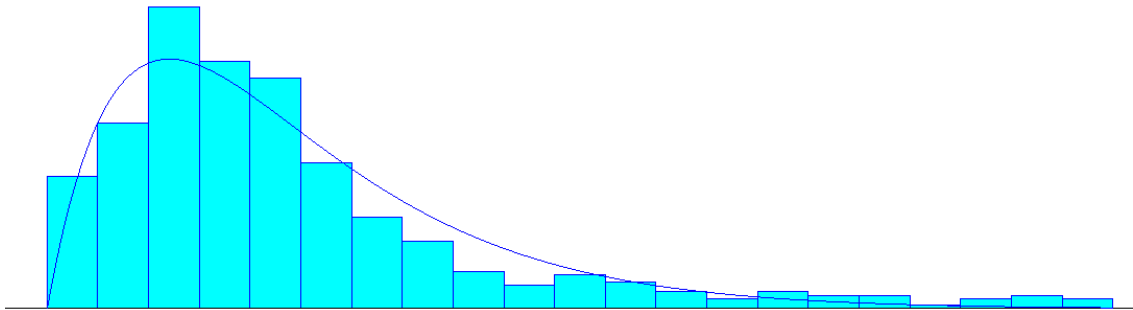
#### Data Summary

Number of Data Points = 615  
Min Data Value = 5.05  
Max Data Value = 48.7  
Sample Mean = 14  
Sample Standard Deviation = 6.84

#### Histogram Summary

Histogram Range = 5 to 49  
Number of Intervals = 24

## Physician 4:



### Distribution Summary

Distribution: Erlang  
Expression:  $5 + \text{ERLA}(6.07, 2)$   
Square Error: 0.003957

### Chi Square Test

Number of intervals = 13  
Degrees of freedom = 10  
Test Statistic = 40.8  
Corresponding p-value < 0.005

### Kolmogorov-Smirnov Test

Test Statistic = 0.0625  
Corresponding p-value = 0.0456

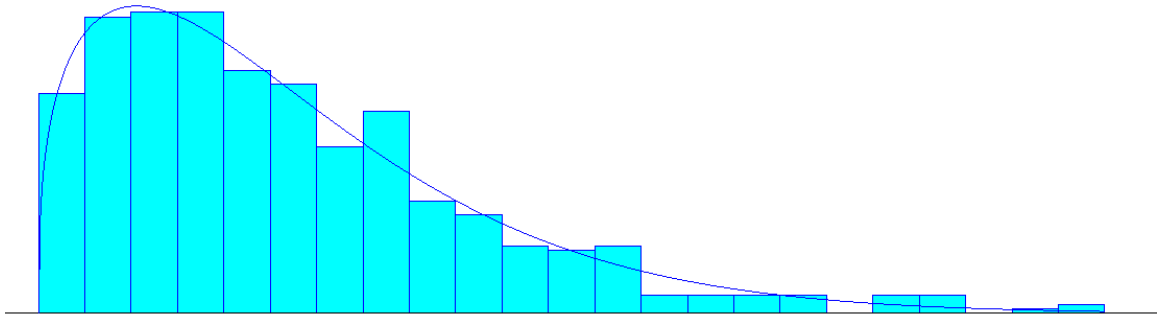
### Data Summary

Number of Data Points = 482  
Min Data Value = 5.02  
Max Data Value = 57.6  
Sample Mean = 17.1  
Sample Standard Deviation = 9.96

### Histogram Summary

Histogram Range = 5 to 58  
Number of Intervals = 21

## Physician 5:



### Distribution Summary

Distribution: Weibull  
Expression:  $5 + \text{WEIB}(13.4, 1.33)$   
Square Error: 0.000773

### Chi Square Test

Number of intervals = 15  
Degrees of freedom = 12  
Test Statistic = 10.7  
Corresponding p-value = 0.557

### Kolmogorov-Smirnov Test

Test Statistic = 0.0211  
Corresponding p-value > 0.15

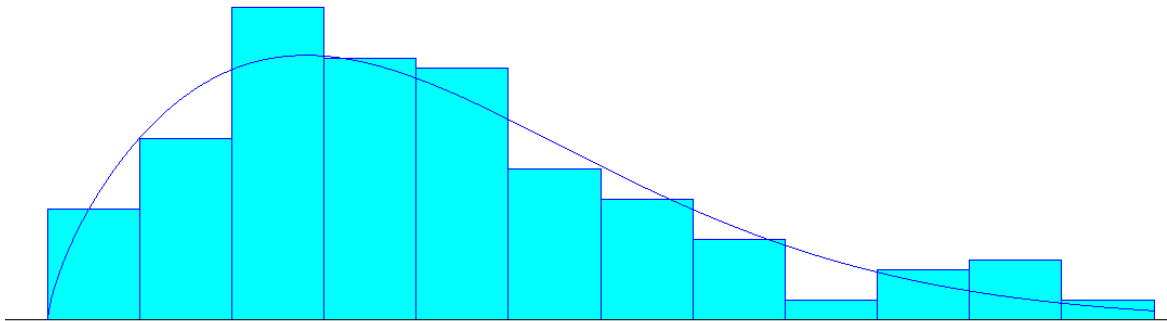
### Data Summary

Number of Data Points = 554  
Min Data Value = 5  
Max Data Value = 56.6  
Sample Mean = 17.3  
Sample Standard Deviation = 9.3

### Histogram Summary

Histogram Range = 5 to 57  
Number of Intervals = 23

## Physician 6:



### Distribution Summary

Distribution: Weibull  
Expression:  $5 + \text{WEIB}(20.3, 1.69)$   
Square Error: 0.003580

### Chi Square Test

Number of intervals = 8  
Degrees of freedom = 5  
Test Statistic = 4.38  
Corresponding p-value = 0.497

### Kolmogorov-Smirnov Test

Test Statistic = 0.0475  
Corresponding p-value > 0.15

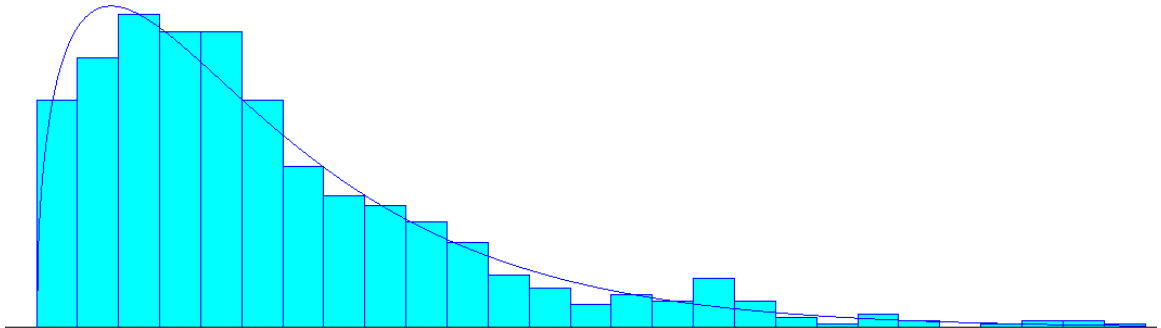
### Data Summary

Number of Data Points = 161  
Min Data Value = 5.2  
Max Data Value = 55.9  
Sample Mean = 23.1  
Sample Standard Deviation = 11.1

### Histogram Summary

Histogram Range = 5 to 56  
Number of Intervals = 12

## Physician 7:



### Distribution Summary

Distribution: Gamma  
Expression:  $5 + \text{GAMM}(7.88, 1.46)$   
Square Error: 0.001130

### Chi Square Test

Number of intervals = 18  
Degrees of freedom = 15  
Test Statistic = 16.2  
Corresponding p-value = 0.383

### Kolmogorov-Smirnov Test

Test Statistic = 0.03  
Corresponding p-value > 0.15

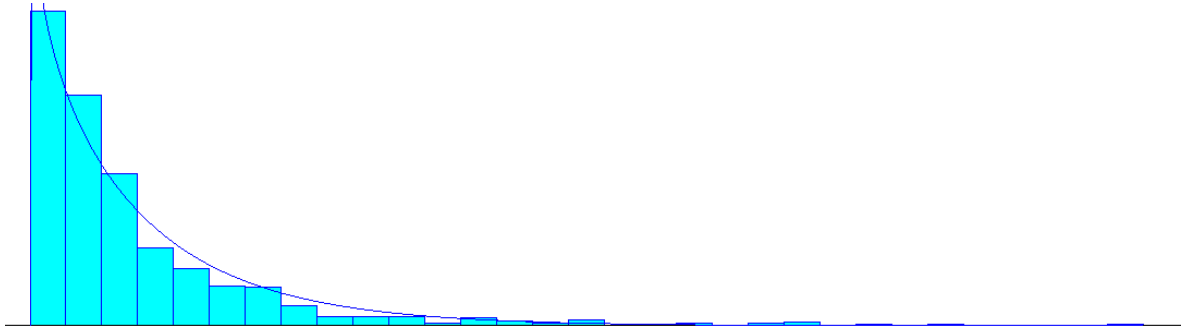
### Data Summary

Number of Data Points = 771  
Min Data Value = 5.07  
Max Data Value = 59  
Sample Mean = 16.5  
Sample Standard Deviation = 9.28

### Histogram Summary

Histogram Range = 5 to 59  
Number of Intervals = 27

## Physician 8:



### Distribution Summary

Distribution: Gamma  
Expression:  $5 + \text{GAMM}(5.9, 0.867)$   
Square Error: 0.002852

### Chi Square Test

Number of intervals = 13  
Degrees of freedom = 10  
Test Statistic = 44.8  
Corresponding p-value < 0.005

### Kolmogorov-Smirnov Test

Test Statistic = 0.0542  
Corresponding p-value < 0.01

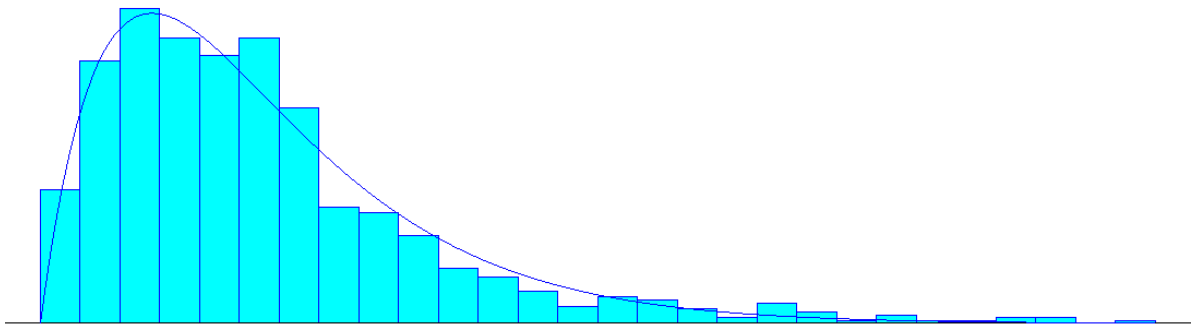
### Data Summary

Number of Data Points = 968  
Min Data Value = 5  
Max Data Value = 56.1  
Sample Mean = 10.1  
Sample Standard Deviation = 6.66

### Histogram Summary

Histogram Range = 5 to 57  
Number of Intervals = 31

## Physician 9:



### Distribution Summary

Distribution: Erlang  
Expression:  $5 + \text{ERLA}(5.31, 2)$   
Square Error: 0.001228

### Chi Square Test

Number of intervals = 16  
Degrees of freedom = 13  
Test Statistic = 24.6  
Corresponding p-value = 0.0259

### Kolmogorov-Smirnov Test

Test Statistic = 0.0379  
Corresponding p-value > 0.15

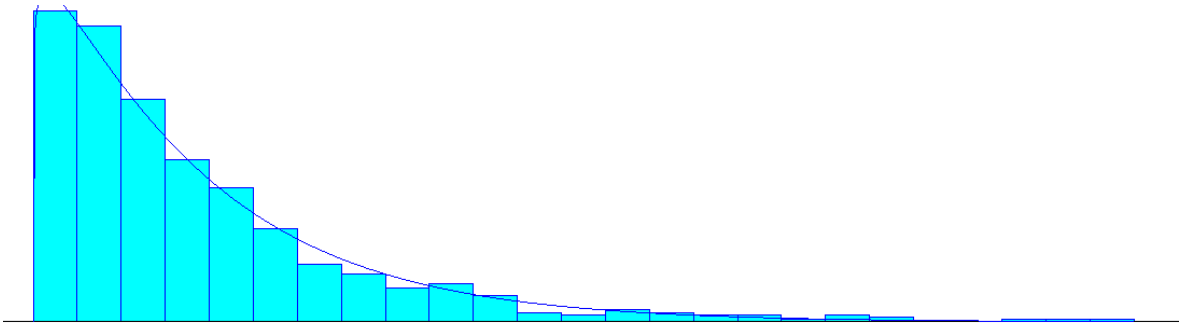
### Data Summary

Number of Data Points = 812  
Min Data Value = 5.08  
Max Data Value = 57  
Sample Mean = 15.6  
Sample Standard Deviation = 8.14

### Histogram Summary

Histogram Range = 5 to 58  
Number of Intervals = 28

## Physician 10:



### Distribution Summary

Distribution: Gamma  
Expression:  $5 + \text{GAMM}(3.2, 1.09)$   
Square Error: 0.000713

### Chi Square Test

Number of intervals = 13  
Degrees of freedom = 10  
Test Statistic = 11.3  
Corresponding p-value = 0.346

### Kolmogorov-Smirnov Test

Test Statistic = 0.0385  
Corresponding p-value > 0.15

### Data Summary

Number of Data Points = 626  
Min Data Value = 5.02  
Max Data Value = 27.9  
Sample Mean = 8.47  
Sample Standard Deviation = 3.5

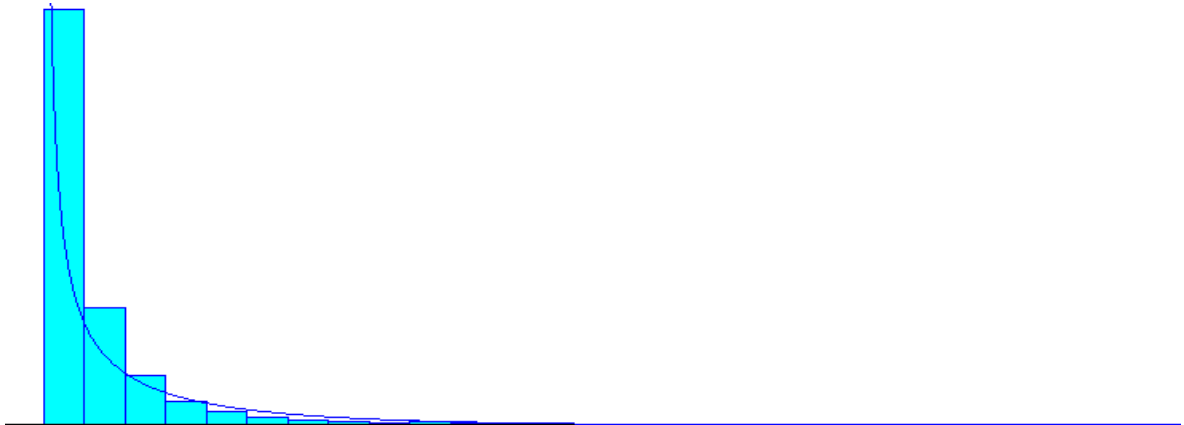
### Histogram Summary

Histogram Range = 5 to 28  
Number of Intervals = 25



# APPENDIX C: INTER-ARRIVAL TIME DISTRIBUTION FOR RANDOM WALK-IN PATIENTS

Inter-arrival Data distribution for Random Walk-in with Early & On Time Patients:



## Distribution Summary

Distribution: Beta  
Expression:  $-0.001 + 484 * \text{BETA}(0.267, 7.44)$   
Square Error: 0.006909

## Chi Square Test

Number of intervals = 19  
Degrees of freedom = 16  
Test Statistic = 978  
Corresponding p-value < 0.005

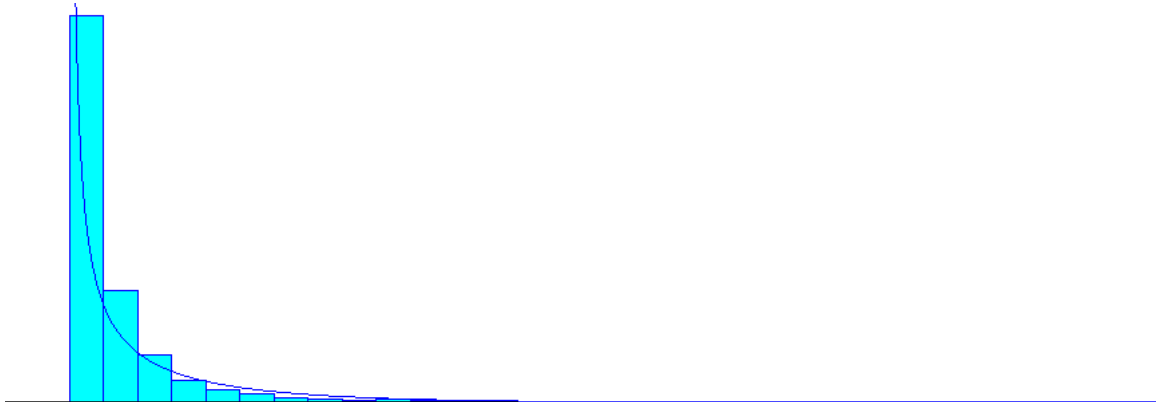
## Data Summary

Number of Data Points = 14016  
Min Data Value = 0  
Max Data Value = 484  
Sample Mean = 16.7  
Sample Standard Deviation = 30

## Histogram Summary

Histogram Range = -0.001 to 484  
Number of Intervals = 40

Inter-arrival Data distribution for Random Walk-in without Early & On Time Patients:



### **Distribution Summary**

Distribution: Beta  
Expression:  $484 * \text{BETA}(0.273, 7.48)$   
Square Error: 0.006712

### **Chi Square Test**

Number of intervals = 19  
Degrees of freedom = 16  
Test Statistic = 972  
Corresponding p-value < 0.005

### **Data Summary**

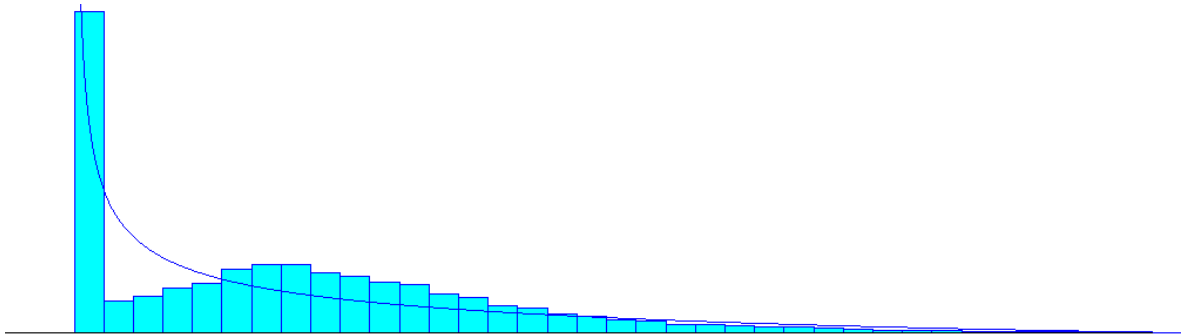
Number of Data Points = 13752  
Min Data Value = 0.0167  
Max Data Value = 484  
Sample Mean = 17.1  
Sample Standard Deviation = 30.2

### **Histogram Summary**

Histogram Range = 0 to 484  
Number of Intervals = 40

## APPENDIX D: ASSESSMENT NURSE DISTRIBUTIONS

Nurse Assessment Distribution for Service Times Between 0 and 15 minutes:



### Distribution Summary

Distribution: Beta  
Expression:  $15 * \text{BETA}(0.48, 2.22)$   
Square Error: 0.010722

### Chi Square Test

Number of intervals = 39  
Degrees of freedom = 36  
Test Statistic =  $5.02e+003$   
Corresponding p-value < 0.005

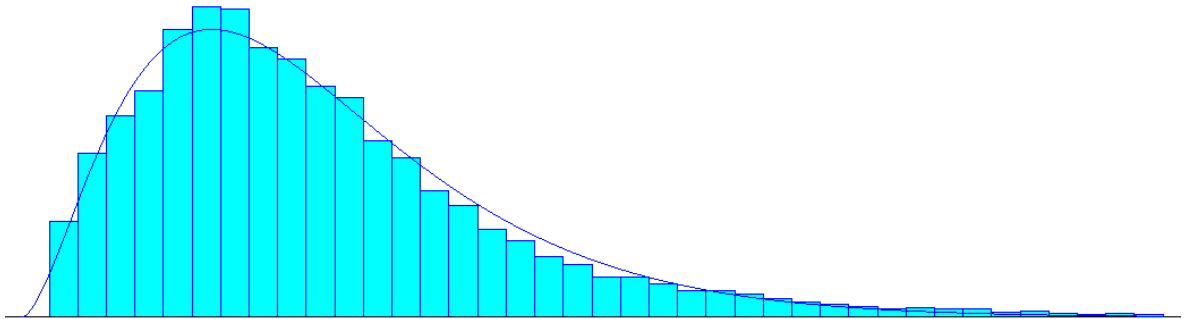
### Data Summary

Number of Data Points = 24582  
Min Data Value = 0.0167  
Max Data Value = 15  
Sample Mean = 2.8  
Sample Standard Deviation = 2.68

### Histogram Summary

Histogram Range = 0 to 15  
Number of Intervals = 40

Nurse Assessment Distribution for Service Times Between 0.5 and 15 minutes:



### **Distribution Summary**

Distribution: Gamma  
Expression: GAMM(1.4, 2.79)  
Square Error: 0.000309

### **Chi Square Test**

Number of intervals = 38  
Degrees of freedom = 35  
Test Statistic = 356  
Corresponding p-value < 0.005

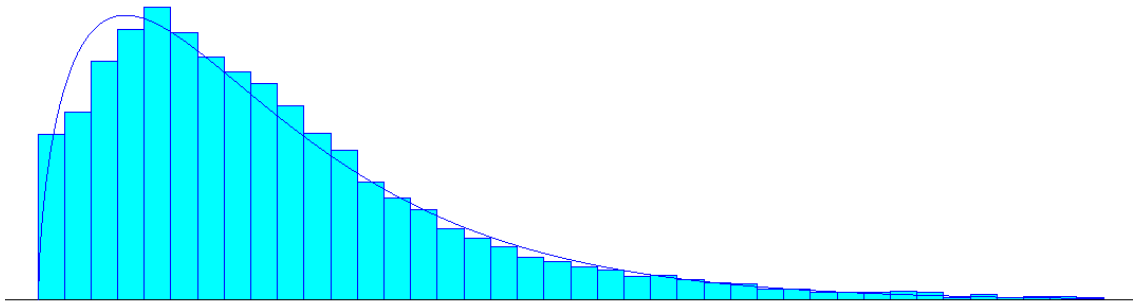
### **Data Summary**

Number of Data Points = 17563  
Min Data Value = 0.5  
Max Data Value = 15  
Sample Mean = 3.9  
Sample Standard Deviation = 2.41

### **Histogram Summary**

Histogram Range = 0 to 15  
Number of Intervals = 40

Nurse Assessment Distribution for Service Times Between 1 and 15 minutes:



### **Distribution Summary**

Distribution: Gamma  
Expression:  $0.999 + \text{GAMM}(1.93, 1.59)$   
Square Error: 0.000634

### **Chi Square Test**

Number of intervals = 39  
Degrees of freedom = 36  
Test Statistic = 222  
Corresponding p-value < 0.005

### **Data Summary**

Number of Data Points = 16608  
Min Data Value = 1  
Max Data Value = 15  
Sample Mean = 4.08  
Sample Standard Deviation = 2.36

### **Histogram Summary**

Histogram Range = 0.999 to 15  
Number of Intervals = 40