A MENTAL WORKLOAD BASED PATIENT SCHEDULING MODEL FOR AN ONCOLOGY CLINIC

by

Anali Glamary Huggins Davila

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

Doctor of Philosophy

in

Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 2016

DEDICATION

To my daughter, Ana Rivas, who has shared many uncertainties, challenges, and sacrifices for completing this disertation.

To my parents, Anaida de Huggins and Marcial Huggins, whose encouragement and constant love sustained me throughout my life.

To my siblings, Carlos and Nataly, whose friendship over the years is immeasurable.

To my groups of friends, “Jovenes Aun” and “Athletic Girls”, whose friendship over the years is immeasurable.

ACKNOWLEDGEMENTS

My sincere thanks to my adviser Dr. David Claudio for the continuous support, guidance, and stimulating discussions. I also would like to express my gratitude to my committee members Dr. Maria Velazquez, Dr. Eduardo Perez, Dr. Yiyi Wang, and Dr McGreenwood for their encouragement and insightful comments. I thank Bozeman Deaconess Cancer's Staff for all their support and collaboration. I thank the Department of Mechanical and Industrial Engineering, especially Dr. Daniel Miller, Kathy Campbell, Michelle Woodbury, Laura Andersen, and Rhea Papke for their patience and support. Last but not least, I thank Dr. Maria Luz Camargo, Dr Marianela Alcalde, and Dr. Bianey Ruiz for encouraging me to pursue a PhD degree at MSU.

TABLE OF CONTENTS

TABLE OF CONTENTS-CONTINUED

LIST OF TABLES

LIST OF TABLES-CONTINUED

LIST OF FIGURES

Figure Page

LIST OF FIGURES-CONTINUED

Figure Page

TABLE OF FIGURES-CONTINUED

Figure Page

TABLE OF FIGURES-CONTINUED

ABSTRACT

The healthcare systems in the United States have faced competing challenges such as reducing costs and improving outcomes. Currently, the United States healthcare system is considered the most expensive in the world; 53% per capita more than the second-highest country. This study was focused on increasing resource productivity and efficiency in the healthcare system specifically at Bozeman Deaconess Cancer Center (BDCC) taking into consideration mental workload. The demand of the center has increased in approximately 16% each year since 2011. The BDCC strategic objectives are to improve the distribution and supply of resources, to maximize service coverage, to minimize waiting time of patients, and maximize service capacity. This research measured and validated mental workload in the infusion area of BDCC using two perceptual tools, NASA-TLX and SWAT, as well physiological responses. The purpose is to balance patient appointment and increase resource utilization. This study took into consideration the balance of human resource workload as a main part of the proposed model rather than only a mathematical solution balancing the capacity of the human resources without overloading them. A mathematical model was be developed and tested through a discrete event simulation to validate and explore the feasibility of the scheduling polices. In conclusion this thesis was able to successfully build a patient scheduling model considering nurses workload. It was proved that the model balanced patient appointments through the day by leveling the workload of nurses and pharmacists. Sensitivity analysis showed that the patient demand of the center could be increased up to 40% in some instances without negatively impacting patient service. This research is one of the first of its kind to include mental workload as a mathematical constraint in a scheduling model.

CHAPTER 1

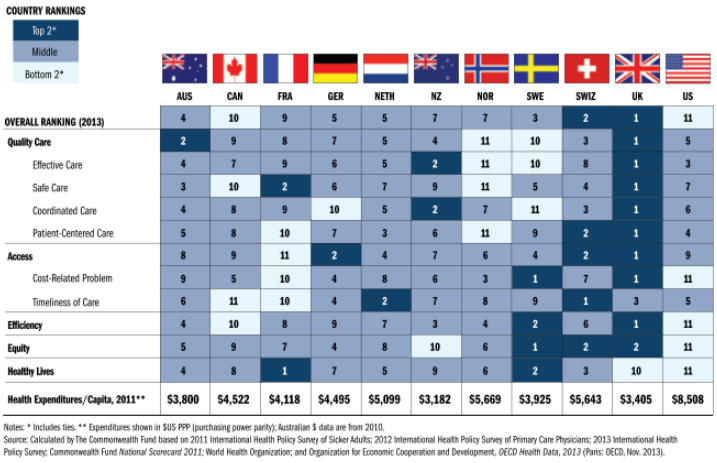
INTRODUCTION

Thesis Overview

Over the past decade, the healthcare system in the United States has faced competing challenges such as reducing costs and improving outcomes [1]. Currently, the United States healthcare system is considered the most expensive in the world; 53% per capita more than the second-highest country [2]. The Commonwealth Fund presents annually a report that compares the performance of the Unites States healthcare system among 10 nations- Australia, Canada, France, Germany, the Netherlands, New Zealand, Norway, Sweden, Switzerland, and the United Kingdom— using five dimensions as measured system. These dimensions are quality, access, efficiency, equity, and heathy lives [2]. Figure 1.1 summarizes the rankings of the different healthcare systems around the world. The figure shows that the U.S. ranks last in dimensions such as efficiency, equality, and healthy lives, and the United Kingdom ranks first, followed closely by Switzerland [2]. This situation has trigger the need of generating effective polices and strategies that could impact positively the quality of the healthcare in the United States.

A wealth of knowledge and experience in enhancing the quality of healthcare has accumulated globally over many decades. Even when health systems are well developed and resourced in the United States, there is clear evidence that quality remains a serious concern. To understand quality, the Institute of Medicine (IOM) defines quality of healthcare in terms of standards such as *'the degree to which health services for*

individual and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge'. It is centered on the conceptual components of quality: quality of care is safe, effective, patient centered, timely, efficient, and equitable [3]. Meanwhile, the quality definition of the American Academy of Nursing Expert Panel on Quality Health is focused on the following positive indicators of high quality care that are sensitive to nursing input achievement of appropriate self-care, demonstration of health-promoting behaviors, health related quality of life, perception of being well cared for [4]. According to these concepts, it is evident that the United States has failed to achieve better healthcare services for Americans [1]. The efforts should be based on making significant strides in improving the delivery, coordination, production, and equity of the healthcare system. The main objective of this study is focused on increasing the productivity and efficiency of the resources in the delivery and improvement of quality in the healthcare system that are fundamental factors to meet the expectations of both patients and healthcare workers.



COUNTRY RANKINGS
Top 2*
Middle
Bottom 2*

	AUS	CAN	FRA	GER	NETH	NZ	NOR	SWE	SWIZ	UK	US
OVERALL RANKING (2013)	4	10	9	5	5	7	7	3	2	1	11
Quality Care	2	9	8	7	5	4	11	10	3	1	5
Effective Care	4	7	9	6	5	2	11	10	8	1	3
Safe Care	3	10	2	6	7	9	11	5	4	1	7
Coordinated Care	4	8	9	10	5	2	7	11	3	1	6
Patient-Centered Care	5	8	10	7	3	6	11	9	2	1	4
Access	8	9	11	2	4	7	6	4	2	1	9
Cost-Related Problem	9	5	10	4	8	6	3	1	7	1	11
Timeliness of Care	6	11	10	4	2	7	8	9	1	3	5
Efficiency	4	10	8	9	7	3	4	2	6	1	11
Equity	5	9	7	4	8	10	6	1	2	2	11
Healthy Lives	4	8	1	7	5	9	6	2	3	10	11
Health Expenditures/Capita, 2011**	$3,800	$4,522	$4,118	$4,495	$5,099	$3,182	$5,669	$3,925	$5,643	$3,405	$8,508

Notes: * Includes ties. ** Expenditures shown in $US PPP (purchasing power parity); Australian $ data are from 2010.
Source: Calculated by The Commonwealth Fund based on 2011 International Health Policy Survey of Sicker Adults; 2012 International Health Policy Survey of Primary Care Physicians; 2013 International Health Policy Survey; Commonwealth Fund *National Scorecard 2011*; World Health Organization; and Organization for Economic Cooperation and Development, *OECD Health Data, 2013* (Paris: OECD, Nov. 2013).

Figure 1.1 Overall ranking [2]

Cancer remains the second most common cause of death in the United States. In 2014, there will be an estimated 1,685,210 new cancer cases diagnosed and 595,690 c are expected to die of cancer in 2016, which translates to about 1,630 people per day [5]. That changes the approach that healthcare system has over the centers that provide cancer treatments. Cancer care over the last 50 years has evolved from its primary focus on local disease to a sophisticated, multidisciplinary approach to achieve the level of high quality care that is necessary in the United States. The present study will be conducted at the Bozeman Deaconess Cancer Center (BDCC) which provides care services in Bozeman and its surrounding areas. BDCC provides the latest cancer technologies and treatment options in an integrated center that promotes a team approach to oncology care. The demand of the center has increased in approximately 16% each year since 2011 [6]. The BDCC strategic objectives are to improve the distribution and supply of resources, to maximize service coverage, to minimize waiting time of patients, and to maximize service capacity of the center. As a consequence, management is looking to incorporate a scheduling system that corresponds with these objectives.

Currently, more than 85 % of patients who are treated on BDCC are using infusion service daily that makes the infusion area the core of BDCC. The present study focused mainly on this area. Infusion scheduling is a highly complex process involving a multitude of (often shared) resources, as well as a high degree of dynamics and uncertainty. The term *Infusion Scheduling* covers planning tasks at different levels of detail and time scale. Since the early 1950s, researchers have approached scheduling systems using theories mainly from fields such as mathematics, computer science,

economics, and engineering [7]. Even though mathematical and simulation models were used in healthcare systems effectively [8] [9] [10] [11], they do not fulfill the healthcare aims completely. One reason is deficiency to incorporate human factor theories as the center of quantitative models.

Human factor is the discipline that takes into account human strengths and limitations in the design of interactive systems that involve people, tools and technology, and work environments to ensure safety, effectiveness, and ease of use [12]. Human factor projects are based on studying and examining a particular activity in terms of its component tasks, and then assesses the physical demands, skill demands, mental workload, team dynamics, aspects of the work environment, and device design required to complete the task optimally [12]. In essence, human factor theories are focused on how systems work in actual practice, with real—and fallible—human beings responsible for the controls, and attempts to design systems that optimize safety, quality and minimize the risk of error in complex environments [13].

This research studied different techniques to measure staff workload taking into consideration mental and physical workload, and validated and integrated them into a mathematical model. This study took into consideration the balance of human resource workload as a main part of the proposed model rather than only a mathematical solution balancing the capacity of the human resources without overloading them.

Fields such as psychology and human factors have conceptualized and measured workload in the last decade. This study conceptualizes workload as a dynamic balance between the challenge of the tasks and the individual’s responses to a task or activity

[14]. This concept compiles elements such as task allocation, level of performance, task demand, mental and physical effort, and operator's perception [15]. Another concept that was used frequently throughout this study is mental workload as the capacity of individuals to process, analyze, and manage information. These concepts represent a high level of abstractness as a result only a few tools have been developed to measure them. Even though these tools have been applied in different areas not all of them have been validated especially in the healthcare field. This research measured and validated mental workload in the infusion area of BDCC using two perceptual tools NASA- Task Load Index and Subjective (NASA-TLX) and Workload Analysis Technique (SWAT) and physiological responses simultaneously. The objective was to establish the number of nurses and pharmacists necessary in the infusion area to keep an optimal balance of the activities.

Furthermore, an acuity model was developed which was used for patient categorization. The patient category was determined by the type of treatment, which determines the length of therapies of the patients. The acuity category was determined by the patient treatment type which was used in the model along with the patient sequence to determine the optimal mix of patients throughout day.

Finally, the integration of an optimization model and a simulation model has been successful for decision-making in complex systems [16] [17] due to the fact that computer simulations provide good operational decision support as it allows for the creation of multiple scenarios that can be representative of any given day [10]. As a

result, a mathematical model and simulation model were developed. Using the last one as a tool to validate and explore the feasibility of the schedule polices.

Description of Problem

As was previously discussed, patient demand has increased substantially at BDCC in the last years. This situation triggered different problems such as imbalances among service areas, long periods of patient waiting time, and high levels of human resource workload. All these problems are generated by inefficiency of the scheduling system which is meant to give adequate response to the complexity of the healthcare system.

The tasks at BDCC involve a high level of complexity due to the variability in treatment requirements, variability in patient response, internal delays in services, and high information flow requirements. BDCC currently operates 5 days a week from 8 AM to 5 PM. Some employees often work overtime, especially nurses who must finish the care of all the patients that are in the system [18]. This overtime is caused by several delays in the work schedule across the system. The cancer center treat more than 60 patients per day which are mixed according to patient needs and availability of resources. Out of these, the infusion area sees anything between 24 and 35 patients per day. Each day represents a new challenge for management which needs to guarantee opportune and reliable patient service.

To understand the patient flow, it was necessary to divide the patient type into seven categories which represent the different paths patients follow through the system. Table 1.1 presents the sequence of activities of different types of patients. The patients go

through the different routes or paths depending on their needs. Each route has a cycle time and its own characteristics. For example, patient type 4 goes to the lab and subsequently goes to doctor's appointment (Consult)

Table 1.1 Type of patient according to flow

Patient Type	Lab	Consult	Infusion
1		✓	
2			✓
3	✓		
4	✓	✓	
5		✓	✓
6	✓		✓
7	✓	✓	✓

Similarly, Figure 1.2 shows the routs that patients follow. For example, the current patient flow at BDCC starts with checking-in at the reception followed by going to laboratory for blood draw. Not every patient needs to go through the laboratory every day, some patients come the day before their appointment for blood draw (Type 3), some patients don't require a blood test (i.e. Type 1, 2, & 5). After that, patients are escorted by a nurse to a consult room for vitals check followed by doctor's examination. Then patients go to the infusion area for treatment. Again, not all patients require a doctor's examination before infusion treatment (i.e. Type 1, 3, & 4).

The cycle time and the frequency of treatments could change depending on individual needs of each patient, such as patient's response to different treatment, provider style, the availability of human resources in the system such as nurses, pharmacy technicians, lab technicians, and doctors, and the design of the process. The complexity of the scheduling system is based on the balance between the available resources and the mix of patient types. The objective of this research was to establish

different models that permit the reduction of the gap between the actual schedule and the projected schedule, keeping high quality of service and also effective resource utilization considering the workload of human resources through the system.

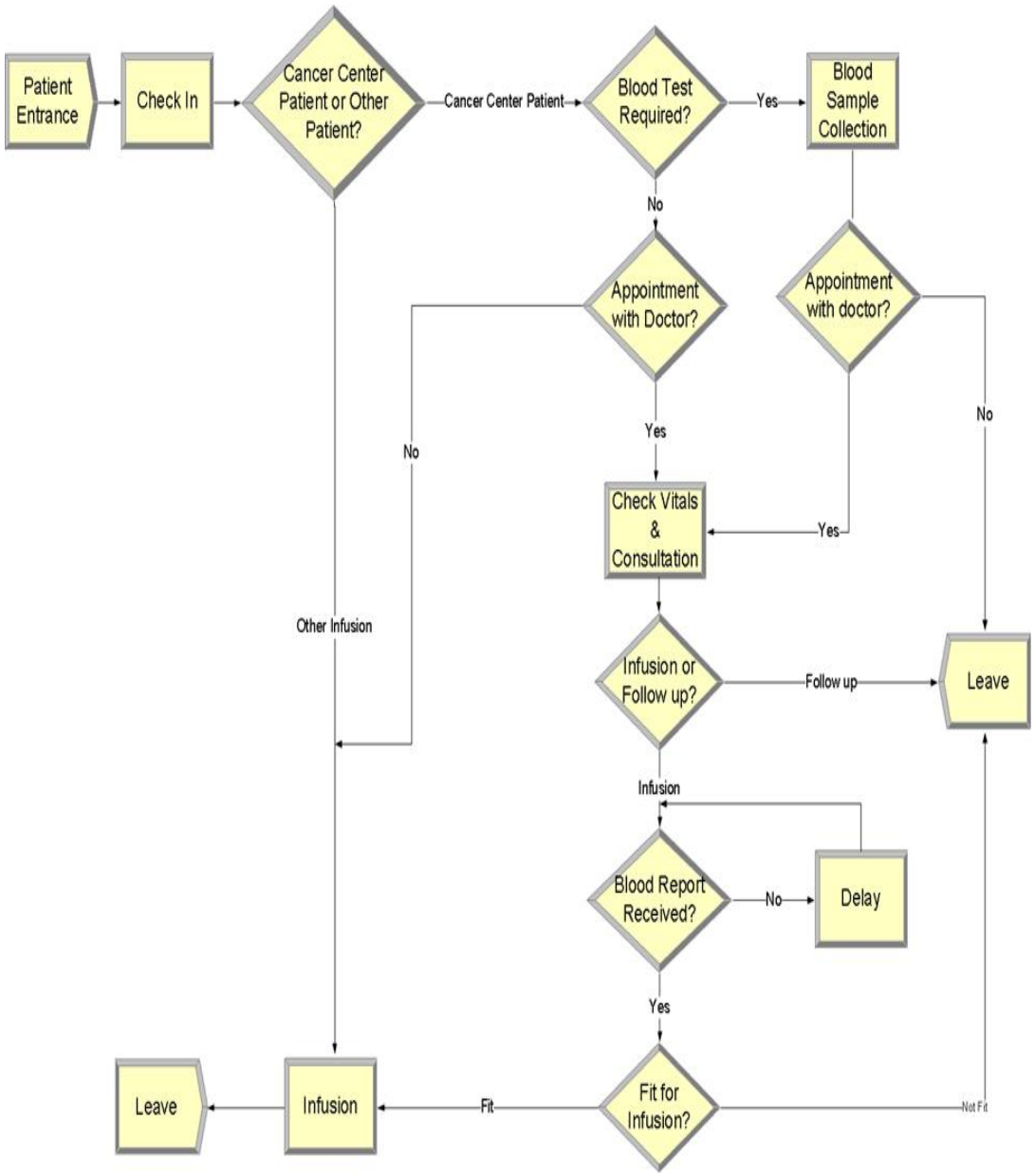


Figure 1.2 Cancer center patient flow chart

Research Questions and Contributions

The present research used workload measurements as a basic component of analytical models in the healthcare area. Figure 1.3 displays an overview of this research. The study was divided into six phases. Phase 1 measured workload using physiological responses and perceptual instruments such as NASA-TLX and SWAT. Phase two validated physiological workload and perceptual workload measurements. Until now, some studies have shown where perceptual workload instruments have been used in healthcare settings to measure workload, however, none of them have validated these instrument in that field [19] [20] [21] [22]. Phase 3 developed workload constraints to build a completed mathematical model in phase 4. The objective of this mathematical model was to maximize resource utilization without overloading the human resources.

Consequently, phase 5 developed a simulation model of the system to validate the mathematical model. Finally, phase 6 integrated all the results in scheduling policies to improve the patient flow of the current system.

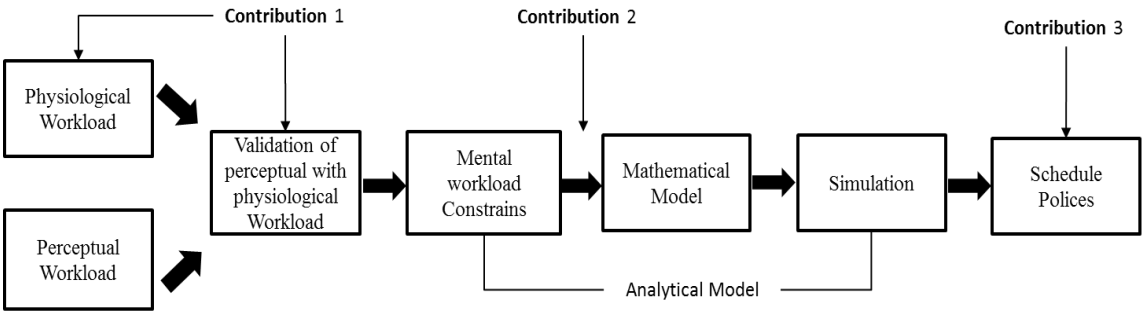


Figure 1.3 Research overview

From the figure, it can also be see the three primary contributions of proposed research. Contribution 1 was focused on measurement and validation of workload tools; contribution 2 was focused on incorporation of workload measurements in to a mathematical model; and contribution 3 was focused on the development of scheduling polices for an oncology clinic. Likewise, the present research explored several research questions through the methodology. These questions were gathered in the next research hypothesis

Physiological workload (Part of contribution 1)

H_{01} Physiological responses and number of patients seen during the day in infusion area are correlated.

Perceptual workload (Part of contribution 1)

H_{02} The workload measurements obtained from NASA-TLX are correlated to SWAT measurements

H_{03} The workload measurements obtained from NASA-TLX are similar to the measurement obtained from the equal weight calculation method

Physiological and perceptual workload (Part of contribution 1)

H_{04} The workload measurements obtained from the NASA-TLX and the physiological responses are correlated.

Analytical model and scheduling model (Part of contribution 2)

H_{05} The total cycle time of the patients in the real system and the simulation model is the same

H_{06} The total cycle time of the patients in the actual system and the proposed model is the same (Part of contribution 2).

H_{07} The number of patients that are serviced during a day in the Cancer Center will increase with the new schedule policies (Part of contribution 2).

H_{08} The percentage of the chair utilization of the infusion area will increase with the new schedule policies. (Part of contribution 2).

This research integrated concepts such as modeling, simulation, and human factors in a complex healthcare systems.

The rest of the document is divided as follow Chapter 2 presents a comprehensive review of the literature; Chapter 3 presents a description of the methodology followed in this research; Chapter 4 determines the maximum number of patients a nurse is capable of handling without exceeding certain mental workload levels using human factor analysis; Chapter 5 builds a mathematical model integrating the human factor constraints; Chapter 6 analyzes the impact the proposed schedules have over patient care using discrete event simulation; Chapter 7 develops general patient scheduling policies for the infusion area. Figure 1.4 illustrates the research overview fragmented by chapter and hypotheses.

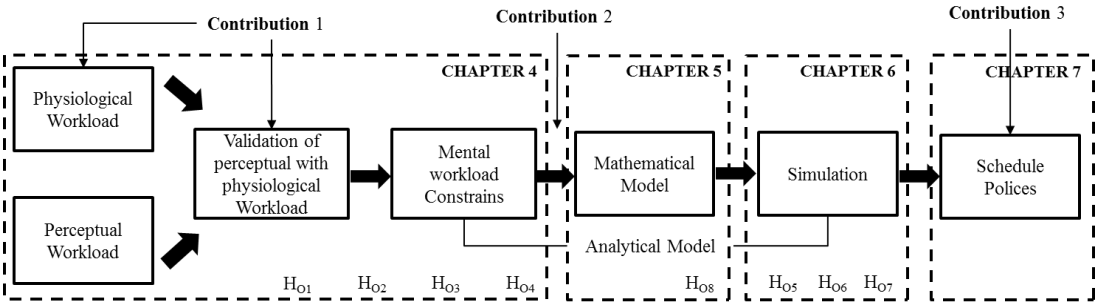


Figure 1.4 Research overview fragmented by chapter and hypotheses

CHAPTER 2

LITERATURE REVIEW

Workload Measures

A factor to consider in this research was the measurement of human resources workload, especially for nurses and pharmacists. Nursing workload measurement can be used as an information source for management to determine the requirements and allocation of nurses with the objective to obtain a balance between supply and demand [19]. Previous research has defined nursing workload as the action to measure the level of direct and indirect patient care in related nursing activities which are based on dependency level of the patient, the severity of the illness or injury, the time required for managing their care, and the complexity of the care provided [23].

Furthermore, mental workload is based on the assumptions that each person has a fixed cognitive capacity, and is defined as the difference between cognitive demands of a job or task and the person's attention resources [19] [24]. It represents the perception of pressure related to the amount of work and task heaviness which indicates the degree to which a job taxes the nurse in terms of mental effort [25]. The variability of workload measurements could be analyzed through four key concepts such as patient-nursing condition, medical condition, caregiver characteristic, and the environment. The complexity of combining all these concepts generates an evolution in the system from a descriptive approach to an industrial management engineering approach which is a key factor of this proposed study [26].

In general, measuring workload is based on three methods physiological, procedural and perceptual [22]. Physiological measurements are related to elements which include heart rate and blood pressure as responses to stress. Procedural measurement use tools which determine time spent to perform the activities. The last method, perceptual, measures the individual perspective of responders and it is considered more subjective than the last two. It frequently uses surveys with an objective to evaluate the participants' perceived workload [22]. Table 2.1 shows a summary of the methods used to measure workload [21]. Each of them are related to the assumptions of method, most frequent indicators for their validations, and the corresponding limitations of the methods.

Table 2.1 Methods to measure workload

Method	Assumptions	Indicators	Limitations
Physiological	This method assumes that people's physical functioning changes when the cognitive demands change	The most frequent indicators are heart rate, heart rate variability, respiratory changes, blood pressure fluctuations, eyes blinks, cortisol level, skin potential level, and oxygen consumption	Validity of result is impacted by presence confiding factors and extraneous variables that could have an effect on physiological indicators
Procedural	Attention load changes cause performance or behavior changes that can be measured and predicted	Change in reaction time and accuracy of the task or performance measure	Participant must perform a second task in order to assess the processing demands of primary task
Perceptual	Participants are aware of their mental workload or attention capacity and can estimate variations in mental workload and attention capacity	Self-reports as NASA-TLX and SWAT are based on questions about the amount of work or mental processing required to complete the task	Validity relies on the human's ability to provide information about the effort investment required to complete the work

The present study used physiological workload measure to validate subjective workload methods. Physiological workload responses in mental task situations have been

conducted frequently in the medical field and human factors and ergonomics field. Some authors established that not only physiological workload but also the mental workload has a clear impact on body responses [27]. In other words, workload can be assessed by the measurement and processing of the appropriate physiological variables which are classified into three categories as a function of the organs involved brain-related, eye-related, and heart-related. Table 2.2 displays the physiological measures according to three major categories [28].

Table 2.2 Physiological measures

Brain related measures	Eye related measures	Heart related measures
Functional magnetic (FMRI)	Electrooculography (EOG)	Electrocardiography (ECG)
Resonance imaging (MRI)	Blink interval	Heart rate variability (HRV)
Electroencephalography (EEG)	Blink closure duration	Heart rate
Event related potentials (ERPs)	Blink rate	Blood pressure

Several researchers have investigated how mental workload affects physiological responses over an individual. For example, DiDomenico and Nussbeum [29] investigated if there is a differential effect of various types of physical activity on both mental workload and cognitive performance. The aim of the study was to determine the impact physiological components might have over mental workload. One finding was that levels of both physical and mental activity impair mental processing or decrease performance.

Similarly, Ryu and Rohae [28] developed a combined measure based on various physiological indices to evaluate mental workload during a dual task. The physiological indices that were considered in this research were: 1) the suppression of alpha rhythm

which uses the signal of electroencephalogram (EEG); 2) electroencephalogram (EEG) which uses the signal of electrooculogram (EOG); and 3) heart rate variability (HRV) which uses the signal of electrocardiogram (ECG). Additionally, the authors used NASA-TLX to obtain the participants' mental workload perception. A multiple regression analysis was used in physiological measures to predict the subjective workload. In conclusion, the study showed that both factor analysis and multiple regression analysis can be useful tools as a combining method.

Finally, Miyake [30] investigated a new method of mental workload assessment in which multiple physiological parameters and subjective indices were integrated into one index using multivariate analysis. The present research integrated physiological measures and the subjective measures to assess levels of workload for different tasks in the infusion area.

Over the years, several tools have been applied to measure perceptual workload. Two of the most widely known perceptual workload measure tools are the National Aeronautics and Space Administration Task Load Index (NASA-TLX) and Subjective Workload Analysis Technique (SWAT). They are a multidimensional measures based on rating responses, and they have been validated in different settings but not in healthcare as perceptual workload instruments [19]. In fact, NASA-TLX is one of the most widely used instruments to assess overall subjective workload, and it has been used in complex environments to assess operator workload [20] [31]. NASA-TLX is a rating scale commonly used in human factors research which is based on six dimensions mental demand, physical demand, temporal demand, effort, frustration level, and performance. It

has been successfully applied to different sectors of which the most relevant are aeronautics, computer systems, transportation, and healthcare [24] [32] [33]. This tool has been used in dozens of previous studies addressing human factors related to accidents, errors, and workload characteristics which are considered fundamental factors in healthcare delivery [34]. In healthcare this tool has been used in specific areas such as intensive care units [20, 22], operating rooms [35], and emergency departments [36]. NASA-TLX has also been used to compare the workload between physicians and nurses when new technologies are implemented, such as the use of electronic medical records. In addition, NASA-TLX has been used to determine the necessity of operative personnel in different healthcare areas. These represent only a few examples of the different applications of NASA-TLX in healthcare delivery systems [37].

Likewise, SWAT is a subjective technique that is composed of three dimensions time load, mental effort load, and psychological stress load [24] [38] [39] [40]. Several authors have applied SWAT in healthcare settings. For example, Jacoboson et al. [41] used SWAT to describe subjective and temporal work intensity dimension for physicians in clinical settings. The objective was to study how the work intensity affects the quality of care, patient safety, and physician job-satisfaction. Others authors such as Moroney, Biers and Eggemeier [42] used workload rating from SWAT and NASA-TLX and combined their procedures and subscales into one overall estimate of subjective workload [42]. Even though SWAT has been used with success in several fields, the literature shows no evidence of having been validated in the healthcare field. The proposed research will combine results from SWAT, NASA-TLX and physiological

workload to validate and analyze the sensitivity of workload measurements in a healthcare settings specifically at the infusion area of BDCC.

This research took into consideration the balance of human resources workload to develop a model more oriented to human factors rather than only to mathematical solutions. The integration of multiple points of view from nurses, physicians, and even from patients is a common practice for the improvement of healthcare systems. The use of different decision making methods represents a systematic and reliable approach for the decision making of healthcare management. A holistic approach in the decision making process does not consider independently the viewpoint of each of the decision makers. It is based on the idea that "everything influences everything else," which makes it more complex to integrate all opinions and generate a common idea [43]. In healthcare systems, there are several departments that may face a single problem. However, they are different views to solving the problem, based on the relative importance of dissimilar criteria areas among departments [44].

Analytical Models

Optimization models have been used frequently in research oriented to develop mathematical models to improve healthcare systems. For example, Van Houdenhoven et al. [45] were able to increase operation room (OR) utilization by applying mathematical algorithms. They also argued that mathematical algorithms were not enough; hence, they needed to lower the organizational barriers that were limiting departments to scheduling surgeries in certain rooms. Similarly, Ozkarahan [46] used goal programming to allocate

surgeries to operating rooms. Denton el al. [8] combined mathematical optimization with simulation in order to minimize waiting times, idle times and overtime in an OR. Most of the articles found in the literature are focused either in ORs or emergency rooms (ER).

Computer simulation has been used to aid healthcare decision making from the early 1950's [47] [48]. England and Roberts [49] presented a comprehensive literature review about the application of simulation in healthcare before 1978. They cited 92 simulation models to explain the use of computer simulations in twenty one different healthcare areas. A similar bibliography was presented by Klein et al. [50], who cited articles to exhibit the application of computer simulation in operational decision making, medical decision making, system dynamics, and epidemiology, among others. Discrete event simulation is the most popular and widely used simulation technique adopted by researchers in healthcare. This may be attributed to the numerous successful studies reported using simulation to address healthcare system problems and the ever increasing sophistication of simulation software packages [16] [51].

Baesler and Sepulveda [52] [53] presented a case study on combining simulation and multi-objective optimization heuristics to target four objectives at a Cancer Center such as minimizing patient's waiting time, maximizing chair utilization, minimizing closing time, and maximizing nurses' utilization. The authors used a new building analysis to identify a waiting room area that was too small for the increased patient flow. It would allow a 30% increase inpatient throughput with the same resources. Additionally, Swisher et al. [54] [55]showed that under certain conditions staffing reductions could be made without sacrificing patient throughput or increasing staff

overtime. They experimented with several models with different patient mixes. They also showed that scheduling more of a certain type of patient (patients that require extensive physician interaction; longer service time) in the morning reduces employee overtime significantly. Meanwhile, Harper and Gamlin [56]tested a number of different appointment schedules and showed how patient wait times can be significantly reduced through improved planning of the schedule and management engagement. Furthermore, Rohleder and Klaseen [57] studied the use of rolling horizon appointment scheduling and considered two common management policies Overload Rules (OLR) and Rule Delay (RD). The results showed that managers of appointment scheduling systems must carefully consider which measures are most important to them since the best choices of OLR and RD vary substantially by measure.

In a similar way, Coelli et al. [9] used discrete event system simulation (DESS) to take into consideration the global assessment of patient flow, equipment utilization, available personnel (technicians and physicians), equipment maintenance scheduling schemes, and exam repeat rates. Similarly, Cote [58] developed a simulation model which was based on the physician's practice to study the impact of examining room capacity and patient flow. The study found that increased resource utilization does not necessarily imply longer waiting lines nor longer patient flow times, and a reduction in the number of examining rooms did not result in individual patient delays. Finally, Akas et al. [59] developed two models with different points of view length of stay (LOS) and a management-oriented decision support system (DSS) that was used to represent the conditional dependencies as well as the uncertainties of variables affecting system

efficiency. The authors proposed a framework that acts as a useful guide for policy-makers improving the performance of systems as well as the allocation of scarce resources subject to limited budget.

Even though all the authors mention above used simulation as a primary tool whereas in this research, the primary tool is the optimization model and the simulation is used to test the validity and robustness of the model which will be optimized simulating the different schedule policies and also varying the patient mix of patient demand. Consequently, this research considers discrete-event system simulation as a useful tool for defining optimal operating conditions for outpatient clinics, indicating the most adequate capacity configuration of equipment and human resources based on patient scheduling.

Scheduling Models

Scheduling models have been studied widely in the manufacturing industry. Several studies highlight the scheduling system as problematic in optimizing resources subject to constraints or restrictions in a complex system [60] [61]. Scheduling models interact with other types of models and theories, such as long term strategic models, facility location models, demand management models, and forecasting models [62]. Some factors that are addressed in the scheduling system are the uncertainties which conceptualize as complete unknown and known events caused by external factors. These factors could be grouped into three categories complete unknowns, suspicions about the future of the decision maker, and known uncertainties [63]. In the healthcare sector, we

find different applications of scheduling models. For example, Hahn-Goldberg et al. [64] took into consideration the nature of the healthcare environment using an optimization model to create a dynamic schedule template which was compared to a proactive template and the actual performance of the cancer center. They found that improvements of twenty percent when using dynamic template scheduling compared to current practice.

In a similar way, Turkcan el al. [65] developed operations and scheduling methods for chemotherapy patients with the objective of minimizing the deviation from optimal treatment plans due to limited availability of clinic resources. The computational result showed that the planning and scheduling problems could be solved in reasonable times, and the proposed planning and scheduling models could be used as a decision making tool in determining the optimal staffing levels.

Perez et al. [66] derived algorithms for scheduling nuclear medicine patients and resources and validated them using simulation of a nuclear medicine clinic system. Also, Vasilakis et al. [67] developed a simulation model used to evaluate the likely impact of the scheduling method in clinic operations. Other mathematical models were designed to move away from block scheduling by assigning elective patients to different ORs or days to minimize costs associated with overtime which occur when surgeons overbook an OR to complete a large roster of patients in a single day [68] [69].

Several studies have used simulation as a method to compare the scheduling system with the objective of improving the efficiency of the systems by reducing patient wait times, increasing resource utilization, or decreasing human resources overtime [55]

[70] [71] [72]. The proposed research combined different scheduling models with the purpose of optimizing the resources utilization and increasing the cancer center capacity.

Finally, a recent study developed a fatigue nurse scheduling model adding nurse preferences and fatigue [73]. The study showed that solely using nurses' preference is not enough to create an optimal schedule that can reduce the fatigue effectively. Consequently, the authors combined three objectives, which are nurses' preferences, survey-based fatigue, and function-based fatigue, to create a better schedule model [73].

The proposed research differs from the previous work by in incorporating physical workload, perceptual workload, mathematical models, and simulation models in the development of a more realistic and efficient scheduling system. Finally, the objective was to propose scheduling polices that consider the system as holistic and also keep the balance of resources without affecting the balance of others. A detail description of the methodology used in this research is shown in the next chapter.

CHAPTER 3

METHODOLOGY

Location for Research Study

The research will took place at Bozeman Deaconess Cancer Center (BDCC), located in Bozeman, MT, which is fully accredited with commendation by the American College of Surgeons Commission on Cancer. BDCC currently serves to 1,845 active patients and adds proximally 600 new patients each year. Management is concerned about the imbalance in resource utilization which is linked mainly to the scheduling system.

Subjects

An IRB was approved with the purpose of conducting all the activities related to participation of human subjects in the project.

Subjects were divided in two different groups of patients and clinic staff. The last one is composed of nurses, pharmacist, providers, managers, technicians, and administrative personnel. Medical records were used to collect information about patient arrival time, treatment frequency, and treatment duration. In addition, part of the data was obtained from Meditech and Mosaic software used by the clinic to manage patient appointments and patient medical information. Patients were not disturbed at any time during their treatment. Interviews and surveys were applied to clinic staff. The

information managed in the research was confidential and it was not used to measure performance of the human resources.

Materials

As part of the research it was necessary to use different software to analyze data and build the models. ARENA (version 14.0) was used to simulate the patient flow and validate the scheduling model; GAMS (version 24.1.2) was used to model and solve the optimization models; Minitab (version 17); and SPSS (version 22) were used to process all the statistical data. NASA-TLX and SWAT were applied to measure human resource workload. In addition, Equivitalth TnR was used to measure physiological responses of nurses and pharmacists.

Procedure

This research was divided in six tasks which represent the proposed methodology of the study.

Task 1 - Measure and Analyze System Workload

Determining the optimal balance of task assignment that ensures high quality care in a nurse workstation is challenging. Tools such as work sampling, NASA-TLX, and SWAT were conducted to measure workload in all areas of BDCC.

Work sampling was used to find the amount of time spent on each task. It was chosen over other work measurement techniques due to the high number and variability of tasks. Time studies, for example, are primarily used to determine the duration of a task

in order to develop time standards [74]. This can be difficult in this type of setting since nurses have a high number of tasks with some of them sometimes having a preemptive priority over others. Work-sampling, on the other hand, has been proven to work when the desired output is the proportion of time a person is busy in a specific task [75] [76] [77][75,77,78].

The theory of work-sampling relates the probability of an event or condition to be present with the fact that there are only two possible outcomes either present or absent. This results in a binomial distribution with mean *np*, and variance equal to *npq*. For a large enough sample size, the binomial distribution can be approximated to a normal distribution. Therefore, using the properties of the binomial distribution, a statistical error of each proportion was calculated using equation 3.1 [74]

$$l = Z\alpha/_2\sqrt{\frac{pq}{n}} \tag{3.1}$$

Where *l*= the acceptable limit error, p = probability of single occurrence, q = probability of an absence of occurrence, and n= number of observations.

A confidence interval was also calculated using equation 3.2

$$\hat{p} - Z\alpha/_2\sqrt{\frac{pq}{n}} < p < \hat{p} + Z\alpha/_2\sqrt{\frac{pq}{n}} \tag{3.2}$$

With $\alpha = 0.05$ for a 95% confidence.

Work-sampling methods have been employed successfully in healthcare settings since the early 1950s; one of the first examples of work-sampling found in hospitals was intended to determine staff requirements at a surgical unit [78].Work-sampling has been used in different departments of healthcare delivery systems; for example, it was used in

an outpatient oncology unit to measure workload and to identify roles of oncology nurses [75], in a pediatric emergency department to analyze patient's wait times [79] and in pharmacies to identify the proportion of time pharmacists spent on different tasks [76] [77] [77,78]. It has been applied to nursing personnel [80] and to midlevel health professionals [81] to provide a comprehensive description of the tasks associated with the person's workload.

NASA-TLX measured workload based on six dimensions mental demand, physical demand, effort, frustration level, and performance. Table 3.1 provides a summary of description for each dimension as well as the endpoints used in their measuring scale [32]. This tool has been used in several situations to assess operator workload in complex environments [31]. NASA- TLX uses a weighting procedure to combine the six individual scale ratings into a global score; this procedure required a paired comparison task to be performed prior to the workload assessments.

Figure 3.1 shows an example of the cards that are used to compare each dimension. This procedure was done only one time in the beginning of the data collection. Each card was shown one by one to the participants. The objective was to rate the dimensions that have more impact over workload. Finally, Figure 3.2 shows an example of the weight scale that was used during this project. This scale was given randomly to participants who then valued the level of each dimension during a normal workday.

Table 3.1 Rating scale definitions and endpoints from the NASA-TLX

Title	Endpoints	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g. pushing, pulling, turning, controlling activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace which the task or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experiment? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

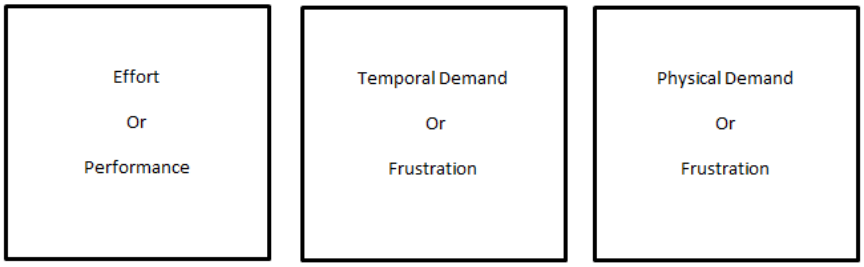


Figure 3.1 An example of sources of workload comparison cards – NASA-TLX

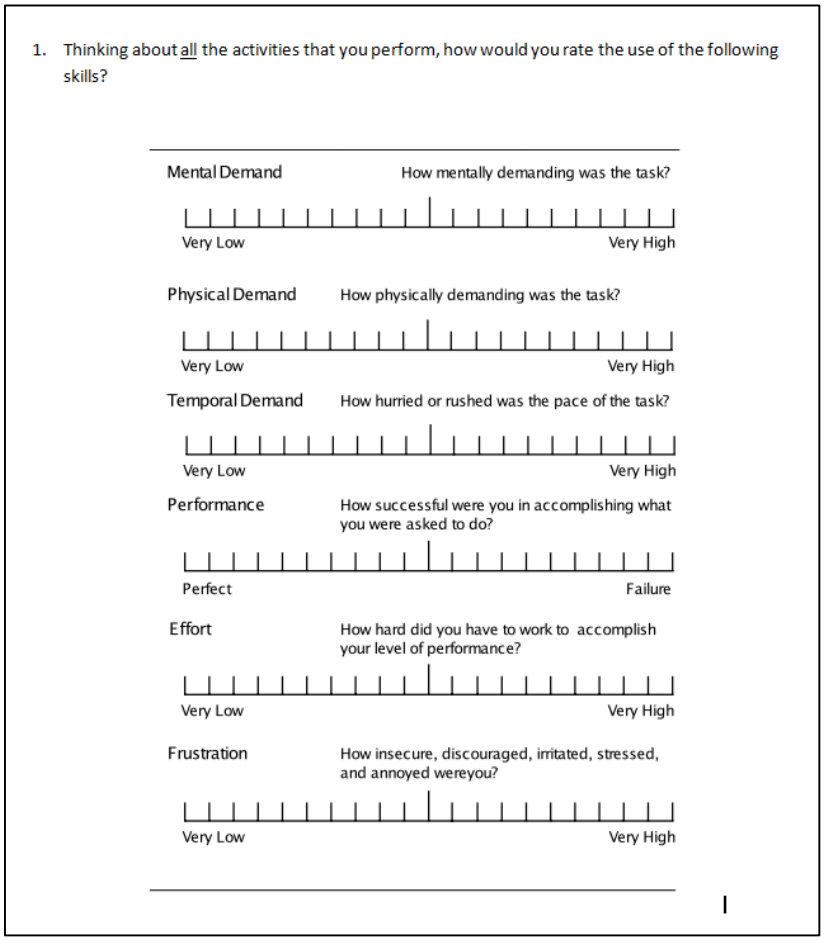


Figure 3.2 Rating sheet of NASA- TLX

Similarly SWAT was applied to measure workload into the infusion area. SWAT is a subjective rating technique that uses three levels: low, medium, and high, the each dimension of time load, mental effort and physiological stress load. Table 3.2 describes in detail each dimension and raking scale of these dimensions.

Table 3.2 SWAT rating scale dimensions.

Title	Descriptions
Time Load (T)	1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all 2. Occasionally, have spare time. Interruptions or overlap among activities occur infrequently 3. Almost never, have spare time. Interruptions or overlap among activities are very frequently or occur all the time
Mental Effort Load (E)	1. Very little conscious mental effort or concentration required. Activity is almost automatic requiring little or no attention. 2. Moderate conscious mental effort or concentration required. Complexity is moderately high due to uncertainly, unpredictability, or unfamiliarity. Considerable attention required. 3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention
Physiological Stress Load (S)	1. Little confusion, risk, frustration, or anxiety exist and can be easily accommodated. 2. Moderate stress due to confusion frustration or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance. 3. High to very intensive stress due to confusion, frustration, or anxiety. High extreme determination and self-control required.

SWAT was divided in two phases scale development and event scoring [38]. The scale development consisted of ranking the perception of the workload perception of participants using all the possible combinations of the three levels for each of the three dimensions. Each participant sorted the cards into the rank order that reflected his or her perception. Figure 3.3 shows the cards that was shown to participants to rate the three dimensions. The scale development phase was performed only one time at the beginning of the data collection. In other words, participants used pairwise comparison to determine between the three dimensions (T,E,S) what are perceived as the most important for each of them.

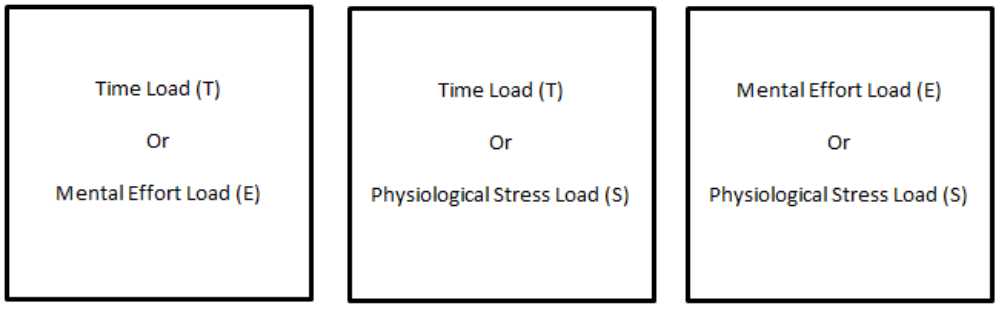


Figure 3.3 PWC procedure for SWAT

The second phase, the event scoring was the actual rating of workload for a given task. This phase was performed randomly during workdays. Even though SWAT has been considered very suitable as a mental workload technique, it has been constantly criticized as having low sensitivity for low mental workloads. In addition, it has been criticized for the time-consuming requirements for scale development (card sorting pre-task procedure).

The present research used a variant in the methodology with the objective to increase the sensitivity and reduce the time consuming requirements of its application. Luximon and Goonetillek [82] presented five variations of SWAT as an effort to overcome its limitations. The proposed research used the continuous SWAT (C-SWAT) dimensions proposed by the authors. This methodology uses a scale with minimum weight equal to zero (W_0) and a maximum equal to five (W_5). Figure 3.4 shows the weight scale for dimensions that are ranked between zero (0) to five (5) according on workload level, where zero (0) corresponds to the lowest level of workload and five (5) the highest level of workload perceived by participants. The proposed research incorporated two more levels (from 3 to five) in the dimension scale with the purpose to increase the sensitivity of this tool.

Day:_____ Time:_____ Activity:_____ Participant's code:_____

1. Thinking about the activity that you just performed, how would you rate the use of the following cognitive skills? Use a rate values between 0 to 5, where 0 is lower level and 5 is highest level.

Cognitive Skill	Level					
	0	1	2	3	4	5
Time Load (T)						
Mental Effort Load (E)						
Physiological Stress Load (S)						

Figure 3.4 Rating sheet of SWAT

Task 2- Measuring Physiological
Response of Nurses and Pharmacist

Some studies have doubted the ability of people to report on their cognitive process which implies a possible dissonance in self-perception of the cognitive process [83]. In order to reduce the uncertainty generated at the moment that nurses or pharmacist report the perception of the workload, the present study measured the physiological responses of participants during the performance of the tasks with the objective to validate the responses obtained by the subjective tools (NASA-TLX and SWAT). Table 3.3 summarizes the main features of different devices, and compiles a synthesis of the previous research papers where these devices have been used to measure physiological responses.

Table 3.3 Physiological measures devices

Devices	Company	General Description	FDA Approval	Papers related to Physical measures	Authors
ViSi Mobile System	Sotera Wireless	ECG, heart/pulse rate, SpO2, blood pressure (cuff-based and now also cuff less on a beat-to-beat basis), respiration rate, skin temperature. Placement chest and arm	FDA Cleared	The authors discussed here the development of one example of a wireless on-body digital architecture, that enables ambulatory continuous vital signs monitoring, to highlight the possibility of designing for alarm management, cost efficiency, and wear- ability [85-87] The authors investigated some of the challenges faced by a body worn using of a continuous noninvasive blood pressure on patients undergoing surgery [84]	Welch, Moon, and McCombie [85]. Sempeles [86]. Skelton [87]. Zhang et al. [84].
The BioRadio™	The BioRadio™	Physiological or transducer signal including ECG, EMG, EEG, respiration, force, blood pressure and more. Placement arm	FDA Cleared	The authors reported on the implementation of a non-invasive electroencephalography-based brain-computer interface to control functions of a car in a driving simulator [88]. The authors utilized surface electromyography EMG to describe a method for identifying ergonomic differences between laparoscopic and robotic platforms using validated task [89]	Hood et al. [88]. Zihni el al. [89].
Equivital™ TnR	Equivital	ECG, HR,IBI, Respiratory rate, Skin and core temperature. Galvanic skin response, tri axis accelerometer, SpO2 and PPG. Placement Biohearness	FDA Cleared	The authors described the multiparametric sensorized garments and measurement instrumentation implemented of a project that required to evaluate physiological indicators and recording candidates that can be useful for detection of mental stress [91,92].	Seoane et al. [90] Seoane et al. [91].
Bioharness 3	Zephyr Technology	Heart Rate, R-R Interval, ECG, Respiration, Accelerometry, Posture, Activity Level. Placement Biohearness	FDA Cleared	The construction environment affects workers' physical responses as well as individual and crew-level performance, in other words, they analyzed the relationship between worker performance and severe environments [92]. The study investigated physiological responses during an on-road driving task for older and younger drivers [93]	Lee and Migliaccio [92]. Koppel et al. [93].

After a comparative study between the devices, Equivital™ TnR [94]was chosen. The system was not the most economic, however, it gives several advantages that the

others didn't offer such as very high data quality with very low data loss rates, light-weight and comfortable to wear, flexible software platforms, and the opportunity to adapt more accessories to measure other responses that permits its use for future research projects. The Equivital system consists of a belt and electrodes that participants used during their workday. The Equivital™ TnR is an FDA approved equipment which has been validated in previous researcher studies [95] [96] [97] [98] [99].

Figures 3.5 presents how the chest belt and EQ02 device was placed in participants. The belts were adjusted to the size of each participant, and the data was sent to the computer using a Bluetooth connection which gives the participants free mobility and the capacity to perform any regular task without interruptions. Data was used only with the purpose of measuring workload. All recorded data was kept confidential, only the researchers had access to the collected data. The data was processed by two types of software, the Equivital Manager (version 1.2) and the Equivital Professional (version 1.2) which permits data collection in real time and also data exportation to Excel for subsequent analysis.

Figure 3.5 Equivital™ TnR **[94]**

The use of the system requires following very specific steps which are

1. Calibration this step compiles information of age and weigh of the participants. This steps is of vital importance to calculate and evaluate the energy expenditure and heart rate variation of the participants.
2. Placement the use of the correct chest belt size is essential to obtain correct readings. The belt cannot be too tight or lose. The electrodes most be moistened with clean water before placing the chest belt. The EQ02 device cannot be connected before to place it into the chest belt.
3. Transmit the EQ02 device senses, records, monitors and intelligently processes data captured from the participants and is able to transmit using Bluetooth connection.

Task 3- Validation

Despite of the applicability of workload measurements, the validation represents an effort to prove that NASA-TLX, SWAT, and physiological responses can be used to provide a valid prediction of workload of nurses and pharmacists. The proposal study was divided this task in two parts. The first part studies the relationship between both perceptual methodologies, NASA-TLX and SWAT, and the second part studies the relationship between perceptual methodology and physiological responses. The association of the covariates to workload was assessed using Pearson's correlation coefficient or 2-sample t test depending on limitation of the data.

Task 4-Simulation Model

A discrete event simulation model was developed to achieve two main purposes. First, it validated the mathematical model and second analyzed different scheduling polices. The simulation represents a detailed model of the patient flow, information flow, resource interactions, and the task requirements of the infusion area. The simulation considers nurses and pharmacist as limited resources. The simulation was developed using ARENA (version 14.0) and output data was analyzed using Excel and Minitab. Historical data and direct observations were used to establish the input necessary for the model. A comparative study was performed using the simulation to compare different scheduling polices proposed in this study.

Task 5- Mathematical Model

A deterministic model was developed to determine the optimal schedule policies oriented to increase the utilization of the resources, increase the capacity of the infusion area, and balance the workload of human resources. The model considers workload concept as key in balancing of resources.

Task 6- Develop and Analyze Scheduling Models

The scheduling model for outpatient clinics faces several challenges which make the system design a complex problem. It involves multiple stakeholders, sequential booking process, random arrivals, no-shows, varying degrees of urgency of different patients' needs, service time variability, and patient and provider preferences.

This study included the scheduling models concepts which have been addressed independently by other studies such as operation management and human resources workload. The operation management concepts will be used with the purpose of improving processes in the system and to help balance of the usage of cancer center resources. Also, this research added constraints related to human resources workload. The new model considered the human resources in department such as pharmacy and nursing.

Research Scope

The following assumptions were made to assist in creating boundaries around the research scope.

1. No-shows or cancellations were not part of this research. Currently the clinic where the study was conducted has a low rate of no-shows and last-minute cancellations.
2. Delays are not significant in patient arrival time.
3. Overbooking resources is not allowed.
4. Patients got the treatment they came for and no complication happened during treatment. The study uses average total time.
5. Resources were fixed throughout the day (i.e. same number of nurses, chairs, and pharmacists).
6. This research was conducted in the infusion area, and did not consider consult area as a part of the study.

CHAPTER 4

DEVELOPMENT OF MENTAL WORKLOAD CONSTRAINT

This chapter was divided in three sections. The first section compares the results obtained from applying the NASA-TLX and C-SWAT to nurses and pharmacists in the infusion area of the Cancer Center. Subsequently, the second section compares two different weight assignment techniques to calculate NASA-TLX scores. Finally, the third section discusses the derivation of the mental workload constraint taking into consideration NASA-TLX scores, number of patients, acuity, heart rate, breathing rate, and ECG. The purpose of this chapter is to determine the maximum number of patients a nurse is capable of handling without exceeding certain mental workload levels. This section was developed to give a response to research hypotheses one through four. Figure 4.1 shows a general description of this chapter.

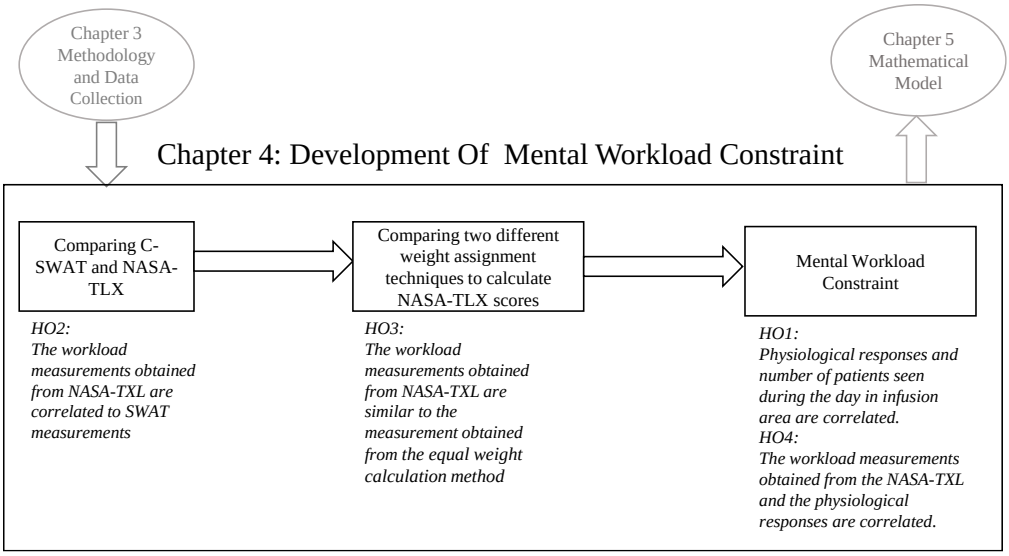


Figure 4.1 General description Chapter 4

Comparing C-SWAT and NASA-TLX

This section discusses a comparison between NASA-TLX and C-SWAT. The purpose of the comparison was to decide which of the subjective workload tools to include in the derivation of the mental workload constraint. The analysis in this section focused on two aspects it first compared the overall results between NASA-TLX and C-SWAT, and then it compared each individual dimension for both tests.

The overall mental workload scores obtained from NASA- TLX and C-SWAT were used to correlate the results obtained from both techniques. Figure 4.2 presents the workload values obtained from the nurses at the infusion area of the Cancer Center. The results show a similarity between the C-SWAT and the NASA-TLX for the overall mental workload scores. However, although the figure shows very similar trends from both tools, this information is not enough to conclude that both tools measure the same factors or dimensions.

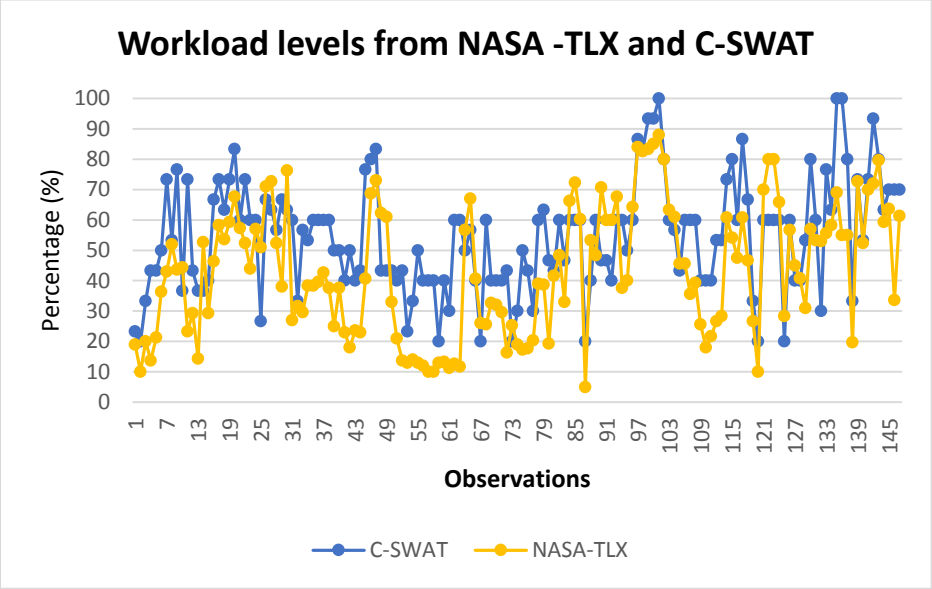


Figure 4.2 C-SWAT and NASA-TLX values obtained from the nurses at the infusion area

A Pearson product-moment correlation coefficient was computed to assess the relationship between C-SWAT and NASA-TLX. Figure 4.3 summarizes the results obtained from the analysis. Results showed a positive correlation between the two variables ($\rho = 0.691$; $n = 147$; p-value = 0.0001). Overall, there was a positive correlation between both methods; however, the correlation value was not exceptionally high which suggests differences between both instruments.

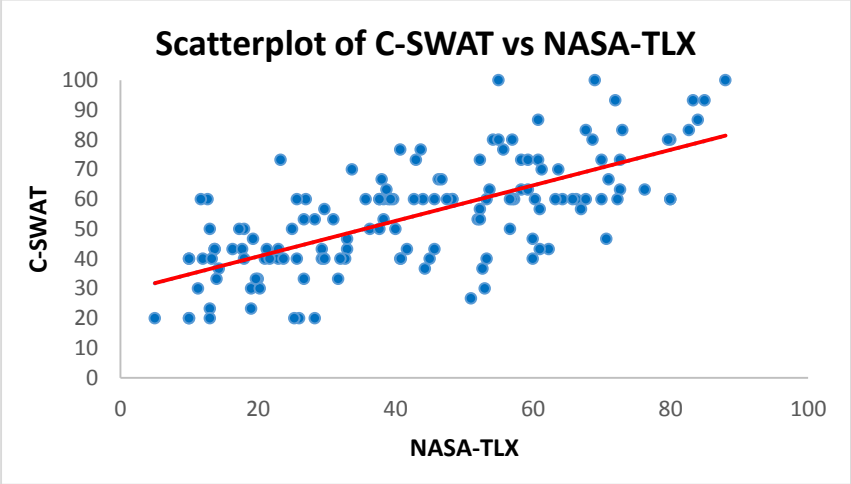


Figure 4.3 Scatterplot of C-SWAT vs NASA-TLX

Since it was of interest to explore the possibility of using C-SWAT as a tool to predict NASA-TLX, a regression analysis was performed using C-SWAT as the predictor and NASA-TLX as the response. The purpose for this analysis was to explore the possibility of substituting NASA-TLX with C-SWAT in future research studies as SWAT has fewer dimensions and thus requires fewer questions to be asked during tasks. The regression analysis on the overall mental workload scores showed a significant value of C-SWAT as a predictor of the NASA-TLX response. Table 4.1 shows the results obtained from the regression analysis where C-SWAT is a significant factor with a p-value of 0.021 (significance level of 0.05)

Table 4.1 Regression analysis; NASA-TLX vs C-SWAT

Source	DF	Adj SS	Adj MS	F-Value	P-value
Regression	2	31206.6	15603.3	65.89	0.000
C-SWAT	1	1287.5	1287.5	5.44	0.021
C-SWAT*C-SWAT	1	0	0	0	0.992
Error	144	34102.3	236.8		
Lack of fit	30	6772.8	255.8	0.94	0.559
Pure Error	114	27329.5	239.7		
Total	146	65308.9			

Regression Equation

$$NASA - TXL = -0.36 + 0.796\, C - SWAT + 0.00003\, C - SWAT * C - SWAT \quad (4.1)$$

The previous results support the hypothesis that there is a correlation between the results of both perceptual tools. However, the model showed a coefficient of variation (R^2) of 47.78% which suggests that C-SWAT doesn't account for the majority of the variability that NASA-TLX presented.

Table 4.2 Summary of Pearson correlation between C-SWAT vs NASA-TLX dimensions

	C- SWAT Dimensions		
NASA-TLX Dimensions	Time Load (T)	Mental Effort Load (E)	Physiological Stress Load (S)
Mental Demand	0.787	0.805	0.770
Physical Demand	0.839	0.763	0.768
Temporal Demand	0.873	0.801	0.736
Performance	**0.327**	**0.505**	**0.384**
Effort	0.830	0.829	0.764
Frustration Level	0.700	0.629	0.698

Consequently, it was imperative to perform an additional analysis to understand if the three dimensions of SWAT were enough to capture the same information NASA-TLX gathers with its six dimensions. To have a better understanding of the relationship between the different dimensions of both tools, a correlation analysis was performed breaking down each tool in their different dimensions. Table 4.2 summarizes the correlation analysis between the three dimensions of C-SWAT and the six dimensions of NASA-TLX. The results show a strong positive relation between all the dimensions

except for the three dimensions of C-SWAT against the NASA-TLX dimension of *performance*.

A principal component analysis (PCA) was performed to explore the possibility of finding a better model to predict the relationship between the NASA-TLX and C-SWAT dimensions. Figure 4.4 presents the results from the PCA where it shows that five out of the six dimensions of NASA-TLX follow the same trends as the three dimensions of C-SWAT. Once again, the dimension of *performance* was weakly related to any C-SWAT dimension measure.

It was decided then to explore any possible non-linear relationships between the dimensions of one method and their ability to predict the total score of the other one. For example, one analysis used NASA-TLX scores as a response and the three dimensions of C-SWAT as independent variables.

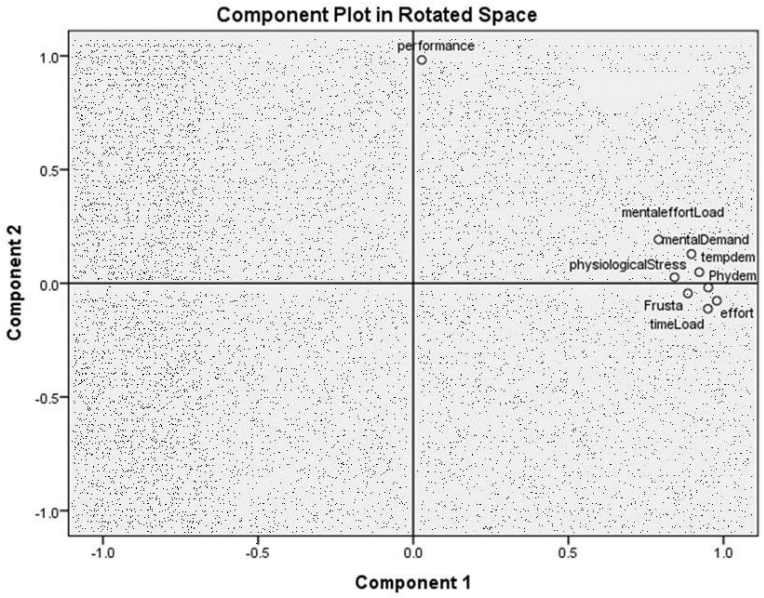


Figure 4.4 PCA between NASA-TLX and C-SWAT dimensions

Modern nonparametric regression analysis can be used to model non-linear behavior without prior specification to the form of data behavior. Multi Adaptive Regression Spines (MARS) was used as it is a modern nonparametric regression analysis method [100]. It was developed to be used for data analysis and to build flexible models by fitting piecewise linear regression. The method was used to compare the dimensions of NASA-TLX and C-SWAT and their capacity to predict the behavior of each other. MARS uses Generalized Cross Validation (GCV) to compare the performance of obtained models, lower values of GCV are better. The GCV can be considered as a form of regularization by trading off goodness-of-fit against model complexity. Table 4.3 summarizes GCV and R^2 for both models.

It can be observed from table 3 that the MARS model that uses NASA-TLX dimensions to predict SWAT dimensions represents a better model with a smaller GCV and higher R^2. This implies that NASA-TLX is a better predictor of C-SWAT than the C-SWAT is for NASA-TLX. An in-depth analysis revealed that the three dimensions of C-SWAT, time load, mental effort load, and physiological stress, are important for predicting NASA-TLX results; however, the dimensions such as performance and frustration of the NASA-TLX are not represented in the scores obtained from SWAT. Tables 4.4 and 4.5 summarize these results.

Table 4.3 Summary of MARS GCV and R^2

Model error measures	NASA-TLX Dimensions to predict SWAT results	SWAT Dimensions to predict NASA-TLX results
GCV	155.5133	409.8897
R^2	0.89996	0.35441

Table 4.4 The significance level of meaningful explanatory variables in the model C-SWAT dimensions to predict NASA-TLX results

Dimensions	**Score**	
Time Load	100.00	||||||||||||||||
Mental Effort Load	95.77	||||||||||||||||
Physiological Stress	91.33	||||||||||||||||

Table 4.5 The significance level of meaningful explanatory variable in the model NASA-TLX dimensions to predict C-SWAT results

Dimensions	**Score**	
Mental Demand	100.00	||||||||||||||||
Effort	85.92	||||||||||||||||
Temporal Demand	67.78	||||||||||||
Physical Demand	65.83	||||||||||||
Performance	60.03	||||||||||
Frustration	57.73	||||||||

The results obtained from the analysis showed that for this particular setting, the individual dimension scores obtained from NASA-TLX can be used to predict the total score of C-SWAT; however, it is not true the other way around. The results show that SWAT fails to include the dimensions of performance and frustration and weakly include the dimensions of physical and temporal demand.

From the analysis, it could be concluded that although both tools were designed to measure subjective workload, they are not completely alike. The results showed NASA-TLX was a better predictor for C-SWAT than C-SWAT was to NASA-TLX. In other words, NASA-TLX covers all the dimensions that are measured by C-SWAT. The results also suggest that a difference between both tools is found in the fact that C-SWAT doesn't have the capability to integrate the perception of performance and frustration. Therefore, C-SWAT could be used in studies where these dimensions do not represent

important factors for the study; alternatively, additional tools should be incorporated to include these factors.

As a result of the discoveries made through the different analyses, it was decided to use the measurements of mental workload obtained by applying NASA-TLX and to drop the C-SWAT values.

Comparing Two Different Weight Assignment Techniques to Calculate NASA-TLX Scores

After selecting the NASA-TLX as the measurement tool for mental workload, the next objective was to determine a weighting scheme to calculate the total score for NASA-TLX. As previously mentioned, the literature presents two methods to calculate the percentage of workload one method assigns equal weights to all six dimensions while the other method assigs weights determined by participant preferences. The method involving preferences requires an extra step in the procedure in order to combine the six individual scale ratings into a global score; the extra step requires a paired comparison task to be performed prior to the workload assessments. The equal weights method assigns the same weight to all six dimensions and thus, does not require pair-wise comparisons.

Similar to the previous analysis, a comparative study was conducted to determine which weight scheme to use. A total of seven nurses, four pharmacists and two technicians participated in the study, which represents 100% of the staff assigned to this area. Before the data collection, the researcher conducted pair-wise comparisons of the different dimensions to each of the participants.

The data collection process resulted in a total of 428 observations. The researcher then estimated the NASA-TLX final score using both weight schemes. A correlation analysis was conducted to compare the scores obtained with preference weight and with equal weight (NASA-TLXEW). Previous studies have reported no differences between the two weight schemes [42] [101] [102]. However, the studies were applied in controlled environments and only showed the correlation of the overall indicator without mentioning the effect over the particular dimensions. The study reported here was applied in a real healthcare setting on a normal day of work (non-controlled environment).

Pearson's correlation coefficient (ρ) was used to measure the strength of the association between these two values obtained using both methodologies. Figure 4.5 shows a positive association between the NASA-TLX with preference weight and NASA-TLXEW. Additionally, a correlation test was performed using the statistical package R (version 3.1.2). The test shows a correlation $\rho = 0.9476$ with p-value $< 2.2e\text{-}16$ and a 95% confidence interval of $0.9370 < r < 0.9565$. The result suggested a strong linear and positive association between the overall result of NASA-TLX and NASA-TLXEW. In other words, the study didn't find a significant difference in the results obtained using preference weights or versus equal weights for the NASA-TLX overall score.

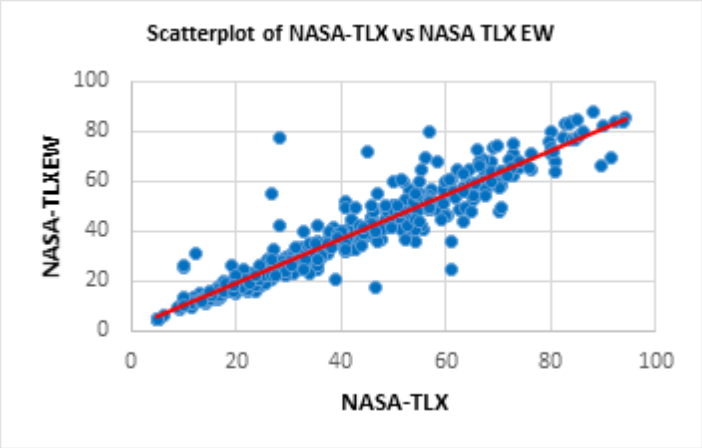


Figure 4.5 Scatterplot NASA-TLX weight vs NASA-TLX equal weight

After this analysis the individual dimensions were compared for NASA-TLX (preference weights) versus NASA-TLXEW (equal weights). The results showed that for each individual dimension, there were low levels of correlations between NASA-TLX and NASA-TLXEW. Figures 4.6 to 4.11 show low correlations between each one of NASA-TLX dimensions.

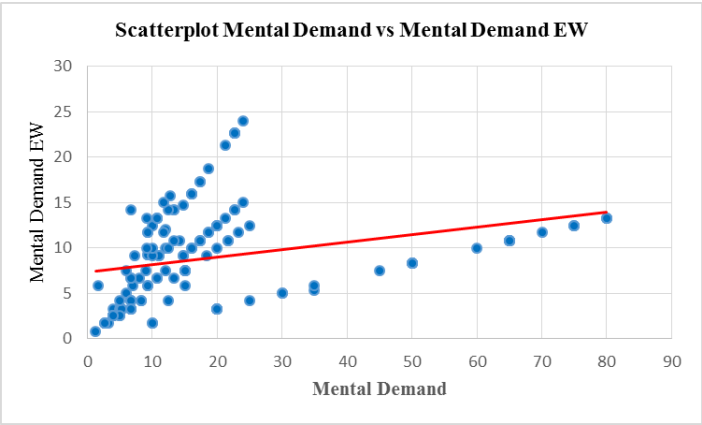


Figure 4.6 Mental demand weight vs. mental demand equal weight

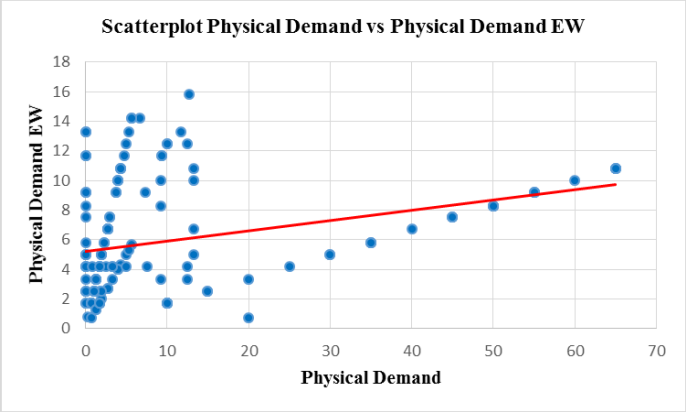


Figure 4.7 Physical demand weight vs. physical demand equal weight

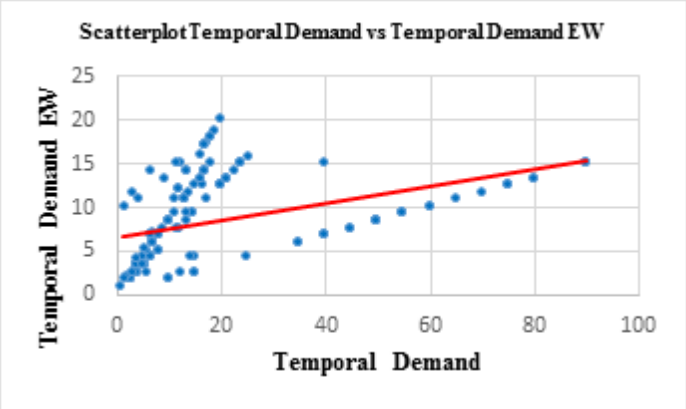


Figure 4.8 Temporal demand weight vs. temporal demand equal weight

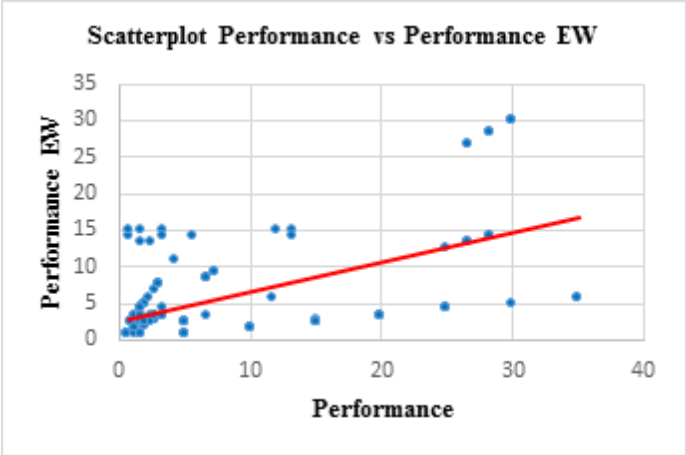


Figure 4.9 Performance weight vs. performance equal weight

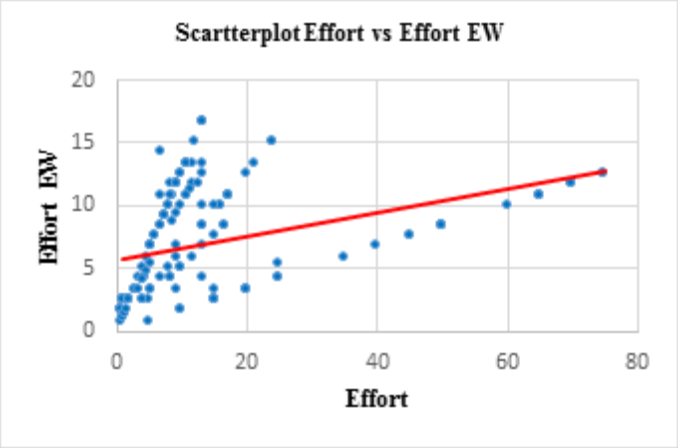


Figure 4.10 Effort weight vs. effort equal weight

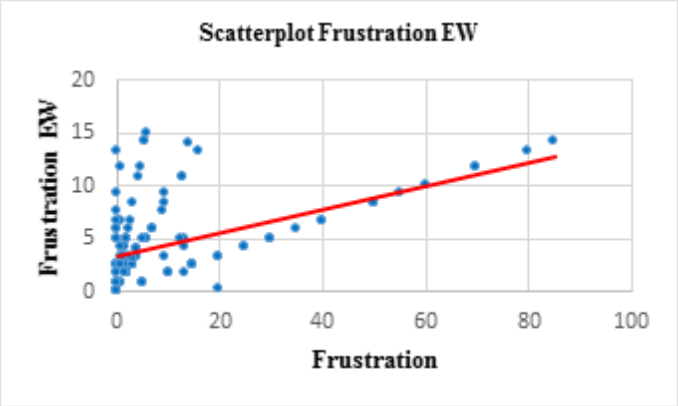


Figure 4.11 Frustration weight vs. frustration equal weight

From the analysis, it can be concluded that for this research, there was no significant difference between the overall score of NASA-TLX using preference weight or equal weight. However, there is no correlation between the values for each dimension at the individual level. Consequently, NASA-TLXEW could be used in cases where the individual analysis of a dimension is not relevant which will eliminate one step in the methodology. On the other hand, if researchers are interested in considering one or more dimensions independently, then the preference weights would be a better approach. With respect to the present study, NASA-TLXEW was used since the mental workload

constraint will be emphasizing on the total mental workload score rather than treating each dimension independently.

Mental Workload Constraint

The objective of this section was to develop a constraint which would limit the number of patients per nurse without overloading the capacity and the performance of each nurse. It is important to recall that this study was pursued in a real setting which led to some limitations in the process of collecting data. The data collection days were scheduled in agreement with the nurse manager, with the ultimate goal of avoiding unnecessary distractions and interruptions.

Since the data came from a longitudinal study, which contained both variation within subjects (over time) and between subjects, this work might present some limitations in generalizing the results into other settings. However, the methodology is applicable to any setting which is why it was important to decide the appropriate mental workload assessment tool as well as the weighing scheme. In other words, in the future, researchers may want to assess their nurses' mental workload by following the procedure explained here, which recommends using NASA-TLX and equal weights. Similarly, the development of the mental workload constraint can follow the procedure explained here.

After deciding on the mental workload assessment tool and the weighting scheme to estimate the total score, the researcher was ready to develop the mental workload constraint. For the model development, the researchers used 131 observations from the seven nurses at the infusion area. The variables of interest for each observation were

heart rate, ECG, breathing rate, number of patients present, acuity, and nurses' ID as independent variables, and NASA-TLX as the dependent variable. Acuity level is defined as the level of severity of the illness. This is one of the parameters considered in the patient classification system used for the allocation of nursing staff at the cancer center. Therefore, it was important to consider this variable in the model.

Initially, this study explored the possibility of using mixed model statistical analysis to explain the relationship of the variables and reduce the possible random effects. Although a mixed model could absorb better the variability generated by nurses, it could also imply that the mathematical model would need to be specific to each nurse. Instead, it was decided to use a linear model which represented an advantage on the applicability of the model. Therefore, multiple regression was used to develop a constraint that would describe the relationship of mental workload levels with variables such as physiological response, number of patients and acuity.

However, upon further analysis it was discovered that the complexity of the data that measures stress and mental workload resulted in two explanatory variables correlated among each other. Table 4.6 summarizes ρ values (Pearson's correlation) and level of significance of the values (p-values). From the table, it can be seen that there was a positive strong correlation between the *number of patients* and the *acuity leve*l with $\rho = 0.927$ ($p - value = 0.000$). As expected, if nurses increase the number of patients they take care of, that will have an impact over the acuity level managed by them.

Table 4.6 Correlation summary (with p-value in parenthesis)

Variables	No of Patients	Acuity	Hearth Rate	Breath Rate	ECG
NASA-TLX	0.197 (0.024)	0.253 0.003	-0.294 0.001	0.434 0.000	0.098 0.263
No of Patients	-	0.927 0.000	0.060 0.496	0.176 0.043	0.092 0.295
Acuity	-	-	0.068 0.438	0.144 0.098	0.019 0.825
Hearth Rate	-	-	-	0.163 0.061	0.610 0.001
Breath Rate	-	-	-	-	0.442 0.000

This multicollinearity limited the analysis because this effect on the response can be due to either true synergistic relationships among the variables or spurious correlations [103]. To avoid these possible problems, the acuity level variable was removed from the modeling of this human factor constraint. Nevertheless, the acuity level is an important variable on the overall model; hence, it will be included in the general mathematical model as an individual constraint, which will be explained in detail in the next chapter.

In light of the previous considerations, a regression model was calculated to predict mental workload (NASA-TLX) based on number of patients, hearth rate (HR), breathing rate (BR), and ECG. A significant regression equation was found with an $R^2$of 36.47%. Tables 7 and 8 summarize the result of the analysis of variance.

Table 4.7 Regression analysis of NASA-TLX

Source	DF	F-Value	P-value
Regression	4	18.23	0.000
# of Patients	1	3.67	0.058
HR (bpm)	1	30.94	0.000
BR (bpm)	1	24.84	0.000
ECG (bpm)	1	3.99	0.078
Error	127		
Total	131		

Table 4.8 Coefficients

Term	Coef	P-Value	VIF
Constant	22.00	0.086	
No of Patients	3.83	0.058	1.03
HR (bpm)	-0.710	0.000	1.51
BR (rpm)	3.002	0.000	1.34
ECG BR (rpm)	1.105	0.048	1.89

Table 4.8 shows that the coefficients are significant for the model with a p-value < 0.1. Also, Variance Inflection Factors (VIF) are less than 2 indicating a satisfactory multicollinearity among independent variables. Based on this model, the calculation of number of patients was performed using standard values for NASA-TLX level, HR, BR and ECG, which were obtained from the literature and data collection. The following equation summarizes the regression model.

$$NASA - TLX = 22 + 3.83(\#\ of\ patients) - 0.710(HR) + 3.002(BR) + 1.105(ECG) \quad (4.2)$$

According a John Hopkins's report about the normal vital values, the normal pulse for healthy adults ranges from 60 to 100 beats per minute. This research considered a HR of 70 beats per minute. Other values such as BR and ECG were 19 and 20 respectively. These values used for HR, BR and ECG are considered standard values for a healthy adult. Meanwhile, determining the value of NASA-TLX was more complex since the literature does not establish a value that could be considered normal or high [104].

Therefore, this study used the measurements obtained from the data collection as a reference. The level of NASA-TLX was calculated using the 80^{th}percentile of data which corresponds to a workload value of 61.66%, as shown in Table 4.9. Based on Pareto principle, the top 20^{th} percentile accounts for approximately 80% of the times that

the nurses worked on overload conditions. In essence, values of NASA-TLX over the 80th percentile (top 20% of observed workload levels) represent high workload levels which might be accepted for small time periods but not values recommended to be sustained throughout the entire work day. The objective was to guarantee a manageable NASA-TLX level for nurses in this setting throughout the day.

Table 4.9 Workload level on 80% percentile

Observation #	Percentile of observations	Mental Workload Score (NASA-TLX EW)
104	78.20%	60.33%
105	79.95%	61.00%
106	79.70%	61.66%
107	80.45%	61.66%
108	81.20%	62.50%
109	81.95%	63.33%

Substituting values into the equation yields

$$61.66 = 22 + 3.83\,(\#\ of\ patients) - 0.710(70) + 3.002(19) + 1.105(19) \quad (4.3)$$

After the calculation, the maximum number of patients that should be assigned to a nurse is 2.87 persons. This value was approximated to 3 which, referring back to table 9, represents a workload level of 62.175 located between 80.45% and 81.20% percentile.

In conclusion, in order to limit the level of mental workload for nurses in the current setting to no higher than 81.2% of the observed instances it is necessary to assign up to three patients per nurse at any given time. This value will be part of the capacity constraint for the mathematical model that will be discussed in Chapter 5.

CHAPTER 5

MATHEMATICAL MODEL

This research study developed an optimization model for the infusion area at the Bozeman Deaconess Cancer Center, and established general assumptions and restrictions to design scheduling policies for patient appointments. A linear model was developed to obtain optimal schedules for the system. The present chapter was divided in four sections. The first section describes the infusion area and establishes the parameters used in the model. The second section explains the model and the associated constraints. The third compares the actual schedules used by the staff at the cancer center against the proposed schedules generated by the mathematical model. Finally, the last section establishes the maximum capacity of the infusion area per each patient mix. Figure 5.1 shows a general description of this chapter

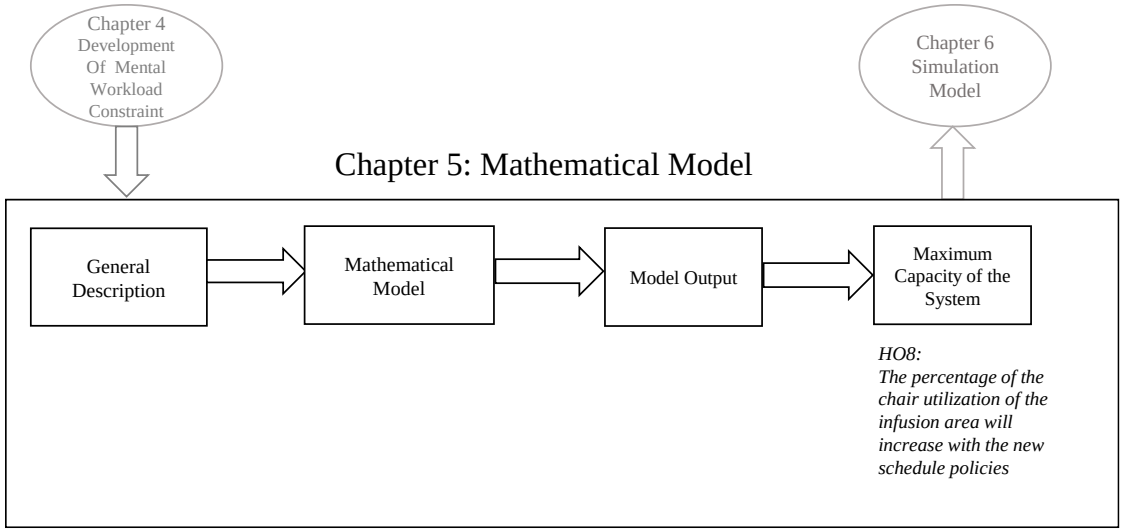


Figure 5.1 General description Chapter 5

General Description

Previously, chapter 1 explained how the cancer center operates and the general flow of patients through the system. However, it is necessary to expand on the explanation of the complexity of the process at the infusion area in order to facilitate a better understanding of the mathematical model.

The infusion area is a complex system that requires a variety of resources and a logical sequence of steps. Generally, patient arrivals follow an appointment system, and they are scheduled between 8:00 am and 4:00 pm. The cancer center uses 20-minute time slots to generate the patient schedules; this means that all the resources are planned using these time slots as a base.

The day before the appointment, the head nurse assigns an acuity level to each patient and also distributes patients according to nurses' availability. The area has 19 infusion chairs, five nurses, and two pharmacists available every day. This research classified patients into one of 12 types based on the length of infusion treatment as presented in Table 5.1.

The constraints for the model were divided into three categories. The first categories were related to logical constraints such as only one patient per chair during treatment at the same time, no overtime, and patient mix which determined the number of patients by type that would arrive into the system on a day.

Table 5.1 Patient type based on duration of the treatment

Patient Type	Expected treatment time (min)	No. of 20-min slots
Type 1	20	1
Type 2	40	2
Type 3	60	3
Type 4	80	4
Type 5	100	5
Type 6	120	6
Type 7	160	8
Type 8	180	9
Type 9	220	11
Type 10	320	16
Type 11	380	19
Type 12	420	21

The second category determined the capacity of the system, for example time available for the area, number of chairs, and number of nurses and pharmacists in the system. Finally, the human factor constraints were oriented to consider the mental workload and the capacity of nurses and pharmacists, patient acuity assignment, uninterrupted lunch times, and the maximum level of acuity that could be assigned to a nurse on a given day and at any point in time within that day. The following section presents the mathematical model and explains variables, indices, and constraints used in the optimization model.

Mathematical Model

Indices

i Index representing chair number (ID chairs); $i \in \{1,2,\ldots,19\}$

j Index representing patient type (treatment duration); $j \in \{1, 2, \ldots, 12\}$

t Index representing 20-min. time slot (t=1 for 8 00AM, t=2 for 8 20AM, etc.); $t \in \{1, 2, \ldots, 28\}$

a Index representing acuity level; $a \in \{1, 2, \ldots, 5\}$

n Index representing each nurse; $n \in \{1, 2, \ldots, 5\}$

Parameters

c Total number of chairs available (c=19)

p Total number of patient types according to treatment duration (p=12)

k Last time slot at which new arrivals can be scheduled (k=23; this represents 3 40PM and thus no new arrivals after 4 00PM)

b Total number of acuity levels (b=5)

r Total number of nurses available at the infusion area (r=5)

f Total number of pharmacists available at the infusion area (f=2)

p_j Number of type j patients arriving into the system daily (patient mix)

Variables

y_{ijtan} { 1 if for chair *i*, a patient of type *j* begins treatment at period *t*, with acuity level *a* and nurse *n*; 0 otherwise

x_{ijtan} { 1 if for chair *i*, a patient of type *j* continues treatment at period *t*; with acuity level *a* and nurse *n*; 0 otherwise

Objective Function

$$\max z = \sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{t=1}^{k}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \tag{5.1}$$

Subject to

Patient type continuity

$$for\ j = 1 \qquad x_{ijtan} = 0 \qquad \forall\ i,t,a,n \tag{5.2}$$

$$for\ j \geq 2 \qquad \sum_{u=t+1}^{t+j-1} x_{ijuan} = (j-1)y_{ijtan} \qquad \forall\ i,j \geq 2, t \leq u-j+1, a, n \tag{5.3}$$

No more than one patient per chair at any point in time

$$\sum_{j=1}^{p}\sum_{a=1}^{b}\sum_{n=1}^{r} x_{ijtan} + \sum_{j=1}^{p}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \leq 1 \qquad \forall\ i,t \tag{5.4}$$

Workload capacity for nurses

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \leq 3r \qquad \forall\ t \tag{5.5}$$

Workload capacity for pharmacists

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \leq 2f \qquad \forall\ t \tag{5.6}$$

Patient mix per type

$$\sum_{i=1}^{c}\sum_{t=1}^{k}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \geq p_j \qquad \forall\ j \tag{5.7}$$

No patient arrival during lunch time

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{t=13}^{15}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} = 0 \tag{5.8}$$

Acuity level per nurse at any given time

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{a=1}^{b} a y_{ijtan} + \sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{a=1}^{b} a x_{ijtan} \leq 15 \qquad \forall\ t,n \tag{5.9}$$

Total acuity level per nurse in a day

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{t=1}^{k}\sum_{a=1}^{b} a y_{ijtan} \leq 20 \qquad \forall\, n \tag{5.10}$$

Acuity level distribution per patient type

$$\sum_{i=1}^{c}\sum_{j=1}^{5}\sum_{t=1}^{k}\sum_{a=4}^{b}\sum_{n=1}^{r} y_{ijtan} + \sum_{i=1}^{c}\sum_{j=1}^{5}\sum_{t=1}^{k}\sum_{a=4}^{b}\sum_{n=1}^{r} x_{ijtan} = 0 \tag{5.11}$$

$$\sum_{i=1}^{c}\sum_{j=9}^{12}\sum_{t=1}^{k}\sum_{a=1}^{3}\sum_{n=1}^{r} y_{ijtan} + \sum_{i=1}^{c}\sum_{j=9}^{12}\sum_{t=1}^{k}\sum_{a=1}^{3}\sum_{n=1}^{r} x_{ijtan} = 0 \tag{5.12}$$

Objective Function Description

The objective function seeks to maximize the number of patients that the infusion area of the cancer center can handle at any given day. Hence, equation 5.1 only contains the variable representing a patient beginning treatment in a day and the final value of z represents the total number of patients to be scheduled for a particular day.

$$max\ z = \sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{t=1}^{k}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \tag{5.1}$$

Constraints Description

Constraints 5.2 and 5.3 were designed to guarantee the continuity of patients in the system. These constraints allow for the model to recognize the patient in the system; and hence to hold the same resources (such as chairs, pharmacist and nurses) for that patient until departure time.

$$for\ j = 1 \qquad x_{ijtan} = 0 \qquad \forall\ i,t,a,n \tag{5.2}$$

$$for\ j \geq 2 \qquad \sum_{u=t+1}^{t+j-1} x_{ijuan} = (j-1) y_{ijtan} \qquad \forall\ i,j \geq 2, t \leq u-j+1, a, n \tag{5.3}$$

For example, a patient type 3 (j=3; treatment=60 minutes) with acuity level 1 (*a*=1) arrives into the infusion area at 8:20 AM (t=2) and is assigned to chair 1 (i=1) and nurse 2 (n=2). This arrival is represented by y_{13212} =1. According to the type, this patient must remain in the same chair with the same nurse for time periods 8:40AM (t=3) to 9:00AM (t=4) and then depart at 9:20 AM. According to the previous statement, the following must be true then $x_{13312} = x_{13412} = 1$. Alternatively, it can be written as $x_{13312} + x_{13412} = 2$. This continuity is achieved by constraint 5.3.

Constraint 5.2 ensures there is no continuity for type 1 patients as they are scheduled to be at the infusion area only for 20-minutes, and hence, this time period is covered by the *y* variable.

Constraint 5.4 ensures that for any time period once a chair is assigned to a patient, either a new or a continuing patient, the chair is not assigned to any other patient at the same time. On other words, at most one patient at any time in any chair.

$$\sum_{j=1}^{p}\sum_{a=1}^{b}\sum_{n=1}^{r} x_{ijtan} + \sum_{j=1}^{p}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \leq 1 \qquad \forall\ i,t \tag{5.4}$$

Constraints 5.5 and 5.6 incorporated the human factor analysis. The value determining the capacity of nurses and pharmacists was calculated based on elements such as mental workload and stress using NASA-TLX and physiological response as discussed in Chapter 4. For example, constraint 5.5 states that each nurse should be receiving no more than three new patients at any point in time.

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \leq 3r \qquad \forall\ t \tag{5.5}$$

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \leq 2f \qquad \forall\, t \tag{5.6}$$

Constraint 5.7 considered the change on the demand per type of patients on a given day. In other words, since the cancer center has high variability in the patient mix, this constraint permits the mathematical model to change the patient mixes for further explorations.

$$\sum_{i=1}^{c}\sum_{t=1}^{k}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} \geq p_j \qquad \forall\, j \tag{5.7}$$

Constraint 5.8 is related to operational polices which could be different for other settings. The current policy at the cancer center does not permit patient arrivals during lunch time, and it is between time slots 13 to 15 on each day.

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{t=13}^{15}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} = 0 \tag{5.8}$$

The next constraints were built to consider the acuity system used to classify patients according to the level of complexity in order to assign patients equitably among nurses. The acuity score is a discrete number between 1 and 5, where 1 corresponds to a low complexity, and 5 corresponds to a high complexity. Consequently, patients are assigned to nurses following these rules.

The total acuity of patients assigned to a nurse (new and continuing patients) at any time should be less or equal to 15 at any point in time.

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{a=1}^{b} a y_{ijtan} + \sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{a=1}^{b} a x_{ijtan} \leq 15 \qquad \forall\, t,n \tag{5.9}$$

The cumulative acuity score of patients assigned to a nurse on a given day should be less or equal to 20.

$$\sum_{i=1}^{c}\sum_{j=1}^{p}\sum_{t=1}^{k}\sum_{a=1}^{b} a y_{ijtan} \leq 20 \qquad \forall\, n \tag{5.10}$$

Acuity represents the aggressiveness of a treatment which is related to the quantity and intensity of drugs that a patient receives in a chemo section, and therefore, acuity is considered to have a high relation to the length of the treatment. In other words, the acuity level is tied to patient type. Table 5.2 summarizes the probabilities of occurrence of acuity score for each type of patient according to historical data from the cancer center.

Table 5.2 Acuity matrix

	Acuity Level				
Patient Type	1	2	3	4	5
Type 1	67%	32%	2%	0%	0%
Type 2	63%	35%	1%	0%	0%
Type 3	62%	34%	5%	0%	0%
Type 4	5%	71%	24%	0%	0%
Type 5	2%	63%	35%	0%	0%
Type 6	1%	16%	69%	6%	7%
Type 7	1%	5%	62%	31%	1%
Type 8	1%	1%	27%	58%	13%
Type 9	0%	0%	0%	18%	82%
Type 10	0%	0%	0%	0%	100%
Type 11	0%	0%	0%	6%	94%
Type 12	0%	0%	0%	0%	100%

Therefore, constraints 5.11 and 5.12 were developed to assign patient acuity scores using the probability that a patient type has for each acuity level.

$$\sum_{i=1}^{c}\sum_{j=1}^{5}\sum_{t=1}^{k}\sum_{a=4}^{b}\sum_{n=1}^{r} y_{ijtan} + \sum_{i=1}^{c}\sum_{j=1}^{5}\sum_{t=1}^{k}\sum_{a=4}^{b}\sum_{n=1}^{r} x_{ijtan} = 0 \tag{5.11}$$

$$\sum_{i=1}^{c}\sum_{j=9}^{12}\sum_{t=1}^{k}\sum_{a=1}^{3}\sum_{n=1}^{r} y_{ijtan} + \sum_{i=1}^{c}\sum_{j=9}^{12}\sum_{t=1}^{k}\sum_{a=1}^{3}\sum_{n=1}^{r} x_{ijtan} = 0 \tag{5.12}$$

As a result, patient types 1 through 5 show a probability of zero for acuity levels four and five. Similarly, patient types 9 through 12, which are the longest treatment durations, show a probability of zero acuity levels one through three. Constraints 5.11 and 5.12 guaranteed that these conditions were met.

Model Output

The mathematical model was solved using a General Algebraic Modeling System (GAMS) software (version 24.1.2). The GAMS code is included in Appendix A. GAMS is a high-level modeling system which consists of a language compiler and a stable of integrated high-performance solvers. GAMS is tailored for complex, large scale modeling applications, and allows the user to build large maintainable models that can be adapted quickly to new situations [105]. For the purpose of this research study, CPLEX was used as the optimizer solver behind GAMS.

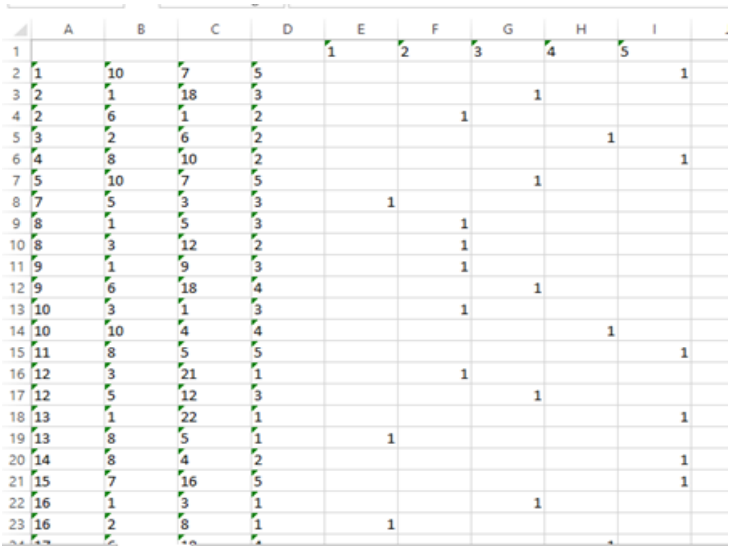
In order to test the mathematical model, ten days obtained randomly from historical data were considered. This information was used to build the actual (original) schedule which represents how patients were actually scheduled in that day. Likewise, this information was used as input for the mathematical model to establish a proposed schedule for each day. The aim was to compare these results using the original schedule and the proposed schedule. According to the data obtained for each of the ten days, a patient mix was determined for each of the days as presented in Table 5.3.

Once GAMS ran the mathematical model, it provided an xls output with the solution similar to the one shown in Figure 5.2. The first column (A) represents the chair

number that is assigned to a patient; the second column (B) corresponds to patient type that is arriving. Column C represents the time slot of the patient arrival whereas column D corresponds to the acuity level of the scheduled patient.

Table 5.3 Patient mix per day

	Day									
Patient Type	1	2	3	4	5	6	7	8	9	10
Type 1	5	3	2	1	1	4	6	3	2	3
Type 2	2	1	0	1	0	1	2	0	0	2
Type 3	4	5	3	6	3	5	6	5	2	7
Type 4	0	0	0	0	0	0	0	0	0	0
Type 5	3	1	2	1	1	0	0	1	2	1
Type 6	3	3	3	3	3	2	3	2	4	4
Type 7	1	0	4	3	4	1	1	4	1	0
Type 8	4	2	4	2	2	0	3	3	1	3
Type 9	0	7	8	3	2	2	5	2	3	0
Type 10	5	5	2	1	2	6	2	3	2	5
Type 11	0	0	0	3	0	2	1	0	2	1
Type 12	0	0	0	2	0	0	1	0	0	0
Total	27	27	28	26	18	23	30	23	19	26

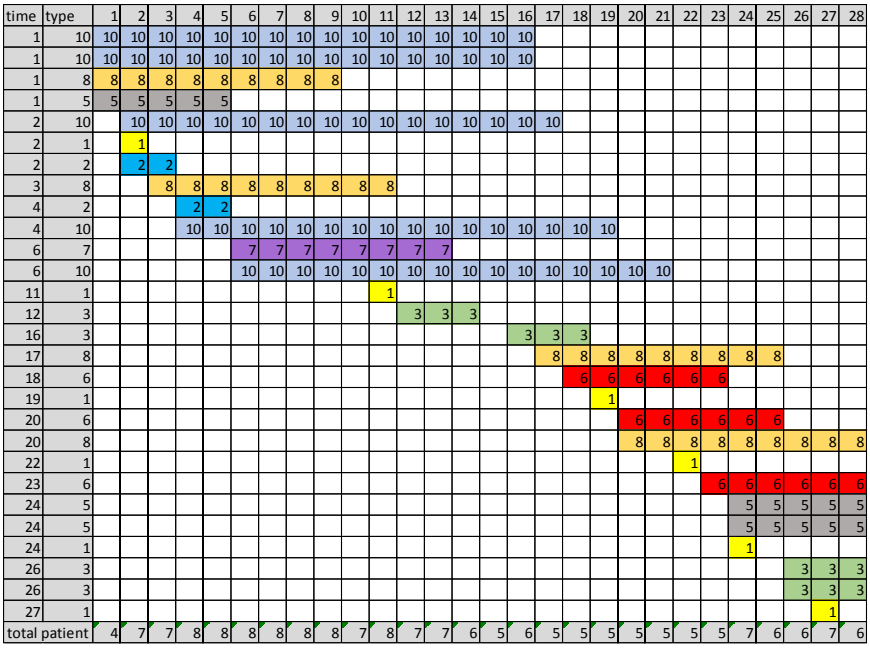


	A	B	C	D	E	F	G	H	I
1					1	2	3	4	5
2	1	10	7	5					1
3	2	1	18	3				1	
4	2	6	1	2			1		
5	3	2	6	2					1
6	4	8	10	2					1
7	5	10	7	5				1	
8	7	5	3	3		1			
9	8	1	5	3			1		
10	8	3	12	2			1		
11	9	1	9	3			1		
12	9	6	18	4				1	
13	10	3	1	3			1		
14	10	10	4	4					1
15	11	8	5	5					1
16	12	3	21	1			1		
17	12	5	12	3				1	
18	13	1	22	1					1
19	13	8	5	1		1			
20	14	8	4	2					1
21	15	7	16	5					1
22	16	1	3	1				1	
23	16	2	8	1		1			

Figure 5.2 GAMS output for day 1

Finally the first row between columns E and I corresponds to identification (id) number of the nurses assigned to the patients. Since the original GAMS output was not

well organized or visually pleasant, a new schedule format was implemented using the GAMS output. Figure 5.3 presents the proposed schedule for day 1 using a clearer visual representation.



time	type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	8	8	8	8	8	8	8	8	8	8																			
1	5	5	5	5	5	5																							
2	10		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10											
2	1		1																										
2	2		2	2																									
3	8			8	8	8	8	8	8	8	8	8																	
4	2				2	2																							
4	10				10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10									
6	7						7	7	7	7	7	7	7	7															
6	10						10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10							
11	1											1																	
12	3												3	3	3														
16	3																3	3	3										
17	8																	8	8	8	8	8	8	8	8				
18	6																		6	6	6	6	6	6					
19	1																			1									
20	6																				6	6	6	6	6	6			
20	8																				8	8	8	8	8	8	8	8	8
22	1																						1						
23	6																							6	6	6	6	6	6
24	5																								5	5	5	5	5
24	5																								5	5	5	5	5
24	1																								1				
26	3																										3	3	3
26	3																										3	3	3
27	1																											1	
total patient		4	7	7	8	8	8	8	8	8	7	8	7	7	6	5	6	5	5	5	5	5	5	5	7	6	6	7	6

Figure 5.3 Proposed schedule day 1

This leveling pattern manifested the majority of the days. The results for the other nine days are summarized in Appendix B. This goes after

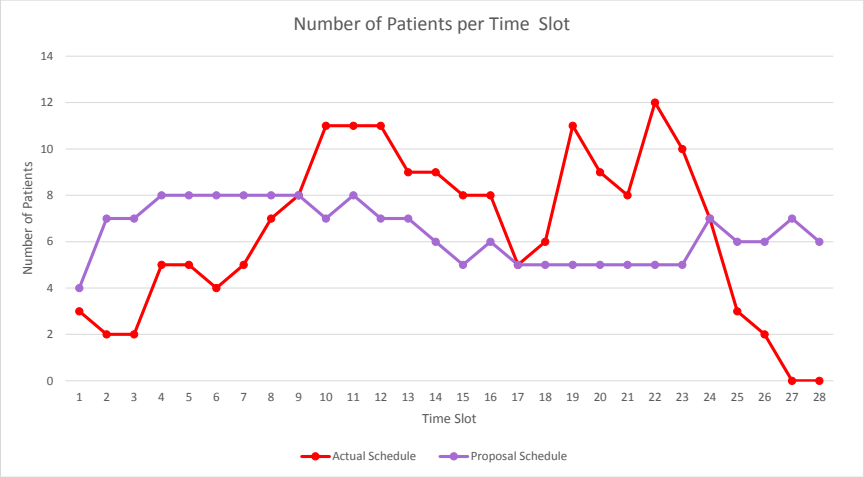


Figure 5.4 Total number of patients per time slot

The total number of patients per time slot was calculated for both schedules (actual and proposed). This number includes both new and recurring patients at any point in time. The aim was to visualize the differences between the original schedule and the proposed schedule. Figure 5.4 compiles the total number of patients for both schedules at any 20-minutes time slote. The red line represents the actual schedule, and the purple line represents the proposed schedule. From the figure, it can be seen that the schedule obtained from the mathematical model (proposed schedule) is leveled when compared to the original. The proposed schedule keeps a balance in the number of patients in the system throughout the day and avoids peaks of demand during the day.

Maximum Capacity of the System

Given the success of the mathematical model to level patient demand throughout the day, it was decided to estimate the maximum capacity for the system for each patient mix. Instead of using the number of patients per type as an input, the model used the

percentage for each type of patient which allows for the allocation of the maximum number possible of each patient type according to the patient mix. Constraint (5.7) was then modified to achieve this objective. The new constraint became

$$\frac{\sum_{i=1}^{c}\sum_{t=1}^{k}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan}}{\sum_{i=1}^{c}\sum_{t=1}^{k}\sum_{a=1}^{b}\sum_{n=1}^{r} y_{ijtan} + \sum_{i=1}^{c}\sum_{t=1}^{k}\sum_{a=1}^{b}\sum_{n=1}^{r} x_{ijtan}} \geq p_j \qquad \forall\, j \qquad (5.7b)$$

Where p_j represents the percentage of each patient type according to the patient mix of the day. Table 5.4 summarizes the patient type percentages per day.

Table 5.4 Patient percentage per day

	Day									
Patient Type	1	2	3	4	5	6	7	8	9	10
Type 1	19%	11%	7%	4%	6%	17%	20%	13%	11%	12%
Type 2	7%	4%	0%	4%	0%	6%	7%	0%	0%	8%
Type 3	15%	19%	11%	23%	17%	28%	20%	22%	11%	27%
Type 4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Type 5	11%	4%	7%	4%	6%	0%	0%	4%	11%	4%
Type 6	11%	11%	11%	12%	17%	11%	10%	9%	21%	15%
Type 7	4%	0%	14%	12%	22%	6%	3%	17%	5%	0%
Type 8	15%	7%	14%	8%	11%	0%	10%	13%	5%	12%
Type 9	0%	26%	29%	12%	11%	11%	17%	9%	16%	0%
Type 10	19%	19%	7%	4%	11%	33%	7%	13%	11%	19%
Type 11	0%	0%	0%	12%	0%	11%	3%	0%	11%	4%
Type 12	0%	0%	0%	8%	0%	0%	3%	0%	0%	0%

Table 5.5 compares the actual system and the maximum capacity that the infusion area could have managed on each of those days without exceeding the mental workload levels for nurses and pharmacists. From the table, it can be seen that the mathematical model allows the capacity of the infusion area to increase by at least 50 % per day.

Table 5.5 Patient percentage per day (actual capacity (C_{act}), maximum capacity (C_{Max}))

		Patient Type													
Day	Capacity	1	2	3	4	5	6	7	8	9	10	11	12	Total	% Increase
1	C_{act}	5	2	4	0	3	3	1	4	0	5	0	0	27	133.3
	C_{Max}	9	7	8	0	7	7	3	10	0	12	0	0	63	
2	C_{act}	3	1	5	0	1	3	0	2	7	5	0	0	27	55.6
	C_{Max}	3	2	8	0	2	5	0	3	11	8	0	0	42	
3	C_{act}	2	0	3	0	2	3	4	4	8	2	0	0	28	50.0
	C_{Max}	0	0	5	0	3	5	6	6	13	4	0	0	42	
4	C_{act}	1	1	6	0	1	3	3	2	3	1	3	2	26	92.3
	MC	2	1	12	0	3	7	6	4	7	2	6	0	50	
5	C_{act}	1	0	3	0	1	3	4	2	2	2	0	0	18	216.7
	C_{Max}	3	0	10	0	0	10	13	7	7	7	0	0	57	
6	C_{act}	4	1	5	0	0	2	1	0	2	6	2	0	23	52.2
	C_{Max}	6	2	7	0	0	3	2	0	3	9	3	0	35	
7	C_{act}	6	2	6	0	0	3	1	3	5	2	1	1	30	110.0
	C_{Max}	12	2	10	0	7	7	3	10	0	12	0	0	63	
8	C_{act}	3	0	5	0	1	2	4	3	2	3	0	0	23	117.4
	C_{Max}	8	0	11	0	2	0	9	7	6	7	0	0	50	
9	C_{act}	2	0	2	0	2	4	1	1	3	2	2	0	19	136.8
	C_{Max}	1	0	5	0	5	10	3	3	8	5	5	0	45	
10	C_{act}	3	2	7	0	1	4	0	3	0	5	1	0	26	92.3
	C_{Max}	6	1	14	0	2	8	0	6	0	11	2	0	50	

Additionally, the results show a variability among the days which is caused by the differences in the patient mix. Days 5 and 9 exhibited the largest percentage increase of capacity with values of 216.7% and 136.8% respectively. In contrast, days 1 and 7 do not show high percentages but they do exhibit increased number of patients per day with a value of 63 for both of them. Finally, day 3 showed a potential increase of only 50%. This is due to the fact that day 3 had many long-duration patients (four level 8, eight level 9, and two level 10).

In conclusion, applying the model improves the schedule in the infusion area in two ways 1) it balances the patient schedule, avoiding peaks caused by patient arrivals, and 2) it helps to increase the capacity of the cancer center. However, all these improvements have been analyzed only from the viewpoint of the center's productivity,

in other words, considering only the capacity and the mental workload of nurses and pharmacists. Chapter 6 will take a patient-centered approach, discussing the effect of the proposed schedules on patient time.

CHAPTER 6

SIMULATION MODEL

This chapter looks at the impact the proposed schedules have over patient care using discrete event simulation as a comparison tool. The chapter was divided in three sections. The first section presents a simulation model conceptualization and validation. The second section presents a comparison between the actual schedules against the proposed schedules. Finally, the third section presents the simulation results for different scenarios to assess the robustness of the model and the possible impact over the real system. Figure 6.1 shows a general description of this chapter.

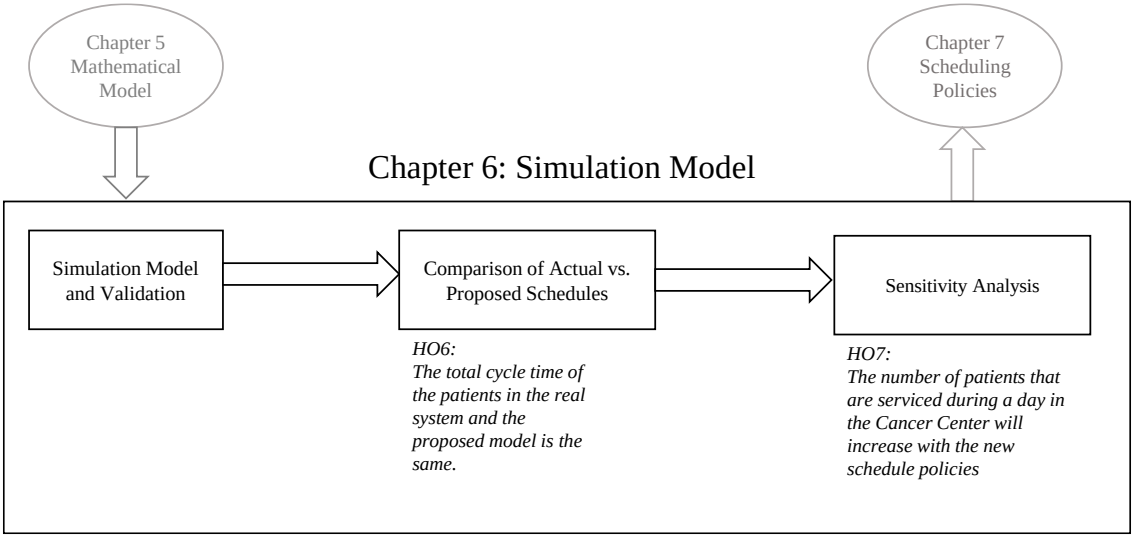


Figure 6.1 Chapter 6 general description

Simulation Model Conceptualization

Previous chapters helped us understand the complexity of the system. A discrete event simulation model of patient flow was developed for BDCC. Figure 6.2 presents the conceptualization of the infusion area process at the Cancer Center. It was used in the development of the computer simulation model which was used as a tool to compare the results obtained from the mathematical model against the actual schedules. This research determined the average total cycle time for each type of patient which was considered as an initial metric in the comparison of the different models. The following is a description of the conceptual model of patient and information flow as presented in Figure 6.2.The infusion area at the clinic is a complex system which includes several processes working in parallel that are required to provide infusion services to patients. There are two main processes which take into account information flow and patient flow.

The information flow process is driven by the order and is used by the pharmacy to prepare drugs for patients. This is a critical process as some patients receive infusion in stages. Due to the fact that some drugs have a short shelf life, pharmacy needs to prepare the drugs for each stage only minutes prior to when the drug is needed. For example, a patient scheduled to receive infusion for 5 hours might undergo 5 different drugs (at an average of 1 per hour). The pharmacy cannot prepare the 5 drugs right away as the ones needed for the fourth and fifth stage might expire within 2 hours.

On the other hand, the patient flow process pertains to the patient moving through the different stages of their infusion treatment. Nurses are a critical resource in this

process. To keep the patient flowing through the system it is essential for both the information process and the patient process to be synchronized in a way that would minimize waiting for patients, medication and nurses. Thus, at each stage of the treatment three things need to happen for the treatment to continue 1) patient has to be ready for next drug; 2) next drug has to be ready; and 3) nurses have to be available to administer the new drug.

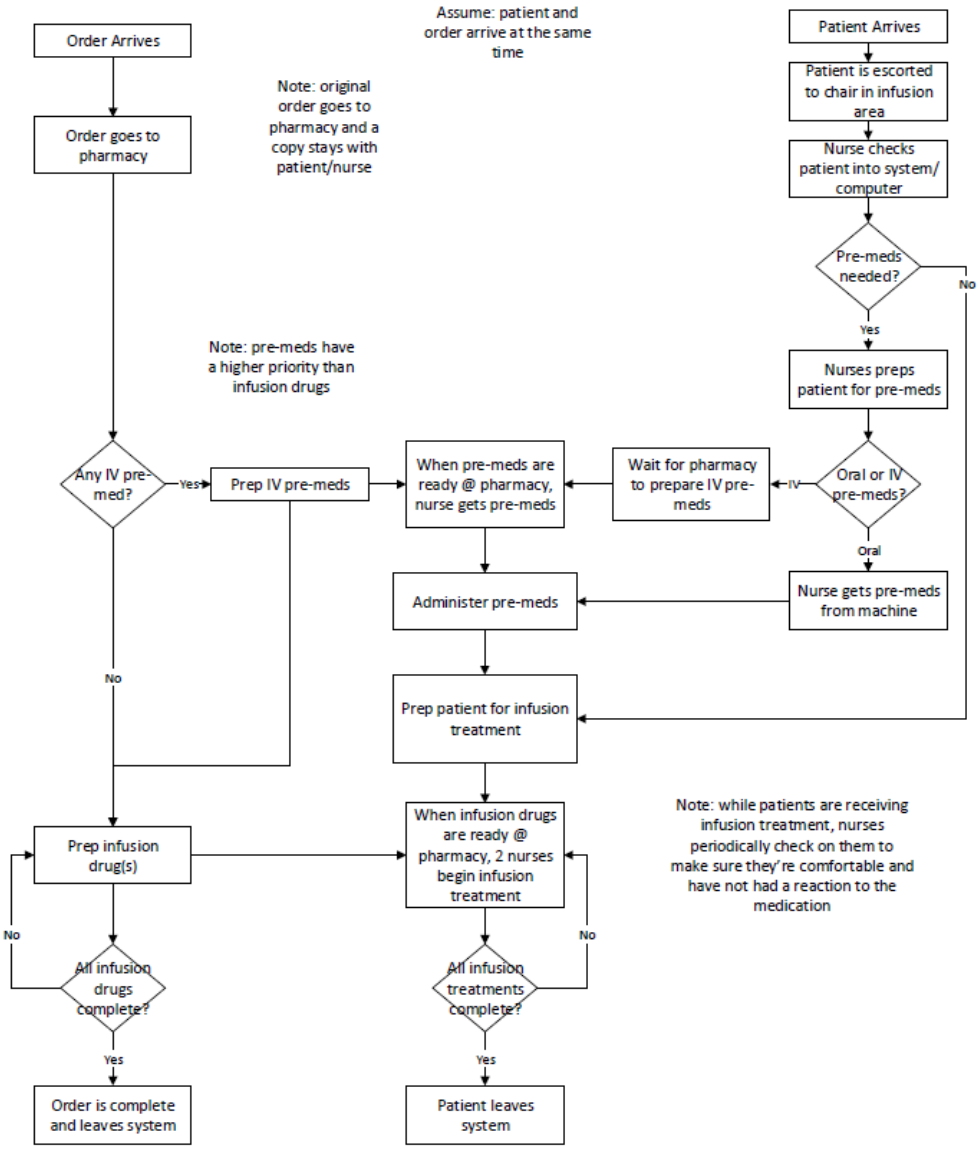


Figure 6.2 Conceptual model of patient and information flow at BDCC

A nurse escorts the patient to his/her preferred seat in the infusion center and gives a copy of the treatment information to the pharmacy. For the purpose of this model, this study assumed that patient arrival at the infusion area and the order placement for drugs to the pharmacy occur at the same time. Upon arrival of a patient, a nurse checks him/her into the system. The nurse collects different information about the patient (body

temperature, blood pressure, patient general condition, etc.) and enters it into the electronic system as a part of the check-in process. The nurse also reviews the treatment plan requirements for premed or hydro fluid, type of premed, and number of infusion drugs, among other things.

If a patient needs the oral premed, the nurse collects it from a medicine cabinet and administers it. If the patient needs an IV-premed, the nurse waits for the pharmacy to prepare it and then collects it when ready to administer to the patient. The nurse may attend to another patient during this wait time. After the completion of administering premed, or if there is no premed required, the nurse prepares the patient for the infusion drug(s). When the pharmacy completes preparing the first infusion drug, the nurse brings it for administration. A second nurse joins the first nurse at this point to cross-check everything prior to administering the infusion drug. The infusion drug is then administered. The patient waits in the chair for the infusion treatment to be completed. The nurse may attend to other patients during this time. However, he/she comes back a few times to check on the patient while the treatment is ongoing.

If the patient requires more infusion drug(s), the nurse brings it from the pharmacy after they are done preparing it. The same process of administering infusion drugs continues. When the patient is done with the entire infusion treatment, he/she leaves the chair and the infusion center releasing all the resources he/she seized during his/her stay. The work flow of the infusion center is very much dependent on the activities of the pharmacy. The pharmacy prepares the IV-premed and infusion drugs for all the patients. To make this preparation process more efficient, the pharmacists follow

different priority rules to prepare different premed/drugs. Pharmacists are responsible to taming the drugs in order to prioritizing the mix of the drugs. Some treatments cannot be prepared with long time a head. Pharmacists plan their activities according to this requirement and the patient arrivals. For example, when the order of medicines arrives at the pharmacy, they make a schedule for preparing the drugs/premeds. In general, IV-premeds get higher priority than the first infusion drugs. However, if a patient needs more than one infusion drug, the pharmacists prepare the first drug at first and schedule the additional infusion drugs for a later time with the highest priority. This time difference is selected based on the tentative time of administering the first (or current) infusion drug. By this way, the pharmacists can prepare the drugs for other patient quickly without keeping the current patients waiting.

The simulation model was built using Arena, (version 14.0). Appendix C contains a short description of the development of the most important elements of the simulation model. It also contains print screens from the Arena model and the general assumptions. It should be mentioned that the conceptual model along with the Arena simulation model was presented and published at the proceedings of the 2014 Winter Simulation Conference [106]

The simulation model was validated by comparing the average time a patient spent in the system from the simulation against the real system (from historical data). A total of six days from 2015 were used to validate the model. The historical schedules were also used to establish the inter-arrival time of patients to the system. It was

determined that 10 replications were necessary in order to obtain confidence interval half-width that was within 5% of the mean.

Table 6.1 presents the comparison between the simulation model and the real system. The table shows that the average time value of the real system is included in the 95 % confidence intervals obtained from the simulation output in five out of the six days.

Table 6.1 Comparisons between actual system outputs and simulation outputs

Day	Actual System Average time in system (min)	Simulation Model Average time in system (min)	95% Confidence Interval for simulation Output	Conclusions
1	196.15	197.15	(195.03, 200.01)	Not Significant
2	154.54	155.59	(154.22, 155.59)	Not Significant
3	129.09	133.85	(132.01, 135.69)	Significant
4	125.71	126.73	(125.50, 127.86)	Not Significant
5	187.62	186.80	(185.20, 188.40)	Not Significant
6	148.46	149.17	(147.81, 150.53)	No Significant

This implies that the results obtained from the simulation model are not significantly different from the historical data; in other words, the simulation model represents satisfactorily the process of the infusion area which makes it suitable to be used to compare the scheduling models. Furthermore, the average time in system for the day that is statistically different from the simulation output is less than three minutes from the lower limit of the confidence interval. This is not enough to discard the simulation model as a close representation of the real system.

This section responded to hypothesis (H_{05}) which stated that the total cycle time of the patients in the real system and the simulation model are the same. In other words,

the simulation model is appropriate as a tools to evaluate the possible impacts that the proposed schedules might have on the real system.

The next sections established an assessment between the original schedules and proposed schedules using the average time per patient as a measurement of comparison. Therefore, different experiments were developed to evaluate different scheduling policies that would allow the clinic to increase its daily throughput while balancing its resources without affecting the quality of the services (measured by patient wait time).

Comparison Actual Schedule vs. Proposed Schedule

The previous chapter revealed how the mathematical model is able to balance the daily patient schedule of the infusion area. However, the impact that the proposed schedule might have over patient service times should be evaluated. This section was concerned with potential differences on average time of patients among the proposed schedules. The simulation model was used to determine the average time for both schedules (original and proposed). Consequently, statistical analysis was performed to determine any significant difference (if any) between both schedules. Ten (10) simulation replications were used in each day which yield the average time in system with the standard deviation for each scheduling method. The simulation outputs were used to compare the actual schedules versus the proposed schedules.

Table 6.2 presents the average time for the actual and proposed schedules along with 95% confidential intervals for the simulation output of the proposed schedules. The objective was to determine the effect of the proposed schedule through the performance

of the real system. The Table 6.2 shows that six of the ten days don't present any statistical difference between the actual and the proposed schedules. The other four days present differences; however, two of them show a significant reduction of the average time from the actual schedule which means an improvement in the performance. Thus, it can be concluded that the mathematical model represented changes that did not worsen the total patient time in the system in 80% of the cases.

Table 6.2 Time comparison between the actual schedule and the proposed schedule

Day	Original Schedule Average time in system (min)	Proposed Schedule Average time in system (min)	95% Confidence Interval for simulation Output	Conclusions
1	140.95	147.62	(-10.11, -3.24)	Significant
2	173.33	168.09	(2.21, 8.28)	Significant
3	172.48	183.26	(-15.72, -5.83)	Significant
4	201.08	197.97	(-0.04, 6.26)	Not Significant
5	161.89	161.76	(-2.84, 3.10)	Not Significant
6	161.80	161.74	(-2.89, 3.05)	No Significant
7	154.23	150.34	(1.39, 6.38)	Significant
8	152.46	153.28	(-3.03,1.39)	Not Significant
9	182.89	182.62	(-2.19, 2.74)	Not Significant
10	152.44	151.78	(-1.18, 2.50)	Not Significant

Figure 6.3 shows an example where the difference between both schedules was found not significant which means that the proposed schedule doesn't have a negative impact over average time of the patient in the infusion area. The figure shows several similarities between the curves.

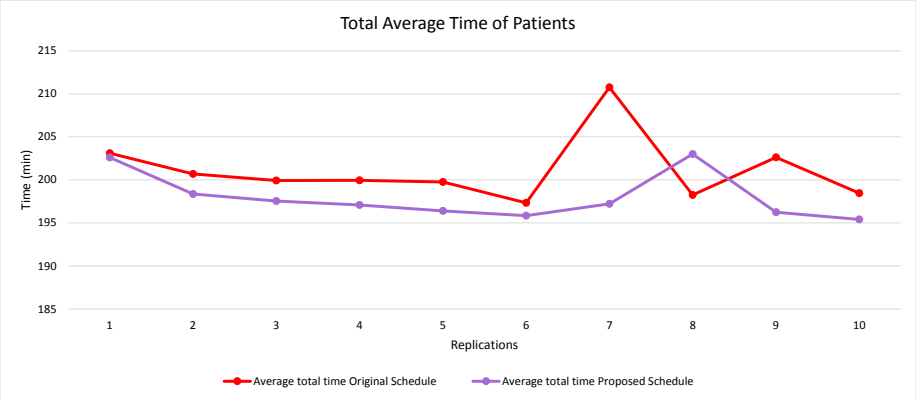


Figure 6.3 Average time per patient- day 4

Conversely, Figure 6.4 shows an example where the average time for the original and the proposed schedule are different; however, the average time per patient decreases which represents an improvement in the schedule. The figure shows the proposed schedule curve is below the actual schedule curve.

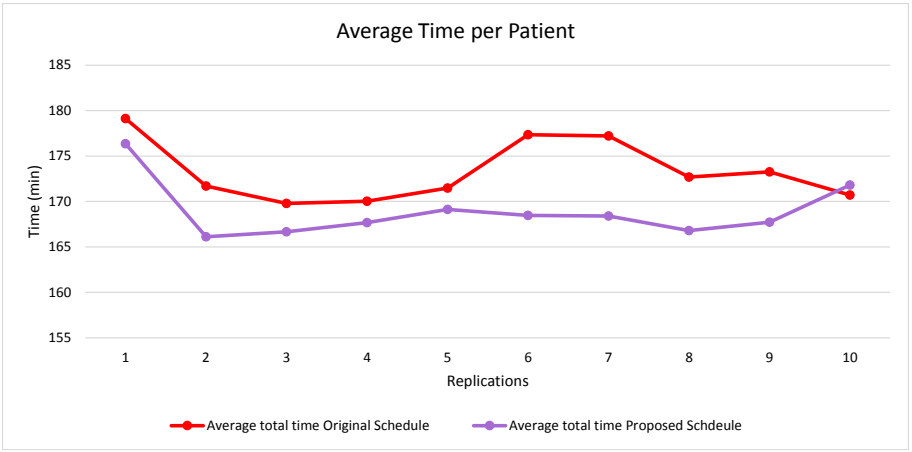


Figure 6.4 Average time per patient- day 2

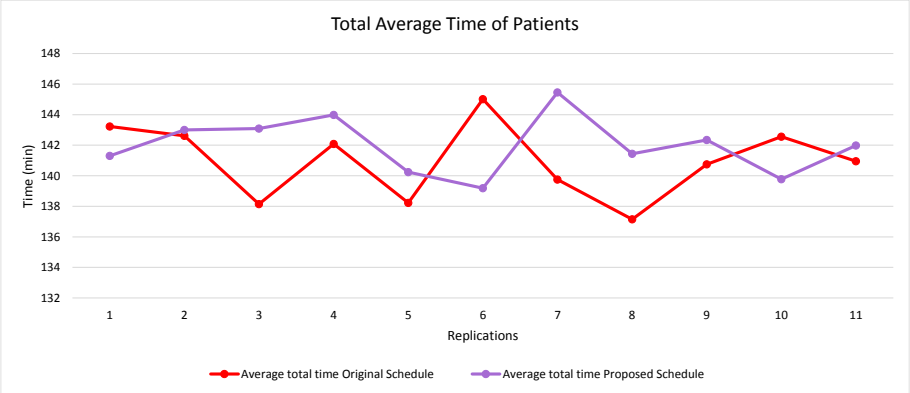


Figure 6.5 Average time per patient- day 1

Finally, figure 6.5 shows an example where the average time per patient for the proposed schedule is bigger than the average time per patient for the original schedule. The figure shows the original schedule curve is below the actual schedule curve.

This section responds to hypothesis H_{06} The total cycle time of the patients in the real system and the proposed model is the same. The results fulfilled this statement on 80% of the cases. The next section was developed to explore the sensitive of the model and the capacity of the system to absorb the increase demand of the center.

Sensitivity Analysis

This section presents a sensitivity analysis of the mathematical model by comparing the actual schedules used on Chapter 4 against three possible scenarios. These scenarios increased proportionally the number of patients that arrive into the system by 15%, 20%, and 40% from the actual demand. Table 6.3 shows the increments of patients per type according to each one of scenarios and days. Each day represents different patient mix which means that they will behave different.

Table 6.3 Comparisons among actual system outputs and simulation outputs

		Patient Type											
Day	Increment	1	2	3	4	5	6	7	8	9	10	11	12
1	Actual	5	2	4	0	3	3	1	4	0	5	0	0
	15%	7	2	5	0	4	4	1	5	0	6	0	0
	20%	7	3	5	0	4	4	2	5	0	6	0	0
	40%	8	4	6	0	4	4	2	6	0	7	0	0
2	Actual	3	1	5	0	1	3	0	2	7	5	0	0
	15%	5	1	6	0	1	4	0	2	8	5	0	0
	20%	5	1	6	0	1	4	0	2	8	6	0	0
	40%	6	1	7	0	1	4	0	3	10	7	0	0
3	Actual	2	0	3	0	2	3	4	4	8	2	0	0
	15%	2	0	3	0	2	3	5	5	9	2	0	0
	20%	2	0	4	0	2	4	5	5	10	2	0	0
	40%	3	0	4	0	3	4	6	6	11	3	0	0
4	Actual	1	1	6	0	1	3	3	2	3	1	3	2
	15%	1	1	7	0	1	3	3	3	3	1	3	3
	20%	1	1	7	0	1	4	4	3	4	1	4	3
	40%	2	2	8	0	2	4	4	3	4	2	4	3
5	Actual	1	0	3	0	1	3	4	2	2	2	0	0
	15%	1	0	4	0	1	4	5	2	2	2	0	0
	20%	2	0	4	0	2	4	5	2	2	2	0	0
	40%	2	0	4	0	2	4	5	3	3	3	0	0
6	Actual	4	1	5	0	0	2	1	0	2	6	2	0
	15%	5	1	6	0	0	2	1	0	2	7	2	0
	20%	5	1	6	0	0	2	1	0	2	8	3	0
	40%	6	2	7	0	0	3	2	0	3	9	3	0
7	Actual	6	2	6	0	0	3	1	3	5	2	1	1
	15%	8	2	8	0	0	3	1	3	6	2	1	1
	20%	8	2	8	0	0	4	1	3	6	2	1	1
	40%	9	3	9	0	0	4	1	4	7	3	1	1
8	Actual	3	0	5	0	1	2	4	3	2	3	0	0
	15%	3	0	6	0	1	2	5	3	2	3	0	0
	20%	4	0	6	0	1	2	5	4	2	4	0	0
	40%	4	0	7	0	1	3	6	4	3	4	0	0
9	Actual	2	0	2	0	2	4	1	1	3	2	2	0
	15%	2	0	2	0	2	5	1	1	3	2	2	0
	20%	2	0	2	0	2	5	1	1	4	2	2	0
	40%	3	0	3	0	3	6	1	1	4	3	3	0
10	Actual	3	2	7	0	1	4	0	3	0	5	1	0
	15%	3	2	8	0	1	5	0	3	0	6	1	0
	20%	4	2	8	0	1	5	0	4	0	6	1	0
	40%	4	3	10	0	1	6	0	4	0	7	1	0

Table 6.3 was used as input into the mathematical model which then provided the arrival time for each patient according to the optimized schedule. This information was then used to run the simulation model. The objectives were to determine average total time that a patient would spend in the system, and to evaluate possible differences between the actual schedule and the different scenarios for increased demand. Once again, ten replications were run for each day and the average time in system with the standard deviation were calculated for each scenario. The outputs were used to compare the actual schedule among proposed scenarios to establish the maximum percentage that the demand could have been increased without negatively impacting the total time of the patients in the system. Table 6.4 summarize the best scenario per day. From the table it can be seen that the cancer center should have the capability to increase up to 40 % the number of patients while keeping the same total average time per patient. The next figures compare actual schedule, proposed schedule and the best scenarios.

Table 6.4 The best sceneries per day

Day	Actual Schedule Average time in system (min)	Proposed Schedule Average time in system (min)	95% Confidence Interval for simulation Output	The Best Scenarios
1	140.95	139.74	(-0.82, 3.24)	15 %
2	173.33	170.70	(-1.11, 6.39)	20%
3	172.48	169.84	(-0.66, 5.94)	40%
4	201.08	201.86	(-5.29, 3.73)	40%
5	161.89	162.91	(-3.99, 1.96)	40%
6	161.80	162.93	(-3.56, 1.90)	40%
7	154.23	150.52	(0.84, 6.57)	40%
8	152.46	154.28	(-3.97,0.32)	40%
9	182.89	183.71	(-3.20, 1.56)	40%
10	152.44	151.53	(-1.14, 2.97)	40%

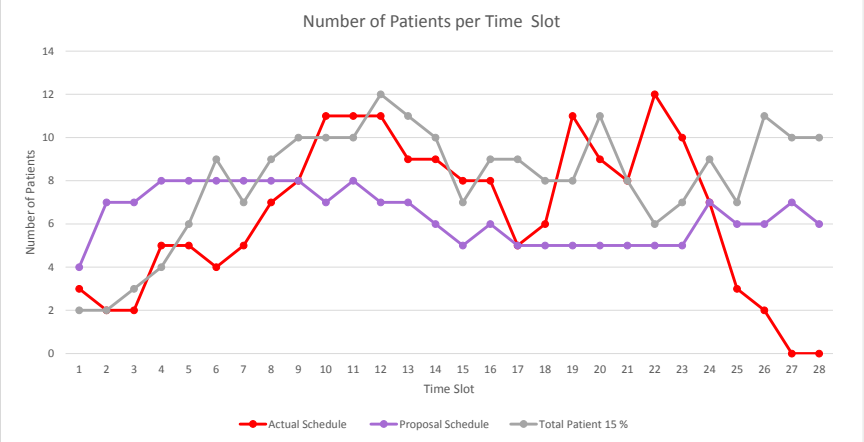


Figure 6.6 Best scenario – day 1

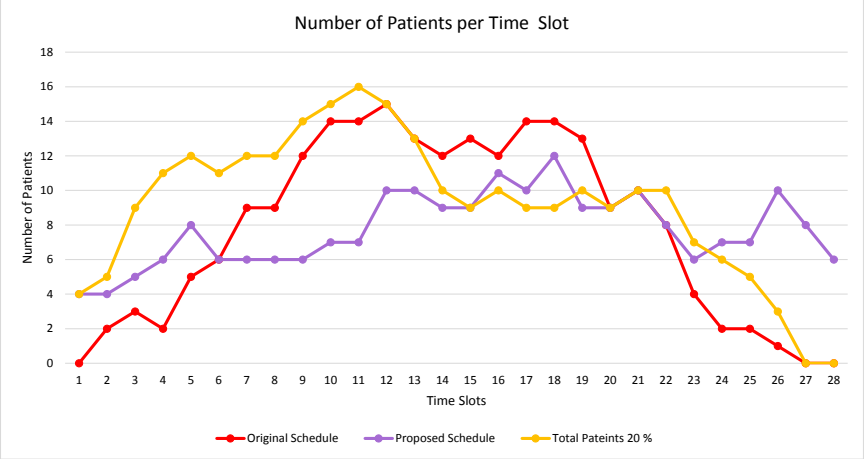


Figure 6.7 Best scenario – day 2

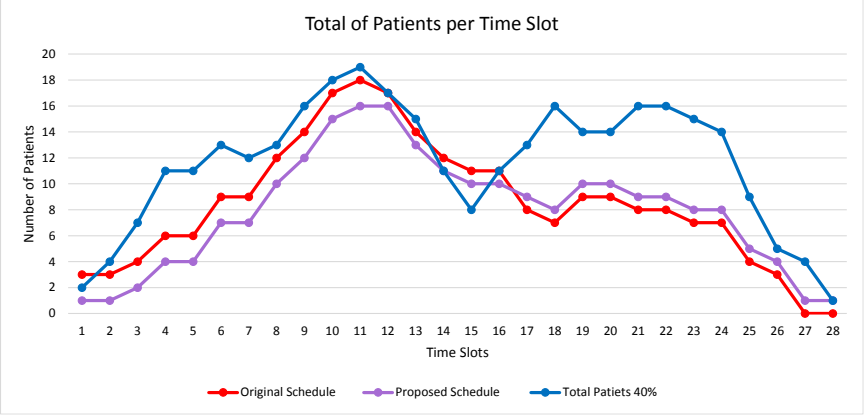


Figure 6.8 Best scenario – day 3

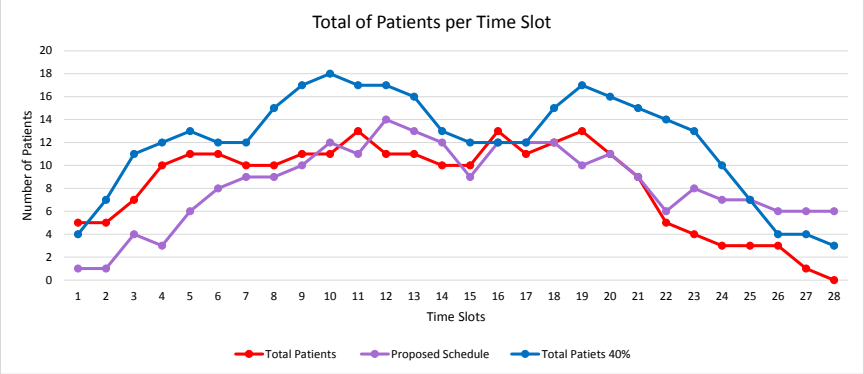


Figure 6.9 Best scenario – day 4

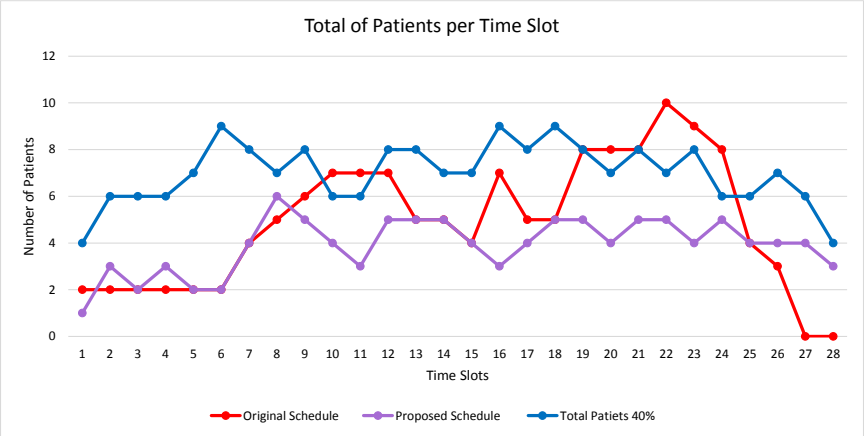


Figure 6.10 Best scenario – day 5

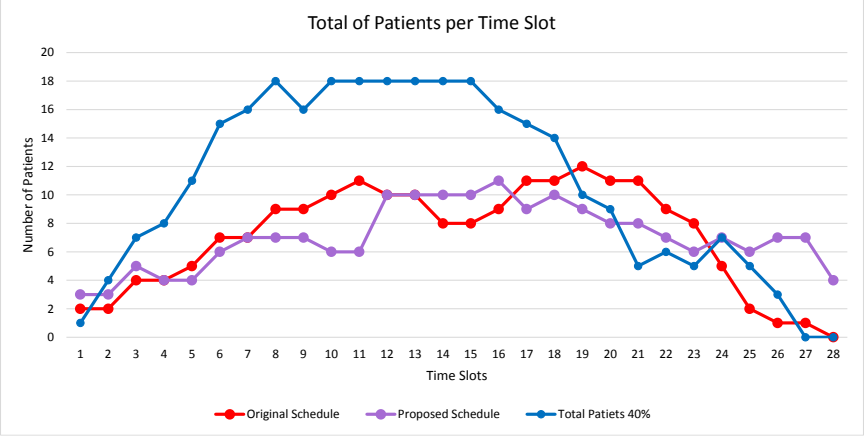


Figure 6.11 Best scenario – day 6

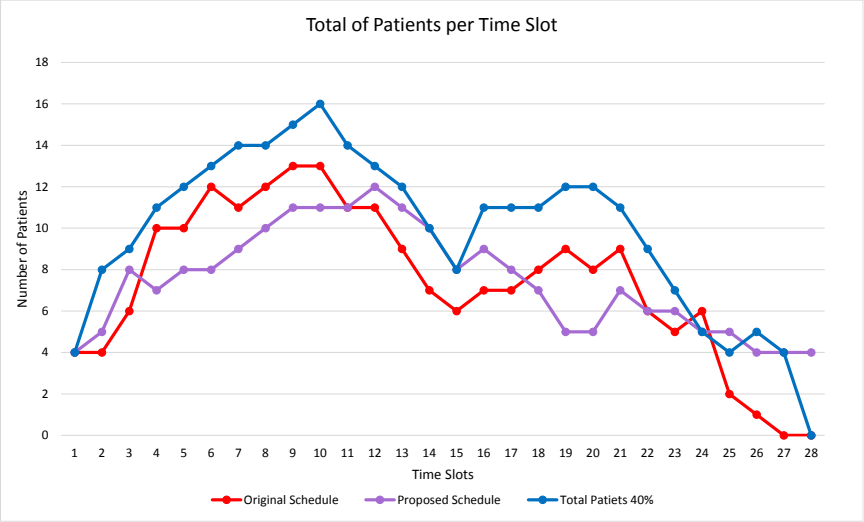


Figure 6.12 Best scenario – day 7

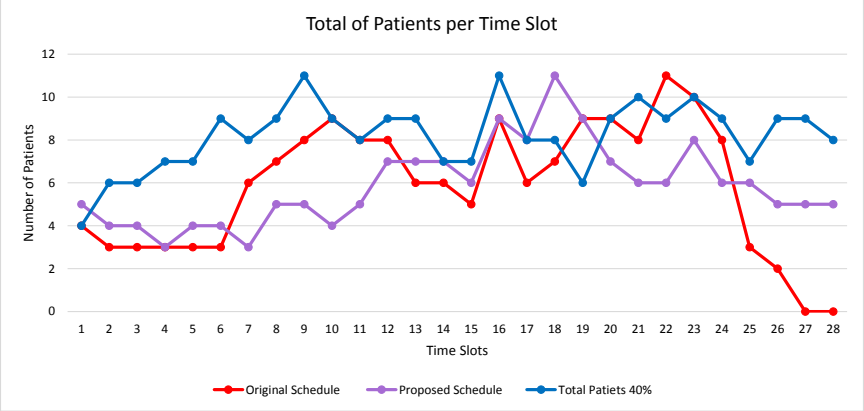


Figure 6.13 Best scenario – day 8

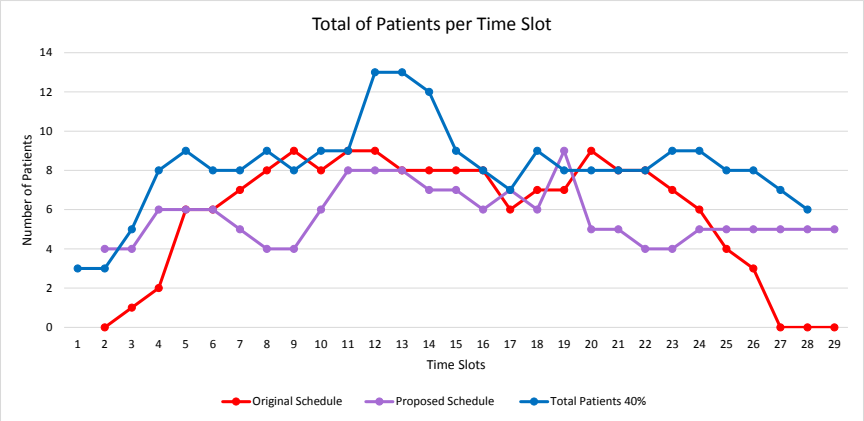


Figure 6.14 Best scenario – day 9

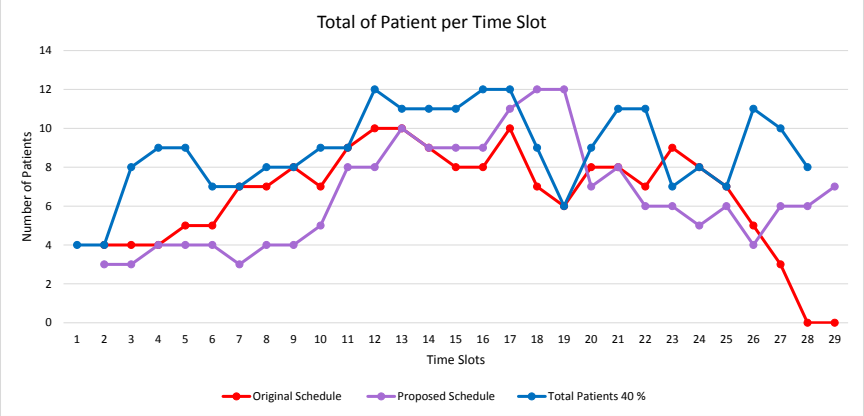


Figure 6.15 Best scenario – day 10

As shown above, the mathematical model allows the cancer center to allocate patient's appointments in a more balanced manner which means that area will be able to increase its capacity without impacting significantly the total average time per patient. These results respond to the hypothesis H_{07} that established the number of patients that are serviced during a day in the Cancer Center will increase with the new scheduling policies. The proposed schedules will permit to schedule more patients using the same resources. However, these proposed schedules were built using real patient mixes which was different every day. This situation didn't permit to generalize scheduling policies for the cancer center. Therefore, the next chapter will be focus on creating several scenarios that will permit to generate general scheduling policies for the center.

CHAPTER 7

SCHEDULING POLICIES

This chapter intends to develop general patient scheduling policies for the infusion area. The previous chapter evaluated different patient mix demands and their increase; however, it was not enough to establish scheduling polices. This chapter explores general criteria that support the schedulers to make decisions about how to allocate patients' appointments into daily schedule. Figure 7.1 shows a general description of this chapter.

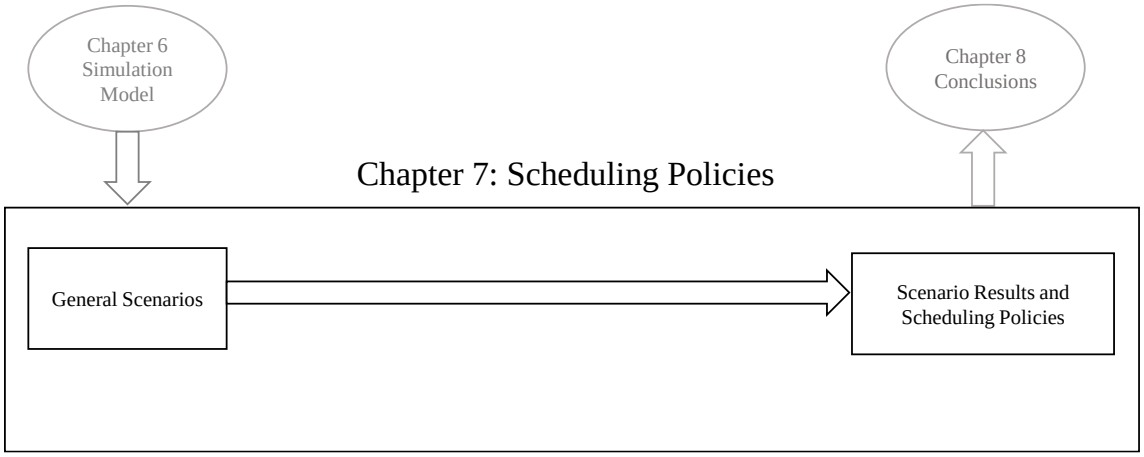


Figure 7.1 Chapter 7 general description

General Scenarios

This section established the scenarios which were used to develop the scheduling policies for Bozeman Deaconess Cancer Center. Until now, the results were oriented to evaluate the performance of the mathematical model over two conditions. The first was

to balance the scheduling system avoiding peaks of patient demands in the infusion area (Chapter 5). The second was to establish the capability of this system to increase the number of scheduled patients without impacting the total patient time in the system (Chapter 6).

Table 7.1 Summary of patient demand per scenario.

		Scenarios													
	Patient Type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Low	Type 1	2	3	2	2	4	1	1	3	5	2	2	7	1	1
	Type 2	2	3	2	2	4	1	1	3	5	2	2	7	1	1
	Type 3	2	3	1	1	4	1	1	3	5	2	2	7	1	1
	Type 4	2	3	1	1	4	1	1	3	5	2	2	7	1	1
Middle	Type 5	2	2	3	2	1	4	1	3	2	5	2	1	7	1
	Type 6	2	2	3	2	1	4	1	3	2	5	2	1	7	1
	Type 7	2	1	3	1	1	4	1	3	2	5	2	1	7	1
	Type 8	2	1	3	1	1	4	1	3	2	5	2	1	7	1
Long	Type 9	2	2	2	3	1	1	4	3	2	2	5	1	1	7
	Type 10	2	2	2	3	1	1	4	3	2	2	5	1	1	7
	Type 11	2	1	1	3	1	1	4	3	2	2	5	1	1	7
	Type 12	2	1	1	3	1	1	4	3	2	2	5	1	1	7
	Total	24	24	24	24	24	24	24	36	36	36	36	36	36	36

However, one of the objectives of this study was to develop some strategies to build a better scheduling system. To achieve this goal seven scenarios were evaluated using two different patient demands as referenced. The patient demand values were 24 and 36 patients which corresponded to average demand of typical days and increased demand, respectively. This section distributed these patient demands among the twelve (12) patient types, and they were sub-classified in three groups (low, middle, and long) according to treatment length. The patient types from 1 to 4 were considered part of low duration group. The patient types from 5 to 8 were classified as middle duration group, and the rest (9-12) were situated as long duration group. The percentage of the patients

assigned for each group was changed through all the scenarios increasing and decreasing the percentage as needed. For example, Scenario 1 (S1) distributed equally the patient demand through all the groups, and Scenario 7 (S7) distributed patient demand as 70 % to long group, and 15 % to low and middle groups. Table 7.1 shows the distribution demand for all scenarios, groups, and patients types.

This information was used in the mathematical model obtaining a schedule for each scenario. Nevertheless, it was found that Scenario 11 (S11), Scenario 13 (S13), and Scenario 14 (S14) were not feasible. The next section analyzed the results for each scenario and the general scheduling policies.

Scenario Results

This section summarized the results obtained for each alternative. The results are composed for a graphical representation of the scheduling appointment of patients and a graphic which represented the total number of patients in the system at any point in time of the day in 20 minute intervals.

Scenario 1 (S1): It is composed of 24 patients distributed equally among the groups which represented eight (8) for short, middle and long group. Figure 7.2 shows the optimal distribution of patient's appointment of S1. From the graph it was concluded that 100% of patients of long duration group and 65 % of the middle duration group should be located no later than noon. Figure 7.3 shows a balanced workload for S1.

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
9	1	9	9	9	9	9	9	9	9	9	9	9																	
9	1	9	9	9	9	9	9	9	9	9	9	9																	
5	1	5	5	5	5	5																							
3	1	3	3	3																									
8	3			8	8	8	8	8	8	8	8	8																	
8	3			8	8	8	8	8	8	8	8	8																	
1	3			1																									
5	3			5	5	5	5	5																					
11	4				11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11					
12	4				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12			
2	5					2	2																						
12	8								12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
1	9									1																			
11	10										11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
6	11											6	6	6	6	6	6												
10	12												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
10	12												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
4	12												4	4	4	4													
4	12												4	4	4	4													
7	17																	7	7	7	7	7	7	7	7				
2	18																		2	2									
6	20																				6	6	6	6	6	6			
7	21																					7	7	7	7	7	7	7	7
3	26																										3	3	3
Total Patients		4	4	8	8	9	8	7	7	8	8	9	9	9	9	9	7	7	8	8	8	9	9	8	8	6	6	6	4

Figure 7.2 Graphical representation of scheduling patients for S1

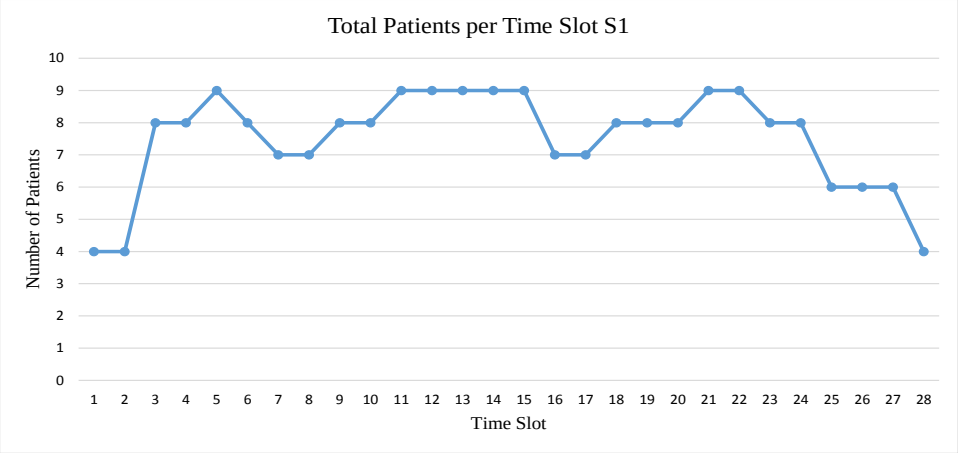


Figure 7.3 Total patients per time slot of S1

Scenario 2 (S2): It is composed of 36 patients allocating 50% for short duration group and 25% for middle and long duration groups. Figure 7.4 shows the optimal distribution of patient's appointment of S2. From the graph it was concluded that 87.5% of patients of long duration group and 50 % of the middle duration group should be assigned no later than noon. Figure 7.5 shows a balanced workload for S2.

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
6	1	6	6	6	6	6	6																						
10	3			10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10										
12	3			12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
8	5					8	8	8	8	8	8	8	8	8															
1	8								1																				
1	10										1																		
11	10										11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
9	10										9	9	9	9	9	9	9	9	9	9	9								
9	11											9	9	9	9	9	9	9	9	9	9	9							
5	12												5	5	5	5	5												
4	12												4	4	4	4													
3	12												3	3	3														
10	12												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
4	16																4	4	4	4									
3	16																3	3	3										
4	16																4	4	4	4									
5	18																		5	5	5	5	5						
1	20																				1								
2	20																				2	2							
2	20																				2	2							
7	21																					7	7	7	7	7	7	7	7
6	23																							6	6	6	6	6	6
2	25																									2	2		
3	26																											3	3	3
	Total patier	1	1	3	3	4	4	3	4	3	6	6	10	10	9	8	10	9	10	8	9	8	5	5	4	5	6	5	4

Figure 7.4 Graphical representation of scheduling patients for S2

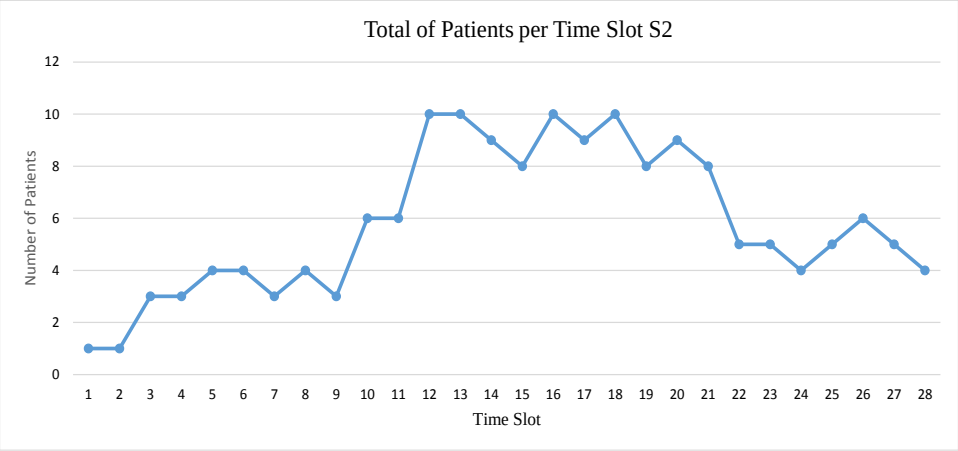


Figure 7.5 Total patients per time slot of S2

Scenario 3 (S3): It is composed of 24 patients allocating 50% for middle duration group and 25% for short and long duration groups Figure 7.6 shows the optimal distribution of patient's appointment of S3. From the graph was concluded that 100% of patients of long duration group and 41% of the middle duration group should be assigned no later than noon. Figure 7.7 shows a balanced workload for S3.

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
6	1	6	6	6	6	6	6																						
9	1	9	9	9	9	9	9	9	9	9	9	9																	
10	1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
5	1	5	5	5	5	5																							
9	3			9	9	9	9	9	9	9	9	9	9	9															
8	3			8	8	8	8	8	8	8	8	8																	
12	3			12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
10	3			10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10										
8	6						8	8	8	8	8	8	8	8	8														
8	6						8	8	8	8	8	8	8	8	8														
7	6						7	7	7	7	7	7	7	7															
1	9									1																			
1	9									1																			
11	10										11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
2	10										2	2																	
4	12												4	4	4	4													
3	16																3	3	3										
5	16																5	5	5	5	5								
7	19																			7	7	7	7	7	7	7	7		
6	21																					6	6	6	6	6	6		
7	21																					7	7	7	7	7	7	7	7
2	23																							2	2				
6	23																							6	6	6	6	6	6
5	24																								5	5	5	5	5
	Total c	4	4	8	8	8	10	9	9	11	11	11	9	9	7	5	6	5	5	4	4	5	5	7	7	6	6	4	4

Figure 7.6 Graphical representation of scheduling patients for S3

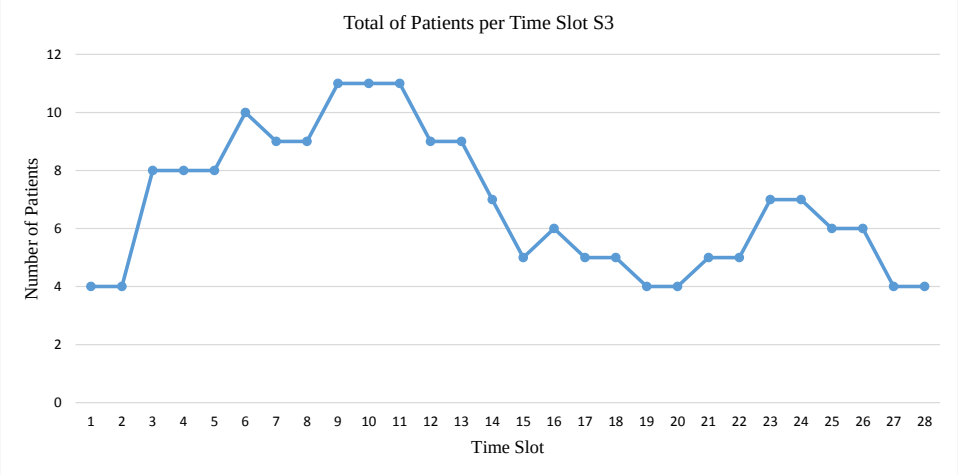


Figure 7.7 Total patients per time slot of S3

Scenario 4 (S4): It is composed of 24 patients allocating 50% for long duration group and 25% for short and middle duration groups. Figure 7.8 shows the optimal distribution of patient's appointment of S4. From the graph was concluded that 83% of patients of long duration group and 50% of the middle duration group should be assigned as later than at noon. Figure 7.9 shows a balanced workload for S4.

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
8	1	8	8	8	8	8	8	8	8	8																			
10	1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
11	1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11									
12	1	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12							
2	5					2	2																						
11	5					11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11					
11	5					11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11					
5	6						5	5	5	5	5																		
10	7							10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
12	8							12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
12	8							12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
3	12												3	3	3														
6	12												6	6	6	6	6	6											
9	12												9	9	9	9	9	9	9	9	9	9	9						
10	12												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
1	16																1												
4	16																4	4	4	4									
2	18																		2	2									
9	18																		9	9	9	9	9	9	9	9	9	9	9
9	18																		9	9	9	9	9	9	9	9	9	9	9
7	21																					7	7	7	7	7	7	7	7
1	23																							1					
6	23																							6	6	6	6	6	6
5	24																								5	5	5	5	5
Total of Patients per T		4	4	4	4	7	8	10	10	10	9	8	12	12	12	11	13	11	13	13	10	11	10	10	8	8	8	8	5

Figure 7.8 Graphical representation of scheduling patients for S4

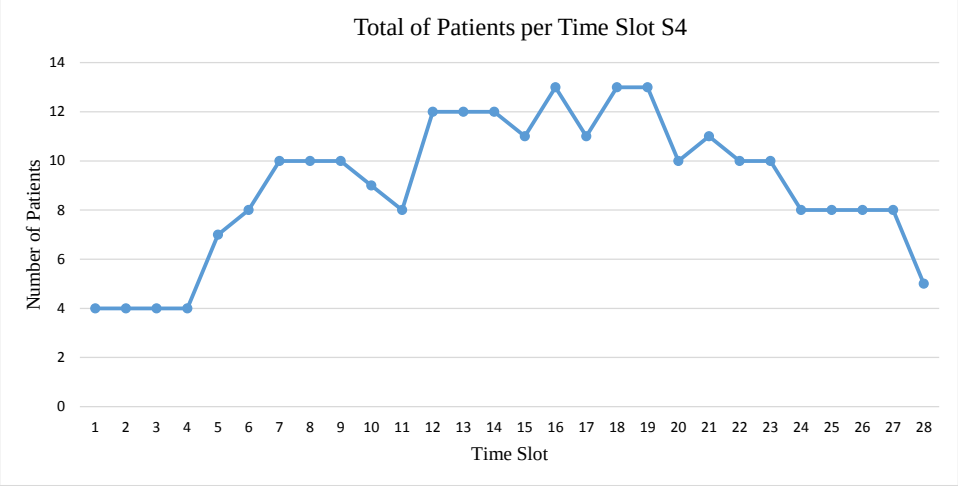
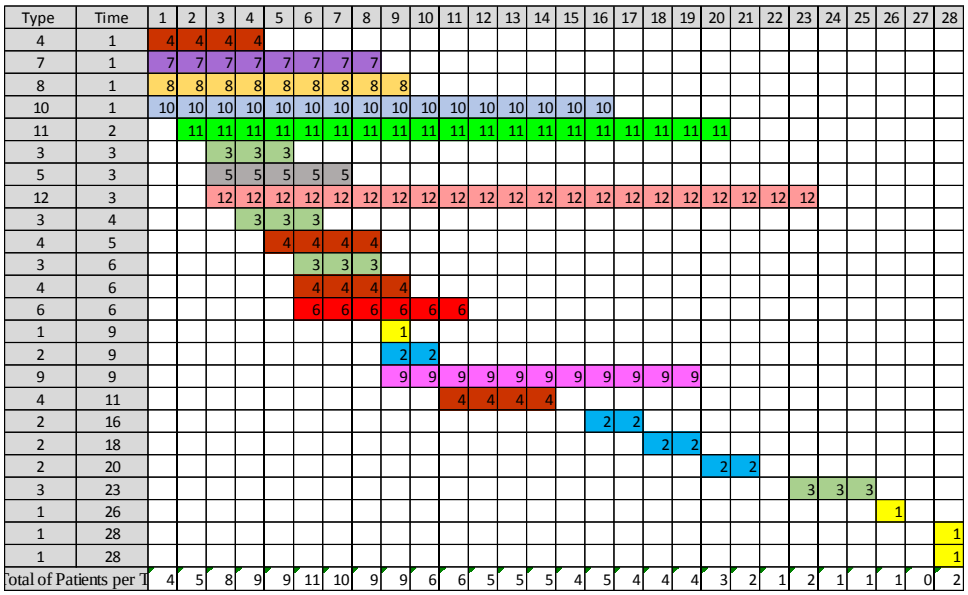


Figure 7.9 Total patients per time slot of S4

Scenario 5 (S5): It is composed of 24 patients allocating 70% for short duration group and 15% for middle and long duration groups. Figure 7.10 shows the optimal distribution of patient's appointment of S5. From the graph was concluded that 100% of patients of long duration group and 100% of the middle duration group should be assigned

no later than noon. Figure 7.11 shows a balanced workload for S5. The figure shows that the short duration group is allocated in the end of the day.



Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
4	1	4	4	4	4																								
7	1	7	7	7	7	7	7	7	7																				
8	1	8	8	8	8	8	8	8	8	8																			
10	1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
11	2		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11								
3	3			3	3	3																							
5	3			5	5	5	5	5																					
12	3			12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
3	4				3	3	3																						
4	5					4	4	4	4																				
3	6						3	3	3																				
4	6						4	4	4	4																			
6	6						6	6	6	6	6	6																	
1	9									1																			
2	9									2	2																		
9	9									9	9	9	9	9	9	9	9	9	9	9									
4	11											4	4	4	4														
2	16																2	2											
2	18																		2	2									
2	20																				2	2							
3	23																							3	3	3			
1	26																										1		
1	28																												1
1	28																												1
Total of Patients per T		4	5	8	9	9	11	10	9	9	6	6	5	5	5	4	5	4	4	4	3	2	1	2	1	1	1	0	2

Figure 7.10 Graphical representation of scheduling patients for S5

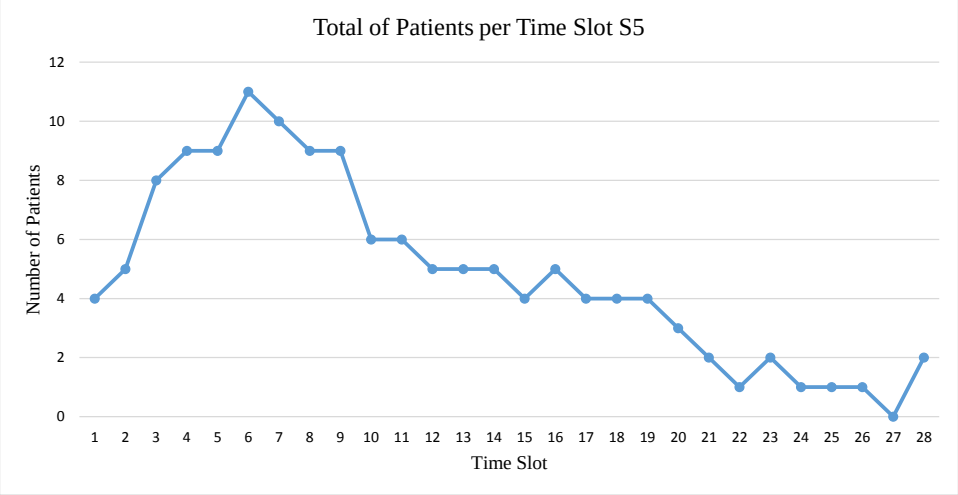


Figure 7.11 Total patients per time slot of S5

Scenario 6 (S6): It is composed of 24 patients allocating 70% for middle duration group and 15% for short and long duration groups. Figure 7.12 shows the optimal

distribution of patient's appointment of S6. From the graph was concluded that 100% of patients of long duration group should be assigned no later than noon. Figure 7.13 shows an unbalanced workload for S6.

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
7	1	7	7	7	7	7	7	7	7																				
8	1	8	8	8	8	8	8	8	8	8																			
8	1	8	8	8	8	8	8	8	8	8																			
10	1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
11	5					11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11					
5	6						5	5	5	5	5																		
7	6						7	7	7	7	7	7	7	7															
8	8								8	8	8	8	8	8	8	8	8												
12	8								12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
1	10										1																		
5	12												5	5	5	5	5												
6	17																	6	6	6	6	6	6						
7	18																		7	7	7	7	7	7	7	7			
8	18																		8	8	8	8	8	8	8	8	8		
9	18																		9	9	9	9	9	9	9	9	9	9	9
5	19																			5	5	5	5	5					
6	19																			6	6	6	6	6	6				
4	21																					4	4	4	4				
7	21																					7	7	7	7	7	7	7	7
6	23																							6	6	6	6	6	6
6	23																							6	6	6	6	6	6
5	24																								5	5	5	5	5
3	26																										3	3	3
2	27																											2	2
otal of Patients per T		4	4	4	4	5	7	7	9	8	7	5	6	6	5	5	5	3	6	8	8	10	10	11	10	8	8	8	8

Figure 7.12 Graphical representation of scheduling patients for S6

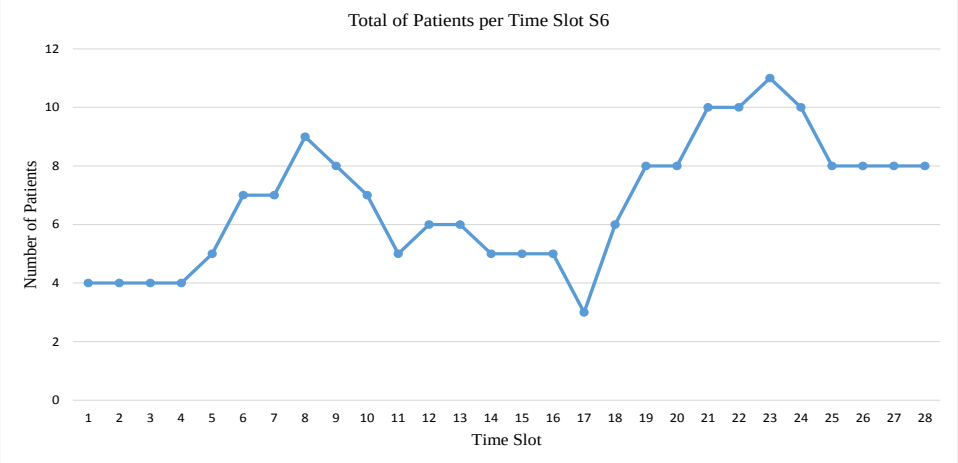


Figure 7.13 Total patients per time slot of S6

Scenario 7 (S7): It is composed of 24 patients allocating 70% for long duration group and 15% for short and middle duration groups. Figure 7.14 shows the optimal distribution of patient's appointment of S6. From the graph was concluded that 100% of patients of long duration group should be assigned no later than noon. Figure 7.15 shows an unbalanced workload for S7. Most of the patient demand is located early morning, and the afternoon doesn't shows so much activity.

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
9	1	9	9	9	9	9	9	9	9	9	9	9																	
11	1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11									
11	1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11									
10	2		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10											
10	2		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10											
11	2		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11								
11	2		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11								
12	3			12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
12	3			12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
12	3			12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
8	4				8	8	8	8	8	8	8	8	8																
9	4				9	9	9	9	9	9	9	9	9	9	9														
12	4				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
3	5					3	3	3																					
7	5					7	7	7	7	7	7	7	7																
1	7							1																					
5	9									5	5	5	5	5															
2	11											2	2																
10	11											10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10		
10	12												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
4	16																4	4	4	4									
6	16																6	6	6	6	6	6							
9	16																9	9	9	9	9	9	9	9	9	9	9		
9	16																9	9	9	9	9	9	9	9	9	9	9		
Total of Patients per T		3	7	10	13	15	15	16	14	15	15	17	17	14	13	12	16	16	14	14	11	9	8	8	5	4	4	1	0

Figure 7.14 Graphical representation of scheduling patients for S7

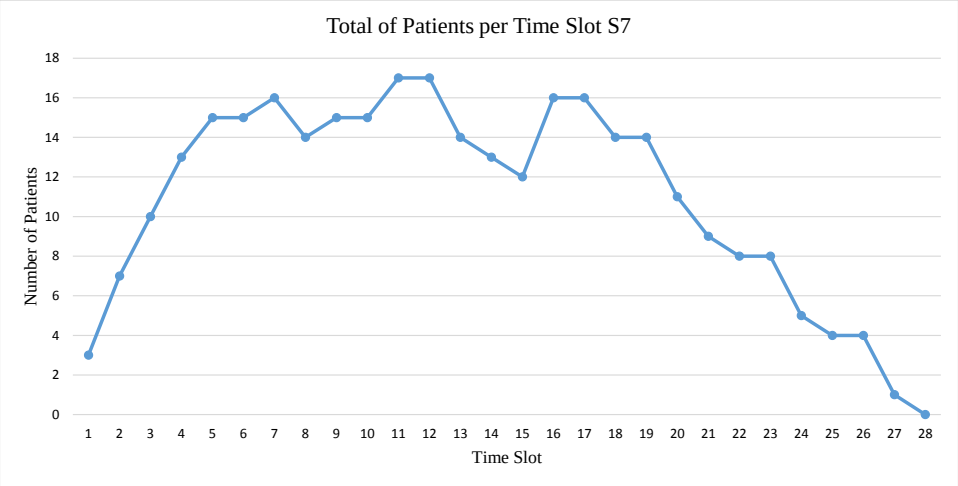


Figure 7.15 Total patients per time slot of S7

Scenario 8 (S8): It is composed of 36 patients distributed equally among the groups which represented twelve (12) for short, middle, and long group. Figure 7.16 shows the optimal distribution of patient's appointment of S8. From the graph was concluded that 100% of patients of long duration group should be located no later than noon. Figure 7.3 shows a balanced workload for S8.

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
2	2		2	2																									
8	2		8	8	8	8	8	8	8	8	8																		
8	2		8	8	8	8	8	8	8	8	8																		
11	2		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11								
4	3			4	4	4	4																						
5	3			5	5	5	5	5																					
5	3			5	5	5	5	5																					
5	3			5	5	5	5	5																					
3	4				3	3	3																						
8	4				8	8	8	8	8	8	8	8	8																
10	4				10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10								
12	4				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12			
2	5					2	2																						
7	5					7	7	7	7	7	7	7	7																
2	6					2	2																						
7	6					7	7	7	7	7	7	7	7																
9	6						9	9	9	9	9	9	9	9	9	9	9												
11	6						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11				
7	7							7	7	7	7	7	7	7	7														
10	7							10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
10	7							10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
12	7							12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
9	8								9	9	9	9	9	9	9	9	9	9	9										
9	8								9	9	9	9	9	9	9	9	9	9	9										
11	8								11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11		
12	8								12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
6	11											6	6	6	6	6	6												
3	17																	3	3	3									
6	19																			6	6	6	6	6	6				
3	20																				3	3	3						
4	21																					4	4	4	4				
6	22																						6	6	6	6	6	6	
4	23																							4	4	4	4		
1	28																												1
1	28																												1
1	28																												1
otal of Patients per T		0	4	8	11	15	17	17	18	18	18	17	17	14	14	13	13	12	12	11	10	10	11	9	9	5	5	3	4

Figure 7.16 Graphical representation of scheduling patients for S8

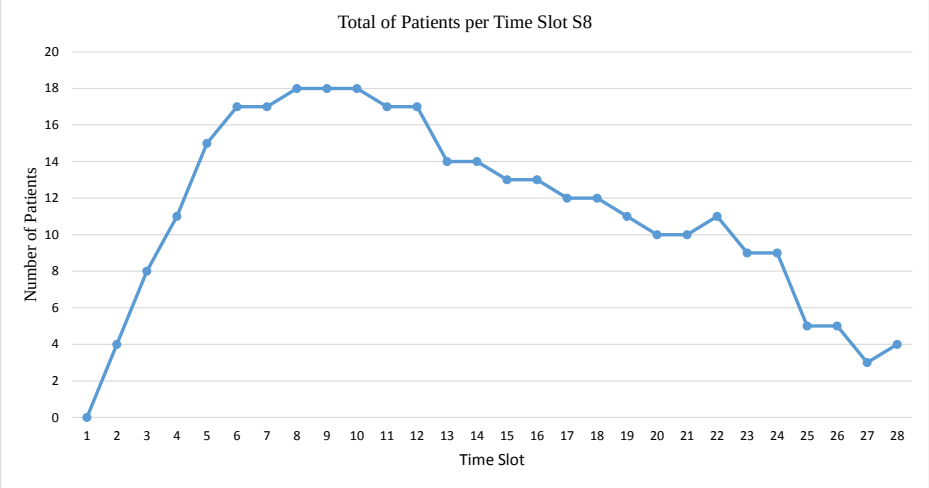
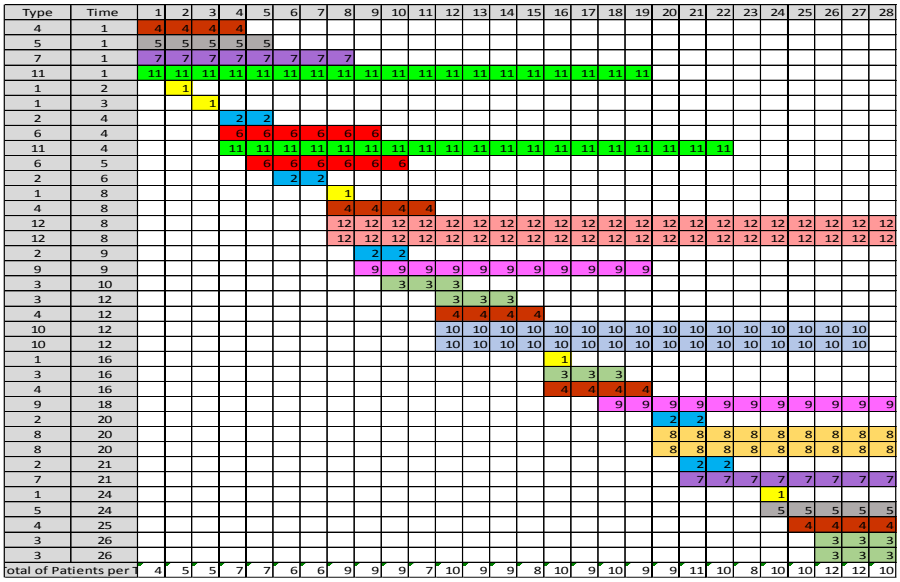


Figure 7.17 Total patients per time slot of S8

Scenario 9 (S9): It is composed of 36 patients allocating 50% for short duration group and 25% for middle and long duration groups. Figure 7.16 shows the optimal distribution of patient's appointment of S9. From the graph was concluded that 87.5% of patients of long duration group and 50 % of the middle duration group should be assigned no later than noon. Figure 7.17 shows a balanced workload for S9.



Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
4	1	4	4	4	4																								
5	1	5	5	5	5	5																							
7	1	7	7	7	7	7	7	7	7																				
11	1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11									
1	2		1																										
1	3			1																									
2	4				2	2																							
6	4				6	6	6	6	6	6																			
11	4				11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11						
6	5					6	6	6	6	6	6																		
2	6						2	2																					
1	8								1																				
4	8								4	4	4	4																	
12	8								12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
12	8								12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
2	9									2	2																		
9	9									9	9	9	9	9	9	9	9	9	9	9									
3	10										3	3	3																
3	12												3	3	3														
4	12												4	4	4	4													
10	12												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
10	12												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
1	16																1												
3	16																3	3	3										
4	16																4	4	4	4									
9	18																		9	9	9	9	9	9	9	9	9	9	9
2	20																				2	2							
8	20																				8	8	8	8	8	8	8	8	8
8	20																				8	8	8	8	8	8	8	8	8
2	21																					2	2						
7	21																					7	7	7	7	7	7	7	7
1	24																								1				
5	24																								5	5	5	5	5
4	25																									4	4	4	4
3	26																										3	3	3
3	26																										3	3	3
otal of Patients per T		4	5	5	7	7	6	6	9	9	9	7	10	9	9	8	10	9	10	9	9	11	10	8	10	10	12	12	10

Figure 7.18 Graphical representation of scheduling patients for S9

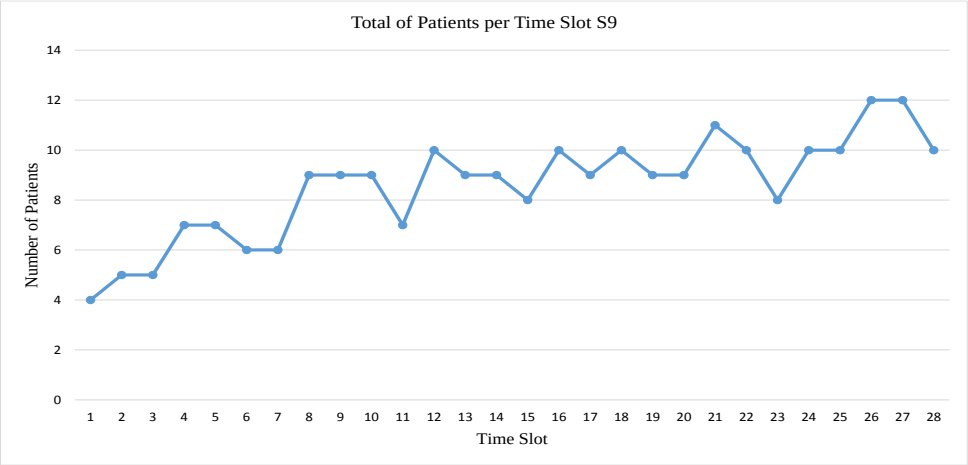


Figure 7.19 Total patients per time slot of S9

Scenario 10 (S10): It is composed of 36 patients allocating 50% for middle duration group and 25% for short and long duration groups Figure 7.18 shows the optimal distribution of patient's appointment of S10. From the graph was concluded that 100% of patients of long duration group and 90% of the middle duration group should be assigned no later than noon. Figure 7.19 shows a balanced workload for S10.

Scenario 12 (S12): It is composed for 36 patients allocating 70% for short duration group and 15% for middle and long duration groups. Figure 7.20 shows the optimal distribution of patient's appointment of S5. From the graph was concluded that 75% of patients of long duration group and 100% of the middle duration group should be assigned no later than noon. Figure 7.21 shows a balanced workload for S12.

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
8	2	8	8	8	8	8	8	8	8	8																			
7	2		7	7	7	7	7	7	7	7																			
11	2		11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11								
8	2		8	8	8	8	8	8	8	8	8																		
5	3			5	5	5	5	5																					
5	3			5	5	5	5	5																					
8	3			8	8	8	8	8	8	8	8	8																	
7	3			7	7	7	7	7	7	7	7																		
7	4				7	7	7	7	7	7	7	7																	
12	4				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
7	4				7	7	7	7	7	7	7	7																	
8	4				8	8	8	8	8	8	8	8	8																
2	5					2	2																						
3	5					3	3	3																					
7	5					7	7	7	7	7	7	7	7																
1	6						1																						
10	6						10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10							
2	6						2	2																					
10	7							10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
1	7							1																					
11	7							11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11			
9	8								9	9	9	9	9	9	9	9	9	9	9										
8	8								8	8	8	8	8	8	8	8	8												
9	8								9	9	9	9	9	9	9	9	9	9	9										
12	8								12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
6	9									6	6	6	6	6	6														
6	10										6	6	6	6	6	6													
5	11											5	5	5	5	5													
6	11											6	6	6	6	6	6												
6	11											6	6	6	6	6	6												
6	12												6	6	6	6	6	6											
3	20																				3	3	3						
4	20																				4	4	4	4					
5	21																					5	5	5	5	5			
4	22																						4	4	4	4			
5	23																							5	5	5	5	5	
otal of Patients per T		1	4	8	12	15	18	19	18	19	18	19	17	15	15	14	12	9	8	6	8	8	8	7	6	5	2	2	1

Figure 7.20 Graphical representation of scheduling patients for S10

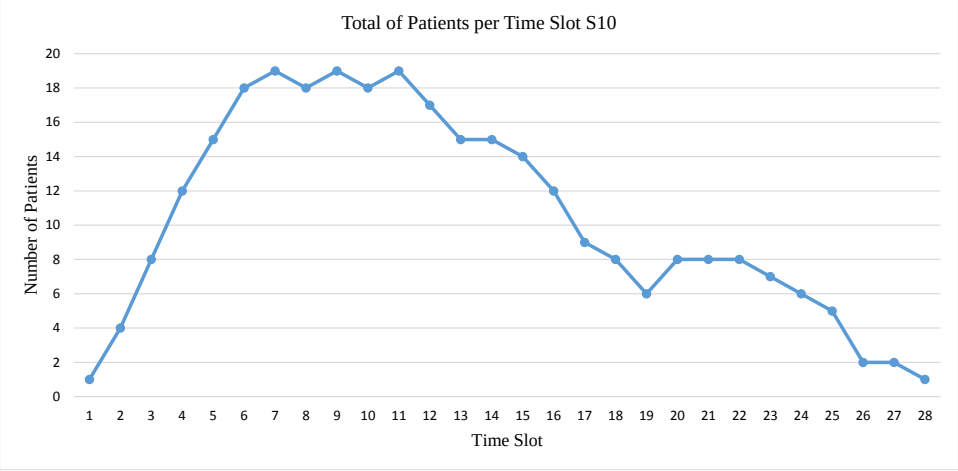


Figure 7.21 Total patients per time slot of S10

Type	Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
4	1	4	4	4	4																								
5	1	5	5	5	5	5																							
3	1	3	3	3																									
12	1	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12							
1	2		1																										
2	2		2	2																									
2	2		2	2																									
1	3			1																									
8	3			8	8	8	8	8	8	8	8	8																	
4	4				4	4	4	4																					
10	5					10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10								
3	5					3	3	3																					
6	6						6	6	6	6	6	6																	
1	7							1																					
2	7							2	2																				
2	8								2	2																			
7	9									7	7	7	7	7	7	7	7												
11	10										11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
4	12												4	4	4	4													
4	12												4	4	4	4													
3	12												3	3	3														
3	12												3	3	3														
3	16																3	3	3										
2	16																2	2											
1	18																		1										
9	18																		9	9	9	9	9	9	9	9	9	9	9
4	20																				4	4	4	4					
2	20																				2	2							
4	22																						4	4	4	4			
1	24																								1				
4	25																									4	4	4	4
2	25																									2	2		
1	25																									1			
3	26																										3	3	3
3	26																										3	3	3
1	27																											1	
otal of Patients per T		4	7	8	5	6	6	8	6	6	6	6	8	8	8	6	6	5	6	4	6	5	4	4	4	6	6	6	5

Figure 7.22 Graphical representation of scheduling patients for S12

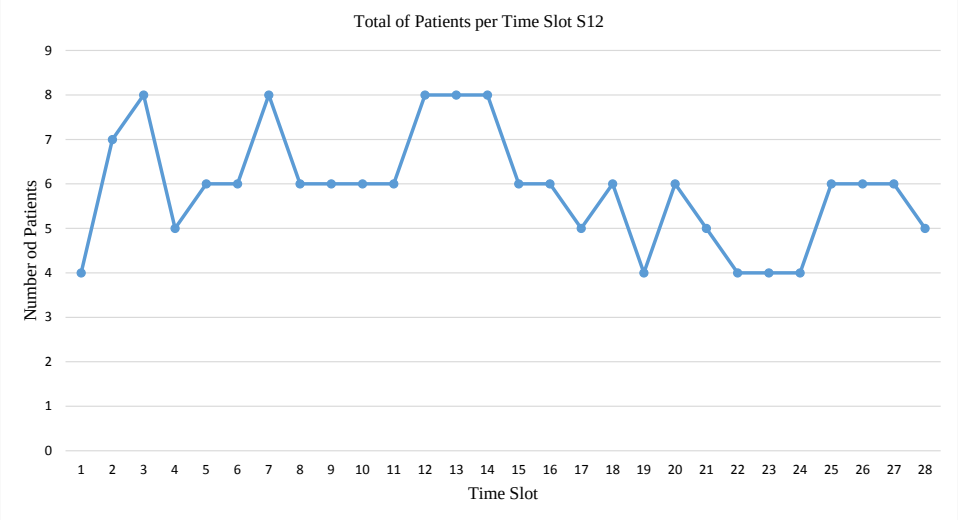


Figure 7.23 Total patients per time slot of S12

Scenario 11 (S11): It is composed of 36 patients allocating 50% for long duration group and 25% for short and middle duration groups. This patient mix was not feasible which means the mathematical model was not able to provide a solution keeping the area requirements

Scenario 13 (S13): It is composed of 36 patients allocating 70% for middle duration group and 15% for middle and long duration groups. This patient mix was not feasible which means the mathematical model was not able to provide a solution keeping the area requirements

Scenario 14 (S14): It is composed of 36 patients allocating 70% for long duration group and 15% for short middle duration groups. This patient mix was not feasible which means the mathematical model was not able to provide a solution keeping the area requirements.

After analyzing the previous scenarios, this study established some general rules that should be followed to build a balanced scheduling system. Overall, long duration appointments should not be programed after midday; as well as the 50 % of middle duration appointments. The infusion area should not receive more than 85 % of middle and long duration. Additionally, the cancer center should not work with a patient mix where total number of long duration patients overpass a value of 18 patients per day.

CHAPTER 8

CONCLUSIONS

This research was divided into six (6) phases with the aim of maximizing resource utilization in Bozeman Deaconess Cancer Center without overloading the human resources. To achieve this, eight (8) hypotheses were developed and tested which resulted in three main contributions of this research. The first contribution was focused on measuring, comparing and validating workload tools. The second contribution was focused on incorporating workload measurements into a mathematical model. The third contribution was focused on the development of scheduling polices for an oncology clinic. This chapter summarizes all the findings giving responses to each of the hypotheses proposed in Chapter 1. For convenience, Figure 8.1 displays the research overview proposed in Chapter 1.

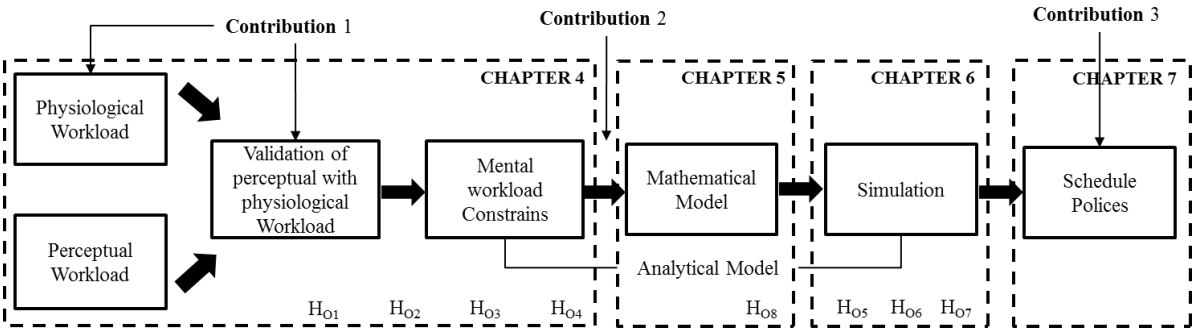


Figure 8.1 Research Overview Summary

Contribution 1

H_{01} *Physiological responses and number of patients seen during the day in infusion area are correlated.*

Chapter 4 performed a correlation analysis of number of patients among physiological responses. The analysis found no correlation between these variables. However a positive strong correlation between the *number of patients* and the *acuity leve*l was found ($= 0.927;\ p - value = 0.000$). Therefore, the study did not considered acuity level in the modeling of the human factor constraint. This variable was removed from the model to avoid multicollinearity between the variables.

H_{02} *The workload measurements obtained from NASA-TLX are correlated to SWAT measurements.*

Chapter 4 performed a comparative analysis between NASA-TLX and SWAT. The objectives were to compare the overall results between NASA-TLX and C-SWAT, and then compare each individual dimension for both tests.

A Pearson product-moment correlation coefficient was computed to assess the relationship between C-SWAT and NASA-TLX. Results showed a positive correlation between the two variables ($\rho = 0.691$; n= 147; p-value = 0.0001). Overall, there was a positive correlation between both methods; however, the correlation value was not exceptionally high which suggests differences between both instruments.

Additional analysis were completed such as Regression Analysis, Principal Component Analysis (PCA), and Multi Adaptive Regression Spines (MARS). The results showed that NASA- TLX was a better predictor for C-SWAT than C-SWAT was to

NASA-TLX. In other words, NASA-TLX covers all the dimensions that are measured by C-SWAT. The results also suggest that a difference between both tools is found in the fact that C-SWAT doesn't have the capability to integrate the perception of performance and frustration. The findings were used in the decision of which, entail workload measuring tools to use in the regression model. It was decided to drop the C-SWAT values.

H_{03} *The workload measurements obtained from NASA-TLX are similar to the measurement obtained from the equal weight calculation method.*

A correlation analysis was conducted to compare the scores obtained with preference weight and with equal weights on Chapter 4. The results established that there was no significant difference between the overall score of NASA-TLX using preference weight or equal weight. However, there was no correlation between the values for each dimension at the individual level. Consequently, NASA-TLXEW (equal weight) could be used in cases where the individual analysis of a dimension is not relevant which will eliminate one step in the methodology. On the other hand, if researchers are interested in considering one or more dimensions independently, then the preference weights would be a better approach.

H_{04} *The workload measurements obtained from the NASA-TLX and the physiological responses are correlated.*

This research established the correlation between NASA-TLX and physiological responses using a regression analysis. A model was calculated to predict mental workload (NASA-TLX) based on number of patients, hearth rate (HR), breathing rate (BR), and

ECG. A significant regression equation was found with an R^2 of 36.47%. The following equation summarized the model.

$$NASA - TLX = 22 + 3.83(\#\ of\ patients) - 0.710(HR) + 3.002(BR) + 1.105(ECG) \quad (4.2)$$

This research used this equation to calculate the number of patients that a nurse can handle without impacting level of stress and workload.

Contribution 2

H_{05} *The total cycle time of patients in the real system and the simulation model are equal.*

Chapter 6 exposed that the simulation model was not significantly different from the historical data; in other words, the simulation model represents satisfactorily the process of the infusion area which makes it suitable to be used to compare the scheduling models.

H_{06} *The total cycle time of patients in the actual system and the proposed model are equal.*

The mathematical model developed in Chapter 5 represented changes that did not worsen the total patient time in the system in 80% of the cases. In other words, this research didn't find significant differences between actual and the proposed schedule containing from the mathematical model.

H_{07} *The number of patients that are serviced during a day in the Cancer Center will increase with the new schedule policies.*

The mathematical model (Chapter 5) allows the cancer center to allocate patient's appointments in a more balanced manner resulting in an increased capacity ranging from 15% to 40% without significantly impacting the total average time per patient.

H_{08} *The percentage of the chair utilization of the infusion area will increase with the new scheduling policies.*

The mathematical model improved the schedule in the infusion area in two ways 1) it balanced the patient schedule avoiding peaks caused by patient arrivals (Chapter 5), and 2) it helps to increase the capacity of the cancer center in at least 15% (Chapter 6) which will increase infusion chair utilization.

In summary this research was able to answer all the research questions through the different chapters of this thesis which are shown on Figure 8.1. In conclusion this thesis work was able to successfully build a patient scheduling model considering nurses' workload. It was proved that the model balanced patient appointments through the day by leveling the workload of nurses and pharmacists. Also, the sensitivity analysis showed that even the patient demand of the cancer center could be increased up to 40% in some instances without negatively impact patient service. This research is one of the first of its kind to include mental workload as a mathematical constraints in a scheduling model.

REFERENCES CITED

[1] T. Rice, P. Rosenau, L. Unruh and A. Barnes, "United States of America: Health system review," *Health Systems in Transition,* vol. 15, no. 3, pp. 1-413, 2013.

[2] K. Davis, K. Stremikis, D. Squires and C. Schoen, "Mirror, Mirror on the Wall How the Performance of the U.S. Health Care System Compares Internationally," The Commonwealth Fund, New York, 2014.

[3] K. Lohr, "Committee to Design a Strategy for Quality Review and Assurance in Medicare, eds. Medicare: a strategy for quality assurance," National Academy Press, Washington, DC, 1990.

[4] P. H.-. Mitchell and N. M. Lang, "Framing the problem of measuring and improving healthcare quality: has the Quality Health Outcomes Model been useful?," *Medical Care,* vol. 42, no. 2, pp. 4-11, 2004.

[5] American Cancer Society, "Cancer Facts & Figures 2016," American Cancer Society, Atlanta, 2016.

[6] Bozeman Decanoess Cancer Center , "2011 Annual Report - Head and Neck Cancers," Bozeman Deaconess Hospital , Bozeman , 2011.

[7] E. Burke , T. Curtois, T. E. Nordlander and A. Riise, "Scheduling and Sequencing," in *Handbook of Helathcare Delivery Systems* , New York , Taylor & Francis Group, 2011, pp. 2301-2315.

[8] B. Denton , A. Rahman, H. Nelson and A. Bailey, "Simulation of a Multiple Operating Room Surical Suit," in *Winter Simulation Conference,* 2006.

[9] F. Coelli , R. Ferreira, R. Almeida and W. Pereira, "Computer simulation and discrete-event models in the analysis of a mammography clinic patient flow," *Computer methods and programs in biomedicine,* vol. 87, no. 3, pp. 201-207, 2007.

[10] C. Duguay and F. Chetouane, "Modeling and improving emergency department systems using discrete event simulation," *Simulation ,* vol. 83, no. 4, pp. 311-320, 2007.

[11] A. Huggins, M. Lovejoy, L. Page, M. Rahman, G. Lommatsch, A. Miller and D. Claudio , "A Complete Methodology to Simulate a Complex Healthcare System," in *Industrial and Systems Engineering Research Conference,* Orlando, 2012.

[12] K. Henriksen, E. Dayton, M. Keyes, P. Carayon and R. Hughes, "Understanding Adverse Events: A Human," in *Patient Safety and Quality: An Evidence-Based Handbook for Nurses*, 2008, pp. 1-19.

[13] "Agency for Healthcare Research and Quality," U.S. Department of Health & Human Services, October 2012. [Online]. Available: http://psnet.ahrq.gov/primer.aspx?primerID=20. [Accessed 02 December 2014].

[14] J. M. Leedal and A. F. Smith, "Methodogical Approaches to Anaesthetists Workload in the Operating Theatre," *British Journal of Anaesthesia,* vol. 94, no. 6, pp. 702-709, 2005.

[15] D. K. Milchell, "Mental Worload and ARL Worload Modeling Tools," Army Research Laboratory, 2000.

[16] J. Jun, S. Jacobson and J. Swisher, "Application of discrete-event simulation in health care clinics: A survey," *Journal of the operational research society ,* vol. 50, no. 2, pp. 109-123, 1999.

[17] S. Jacobson, S. Hall and J. Swisher, "Discrete-event simulation of health care systems," in *In Patient flow: Reducing delay in healthcare delivery*, Springer US, 2006, pp. 211-252.

[18] Bozeman Deaconess Cancer Center, "Bozeman Deaconess Hospital Joins Seattle Cancer Care Alliance Affiliate Network," [Online]. Available: http://www.prnewswire.com/news-releases/bozeman-deaconess-hospital-joins-seattle-cancer-care-alliance-affiliate-network-86227432.html. [Accessed 03 March 2013].

[19] M. Carswell, D. Clarke and B. Seales , "Assesing Mental Workload During Lapariscopic Surgery," *Surgical Innovation,* vol. 12, no. 1, pp. 80-90, 2005.

[20] P. Hoonakker, . P. Carayon, A. Gurses, . R. Brown, A. Khunlertkit, K. McGuire, and J. Walker, "Measuring workload of ICU nurses with a questionnaire survey: the NASA task load index (TLX).," *IIE transactions on healthcare systems engineering* , vol. 1, no. 2, pp. 131-143, 2011.

[21] D. Neill, "Nursing Workload and the Changing Health Care Environment: A Review of the Literature," *Administrative Issues Journal: Education, Practice, and Research* , vol. 1, no. 2, pp. 132-141, 2010.

[22] G. Young, L. Zavelina and V. Hooper, "Assessment of workload using NASA Task Load Index in perianesthesia nursing," *Journal of PeriAnesthesia Nursing,* vol. 23, no. 2, pp. 102-110, 2008.

[23] R. Morris, P. MacNeela, A. Scott, P. Trascy and A. Hyde, "Reconsidering the conceptulization of nursing workload: Literature Review," *The Authors, Journal Compilation* , pp. 463-471, 2007.

[24] S. Rubio , E. Diaz and J. Martin, "Evaluation of Subjective Mental Workload: A Comparision of SWAT. NASA-TXL, and Workload Profile Methods," *International Association for Applied Psychology,* vol. 53, no. 1, pp. 61-86, 2004.

[25] M. Tomic and E. Tomic, "Existential fulfilment, workload and work engagement among nurses," *Journal of Research in Nursing,* vol. 16, no. 5, pp. 468-479, 2011.

[26] L. O'Brien-Pallas, D. Irvine, E. Peereboom and M. Murray, "Measuring Nussing Workload: Understanding the Variablity," *Nursing Economic* , pp. 171-182, 1997.

[27] K. Brookhuis and D. Waard, "Monitoring drivers' mental workload in driving simulators using physiological measures," *Accident Analysis and Prevention,* pp. 898-903, 2010.

[28] K. Ryu and R. Myung, "Evaluation of mental workload with a combined measure based on physiological indices during a dual task of tracking and mental arithmetic," *International Journal of Industrial Ergonomics,* pp. 991-1009, 2005.

[29] A. DiDomenico and N. Maury , "Effects of different physical workload parameters on mental workload and performance," *International Journal of Industrial Ergonomics,* pp. 255-260, 2010.

[30] S. Miyake, "Multivariate workload evaluation combining physiological and subjetive measure," *International Journal of Psychophysiology,* pp. 233-238, 2001.

[31] J. Saleem , E. Patterson, L. Militello, S. Anders, M. Falciglia, J. Wissman and E. Roth, "Impact of Clinical Reminder Redesign on Learnability, Efficiency,

Usability, and Workload for Ambulatory Clinic," *Journal of the American Medical Informatics Association,* vol. 14, pp. 632-640, 2007.

[32] S. G. Hart, "NASA-Task Load Index (NASA-TLX); 20 Years Later," *NASA Ames Research Center*, pp. 1-5, 2006.

[33] S. Hart and L. Staveland, "Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research," *Advances in psychology,* vol. 52, pp. 139-183, 1988.

[34] T. Rutledge, E. Stucky, A. Dollarhide, M. Shively, S. Jain, T. Wolfson, M. Weinger and T. Dresselhaus, "A real-time assessment of work stress in physicians and nurses," *Health Psychology ,* vol. 28, no. 2, p. 194, 2009.

[35] L. Lin, K. Vicente and J. Doyle, "Patient safety, potential adverse drug events, and medical device design: a human factors engineering approach," *Journal of biomedical informatics,* vol. 34, no. 4, pp. 274-284, 2001.

[36] L. Scott, D. France, R. Hemphill, I. Jones, K. Chen, D. Rickard, R. Makowski and D. Aronsky, "Tracking workload in the emergency department," *Human Factors: The Journal of the Human Factors and Ergonomics Society,* vol. 48, no. 2, pp. 526-539, 2006.

[37] J. Møller-Jensen, J. Simonsen and R. Iversen, "Measuring effects on the clinical practice from a configured EHR," *In Scandinavian Conference on Health Informatics*, pp. 58-62, 2006.

[38] G. Reid, P. Scott and B. Jeine, "Subjective Workload Assessment Technique (SWAT): A User's Guide (U)," Armstrong Aerospace Medical Research Laboratory , Ohio, 1989.

[39] G. B. Reid and T. E. Nygren, "The subjective workload assessment Technique : a scaling procedure for measure mental workload," *Advances in Psychology,* vol. 52, pp. 185-218, 1988.

[40] S. Rubio, E. Diaz, J. Martin and J. Puente, "Evaluation of Subjective Mental Workload: A Comparison of Swat, NASA-TLX, and Workload Profile Methods," *Applied Psychology: and Internal Review,* vol. 53, no. 1, pp. 61-86, 2004.

[41] J. Jacoboson , S. Bolon , N. Elder , B. Schroer, G. Matthews, J. Sza-arski, M. Raphaelson and R. Horner, "Temporal and Subjective Work Demands in Office-Bases Patient Care an Exploration of the Dimansions of Physician Work Intensivity," *Medical Care,* vol. 49, no. 1, pp. 52-58, 2011.

[42] W. Moroney , D. Biers and T. Eggemeier, "Some Measurement and Methodological Considerations in the Application of Subjetive Workload Measurement Techniques," *The International Journal of Aviation Psychology ,* vol. 5, no. 1, pp. 87-106, 1995.

[43] J. Ruscio , "Holistic Judgment in Clinical Practice Utility or Futility?," *The Scientific Review of mental ,* vol. 2, pp. 1-18, 2003.

[44] A. Huggins , D. Shuchisnigdha, D. Claudio and . M. A. Velazquez, "A Holistic Approach for Integrated Decision Making in Healthcare Systems," in *Industrial and Systems Engineering Research Conference ,* Puerto Rico , 2013.

[45] M. Van Houdenhoven , J. Van Oostrum, E. Hans, G. Wullink and G. Kazemier, "Improving Operating Room Efficency by Appying Bin-Packing Portafolio Techniques to Surical Case Scheduling," *Anesthesian and Analgesia ,* vol. III, no. 105, pp. 707-714, 2007.

[46] I. Ozcarahan , "Allocation of Surgeries to Operating Rooms by Goal Progarming," *Journal of Medical Systems,* vol. 24, no. 6, pp. 339-378, 2000.

[47] J. Welch and N. Bailey, "Appoiment system hospital outpatient deparments," *The Lancet,* vol. 259, pp. 1105-1108, 1952.

[48] S. Kachhal , G. Klutke and E. Daniels, "Two simulation apliactions to outpatients clinics," in *13th Conference on Winter Simulation,* 1981.

[49] W. England and S. Roberts , "Applications of computer simulation in helath care," in *10 th conference on Winter Simulation,* 1978.

[50] R. Klein , R. Dittus, S. Roberts and J. Wilson , "Simulation Modeling and Helathcare," *Medical Decision Making,* vol. 13, pp. 347-354, 1993.

[51] J. Jun , S. Jacobson and J. Swisher, "Application of discrete-event simulation in health care clinics: A survey," *Journal of the operational research society,* vol. 50, no. 2, pp. 109-123, 1999.

[52] F. Baesler and J. Sepulveda, "Multi-Response Simulation Optimization Ussing Stochastic Genetic Search within a Goal Programming Framework," in *Winter Simulation Conference*, 2000.

[53] F. Baesler and J. Sepulveda, "Multi-Objective Simulation Optimization for Cancer Treatment Center," in *Winter Simulation Conference*, 2001.

[54] J. Swisher , B. Jun, S. Jacobson and O. Balci, "Simulation of Queston physician network," in *29th conference on Winter Simulation*, 1997.

[55] J. Swisher, S. Jacobson, B. Jun and O. Bacil, "Modeling and analyzing a physician clinic environment using discrete-event (visual) simulation," *Computers & Operations Research*, vol. 28, pp. 105-125, 2001.

[56] P. Harper and H. Gamlin , "Reduced outpatient aiting time with improved appoiment scheduling: a simulation modeling approach," *OR Spectrum ,* vol. 5, no. 3, pp. 207-222, 2003.

[57] T. Rohleder and K. Klaseen, "Rolling horizon appointment scheduling: a simulation study," *Haelth Care Management Science,* vol. 5, no. 3, pp. 201-209, 2002.

[58] M. Cote, "Patient flow and resource utilization in an outpatient clinic," *Socio-Economic Planning Sciences,* vol. 33, pp. 231-245, 1999.

[59] E. Aktas , F. Ulengin and S. Sahin, "A decision support system to improve the efficiency of resource allocation in healthcare management," *Socio-Economic Planning Sciences,* pp. 130-146, 2007.

[60] K. R. Baker, Elements of Sequencing and Scheduling, Hanover: Dartmounth College, 2005.

[61] Z. Cao, J. Deng and Q. Wu , "Scheduling for Complex Manufacturing Processes based on Multi-Agent System," *IEEE Conference ,* pp. 726-730, 2011.

[62] S. Kreipl and M. Pinedo, "Planning and Scheduling in Supply Chains: An Overview of Issues in Practice," *Production and Operations Management,* vol. 13, no. 1, pp. 77-92, 2004.

[63] H. Suwa and H. Sandoh, "When to Revise Against Uncertainty," in *Online Scheduling in Manufacturing* , London , Springer-Verlag, 2013, pp. 41-54.

[64] S. Hahn-Goldberg, M. Carter and C. Beck , "Dynamic Template Scheduling to Address Uncertainty in Complex Scheduling Problems: A Case Study on Chemotherapy Outpatient Scheduling.".

[65] A. Turkcan , B. Zeng and M. Lawley, "Chemotherapy operations planning and scheduling," *IIE thansactions on Healthcare Systems Engineering* , vol. 2, pp. 31-49, 2012.

[66] E. Perez, L. Ntaimo, W. Wilhelm , C. Bailey and P. McCormack, "Patient and resource scheduling of multi-step medical procedures in nuclear medicine," *IIE Transactions on Healthcare Systems Engineering*, vol. 1, pp. 168-184, 2011.

[67] C. Vasilakis, B. Sobolev, L. Kurumoto and A. Levy, "A simulation study of scheduling clinic appointments in surgical care: individual surgeon versus pooled lists," *Journal of the Operational Research Society,* vol. 58, pp. 202-211, 2007.

[68] M. Lamiri, F. Grimaud and X. Xie, "Optimization methods for a stochastic surgery planning problem," *International Journal of Production Economics,* vol. 120, no. 2, pp. 400-410, 2009.

[69] . F. Dexter, "A strategy to decide whether to move the last case of the day in an operating room to another empty operating room to decrease overtime labor costs.," *Anesthesia & Analgesia*, vol. 91, no. 4, pp. 925-928, 2000.

[70] B. T. Denton , J. Viapiano and A. Volg, "Optimization of Surgery Sequencing and Scheduling Decisions Under Uncertainty," *Health Care Management Science* , vol. 10, no. 1, pp. 13-14, 2007.

[71] H. Manansang and J. Heim, "n online, simulation-based patient scheduling system," in *In Proceedings of the 28th conference on Winter simulation*, 1996.

[72] C. Vasilakis and L. Kuramoto, "Comparing two methods of scheduling outpatient clinic appointments using simulation experiments," *Clinical and investigative medicine,* vol. 28, no. 6, pp. 368-370, 2005.

[73] R.-C. Lin , M. Sir, E. Sisikoglu, K. Pasupathy and L. Steege, "Optimal nurse scheduling based on model of work-related fatigue," *IIE Transactions on Healthcare Systems Engineering* , vol. 3, no. 1, pp. 23-38, 2013.

[74] Freivalds, "Niebel's methods, standards, & work design," New York, McGraw-Hill, 2009, pp. 545-550.

[75] N. Blay, J. Cairs, J. Chisholm and J. O'Baugh, "Research into the workload and roles of oncology nurses within an outpatient oncology unit," *European Journal of Oncology Nursing,* pp. 6-12, 2002.

[76] K. L. Rascati, C. L. Kimberlin and W. C. McCormiick, "Work measurement in pharmacy research," *American Journal of Health-System Pharmacy* , vol. 43, no. 10, pp. 2445-2452, 1986.

[77] W. M. Dickson, "Measuring pharmacist time use: a note on the use of fixed-interval work sampling," *American Journal of Health-System,* vol. 35, no. 10, pp. 1241-1243, 1978.

[78] M. J. Wright, "Improvement of Patient Care," *G.P. Putnam's Sons. New York,* 1954.

[79] G. Liptak, D. M. Super, N. Baker and K. J. Roghmann, "An analysis of waiting times in a pediatric emergency department," *Clinical pediatrics* , vol. 24, no. 4, pp. 202-209, 1985.

[80] F. G. Abdellah and E. Levine, "Work-sampling applied to the study of nursing personnel," *Nursing Research,* vol. 3, no. 1, pp. 11-16, 1954.

[81] R. A. Reid, "A work sampling study of midlevel health professionals in a rural medical clinic," *Medical care,* pp. 241-249, 1975.

[82] A. Luximon and R. Goonetilleke, "Simplified subjective workload assessment technique," *Ergonomics,* vol. 44, no. 3, pp. 229-243, 2001.

[83] R. E. Nisbett and T. DeCamp Wilson, "Telling More Than We Can Know: Verbal Resports on Mental Process," *Psychological Review* , vol. 84, no. 3, pp. 231-259, 1977.

[84] G. Zhang , S. McCombie, R. Greenstein and D. McCombie, "Assessing the Challenges of a Pulse Wave Velocity Based Blood Pressure Measurement in Surgical Patients".

[85] J. Welch, J. Moon and S. McCombie, "Early Detection of the Deteriorating Patient the Case for a Multi-Parameter Patient-Worn Monitor," *Technology and Design Horizons,* pp. 57-63, 2012.

[86] S. Sempeles, "Continuous Wireless Monitoring Device Passes Test in First Hospital Use," *Journal of Clinical Engineering,* vol. 38, no. 3, pp. 86-87, 2013.

[87] P. Skelton, "Healthcare for the masses," *Connected Home Australia,* p. 42, 2013.

[88] D. Hood, J. Damian, A. Rakotonirainy, S. Sridharan and C. Fookes, "Use of brain computer interface to drive: preliminary results," in *4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 2012.

[89] A. Zihni, I. Ohu, . J. Cavallo, J. Ousley, S. Cho and M. Awad, "FLS tasks can be used as an ergonomic discriminator between laparoscopic and robotic surgery," *Surgical endoscopy,* pp. 1-7, 2014.

[90] F. Seoane , I. Mohino-Herranz, J. Ferreira, L. Alvarez, R. Buendia, D. Ayllón, . C. Llerena and R. Gil-Pita, "Wearable Biomedical Measurement Systems for Assessment of Mental Stress of Combatants in Real Time," *Sensors,* vol. 14, no. 40, pp. 7120-7141, 2014.

[91] F. Seoane, J. Ferreira, . L. Alvarez, . R. Buendia, D. Ayllón , C. Llerena and R. Gil-Pita, "Sensorized Garments and Textrode-Enabled Measurement Instrumentation for Ambulatory Assessment of the Autonomic Nervous System Response in the ATREC Project," *Sensors,* vol. 13, no. 7, pp. 8997-9015, 2013.

[92] W. Lee and G. Migliaccio, "Field Use of Physiological Status Monitoring (PSM) to Identify Construction Workers' Physiologically Acceptable Bounds and Heart Rate Zones," *Computing in Civil and Building Engineering*, pp. 1037-1044, 2014.

[93] S. Kopple, J. Kuo, R. Berecki-Gisolf, R. Boag, X. Hue and J. Charlton, "Examining physiological responses across different driving maneuvers during an on-road driving task: a pilot study comparing older and younger drivers," *Traffic injury prevention (just-accepted),* 2014.

[94] Equivital , "Equivital TnR," Hidalgo , 2014. [Online]. Available: http://www.equivital.co.uk/products/tnr. [Accessed 20 August 2014].

[95] Y. Liu, S. Zhu, G. Wang, F. Ye and P. Li, "Validity and Reliability of Multiparameter Physiological Measurements Recorded by the Equivital Lifemonitor During Activities of Various Intensities," *Journal of Occupational and Environmental Hygiene,* vol. 10, no. 2, pp. 75-85, 2013.

[96] N. Van Wouwe, P. Valk and B. Veenstra, "Sleep monitoring: a comparison between three wearable instruments," *Sleep monitoring: a comparison between three wearable instruments,* vol. 176, no. 7, pp. 811-816, 2011.

[97] F. Agrafioti, F. Bui and D. Hatzinakos, "Medical biometrics in mobile health monitoring," *Security and Communication Networks,* vol. 4, no. 5, pp. 525-539, 2011.

[98] W. Tharicon, M. Buller, A. Potter, V. Goetz and R. Hoyt, "Acceptability and usability of an ambulatory health monitoring system for use by military personnel," *IIE Transactions on Occupational Ergonomics and Human Factors,* vol. 1, no. 4, pp. 203-214, 2013.

[99] F. Agrafioti, D. Hatzinakos and A. Anderson, "ECG Pattern Analysis for Emotion Detection," *IEEE Transactions on Affective Computing,* vol. 3, no. 1, pp. 102-115, 2012.

[100] Salfor Systems, *MARS, User Guide,* San Diego, California : Cal. Stat. SoftWare, Inc, 1999.

[101] J. M. Noyes and D. P. Bruneau, "A self-analysis of the NASA-TLX workload measure," *Ergonomics,* vol. 50, no. 4, pp. 5514-519, 2007.

[102] T. Nygren, "Psychometric Properties of Subjetive Wokload Measurement Techniques: Implications for Their Use in Assessment of Perceived Mental Workload," *Human Factors,* vol. 33, no. 1, pp. 17-33, 1991.

[103] B. G. Tabachnick and L. S. Fidell, "Using multivariate statistics," *HaperCollins,* no. 81, 1996.

[104] S. Casner and B. Gore, "Measuring and Evaluating Workload: A Prime," National Aeronautics and Space Administration, Moffett Field, 2010.

[105] GAMS, "GAMS," GAMS Development Corporation . [Online]. [Accessed 25 February 2016].

[106] . M. Rahman, A. Huggins and D. Claudio, "A simulation Study of an Outpatient Cancer Center," in *Industrial and Systems Engineering Research Conference*, Puerto Rico , 2013.

[107] D. Gmach, J. Rolia, L. Cherkasova and A. Kemper, "Workload Analysis and Demand Prediction of Enterprise Data Aplications," *Workload Characterization ,* pp. 171-180, 2007.

APPENDICES

APPENDIX A

GAMS CODE

```
set     i           chairs id /1*19/;

set     j           patients id /1*60/
                subj1(j)        patient type 1 id /1*5/
                subj2(j)        patient type 2 id /6*10/
                subj3(j)        patient type 3 id /11*15/
                subj4(j)        patient type 4 id /16*20/
                subj5(j)        patient type 5 id /21*25/
                subj6(j)        patient typ5 6 id /26*30/
                subj7(j)        patient type 7 id /31*35/
                subj8(j)        patient type 8 id /36*40/
                subj9(j)        patient type 9 id /41*45/
                subj10(j)       patient type 10 id /46*50/
                subj11(j)       patient type 11 id /51*55/
                subj12(j)       patient type 12 id /56*60/
                subj13(j)       subgroup of patient (1-5)/1*25/
                subj14(j)       subgroup of patient (6-8)/26*40/
                subj15(j)       subgroup of patient (9-12)/41*60/

set     t               stranding time-slot /1*23/
                subt1(t)        time slot for lunch/13*15/;

set     a               acuity level/1*5/
                suba1(a)        acuity level 1/1*2/
                suba2(a)        acuity level 2/3/
                suba3(a)        acuity level 2/4/
                suba4(a)        acuity level 4/5/;

set     n               nurses id /1*5/;


scalar r nurses in the infusion area /5/;


scalar pa pharmacist available /2/;

parameter

b(a) acuity level id / 1 1
                       2 2
                       3 3
```

4 4
5 5 /

variables
z objective function

x(i,j,t,a,n) 1 if for chair i a patient of type j continues treatment of the period t
y(i,j,t,a,n) 1 if for chair i a patient of type j begins treatment of the period t
total(i,j,t,a,n) Sums all the y's and x's in a table

binary Variable x;

binary Variable y;

Equations

Utilization	define objective function
patient_type1	consecutive patient type 1
patient_type2	consecutive patient type 2
patient_type3	consecutive patient type 3
patient_type4	consecutive patient type 4
patient_type5	consecutive patient type 5
patient_type6	consecutive patient type 6
patient_type7	consecutive patient type 7
patient_type8	consecutive patient type 8
patient_type9	consecutive patient type 9
patient_type10	consecutive patient type 10
patient_type11	consecutive patient type 11
patient_type12	consecutive patient type 12
patient_chair	restriction of one patient by chair
nurses_availability	number of patient attend by nurses
pharmacists availability	number of patient attend by pharmacists
patient_mix1	percentage of patient attended patient type 1
patient_mix2	percentage of patient attended patient type 2
patient_mix3	percentage of patient attended patient type 3
patient_mix4	percentage of patient attended patient type 5
patient_mix5	percentage of patient attended patient type 5
patient_mix6	percentage of patient attended patient type 6
patient_mix7	percentage of patient attended patient type 7
patient_mix8	percentage of patient attended patient type 8
patient_mix9	percentage of patient attended patient type 9
patient_mix10	percentage of patient attended patient type 10

patient_mix11 percentage of patient attended patient type 11
patient_mix11 percentage of patient attended patient type 11
patient_mix12 percentage of patient attended patient type 12
lunchtime number the slope used in the lunch time new patient can not arrive
acuity level of acuity
deltaacuity accumulative acuity level
acuity_subgroup1 Distribution of acuity level type (1-5)
acuity_subgroup2 Distribution of acuity level type (1-5)
acuity_subgroup3 Distribution of acuity level type (8-11)
acuity_subgroup4 Distribution of acuity level type (8-11)
minimimun_patient_type4 Minimum number patient 4
nurse_capacity capacity by nurses;

=== Objective Function-Max Ys ===

Utilization .. z =e= sum((i,j,t,a,n),y(i,j,t,a,n))-0.00001* sum((i,j,t,a,n), x(i,j,t,a,n));

=== Subject to ===

=== 1. Nurse Availability ===
nurses_availability (t).. sum((i,j,a,n),y(i,j,t,a,n))=l= 3*r;

=== 2. Pharmacy Availability ===

pharmacists_availability(t).. sum((i,j,a,n),y(i,j,t,a,n))=l= 2*pa;

=== 3. No more than one person in a chair at any time ===

patient_chair(i,t) .. sum((j,a,n),x(i,j,t,a,n))+ sum((j,a,n),y(i,j,t,a,n))=l= 1;

=== 4. Patient Continuity ===

patient_type1.. sum ((i,subj1,t,a,n),x(i,subj1,t,a,n))=e= 0;

patient_type2(i,subj2,t,a,n).. y(i,subj2,t,a,n)=l= x(i,subj2,t+1,a,n);

patient_type3(i,subj3,t,a,n).. 2*y(i,subj3,t,a,n)=l= x(i,subj3,t+1,a,n)+ x(i,subj3,t+2,a,n);

patient_type4(i,subj4,t,a,n).. 3*y(i,subj4,t,a,n)=l= x(i,subj4,t+1,a,n)+ x(i,subj4,t+2,a,n)+ x(i,subj4,t+3,a,n);

patient_type5(i,subj5,t,a,n).. 4*y(i,subj5,t,a,n)=l= x(i,subj5,t+1,a,n)+ x(i,subj5,t+2,a,n)+ x(i,subj5,t+3,a,n)+ x(i,subj5,t+4,a,n);

Patient_type6(i,subj6,t,a,n).. 5*y(i,subj6,t,a,n)=l= x(i,subj6,t+1,a,n)+ x(i,subj6,t+2,a,n)+ x(i,subj6,t+3,a,n)+ x(i,subj6,t+4,a,n)+ x(i,subj6,t+5,a,n);

Patient_type7(i,subj7,t,a,n).. 7*y(i,subj7,t,a,n)=l= x(i,subj7,t+1,a,n)+ x(i,subj7,t+2,a,n)+ x(i,subj7,t+3,a,n)+ x(i,subj7,t+4,a,n)+
x(i,subj7,t+5,a,n)+x(i,subj7,t+6,a,n)+x(i,subj7,t+7,a,n);

Patient_type8(i,subj8,t,a,n).. 8*y(i,subj8,t,a,n)=l= x(i,subj8,t+1,a,n)+ x(i,subj8,t+2,a,n)+ x(i,subj8,t+3,a,n)+ x(i,subj8,t+4,a,n)+
x(i,subj8,t+5,a,n)+x(i,subj8,t+6,a,n)+x(i,subj8,t+7,a,n)+x(i,subj8,t+8,a,n);

Patient_type9(i,subj9,t,a,n).. 10*y(i,subj9,t,a,n)=l= x(i,subj9,t+1,a,n)+
x(i,subj9,t+2,a,n)+ x(i,subj9,t+3,a,n)+ x(i,subj9,t+4,a,n)+
x(i,subj9,t+5,a,n)+x(i,subj9,t+6,a,n)+x(i,subj9,t+7,a,n)+x(i,subj9,t+8,a,n)+x(i,subj9,t+9,a,n)+x(i,subj9,t+10,a,n);

Patient_type10(i,subj10,t,a,n).. 16*y(i,subj10,t,a,n)=l= x(i,subj10,t+1,a,n)+
x(i,subj10,t+2,a,n)+ x(i,subj10,t+3,a,n)+ x(i,subj10,t+4,a,n)+
x(i,subj10,t+5,a,n)+x(i,subj10,t+6,a,n)+x(i,subj10,t+7,a,n)+x(i,subj10,t+8,a,n)+x(i,subj10,t+9,a,n)+x(i,subj10,t+10,a,n)+
x(i,subj10,t+11,a,n)+x(i,subj10,t+12,a,n)+x(i,subj10,t+13,a,n)+x(i,subj10,t+14,a,n)+x(i,subj10,t+15,a,n)+x(i,subj10,t+16,a,n);

Patient_type11(i,subj11,t,a,n).. 18*y(i,subj11,t,a,n)=l= x(i,subj11,t+1,a,n)+
x(i,subj11,t+2,a,n)+ x(i,subj11,t+3,a,n)+ x(i,subj11,t+4,a,n)+
x(i,subj11,t+5,a,n)+x(i,subj11,t+6,a,n)+x(i,subj11,t+7,a,n)+x(i,subj11,t+8,a,n)+x(i,subj11,t+9,a,n)+x(i,subj11,t+10,a,n)+x(i,subj11,t+11,a,n)+
x(i,subj11,t+12,a,n)+x(i,subj11,t+13,a,n)+x(i,subj11,t+14,a,n)+x(i,subj11,t+15,a,n)+x(i,subj11,t+16,a,n)+x(i,subj11,t+17,a,n)+x(i,subj11,t+18,a,n);

Patient_type12(i,subj12,t,a,n).. 20*y(i,subj12,t,a,n)=l= x(i,subj12,t+1,a,n)+
x(i,subj12,t+2,a,n)+ x(i,subj12,t+3,a,n)+ x(i,subj12,t+4,a,n)+
x(i,subj12,t+5,a,n)+x(i,subj12,t+6,a,n)+x(i,subj12,t+7,a,n)+x(i,subj12,t+8,a,n)+x(i,subj12,t+9,a,n)+x(i,subj12,t+10,a,n)+x(i,subj12,t+11,a,n)+
x(i,subj12,t+12,a,n)+x(i,subj12,t+13,a,n)+x(i,subj12,t+14,a,n)+x(i,subj12,t+15,a,n)+x(i,subj12,t+16,a,n)+x(i,subj12,t+17,a,n)+x(i,subj12,t+18,a,n)+x(i,subj12,t+19,a,n)+x(i,subj12,t+20,a,n);

```
*=== 5. Patient Mix ===*

patient_mix1.. sum((i,subj1,t,a,n), y(i,subj1,t,a,n))=g=4;

patient_mix2.. sum((i,subj2,t,a,n), y(i,subj2,t,a,n))=g=1;

patient_mix3.. sum((i,subj3,t,a,n), y(i,subj3,t,a,n))=g=7;

patient_mix4.. sum((i,subj4,t,a,n), y(i,subj4,t,a,n))=g=0;

patient_mix5.. sum((i,subj5,t,a,n), y(i,subj5,t,a,n))=g=1;

patient_mix6.. sum((i,subj6,t,a,n), y(i,subj6,t,a,n))=g=4;

patient_mix7.. sum((i,subj7,t,a,n), y(i,subj7,t,a,n))=g=0;

patient_mix8.. sum((i,subj8,t,a,n), y(i,subj8,t,a,n))=g=3;

patient_mix9.. sum((i,subj9,t,a,n), y(i,subj9,t,a,n))=g=10;

patient_mix10.. sum((i,subj10,t,a,n), y(i,subj10,t,a,n))=g=7;

patient_mix11.. sum((i,subj11,t,a,n), y(i,subj11,t,a,n))=g=0;

patient_mix12.. sum((i,subj12,t,a,n), y(i,subj12,t,a,n))=g=0;

*=== 6. minimum patient type ===*

minimimun_patient_type4.. sum((i,subj4,t,a,n),y(i,subj4,t,a,n))=g=1;

*=== 7. lunch time restriction===*
lunchtime..      sum((i,j,subt1,a,n),y(i,j,subt1,a,n))=e=0;

*=== 8.acuity level in a t time ===*
acuity(t,n)..        sum((i,j,a),b(a)*x(i,j,t,a,n))+sum((i,j,a),b(a)*y(i,j,t,a,n))=l=15;

*=== 9.acuity level accumulate===*
deltaacuity(n)..  sum((i,j,t,a),b(a)*y(i,j,t,a,n))=l=20;

*=== 10. acuity distribution groups ===*
acuity_subgroup1..  sum((i,subj13,t,suba3,n),
x(i,subj13,t,suba3,n))+sum((i,subj13,t,suba3,n),y(i,subj13,t,suba3,n))=e=0;
acuity_subgroup2..  sum((i,subj13,t,suba4,n),
x(i,subj13,t,suba4,n))+sum((i,subj13,t,suba4,n),y(i,subj13,t,suba4,n))=e=0;
```

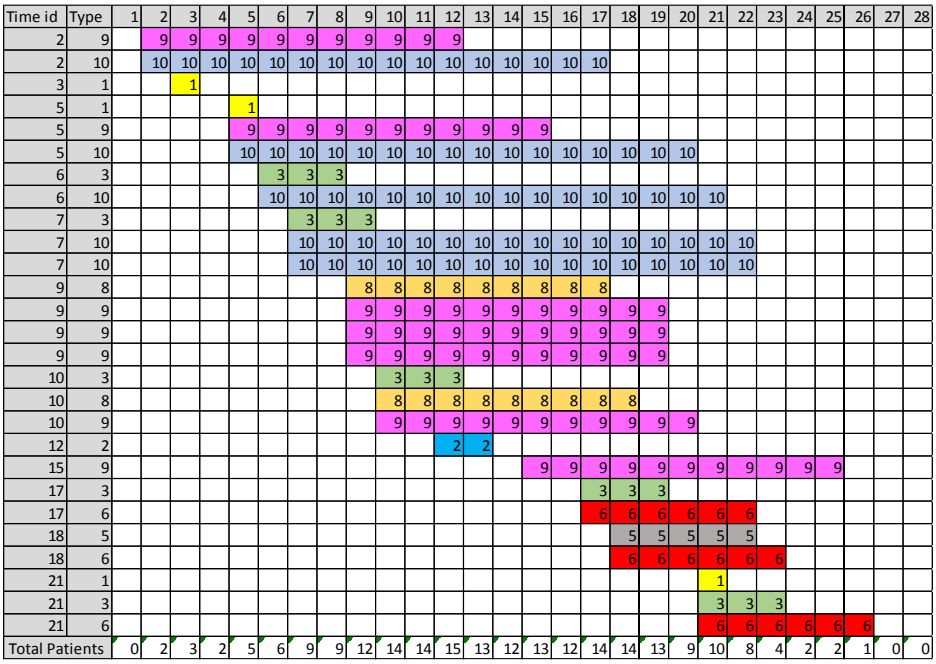
```
acuity_subgroup3..  sum((i,subj15,t,suba1,n),
x(i,subj15,t,suba1,n))+sum((i,subj15,t,suba1,n),y(i,subj15,t,suba1,n))=e=0;
acuity_subgroup4..  sum((i,subj15,t,suba2,n),
x(i,subj15,t,suba2,n))+sum((i,subj15,t,suba2,n),y(i,subj15,t,suba2,n))=e=0;

*=== 11. Maximum capacity by nurse ===*

nurse_capacity (t,n)..  sum((i,j,a),x(i,j,t,a,n))+sum((i,j,a),y(i,j,t,a,n))=l=3;

Model Cancer /all/;

option limrow = 1000;

solve Cancer maximizing z using mip;


*=== Output Display===*

display y.l;

display x.l;

*=== parameter total(i,j,t) used chair;

total.l(i,j,t,a,n)= y.l(i,j,t,a,n)+ x.l(i,j,t,a,n);

display total.l;

display z.l;

display patient_chair.l;

display nurses_availability.l;

display nurse_capacity.l;

*=== Export to excel using GDX utilities
*=== First unload to GDX file (occurs during execution phase)
execute_unload "results1.gdx" y.l
execute_unload "results2.gdx" x.l
execute_unload "results3.gdx" total.l

*=== Now write to variable levels to Excel file from GDX
*=== Since we do not specify a sheet, data is placed in first sheet
```

```
execute 'gdxxrw.exe results1.gdx var=y.l'

*=== write x variable to a different sheet with a specific range

execute 'gdxxrw.exe results2.gdx var= x.l'

*=== write x variable to a different sheet with a specific range   rng=NewSheet!F1 i4'
rng=NewSheet!f1 i4'

execute 'gdxxrw.exe results3.gdx var= total.l'
```

APPENDIX B

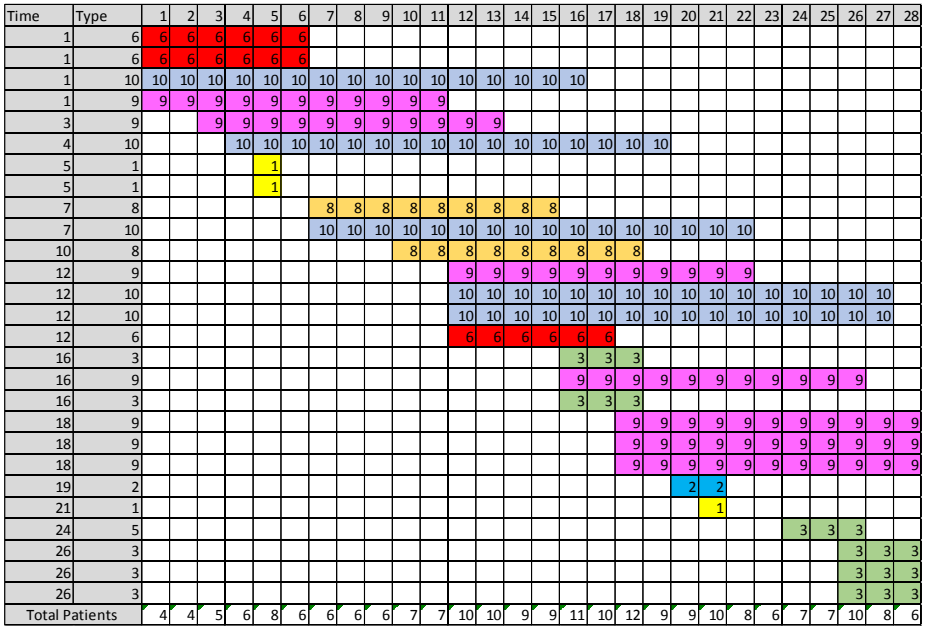
VISUAL SCHEDULES

Day 2



Time id	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
2	9		9	9	9	9	9	9	9	9	9	9	9																
2	10		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10											
3	1			1																									
5	1					1																							
5	9					9	9	9	9	9	9	9	9	9	9	9													
5	10					10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10								
6	3						3	3	3																				
6	10						10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10							
7	3							3	3	3																			
7	10							10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
7	10							10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
9	8									8	8	8	8	8	8	8	8	8											
9	9									9	9	9	9	9	9	9	9	9	9	9									
9	9									9	9	9	9	9	9	9	9	9	9	9									
9	9									9	9	9	9	9	9	9	9	9	9	9									
10	3										3	3	3																
10	8										8	8	8	8	8	8	8	8	8										
10	9										9	9	9	9	9	9	9	9	9	9	9								
12	2												2	2															
15	9															9	9	9	9	9	9	9	9	9	9	9			
17	3																	3	3	3									
17	6																	6	6	6	6	6	6						
18	5																		5	5	5	5	5						
18	6																		6	6	6	6	6	6					
21	1																					1							
21	3																					3	3	3					
21	6																					6	6	6	6	6	6		
Total Patients		0	2	3	2	5	6	9	9	12	14	14	15	13	12	13	12	14	14	13	9	10	8	4	2	2	1	0	0

Figure B-1 Original Schedule Day 2



Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	6	6	6	6	6	6	6																						
1	6	6	6	6	6	6	6																						
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10											
1	9	9	9	9	9	9	9	9	9	9	9	9																	
3	9			9	9	9	9	9	9	9	9	9	9	9															
4	10				10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10								
5	1					1																							
5	1					1																							
7	8							8	8	8	8	8	8	8	8	8													
7	10							10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
10	8										8	8	8	8	8	8	8	8	8										
12	9												9	9	9	9	9	9	9	9	9	9	9						
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
12	6												6	6	6	6	6	6											
16	3																3	3	3										
16	9																9	9	9	9	9	9	9	9	9	9	9		
16	3																3	3	3										
18	9																		9	9	9	9	9	9	9	9	9	9	9
18	9																		9	9	9	9	9	9	9	9	9	9	9
18	9																		9	9	9	9	9	9	9	9	9	9	9
19	2																				2	2							
21	1																					1							
24	5																								3	3	3		
26	3																										3	3	3
26	3																										3	3	3
26	3																										3	3	3
Total Patients		4	4	5	6	8	6	6	6	6	7	7	10	10	9	9	11	10	12	9	9	10	8	6	7	7	10	8	6

Figure B-2 Proposed Schedule Day 2

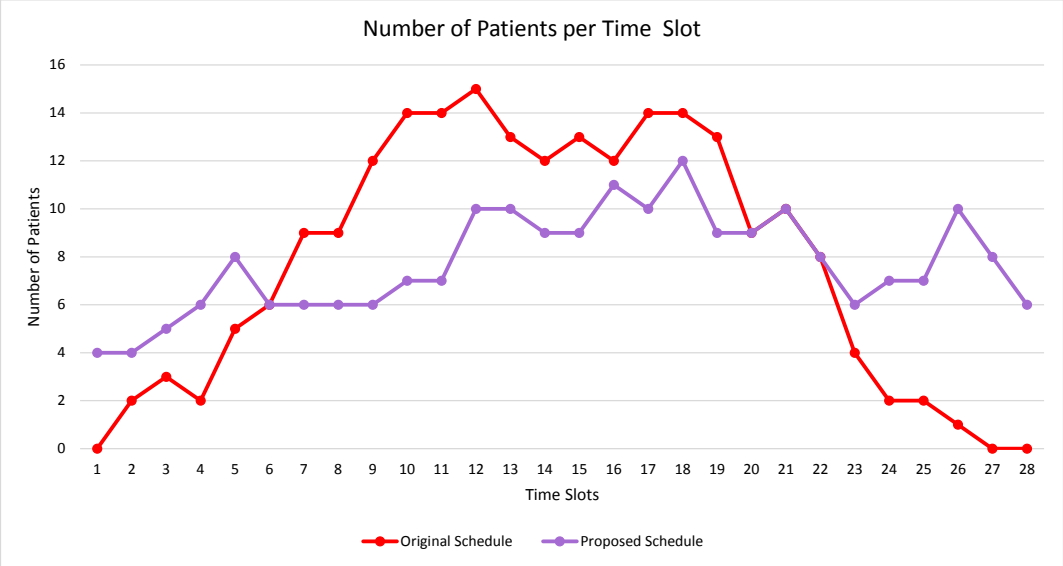


Figure B-3 Total Number of Patients per Time Slot Day 2

Day 3

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	9	9	9	9	9	9	9	9	9	9	9	9																	
3	9			9	9	9	9	9	9	9	9	9	9	9															
4	8				8	8	8	8	8	8	8	8	8																
4	8				8	8	8	8	8	8	8	8	8																
6	5						5	5	5	5	5																		
6	1						1																						
6	6						6	6	6	6	6	6																	
7	9							9	9	9	9	9	9	9	9	9	9	9											
8	5								5	5	5	5	5																
8	7								7	7	7	7	7	7	7	7													
8	7								7	7	7	7	7	7	7	7													
9	8									8	8	8	8	8	8	8	8	8											
9	7									7	7	7	7	7	7	7	7												
10	9										9	9	9	9	9	9	9	9	9	9	9								
10	9										9	9	9	9	9	9	9	9	9	9	9								
10	9										9	9	9	9	9	9	9	9	9	9	9								
11	3											3	3	3															
11	8											8	8	8	8	8	8	8	8	8									
12	3												3	3	3														
16	9																9	9	9	9	9	9	9	9	9	9	9		
16	9																9	9	9	9	9	9	9	9	9	9	9		
18	7																		7	7	7	7	7	7	7	7			
19	6																			6	6	6	6	6	6				
19	6																			6	6	6	6	6	6				
20	3																				3	3	3						
21	1																					1							
21	6																					6	6	6	6	6	6		
22	3																						3	3	3				
Total Patients		3	3	4	6	6	9	9	12	14	17	18	17	14	12	11	11	8	7	9	9	8	8	7	7	4	3	0	0

Figure B-4 Original Schedule Day 3

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
2	9		9	9	9	9	9	9	9	9	9	9	9																
2	9		9	9	9	9	9	9	9	9	9	9	9																
2	9		9	9	9	9	9	9	9	9	9	9	9																
2	10		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10											
3	5			5	5	5	5	5																					
3	8			8	8	8	8	8	8	8	8	8																	
3	5			5	5	5	5	5																					
3	3			3	3	3																							
4	9				9	9	9	9	9	9	9	9	9	9	9														
4	3				3	3	3																						
4	9				9	9	9	9	9	9	9	9	9	9	9														
5	6					6	6	6	6	6	6																		
5	6					6	6	6	6	6	6																		
5	3					3	3	3																					
7	9							9	9	9	9	9	9	9	9	9	9	9											
8	10								10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10				
8	8								8	8	8	8	8	8	8	8	8	8											
9	1									1																			
9	7									7	7	7	7	7	7	7	7												
9	7									7	7	7	7	7	7	7	7												
10	8										8	8	8	8	8	8	8	8	8										
10	9										9	9	9	9	9	9	9	9	9	9	9								
10	7										7	7	7	7	7	7	7	7											
11	1											1																	
11	8											8	8	8	8	8	8	8	8	8									
11	7											7	7	7	7	7	7	7	7										
12	9												9	9	9	9	9	9	9	9	9	9	9						
12	6												6	6	6	6	6	6											
Total Patients		0	4	8	11	14	13	13	12	15	17	18	18	15	15	13	13	10	6	4	3	2	2	1	0	0	0	0	0

Figure B-5 Proposed Schedule Day 3

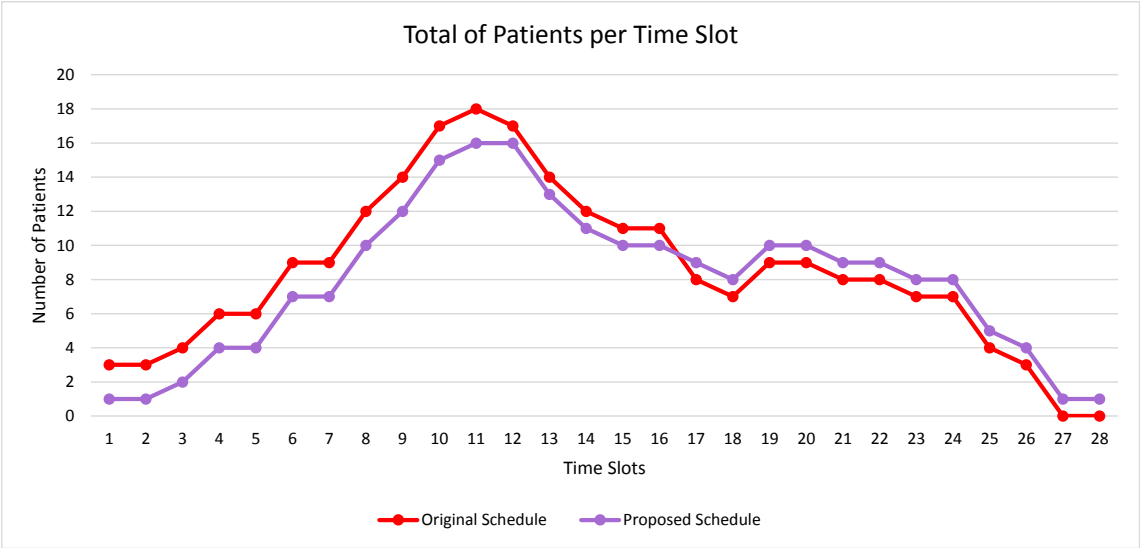


Figure B-6 Total Number of Patients per Time Slot Day 3

Day 4

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11									
1	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12							
1	3	3	3	3																									
1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11									
1	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12							
3	10			10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10										
3	9			9	9	9	9	9	9	9	9	9	9	9															
4	3				3	3	3																						
4	11				11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11						
4	3				3	3	3																						
4	6				6	6	6	6	6	6																			
5	5					5	5	5	5	5																			
7	2							2	2																				
9	3									3	3	3																	
9	7									7	7	7	7	7	7	7	7												
10	9										9	9	9	9	9	9	9	9	9	9	9								
10	7										7	7	7	7	7	7	7	7											
11	1											1																	
11	6											6	6	6	6	6	6												
16	6																6	6	6	6	6	6							
16	7																7	7	7	7	7	7	7	7					
16	9																9	9	9	9	9	9	9	9	9	9	9		
18	8																		8	8	8	8	8	8	8	8	8		
18	3																		3	3	3								
19	3																			3	3	3							
19	8																			8	8	8	8	8	8	8	8	8	
Total Patients		5	5	7	10	11	11	10	10	11	11	13	11	11	10	10	13	11	12	13	11	9	5	4	3	3	3	1	0

Figure B-7 Original Schedule Day 4

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	3	3	3	3																									
3	12			12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12					
3	11			11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11							
3	11			11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11							
5	7					7	7	7	7	7	7	7	7																
5	12					12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12			
5	6					6	6	6	6	6	6																		
6	10						10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10							
6	7						7	7	7	7	7	7	7	7															
7	9							9	9	9	9	9	9	9	9	9	9	9											
9	9									9	9	9	9	9	9	9	9	9	9	9									
10	8										8	8	8	8	8	8	8	8	8										
10	11										11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
12	3												3	3	3														
12	3												3	3	3														
12	3												3	3	3														
16	3																3	3	3										
16	5																5	5	5	5	5								
16	3																3	3	3										
18	9																		9	9	9	9	9	9	9	9	9	9	9
19	2																			2	2								
20	1																				1								
20	8																				8	8	8	8	8	8	8	8	8
21	7																					7	7	7	7	7	7	7	7
23	6																							6	6	6	6	6	6
23	6																							6	6	6	6	6	6
Total Patients		1	1	4	3	6	8	9	9	10	12	11	14	13	12	9	12	12	12	10	11	9	6	8	7	7	6	6	6

Figure B-8 Proposed Schedule Day 4

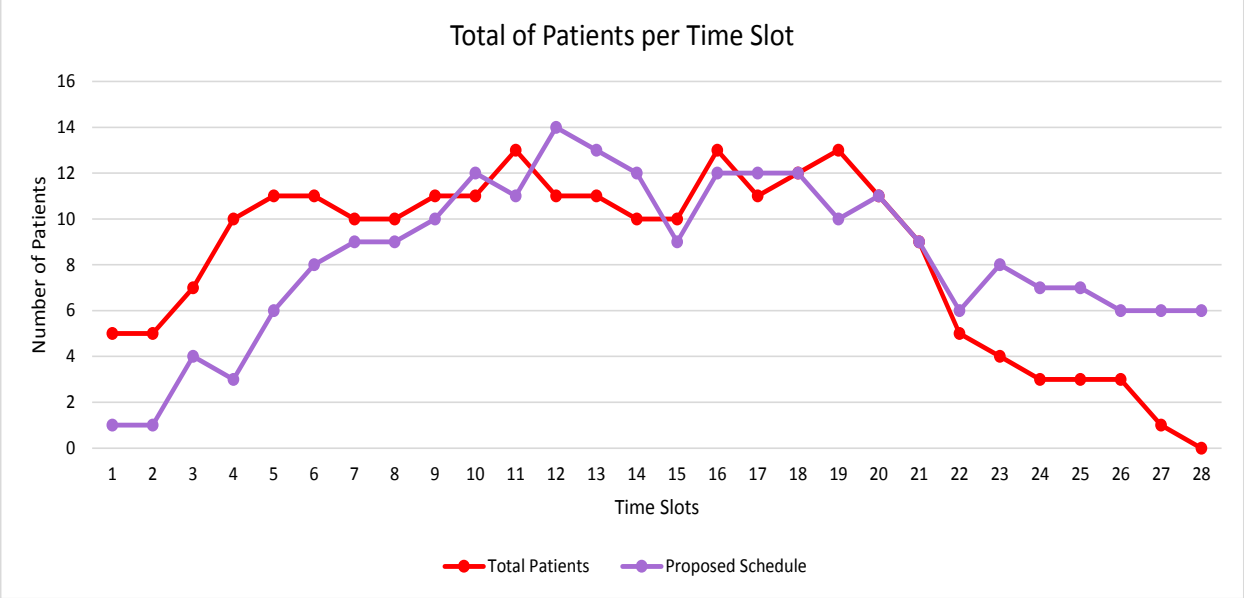


Figure B-9 Total Number of Patients per Time Slot Day 4

Day 5

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	5	5	5	5	5	5																							
6	8						8	8	8	8	8	8	8	8	8														
7	9							9	9	9	9	9	9	9	9	9	9	9											
7	6							6	6	6	6	6	6																
8	10								10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10					
9	7									7	7	7	7	7	7	7	7												
10	3										3	3	3																
16	9																9	9	9	9	9	9	9	9	9	9	9		
16	7																7	7	7	7	7	7	7	7					
16	8																8	8	8	8	8	8	8	8	8				
18	7																		7	7	7	7	7	7	7	7			
19	7																			7	7	7	7	7	7	7	7		
19	6																			6	6	6	6	6	6				
19	6																			6	6	6	6	6	6				
22	1																						1						
22	3																						3	3	3				
24	3																								3	3	3		
Total Patients		2	2	2	2	2	2	4	5	6	7	7	7	5	5	4	7	5	5	8	8	8	10	9	8	4	3	0	0

Figure B-10 Original Schedule Day 5

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	6	6	6	6	6	6	6																						
1	6	6	6	6	6	6	6																						
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	7	7	7	7	7	7	7	7	7																				
2	1		1																										
2	3		3	3	3																								
4	6				6	6	6	6	6	6																			
7	8							8	8	8	8	8	8	8	8	8													
7	7							7	7	7	7	7	7	7	7														
8	3								3	3	3																		
8	3								3	3	3																		
11	8											8	8	8	8	8	8	8	8	8									
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
12	9												9	9	9	9	9	9	9	9	9	9	9						
17	7																	7	7	7	7	7	7	7	7				
18	9																		9	9	9	9	9	9	9	9	9	9	9
21	7																					7	7	7	7	7	7	7	7
24	5																								5	5	5	5	5
Total Patients		1	3	2	3	2	2	4	6	5	4	3	5	5	5	4	3	4	5	5	4	5	5	4	5	4	4	4	3

Figure B-11 Proposed Schedule Day 5

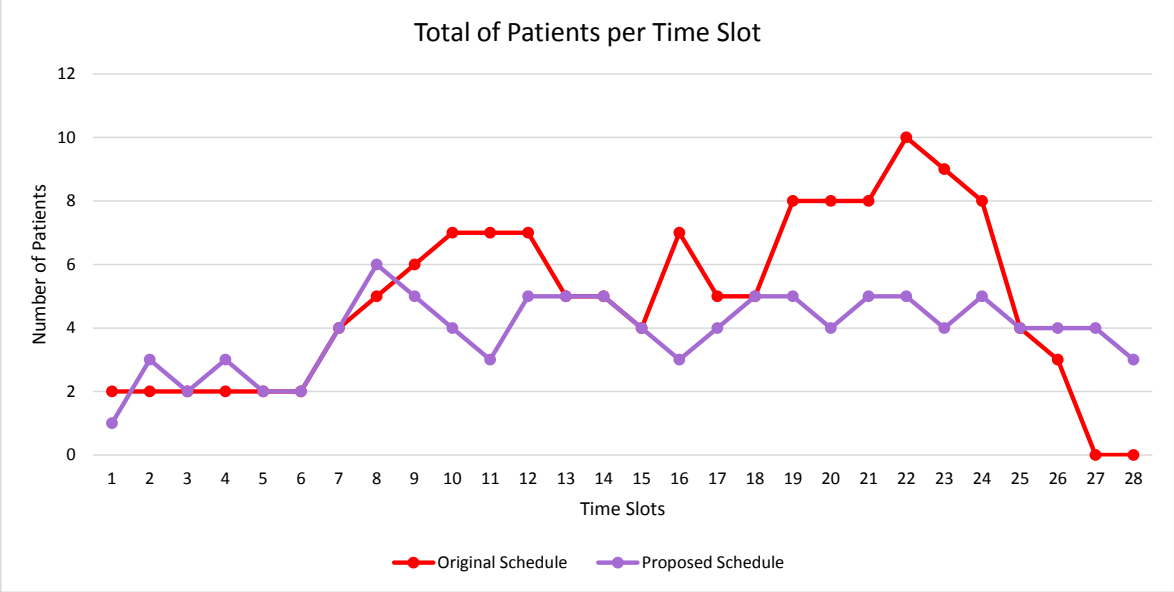


Figure B-12 Total Number of Patients per Time Slot Day 5

Day 6

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	6	6	6	6	6	6	6																						
1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11									
3	9			9	9	9	9	9	9	9	9	9	9	9															
3	9			9	9	9	9	9	9	9	9	9	9	9															
5	10					10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10								
6	3						3	3	3																				
6	11						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11				
7	10							10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
8	10								10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10					
8	1								1																				
9	3									3	3	3																	
9	10									10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10				
10	10										10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10			
11	1											1																	
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
16	6																6	6	6	6	6	6							
17	3																	3	3	3									
17	7																	7	7	7	7	7	7	7	7				
19	3																			3	3	3							
20	3																				3	3	3						
21	1																					1							
22	2																						2	2					
23	1																							1					
Total Patients		2	2	4	4	5	7	7	9	9	10	11	10	10	8	8	9	11	11	12	11	11	9	8	5	2	1	1	0

Figure B-13 Original Schedule Day 6

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	3	3	3	3																									
1	2	2	2																										
3	6			6	6	6	6	6	6																				
3	11			11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11							
3	10			10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10										
6	10						10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10							
6	9						9	9	9	9	9	9	9	9	9	9	9												
7	11							11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11			
9	1									1																			
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
12	9												9	9	9	9	9	9	9	9	9	9	9						
16	3																3	3	3										
18	7																		7	7	7	7	7	7	7	7			
19	1																			1									
22	1																						1						
23	6																							6	6	6	6	6	6
24	1																								1				
26	3																										3	3	3
26	3																										3	3	3
26	3																										3	3	3
Total Patients		3	3	5	4	4	6	7	7	7	6	6	10	10	10	10	11	9	10	9	8	8	7	6	7	6	7	7	4

Figure B-14 Proposed Schedule Day 6

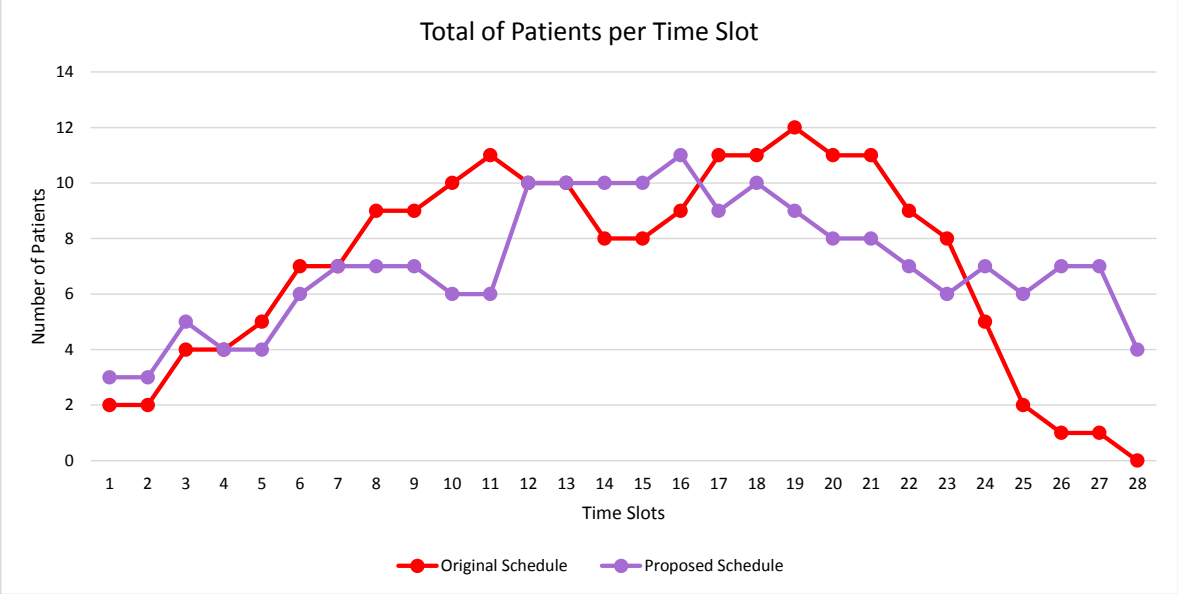


Figure B-15 Total Number of Patients per Time Slot Day 6

Day 7

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	9	9	9	9	9	9	9	9	9	9	9	9																	
1	8	8	8	8	8	8	8	8	8	8																			
1	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12							
1	6	6	6	6	6	6	6																						
3	3			3	3	3																							
3	9			9	9	9	9	9	9	9	9	9	9	9															
4	10				10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10									
4	9				9	9	9	9	9	9	9	9	9	9	9														
4	3				3	3	3																						
4	8				8	8	8	8	8	8	8	8	8																
6	11						11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11				
6	10						10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10							
6	7						7	7	7	7	7	7	7	7															
7	3							3	3	3																			
8	1								1																				
8	9									9	9	9	9	9	9	9	9	9	9	9									
9	8									8	8	8	8	8	8	8	8	8											
10	2										1																		
10	1										1																		
12	1												1																
16	9																9	9	9	9	9	9	9	9	9	9	9		
18	3																		3	3	3								
18	1																		1										
19	6																			6	6	6	6	6	6				
19	6																			6	6	6	6	6	6				
20	3																				3	3	3						
21	1																					1							
22	1																					1							
22	3																						3	3	3				
24	2																								2	2			
Total Patients		4	4	6	10	10	12	11	12	13	13	11	11	9	7	6	7	7	8	9	8	9	6	5	6	2	1	0	0

Figure B-16 Original Schedule Day 7

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	3	3	3	3																									
1	8	8	8	8	8	8	8	8	8	8																			
1	3	3	3	3																									
2	2		2	2																									
3	9			9	9	9	9	9	9	9	9	9	9	9															
3	8			8	8	8	8	8	8	8	8	8																	
3	6			6	6	6	6	6	6																				
4	12				12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12				
4	9				9	9	9	9	9	9	9	9	9	9															
5	6					6	6	6	6	6	6																		
7	9							9	9	9	9	9	9	9	9	9	9	9											
8	11								11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11		
9	9									9	9	9	9	9	9	9	9	9	9	9									
9	10									10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10				
10	6										6	6	6	6	6	6													
11	2											2	2																
12	3												3	3	3														
12	9												9	9	9	9	9	9	9	9	9	9	9						
16	3																3	3	3										
16	3																3	3	3										
20	8																				8	8	8	8	8	8	8	8	8
21	7																					7	7	7	7	7	7	7	7
21	1																					1							
23	1																							1					
25	1																									1			
25	1																									1			
26	3																										3	3	3
27	1																											1	
28	1																												1
Total Patients		4	5	8	7	8	8	9	10	11	11	11	12	11	10	8	9	8	7	5	5	7	6	6	5	5	4	4	4

Figure B-17 Proposed Schedule Day 7

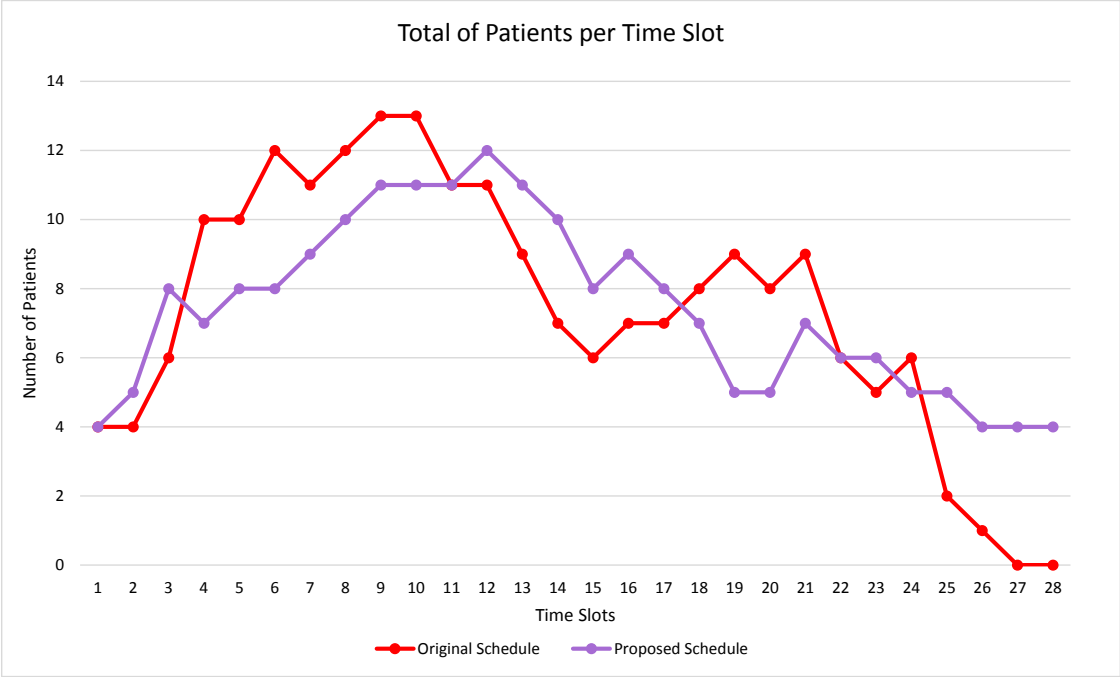


Figure B-18 Total Number of Patients per Time Slot Day 7

Day 8

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	5	5	5	5	5	5																							
3	1	1																											
6	8						8	8	8	8	8	8	8	8	8														
7	9							9	9	9	9	9	9	9	9	9	9	9											
7	6							6	6	6	6	6	6																
7	3							3	3	3																			
8	10								10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10					
9	7								7	7	7	7	7	7	7	7	7												
10	1									1																			
10	3									3	3	3																	
16	9																9	9	9	9	9	9	9	9	9	9	9		
16	7																7	7	7	7	7	7	7	7					
16	8																8	8	8	8	8	8	8	8	8				
16	8																8	8	8	8	8	8	8	8	8				
18	7																		7	7	7	7	7	7	7	7			
18	3																		3	3	3								
19	7																			7	7	7	7	7	7	7	7		
19	6																			6	6	6	6	6	6				
22	1																						1						
22	3																						3	3	3				
22	3																						3	3	3				
Total Patients		4	3	3	3	3	3	6	7	8	9	8	8	6	6	5	9	6	7	9	9	8	11	10	8	3	2	0	0

Figure B-19 Original Schedule Day 8

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	6	6	6	6	6	6	6																						
1	8	8	8	8	8	8	8	8	8	8																			
1	9	9	9	9	9	9	9	9	9	9	9	9																	
1	3	3	3	3																									
4	1	1																											
5	10					10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10								
8	8								8	8	8	8	8	8	8	8	8												
8	10								10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10					
11	8											8	8	8	8	8	8	8	8	8									
12	7												7	7	7	7	7	7	7	7									
12	3												3	3	3														
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
16	3																3	3	3										
16	7																7	7	7	7	7	7	7	7					
16	3																3	3	3										
18	7																		7	7	7	7	7	7	7				
18	7																		7	7	7	7	7	7	7				
18	9																		9	9	9	9	9	9	9	9	9	9	
23	6																							6	6	6	6	6	6
23	1																							1					
24	5																								5	5	5	5	5
26	3																										3	3	3
28	1																												1
Total Patients		5	4	4	3	4	4	3	5	5	4	5	7	7	7	6	9	8	11	9	7	6	6	8	6	6	5	5	5

Figure B-20 Proposed Schedule Day 8

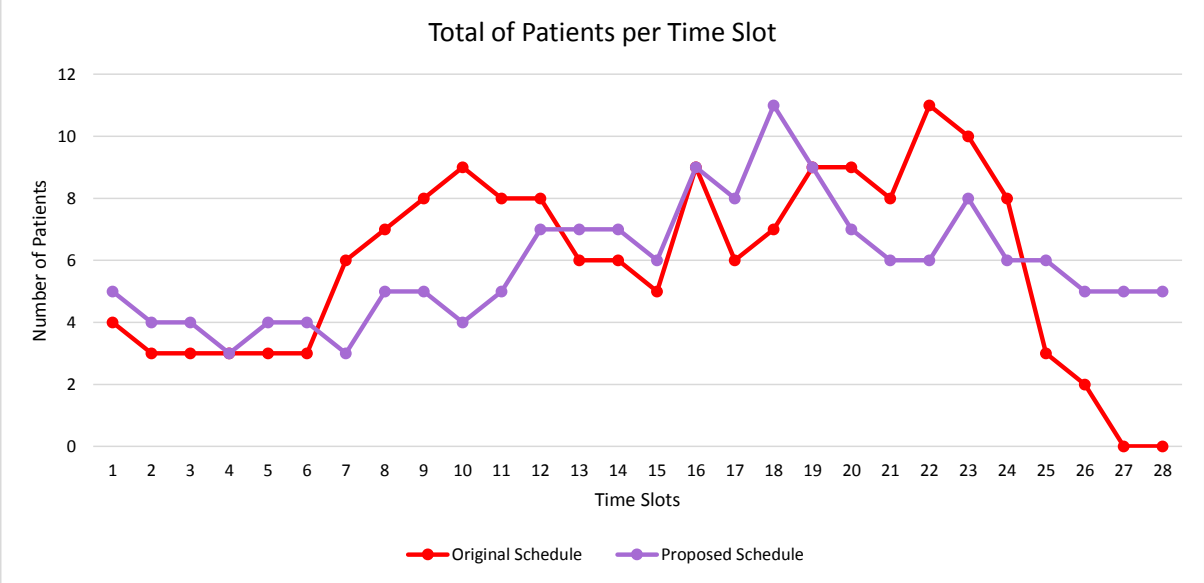


Figure B-21 Total Number of Patients per Time Slot Day 8

Day 9

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
2	3		3	3	3																								
3	6			6	6	6	6	6	6																				
4	6				6	6	6	6	6	6																			
4	10				10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10									
4	11				11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11						
4	1				1																								
5	11					11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11					
5	9					9	9	9	9	9	9	9	9	9	9	9													
6	6						6	6	6	6	6	6																	
7	8							8	8	8	8	8	8	8	8	8													
8	9								9	9	9	9	9	9	9	9	9	9	9										
10	9										9	9	9	9	9	9	9	9	9	9	9								
10	10										10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10			
17	7																	7	7	7	7	7	7	7	7				
19	1																			1									
19	3																			3	3	3							
19	5																			5	5	5	5	5					
20	6																				6	6	6	6	6	6			
21	5																					5	5	5	5	5			
Total Patients		0	1	2	6	6	7	8	9	8	9	9	8	8	8	8	6	7	7	9	8	8	7	6	4	3	0	0	0

Figure B-22 Original Schedule Day 9

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	6	6	6	6	6	6	6																						
1	5	5	5	5	5	5																							
1	8	8	8	8	8	8	8	8	8	8																			
1	9	9	9	9	9	9	9	9	9	9	9	9																	
3	10			10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10										
3	10			10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10										
9	7									7	7	7	7	7	7	7	7												
9	6									6	6	6	6	6	6														
10	9										9	9	9	9	9	9	9	9	9	9	9								
10	11										11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
10	11										11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
12	1												1																
16	3																3	3	3										
18	9																		9	9	9	9	9	9	9	9	9	9	9
18	1																		1										
18	6																		6	6	6	6	6	6					
23	6																							6	6	6	6	6	6
24	5																								5	5	5	5	5
26	3																												
Total Patients		4	4	6	6	6	5	4	4	6	8	8	8	7	7	6	7	6	9	5	5	4	4	5	5	5	5	5	5

Figure B-23 Proposed Schedule Day 9

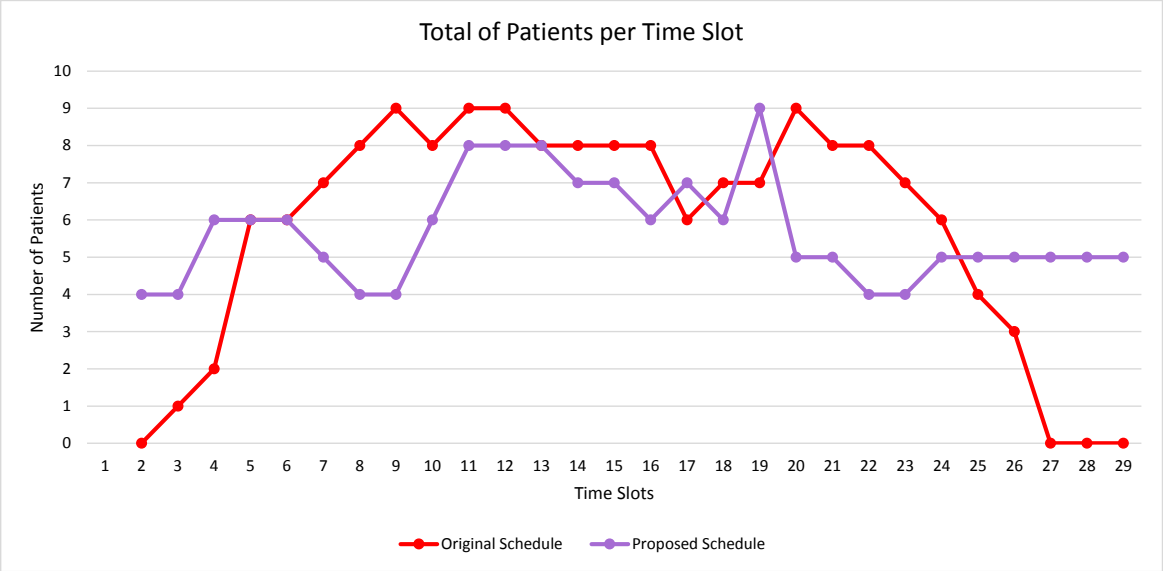


Figure B-24 Total Number of Patients per Time Slot Day 9

Day 10

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	6	6	6	6	6	6	6																						
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10												
1	3	3	3	3																									
4	11				11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11						
4	8				8	8	8	8	8	8	8	8	8																
6	3						3	3	3																				
6	3						3	3	3																				
7	1							1																					
8	10								10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10					
8	6								6	6	6	6	6	6															
9	8									8	8	8	8	8	8	8	8	8											
10	10										10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10			
10	8										8	8	8	8	8	8	8	8	8										
11	10											10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10		
16	1																1												
16	3																3	3	3										
19	6																			6	6	6	6	6	6				
19	2																			2	2								
19	2																			2	2								
19	3																			3	3	3							
21	6																					6	6	6	6	6	6		
22	3																						3	3	3				
22	5																						5	5	5	5	5		
22	3																						3	3	3				
25	1																									1			
Total Patients		4	4	4	5	5	7	7	8	7	9	10	10	9	8	8	10	7	6	8	8	7	9	8	7	5	3	0	0

Figure B-25 Original Schedule Day 10

Time	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	6	6	6	6	6	6	6																						
1	6	6	6	6	6	6	6																						
1	3	3	3	3																									
3	10			10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10										
4	2				2	2																							
7	6							6	6	6	6	6	6																
7	8							8	8	8	8	8	8	8	8	8													
7	2							2	2																				
9	10									10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10				
9	10									10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10				
10	10										10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10			
10	11										11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
10	8										8	8	8	8	8	8	8	8	8										
12	10												10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
12	8												8	8	8	8	8	8	8	8	8								
16	3																3	3	3										
16	3																3	3	3										
16	3																3	3	3										
17	6																	6	6	6	6	6	6						
20	1																				1								
24	5																								5	5	5	5	5
26	3																										3	3	3
26	3																										3	3	3
26	3																										3	3	3
28	1																												1
28	1																												1
Total Patients		3	3	4	4	4	3	4	4	5	8	8	10	9	9	9	11	12	12	7	8	6	6	5	6	4	6	6	7

Figure B-26 Proposed Schedule Day 10

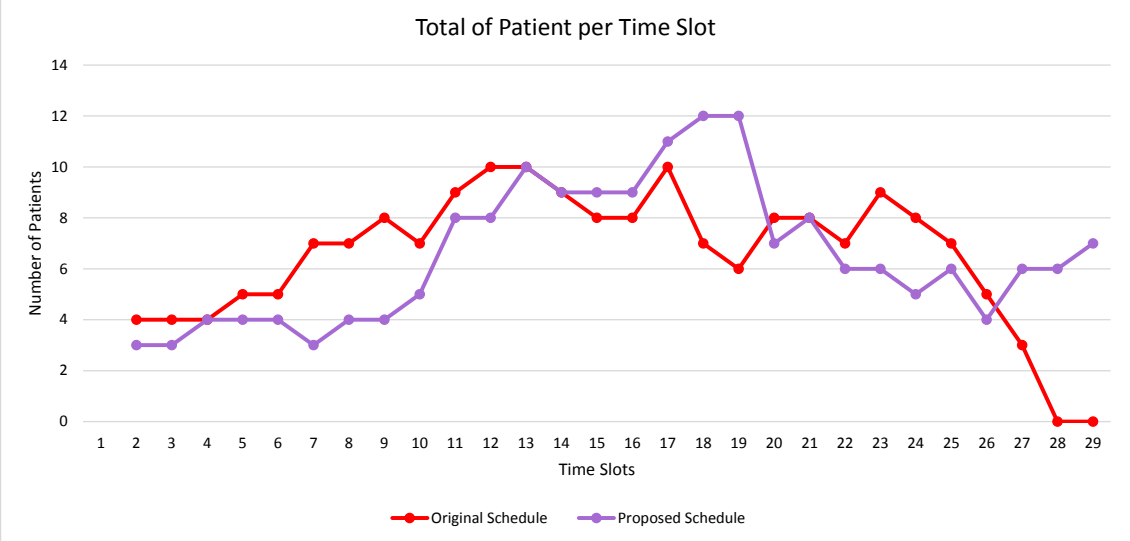


Figure B-27 Total Number of Patients per Time Slot Day 10

APPENDIX C

SIMULATION ARENA

Development of ARENA Simulation Model

Patient Creation: The ARENA model was developed using historical data of different patient types and approximate time of treatment. There are 12 different types of patients based on length of infusion treatment. Patients are scheduled in advance using historical schedules. ARENA reads the scheduled time from a designated excel file. Patients are given appropriate attributes according to the 'patient type'. A cumulative probability matrix was used to assign the number of infusion drugs for each patient, as shown in Table 1. Another cumulative probability matrix was used to decide the type of premed (oral or IV), as shown in Table 2. These two matrices were derived using historical data.

Separating Patient and Information: Immediately after the arrival of each patient, a duplicate of the entity (as information) goes to the pharmacy creating an order of all necessary drugs. The drugs are then processed according to a schedule as explained in the previous section.

Deciding Premed Requirements: The decision if the premed is required or not is made using a variable matrix. If a premed is required, another decision is made to decide type of premed. A percentage distribution has been used to make this decision. If IV-premed is selected, a duplicate of this information goes to the pharmacy for preparing the IV-premed.

Processing of Drugs at Pharmacy: The IV premed is processed with priority 2 and first infusion drug is processed with priority 1. The second infusion drug (if any) is scheduled for processing 15 minutes before the first infusion treatment is scheduled to be

completed. Preparation of any additional drugs follow the same principle. Preparation of second or any additional infusion drugs has priority 1. This priority settings reduce the waiting time of patients between infusion treatments.

Synchronizing patients and drugs: When both the patient and the drug are ready, a match occurs in order to initiate further processing towards the treatment. This matching is carried out using specific identification attribute in order to ensure the prepared drug goes to its intended patient.

Table C-1 Cumulative probability matrix for number of infusion drugs

		# of Infusion Drugs by Patient Type			
		1	2	3	4
Patient Type	Type 1	1	1	1	1
	Type 2	1	1	1	1
	Type 3	1	1	1	1
	Type 4	0.50	0.90	1	1
	Type 5	0.50	0.85	1	1
	Type 6	0.45	0.80	1	1
	Type 7	0.45	0.75	1	1
	Type 8	0.40	75.00	1	1
	Type 9	0.35	0.60	1	1
	Type 10	0.35	0.60	0.85	1
	Type 11	0.25	0.65	0.95	1
	Type 12	0.20	0.35	0.65	1

Table C-2 Cumulative probability matrix for number deciding number of PreMed

		"# of PreMed Requirements by Patient Type	
		1	2
Patient Type	Type 1	1	1
	Type 2	1	1
	Type 3	1	1
	Type 4	0.60	1
	Type 5	0.50	1
	Type 6	0.40	1
	Type 7	0.30	1
	Type 8	0.20	1
	Type 9	0.10	1
	Type 10	0.10	1
	Type 11	0.10	1
	Type 12	0.10	1

Administering Infusion Drug and Cross-checking: A preparation time has been assigned to get the patient ready for the treatment prior to administering it. A single nurse (resource) is seized for this preparation job. After this process, a second nurse is seized with higher priority to cross-check the treatment plan. This cross-checking is a quick process but requires the presence of two nurses.

Nurse Checks on the Patient During the Treatment: After administering the infusion drug, the nurse is then released. Infusion treatment continues as per its time. However, the nurse checks on the patient several times. The number of times to check on the patient during each infusion drug is determined using a probability index [DISC(0.5, 1, 0.8, 2, 1.0, 3)]. Similar checking concept has been applied while the IV-premed treatment is ongoing.

Model Assumptions

Assumptions made while developing the simulation model using ARENA include

1. No-shows or cancellations were not part of simulation process. Currently the clinic where the study was conducted has a low rate of no-shows and last-minute cancellations.
2. Patients arrived to the infusion area at their scheduled time.
3. Patients got the treatment they came for and no complication happened during treatment.
4. The infusion area had two pods of chairs, six chairs in each pod and one private bed. Though each pod has assigned nurses, it was observed that the nurses were switching pods if either side was significantly busier. To simplify the model, both

pods were assumed as a single one and all nurses were assigned to serve patients from any pod.

5. Resources were fixed throughout the day (i.e. same number of nurses, chairs, and pharmacists).

ARENA Screen

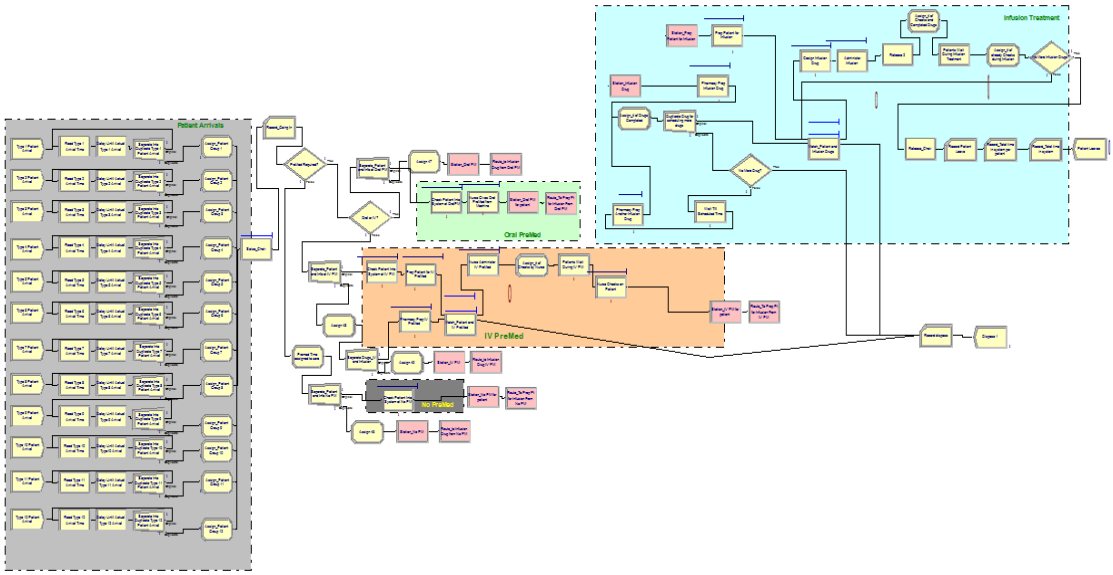


Figure C-1 Total Screen

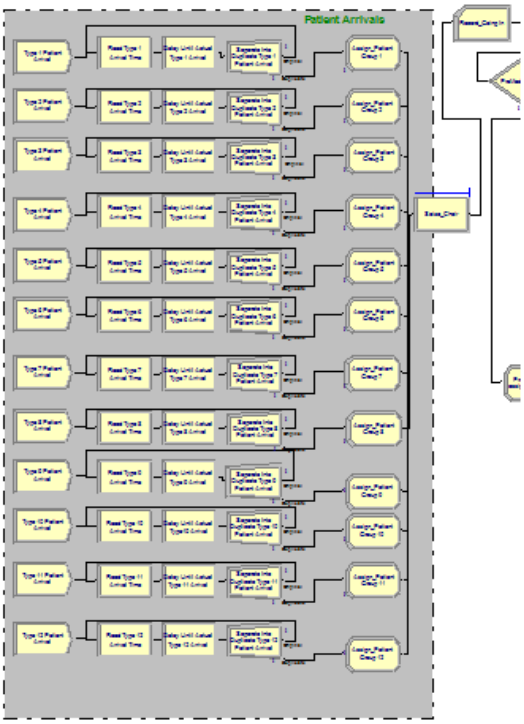


Figure C-2 Section 1 Screen

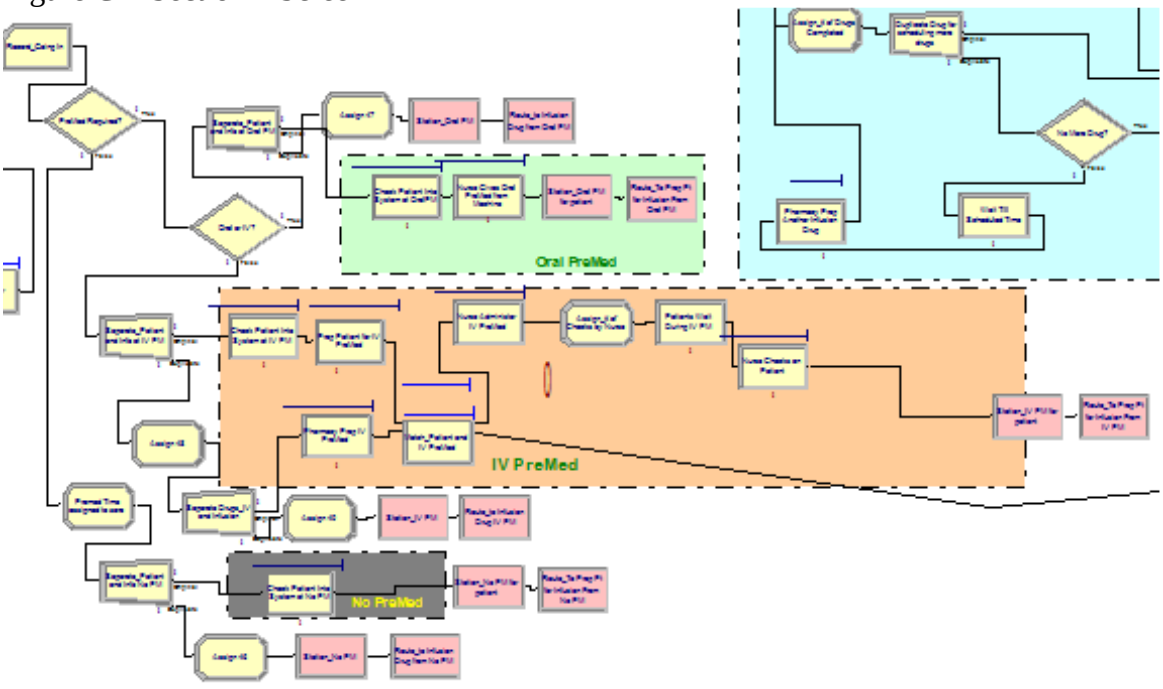


Figure C-3 Section 2 Screen

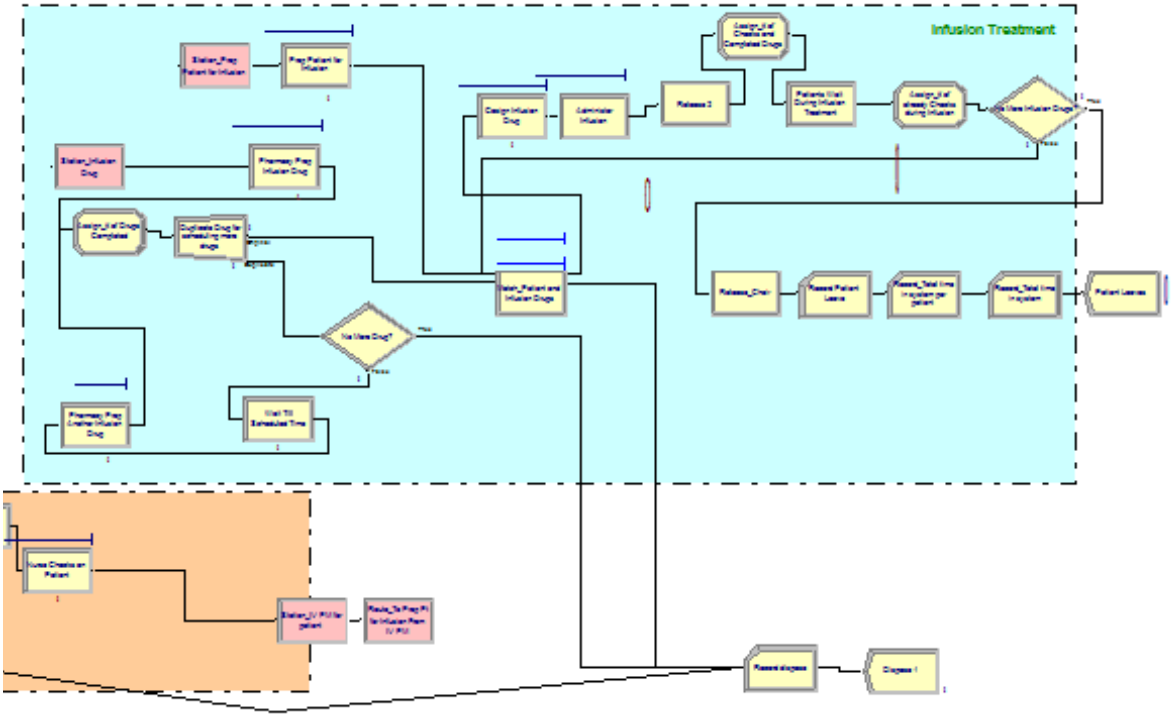


Figure C-4 Section 3 Screen