Using Predictive and Descriptive Models to Improve Nurse Staff Planning and Scheduling

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Abstract

The healthcare industry has recently been given an additional set of guidelines called the Affordable Care Act (ACA). The guidelines (or measurements) will be utilized to assess each hospital compared with other hospitals of similar size, and based on score reimbursed for Medicare payments accordingly. An important measurement in these guidelines pertains to patient satisfaction; therefore, increasing patient satisfaction is an important goal for hospitals. To accomplish this goal, many hospitals are re-evaluating their nurse staffing procedures to try to match patient demand with nurse availability.

Using predictive modeling with optimization, hospital administrators can develop/improve their plans for the future. Each concept provides benefits to the hospital in the utilization of the nursing staff. Predictive modeling uses historical and real time data to forecast plans for the future. This provides the hospital administrators a baseline to estimate the number of nurses needed and the number of nurses to be hired. Optimization provides the best case scenario for the number of nurses required to meet patient demand while minimizing cost to the hospital. This research combines the two ideas into multiple models using AnyLogic and Excel as predictive/analysis tools.

The implementation of these models into a hospital environment provides new insight to the nurse staffing process allowing changes to be made to accommodate new regulations. The models can also provide the ability for management to run “What-If” analysis to understand what the staffing levels should be in a given situation. Results will provide the additional tools required to be prepared for emergencies. Healthcare is an industry where seconds count, and expanding the ability to be prepared is always an asset.

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Chapter 1 Introduction

Increasing costs and the Affordable Care Act (ACA) are creating financial burdens for American hospitals. One major part of the ACA is the Medicare Hospital Value-Based Purchasing Program which will assess hospitals based on the quality of care they provide to Medicare patients. Previously, hospitals were paid based on quantity of services provided. Under the new ACA program, the reimbursement hospitals' receive will be based on three things: quality of care, how closely best clinical practices are followed, and how well hospitals enhance their patients' experience of care during their stay.

The majority of integration of this specific program is occurring between the years of 2013 – 2015 with some minor changes until 2017. Below is a chart summarizing the integration steps for the specified years:

Table 1: Implementation Domains by Year

Fiscal Year	Applicable Domains
2013	Clinical Process of Care Domain Patient Experience of Care Domain
2014	Clinical Process of Care Domain Patient Experience of Care Domain Outcome Domain
2015	Clinical Process of Care Domain Patient Experience of Care Domain Outcome Domain Efficiency Domain

These phases are described in depth in Section 3.1 which explains the Hospital Value-Based Purchasing Program in more detail. Without proper changes to current operations, it will be easy for a hospital to fall behind and possibly even be shut down or bought out by a larger hospital chain.("Hospital Value-Based Purchasing Program," 2013)

From a hospital's perspective, when trying to accommodate for something as complex as this portion of the ACA, the first step is to figure out where to start. The common ground for each of these domains is nurses. Nurses are the face of the hospital. Patients see their nurses several times per day and doctors depend on nurses for support to complete medication passes and provide appropriate care. Nurses cover the entire hospital from the Emergency Department to the Inpatient floors. If the nurses are well equipped to handle their responsibilities, the domains listed in this program can be covered successfully. If nurses are not trained appropriately and/or are not able to meet patient expectations; then, the hospitals' reimbursement will likely be penalized through this program.

For hospitals to be successful and remain successful with the new regulations, they must start with a solid nursing foundation. Studies show that most hospitals are not currently equipped with a nursing foundation to match the requirements of the ACA. Many U.S. hospitals are dealing with low nurse staffing levels which can lead to many adverse hospital events, including decreased quality of care and decreased patient safety. These are all major issues that will penalize the hospital under the Hospital Value-Based Purchasing Program. Unfortunately, low nurse staffing levels are comfortable for hospitals because that is the current mode of operations to meet their financial objectives. With the new regulations, change is required for hospitals to remain open. Predictive modeling, simulation, and optimization principles can be used to offset these changes and help to maintain hospital cash flow. Integrating a nurse staffing model, as well

as a nurse scheduling system to match nursing resources to patient demand will provide the necessary information to hospital administration to allow them to meet ACA standards.

Chapter 2 Problem Definition

Many U.S. hospitals have been dealing with a nursing shortage for several years. Research done in the early 2000‘s suggested that by 2029 there could be a shortage of 800,000 hospital nurses in the U.S. (Admin, 2010). This shortage is caused by several reasons including: changes in workforce expectations (i.e., meaning wanting to be paid more while times for doing less), an increase in patient acuity requiring more time to care for patients, and a decline in nursing skills. To offset this shortage, many hospitals have moved to a team nursing strategy. (Admin, 2010) Team nursing means an RN leads a team of LPN’s and CNA’s to care for a group that could range from 10-20 patients. Work is delegated to each team member at the beginning of the shift and all work performed by non-licensed members of the team is the responsibility of the RN in charge. A summary of care for each patient is given by those working under the RN at the end of each shift. The advantage to this system is fewer nurses are needed and fewer work-related stress/fatigue issues are reported from nurses who work in this environment. (Admin, 2010) A major disadvantage is communication is required and teamwork is essential. Communication and team work are difficult for humans to grasp; therefore, communication barriers are often an issue. Continuity of care leading to patient dissatisfaction is another concern. Support staff is re-shuffled which changes patient assignments confusing nurses and preventing the staff from building relationships and trust with their patients. (Admin, 2010) This methodology does not align with the ACA program discussed.

The other popular methodology used in hospitals is called primary care nursing. Primary care nursing is when a RN is responsible for a given number of patients. During their shift, the RN’s are responsible for all RN tasks for a specific patient and will not receive help with these tasks unless necessary. (Admin, 2010) The advantage of this is that patients are able to gain trust

and build a relationship with their nurse that generally leads to increased patient satisfaction. The disadvantage is the cost. More RN's are required to staff the hospital with less support staff. Support staff costs are less than the average RN's salary which increases the total staffing cost. (Admin, 2010) Primary care nursing leads to outcomes that will satisfy the goals of the Hospital Value-Based Purchasing Program. Aside from the program, increasing patient satisfaction would allow the hospital to reap other benefits including an increased census due to word of mouth advertisement and an all-around better reputation. Although the program goals are satisfied with primary nursing, the costs are still an issue. The question remains, how can hospitals affordably meet the goals of the program, the needs of their patients, and the desires of the nursing staff?

Chapter 3 Literature Review

3.1 Affordable Care Act, Hospital Value-Based Purchasing Program

The Affordable Care Act of 2010 (ACA) placed a huge burden on hospitals and the means by which they are reimbursed. A specific part of the act known as the Hospital Value-Based Purchasing Program is a major reason reimbursement is more difficult to receive. Previously, hospitals were reimbursed based on the quantity of services rendered. With this program, they will be reimbursed based on the quality of care and patient satisfaction during their hospital stay. The act contains several quality dimensions grouped into four main domains which assess hospital performance related to specific quality and patient satisfaction measures. These domains are: clinical process of care, patient experience, outcome, and efficiency. Through this program, Medicare makes incentive payments to hospital based on one of two things:

1. How well they perform on each measure or
2. How much they improve performance on a certain measure compared to their performance during a baseline period.

Each domain contains its own performance measures. The following sections will describe these in some detail. ("Hospital Value-Based Purchasing Program," 2013)

3.1.1 Clinical Process of Care Domain

The clinical process of care domain refers to a number of important processes occurring while a patient is in the hospital. These processes are to verify the hospital is handling significant patient events properly while providing the best quality care possible. Below is a list of the measures in this domain that are collected to integrate into the overall hospital rating score:

Table 2: Clinical Process of Care Domain Measures: Quality, FY 2013-2015

Measure ID	Measure Description
AMI-7a	Fribrinolytic Therapy Received Within 30 Minutes of Hospital Arrival
AMI-8a	Primary PCI Received Within 90 Minutes of Hospital Arrival
PN-3b	Blood Cultures Performed in the Emergency Department (ED) Prior to Initial Antibiotic Received in Hosptial
PN-6	Initial Antibiotic Selection for Community-Acquired Pneumonia (CAP) in Immunocompetent Patients
SCIP-Inf-1	Prophylactic Antibiotic Received Within One Hour Prior to Surgical Incision
SCIP-Inf-2	Prophylactic Antibiotics Selection for Surgical Patients
SCIP-Inf-3	Prophylactic Antibiotics Discontinued within 24 Hours After Surgery End Time
SCIP-Inf-4	Cardiac Surgery Patients with Controlled 6:00 a.m. Postoperative Serum Glucose
SCIP-Inf-9 (for FY 2014 – 2015 only)	Urinary Catheter Removal on Postoperative Day 1 or Postoperative Day 2
SCIP-Card-2	Surgery Patients on a Beta-Blocker Prior to Arrival Who Received a Beta-Blocker During the Perioperative Period
SCIP-VTE-1 (for FY 2013 – 2014 only)	Surgery Patients with Recommended Venous Thromboembolism Prphylaxis Ordered
SCIP-VTE-2	Surgery Patients Who Received Appropriate Venous Thromboembolism Prophylaxis Within 24 Hours Prior to Surgery to 24 Hours After Surgery

These measures are the responsibility of the doctor with assistance from the nurses. Most of the measures must be ordered by the doctor, but the nurse completes the action by giving medication, discontinuing medications, completing procedures, and/or discharging the patient. ("Hospital Value-Based Purchasing Program," 2013)

3.1.2 Patient Experience of Care Domain

The patient experience of care domain summarizes important information on how patient satisfaction will be measured for reimbursement purposes from Medicare. The following is a list of dimensions that will be considered:

1. Nurse Communication
2. Doctor Communication
3. Hospital Staff Responsiveness
4. Pain Management
5. Medicine Communication
6. Hospital Cleanliness and Quietness
7. Discharge Information
8. Overall Hospital Rating

Looking at each dimension, it's obvious that the responsibility falls on either a doctor or in most cases a nurse. Doctors must be good communicators and provide medicine to the patient, and nurses must provide follow up. Nurses must help the patient manage pain, communicate details about the medicine given, be prepared to respond to whatever happens, and provide discharge information to the patient. ("Hospital Value-Based Purchasing Program," 2013)

3.1.3 Outcome Domain

The outcome domain is simple. Each of the five categories listed in Table 3 below is measured to assess the care provided while the patient is in the hospital. These appear to be simple and direct statistics to measure, but most healthcare professionals are against the 30-day mortality rates. After most cases of Acute Myocardial Infarction, people are sent home before the 30 day period is complete. There is no accountability from the hospital staff to assure patients are

following orders communicated at discharge. If a patient leaves the hospital in good condition but continues smoking and does not take medication as prescribed by hospital staff; then, the responsibility for the death of this patient is placed on the hospital for purposes of this metric despite their efforts to heal the patient. This is a very controversial method that will have to be followed for many years as the kinks are worked out. ("Hospital Value-Based Purchasing Program," 2013)

Table 3: Outcome Domain Measures

Measure ID	Measure Description
MORT-30-AMI	Acute Myocardial Infarction (AMI) 30-Day Mortality Rate
MORT-30-HF	Heart Failure (HF) 30-Day Mortality Rate
MORT-30-PN	Pneumonia (PN) 30-Day Mortality Rate
AHRQ PSI-90 composite (for FY 2015 only)	Complication/Patient Safety for Selected Indicators (composite)
CLABSI (for FY 2015 only)	Central Line-Associated Blood Stream Infection

3.1.4 Efficiency Domain

The final category is the efficiency domain. Below is the table of the single metric to be measured in this domain.

Table 4: Efficiency Domain Measures

Measure ID	Measure Description
MSPB-1	Medicare Spending per Beneficiary (MSPB)

The MSPB measure assesses Medicare Part A and Part B payments for services provided to a Medicare beneficiary during a spending-per-beneficiary episode that spans from 3 days prior to an inpatient hospital admission through 30 days after discharge. This measure will be used and compared with other hospitals and then scored based on the results. ("Hospital Value-Based Purchasing Program," 2013)

3.1.5 Scoring

To score each hospital, the domains above are given individual scores (either Achievement or Improvement depending on which is higher) based on the metrics. Once the scores are given, they are then multiplied by a given weight and the final scores for the domain are available. The sum will be taken from the scores in each domain and the hospital will be given their overall score. ("Hospital Value-Based Purchasing Program," 2013)

3.2 Capacity Planning

Predictive Modeling in the healthcare industry can be used for a variety of things including staffing, inventory, room scheduling, etc. In the case of capacity planning, predictive modeling plays a vital role to assist hospital administration in better understanding what will likely be needed in the future. Research/data has been compiled pertaining to capacity planning and predictive modeling in multiple industries. Some have found types of problems that work best using a linear programming approach to identify the appropriate answer. These particular problems will answer questions similar to the following:

> What effect will any given demand forecast have on capacity plans?
>
> What will be the effect of an expected change in ownership of costs?
>
> If prices for leased capacity increase by specific amount, how will plans and costs be affected?
>
> What is the sensitivity of decisions and costs to forecast error? (Fetter, 1961)

All of these are important answers to acquire from a model in specific situations, but sometimes more is required.

The healthcare industry has three main constraints which are (1) time, (2) inventory (referring to employees in this case) and (3) high uncertainty. These specific constraints make using only linear programming an insufficient option. Generally, there are not direct correlations between two given variables and the uncertainty is so great that it cannot be accounted for in simple linear programming. From research, we have learned that creating robust solutions to problems will help to avoid complexities in nonlinear stochastic formulations. (Dimitris Paraskevopoulos, 1991) This allows us to use non-linear predictive modeling to more accurately predict future states with less complexities despite the high uncertainty. Creating models in this

manner allows the user to increase or decrease the emphasis on the defined sensitive term within the model in order to increase or decrease excess capacity (available nurses). This type of model developed for the healthcare industry would allow for administrative "what-if" analysis to be performed and more informed estimates to be provided.

3.3 Simulation in Healthcare

The use of simulation in healthcare is growing in popularity while saving money and becoming more efficient is increasingly more important to hospitals of all sizes. Major complaints from patients are their wait times and the lack of time spent with their health care provider. In the case of an inpatient hospital unit, a common issue from patients is that their nurse is not available when they are needed or wanted. Another complaint is the nurse is seen very little throughout the day. Most complaints received by inpatients at hospitals can be directly related to a staffing issue.

Studies have been performed to try to minimize wages paid by the hospital by predicting the correct staffing range to meet patient demand while minimizing hospital cost using simulation models with minimal inputs to predict optimal ranges. (McHugh, 1989) Other research has been done to test the idea of using simulation to decrease nursing overtime. This is important in an inpatient facility because most nurses working more than their allotted shift are paid overtime pay which costs the hospital additional money. This research revealed that simulation can help hospital administrators stagger nurse scheduling to better meet patient demand throughout the day. (Javad Taheri, 2012) Both areas of research are important in healthcare. Each is targeting a specific portion of the healthcare industry, but the ideals can span many healthcare areas and provide methodologies for improved patient service.

Simulation in healthcare plays a role in the quality of service provided to the patients and can have a role in training new and existing employees. An important tool from simulation is the "What-If" scenario tool. With this tool, real life scenarios can be established and "practiced" in training sessions or analyzed by hospital administration to prepare the healthcare facility for various scenarios that will occur. (Barjis, 2011) This will allow alternative plans to be implemented by the hospital which could help with a broad spectrum of issues from saving money to saving lives.

With specific data, a simulation can portray possible future outcomes given the specified circumstances. This is beneficial in healthcare because it allows administrators to more accurately plan for the future and potentially save money. Simulation has the ability to identify underutilized and over utilized resources and alleviate these concerns. Unfortunately, the healthcare industry has long suffered from a lack of valuable data collection. This led to simulations being run with data that will only predict approximate results. In this instance, the results would likely be subpar in some instances and unreliable to users. It is difficult to accept the benefits of the simulation software due to its potential inaccuracies. (Barjis, 2011) Another issue that arises in the healthcare industry is the constant changing of processes. It is difficult to collect the same data when processes change dramatically. Often, a simulation model is set up to requiring very specific data that may not be readily available after process alterations; therefore, leaving the model as unusable. If a simulation is not set up in a manner that requires simple data entry, it will become obsolete very quickly.

3.4 Nurse Staffing

Nurse staffing has long been a researched issue in the healthcare industry from several different academic areas including industrial engineering, nursing, medicine, business analytics, and operations research. Along with the multiple research areas have come multiple research methods that could be used for nurse staffing. One of the most popular methods is to staff by patient acuity. Research has found that having a computer to update each acuity score by patient two hours before the next shift will help the hospital to accommodate the patients with the appropriate nursing staff. This requires having the appropriate information at the appropriate time and knowing what to do with it when it is available. (Bagg, 1987) While this is a very effective means of staffing nurses, there is no way to forecast the nursing need 2 months out and the idea of using acuity has been an issue in many medical facilities for a long time. Despite the many ways to test acuity, some of the score is still dependent on what the person scoring the patient thinks. This leaves the scores somewhat subjective and therefore they have the potential of being inaccurate as Bagg points out in her research. (Bagg, 1987) Finding ways to improve nursing accountability for their decision making allows for improvement in this system. The overall thought process of the system meets the needs of a nurse staffing department because the multiple facets of the decisions are taken into consideration, but the subjectivity of the process makes it potentially unreliable.

Another method researched for staffing nurses uses a queuing perspective to further understand appropriate nurse to patient staffing ratios. In this method a model is built to match a medical unit at a hospital. This methodology is simple to implement and takes into consideration many of the factors that affect patient satisfaction including nurse fatigue, nurse scheduling, and patient specific delays. (Franci de Vericourt, 2011) Other methods that have been researched for

scheduling nurses include mathematical programming models which take nursing preference into consideration, nurse scheduling optimization using mathematical programming, and a resource allocation approach to staffing nurses on a medical unit. Each of these has benefits and downfalls just as the previous two discussed.

Staffing based on nurse preference is a way to keep nurses happy and has been heavily researched. In this model the algorithms are set up to assign minimum numbers of each nursing type to the schedule for a 4 to 6 week period. (Warner, 1976) The mathematical programming approach that uses two stages for nurse staffing is based on specified constraints. It takes into consideration vacation schedules and nurse schedules in order to create something that will increase both hospital satisfaction and nurse satisfaction while meeting the patient demand (if that is a listed constraint). This is a versatile approach to nurse staffing that can be easily altered to fit other areas of the hospital. (Chang-Chun Tsai, 2010)

The resource allocation method takes a slightly different approach to nurse staffing. Instead of creating a schedule, the point of this model is to use Goal Programming to determine how many nurses of multiple types are needed to meet the needs of patients. (HJ.P. Oddoye, 2007) Again, this is different from the previous approaches researched, but it does provide the intent to satisfy multiple goals that are related to the patient outcome. In this method, targets are set and deviations are found portraying either underachievement or overachievement of the goal. In Goal Programming, the decision maker can assign penalties for deviations which will further constrain the model to most accurately meet the needs of the decision maker. This model provides results (based on the assigned constraints) similar to those of the others, but it takes into consideration different types of nursing staff. (HJ.P. Oddoye, 2007)

A three stage model has also been researched specifically for nurse staffing in acute care facilities. (William J. Abernathy, 1973) This model takes into consideration policy decisions, staff planning, and short-term scheduling as the three times phases. While it is made for the acute care hospitals, it can be implemented in any service industry creating a versatile approach. This is comparable to the aggregate planning models with slight variation because there is no known inventory and back-stock to use in case of an emergency. The issue with nurse staffing is much more finite and contains more constraints. (William J. Abernathy, 1973) Since this model is set up to accommodate large variation, there are some hospital units that would not work as well in the model as others. An example would be the cardiac unit where most patients will have severe cardiac illnesses and need similar care. This leads to a decreased amount of variations in patient demand which is very uncommon in most parts of the healthcare industry.

The staffing models listed plus many other nurse staffing models have been researched over the years. Since nurse staffing is an essential task in manpower planning (Chang-Chun Tsai, 2010) for hospitals, it is important to continue research on this issue to provide a basis for future researchers for continued learning. With the cost of the Nursing Department increasing to over 50% of the hospitals budget, it is imperative to maintain appropriate levels and plan for the future. (Natalia Yakovic, 2011) With the campaign from consumers and government to keep healthcare costs down, the demand is increasing for a better way to provide quality care to patients at a minimal cost.

Chapter 4 Methodology

The importance of staffing nurses efficiently in hospitals is not a new concept to the healthcare industry. As discussed in the Literature Review section, several methods have been created to decrease nursing costs and increase efficiency. With the implementation of new healthcare laws, cost and efficiency are no longer the only important goals related to nurse staffing. With revenue at stake, patient satisfaction has grown more important to hospital administrators reaching the importance of budget needs. To successfully comply with healthcare laws, it is imperative that nurses be able to do their jobs and do them well while feeling comfortable in their position. This is the basis behind the methodology used to complete this research project.

4.1 Data Collection

This section will outline the steps used for this research as well as provide some insight into possible alternatives depending on model purpose for the data collection portion.

One of the first steps in any project is collecting required data. Data collection took several forms ranging from historical data outputs of hospital census levels to shadowing nurses during their shift to collect information about their workload and time constraints. The three main areas of data collection that should be considered for most nurse staffing models are:

1. Historical Data
2. Direct Nursing Data
3. Administrative Preferences

Each of these areas proved necessary for the models to be built.

The first data collection group, Historical Data, can take many forms. Depending on the software used and the goals of the system, this step will vary slightly from project to project. Defining the direction of the model includes understanding the available data related to nurse staffing levels and the purpose of the model defined by hospital administration. Collecting more data than necessary is important. A lack of available data will cause trends and forecasting methodologies (future steps) to become difficult to complete. For purposes of this research, historical data compiling patients' start and end dates was retrieved from the hospital from the previous 7 years. This information allowed further analysis to be completed on census levels by day within the hospital.

The next group, Direct Nursing Data, is equally as important as the first data collection portion. The time spent on this section included asking questions and receiving feedback from those people who live the hectic life of a nurse. This proved to be an important part of data collection because it was during this time that reasons why patient satisfaction scores were declining became obvious. Questionnaires (provided in 5.3.2) were used to collect additional feedback on targeted information based on historical data analysis and hospital administration goals. The summary information from the questionnaires was used as an integral step in furthering data collection from nurse shadowing. Once the nurse shadowing portion began, time studies were completed on several nurse processes including: medication passes, admissions, discharges, procedures, patient consultations, doctor consultations, etc. A majority of this data collection contributes to the creation of the staffing and scheduling tools. It is better to have more data than not enough to provide a better understanding of a nurse workday. The data can be compiled and a more accurate formulation can be made for inclusion in the modeling process.

Talking with hospital administration about their wants/needs for nurse staffing was the third data collection step used in this research. It is important to note that this should not be the final data collection step, but rather integrated into the process or used before the other data collection steps begin. Communication with hospital administration should be one of the first steps taken when creating a model. Hospital administrators are usually the people who request the completion of projects pertaining to nurse staffing levels. If the end product does not follow expectations; then, it is likely the tool will not be implemented in the hospital. The administrators perspectives are extremely important as a basis for model creation and specific research areas.

The three areas of data collection are vital for the success of this project. Depending on the feedback from administrators and nurses, the data collection process could be altered slightly for creation of models at alternate hospitals. These are the base three data types (historical data, direct nursing data, administrative data) that should be considered, but might not be the sole considerations depending on model purpose. Other data collection areas that might be considered:

Departmental Data Collection

Quality Data Collection

Procedural Data Collection

Others not listed might necessary

These will not be required in every instance, but should be considered after the purpose of the model is formulated.

4.2 Forecasting/Capacity Planning

Forecasting means to predict or estimate a future state. Forecasting is a large part of the development phase for this nurse staffing model. During the creation process, multiple forecasting methods were attempted to identify one that would allow for only minor deviations from actual data. The application of each section explained below is shown in Chapter 5 with relation to the hospital where this research was performed.

4.2.1 Forecasting Patient Census

After collecting the historical data required, forecasting the census became the next most important step. The historical data would be the basis of how many nurses the hospital needed to have each day. (The conversion from census to number of nurses is explained later in the methodology section.) To accomplish this task, historical data from the past 7 years was gathered. This data was fed into multiple forecasting formulations and optimized to choose the method that produced the smallest deviation from the actual data. The following methods were all tested for use to forecast the number of beds filled per day: linear prediction, moving average, weighted moving average, and exponential smoothing. None of these methods fit the data accurately, but should be tested as they are plausible methodologies to use with appropriate data. Subsequently, day-to-day, week-to-week, and month-to-month forecasting methodologies were applied by using the percentage change from one time period i to the next time period i+1 (where i = 7+1 = 1 moving from Saturday to Sunday). The change from day to day is optimized using the following formulation:

$i = day\ of\ week$ (1,2,3,4,5,6,7); 1 = Sunday, 2= Monday, 3 = Tuesday, 4 = Wednesday, 5 = Thursday, 6 = Friday, 7 = Saturday; *exception* when i = 7, i +1 = 1

$j = change\ from\ day\ i\ to\ day\ i + 1$ (1,2,3,4,5,6,7); $1 = Sunday\ to\ Monday, 2 = Monday\ to\ Tuesday, 3 = Tuesday\ to\ Wednesday, 4 = Wednesday\ to\ Thursday, 5 = Thursday\ to\ Friday, 6 = Friday\ to\ Saturday, 7 = Saturday\ to\ Sunday$

$k = week\ number\ (1, \ldots, m)\ where\ m\ has\ no\ limit\ in\ this\ model$;

$week\ 1\ starts\ Sunday\ January\ 1, 2006\ and\ continues\ to\ Saturday\ January\ 7, 2006$; *week 2 starts on Sunday January 8, 2006* and so on.

$$minimize\ Actual\ (A_{ik}) - Predicted(P_{ik}) = Difference(D_{ik})$$

$Min\ D_{ik}$ for all i

$$s.t. -5 \leq D_{ik} \leq 5$$

When D_{ik} is established, it can then be used as a guide for day to day changes in the predictive modeling process. Example of this is shown below:

Example 1: $A_1 * (1 + K_1) = P_2$

Example 2: $A_7 * (1 + K_7) = P_1$

For best results, choosing the forecasting methodology that optimizes the results from the above equation for the data provided is required.

4.2.2 Forecasting Admissions and Discharges

Admissions and discharges are forecasted using an alternate method known as exponential smoothing. When using exponential smoothing, an alpha (α) value must be found to predict the next occurrence. The importance of knowing the number of admissions/discharges in the future is to allow for workload increases or decreases by day depending on the number that must be completed. The specific number of each does not matter, but the workload per day

depends on the aggregate forecast of the two; therefore, making it important to forecast as accurately as possible.

Each day (Sunday through Saturday) is forecasted independently in order to accurately predict the number of occurrences most accurately. The alpha values are introduced into the model using the following formulation:

$$F_{t+1} = \alpha D_t + (1 - \alpha) F_t$$

This model forecasts the admissions/discharges one week in advance of the actual data collected for the model. After the first week, historical data is used to predict the workload from admissions and discharges based on an average by day. For example, all Sundays in the data set are averaged together to approximate the forecasted numbers. This contributes partially to the deviation found in the model when forecasting the number of nurses required. Once forecasted, the admissions/discharges are incorporated back into the model and the workload by day is adjusted accordingly. Based on the specific data trend being analyzed, alternate methodologies may prove more effective.

4.2.3 Seasonality

A simple seasonality approach was taken to adjust the model to match the patient census. After analyzing seven years of data, itias obvious that there are more patients during the Winter months than the Summer months. Fall and Spring show similar results. This is very important in creating accuracy in the model when forecasting passed one month of data. Without these adjustments, recognized trends would not be accounted for and the data would be inaccurate. Recognizing these trends is important to improve accuracy in the system. Omitting seasonality adjustment variables could create inaccuracies in the model results causing the model to be unsatisfactory.

4.4 Staffing Model

Much of the information included in the methodology up to this point has reflected how different portions of this predictive modeling tool are formulated. The way the information is compiled and used to work together to create the staffing model is the next step. Steps for building the model are as follows:

1) Forecasting the hospital census based on historical
2) Analyzing the number of rooms filled based on hospital census
3) Calculating the number of nurse hours needed (nurse workload) based on the number of rooms filled and the specified processes included in nurse workload
4) Calculating the number of nurses needed
    a) Obtain Number of Rooms Filled by Day
    b) Calculate number of hours of nurse work by hour
    c) Add all patient demand hours (nurse workload hours) and divide by the staffing variable. In the case of this research, the staffing variable equals six. This is defined by identifying the maximum number of acceptable patients per nurse. Dividing the work hours by six will allow some nurses to have six patients and others to have less than six, but insures none will be burdened with more than six patients.
5) Creating an interface for use by hospital employees to predict future outcomes and input necessary data into the model
6) Incorporating appropriate data into graphs, tables, etc. to provide additional analytical support for decision-making.

These steps were used in the creation of the model at Hospital A which is shown in detail in Chapter 5.

A supplement to the model is an AnyLogic model that can be easily updated with real time information. *AnyLogic is a modeling tool that has the ability to do discrete event simulation, agent based simulation, and system dynamics.* With this model, results for the following day nursing level based on census and workload can be calculated quickly to make schedule adjustment decisions. This model operates with the same parameters as the Excel model, but the changes to it can be made more quickly and efficiently allowing nurse staffing to make more accurate short term decisions. The parameters that can be varied are the percentage of patients in each patient type (easy, medium, difficult med passes), the amount of time for each type of med pass, and the amount of time for admissions and discharges. It is important to enable hospital administration to vary these parameters because there is little consistency in hospital processes that lead to system wide changes. This tool will allow the necessary time for the model administrator to make accurate updates while providing nurse staffing data to the hospital.

4.4.1 Staffing Model Variables

In the staffing model, many calculations are made based on variables that could change in the future. When creating the model, it is important to select these variables carefully and incorporate them in a way they can be varied easily when changes occur. This section will explain the importance of the variables use in the model to provide a better understanding of each.

The first variable relates to the census pattern remaining the same with a slight amount of growth from year to year. If this changes, it is the employee's responsibility to recognize this shift and adjust the factor of growth within the model accordingly. A slight change in the census pattern will directly affect the outcome of the forecasting methods used. It is important to

recognize these minor changes and know how to make the adjustments within the model to continue receiving accurate results. Another variable deals with the distribution of medication passes within the hospital patient population. If this begins changing, it could have an effect on the nurse workload. This is also an adjustable variable in the model. A third variable coincides with the fact that this model represents 86.2% of a nurse's workday using only variables related to medication passes and admissions/discharges. The assumption for the use of the model is that 86.2% of the workday should be used to schedule nurses. If this becomes a problem for the hospital, an additional variable can be added to the model to increase the nurse workload by day and forecast required nurses based on 100% of nurse workload for a 12 hour shift.

Finally, a fourth variable used in the model is the method for changing censes to number of nurses described earlier in the document. The procedure for changing census to number of nurses meets the needs of the hospital where this research is performed. It provides a nurse with the potential of having six patients, but the nurse will not have six patients needing more work than can be done in her 12 hour shift. The process takes hospital preference into consideration as well as nurse workload. The equation provides a methodology to perform this analysis, but should be altered based on the situation (laws, regulations, etc.). Further details involving the specifics of the model are in Chapter 5.

4.5 Scheduling Tool

Completion of the scheduling tool is the final step of this research. For this tool, data collected is compiled to highlight areas of improvement for the nurse scheduling personnel. Necessary data for this tool is as follows:

Number of Patients

Number of Nurse Work hours by Hour

Number of Nurses Working by Hour

Percentage of Patients Receiving each Degree of Medication Pass by Hour

Number of Admissions/Discharges by Hour

Amount of Time to Complete each Degree of Medication Pass

The information is combined to create a visual portraying nurse workload by hour versus the available nurse hours by hour. The workload by hour (time to complete admissions/discharges * the number of admission/discharges per hour + the time to complete each degree of medication pass * the number of each medication pass by hour) is compared to the available nurse working hours by hour to show the areas where the number of nursing hours available exceeds the patient demanded number of hours and vice versa. From this analysis, adjustments in nurse scheduling (by changing shifts, altering shifts, etc.) can be analyzed. Similar assumptions are incorporated into this model as were made in the Staffing Model explained above. The details of this tool can be seen in Chapter 5.

Chapter 5 Case Study and Hospital Implementation

5.1 Background/Current Situation

The hospital where this research is applied is a small, rural hospital with the number of beds ranging from 160 to 210 on any day. This hospital serves surrounding communities and outlying areas with minimal access to other hospitals and medical facilities. Nurse staffing has been an issue at Hospital A for many years leading to the use of several staffing strategies. These strategies include staffing based on the number of beds operational at the hospital, staffing based on the number of beds filled a week in advance, and staffing with the same number of nurses all of the time. Each of these methods caused the hospital to be understaffed during the week and overstaffed on the weekends. This required paying nurses for performing less work on the weekends and paying time plus bonus pay to nurses during the week that had to be called in for the high patient demand. These staffing methodologies have not met the needs of hospital administration or nurses working at the hospital. Ultimately, the problems the hospital is dealing with regarding nurse staffing are an increase in overtime pay, an increase in nurse turnover, and a decrease in patient satisfaction.

5.3 Data Collection

5.3.1 Historical Data

Hospital A (HA) uses MIDAS, a multimedia digital archiving system, to store historical data. From this program, data can be retrieved in several ways to retrieve the information needed. For purposes of this research, data reports were created that include the following information:

Patient Unique ID Number

Patient Admission Time

Patient Admission Date

Patient Admission Location

Patient Encounter Type

Patient Discharge Time

Patient Discharge Date

Patient Discharge Location

This information is necessary for the model related to the current situation at Hospital A. Small adjustments to data collection might be required for different model scenarios depending on the hospital and the type of nurses being considered. This data was used to create tables that provide data for census by specified time period.

Taking HIPAA regulations into consideration, patient Unique ID's provided by HA are altered in data tables to further protect patient identification. An example of the data report is shown below:

Table 5: Example MIDAS Output Summary Report

Account No.	Start Date	Start Time	Admit Source	Enc. Type	Admitting Location	End Date	LOS	End Time	D/C Loc
11111	6/7/ 2007	0605	Home/ Non-Health	S	Outpatient Surgery	6/8/ 2007	1	0825	2N
22222	12/10/ 2007	1508	ER	I	ER	12/17/ 2007	7	1944	4S
33333	12/26/ 2007	2157	ER	I	ER	1/4/ 2008	9	1411	4N
44444	11/15/ 2007	1852	Home/ Non-Health	I	Same-Day Surgery	11/16/ 2007	1	0857	5N
55555	10/7/ 2007	1748	ER	I	ER	10/10/ 2007	3	0724	1N
66666	3/23/ 2007	0303	ER	I	4N	3/28/ 2007	5	1504	4N
77777	3/29/ 2007	2137	ER	I	ER	3/30/ 2007	1	1920	ICU
88888	2/2/ 2007	2112	ER	I	ER	2/6/ 2007	4	2080	4S
99999	11/26/ 2007	1530	Home/ Non-Health	I	Same-Day Surgery	12/5/ 2007	9	1424	5N

This information was then modified to create tables similar to the one shown below:

Table 6: Example Table Used to Determine Hospital Census Levels by Day

Account No.	2/1/07	2/2/07	2/3/07	2/4/07	2/5/07	2/6/07	2/7/07	2/8/07
11111								
22222								
33333								
44444								
55555								
66666								
77777								
88888		1	1	1	1	1		
99999								

The table can be read as follows: Table 6 shows that patient 888888 was in the hospital from 2/2/2007 to 2/6/2007. The table also provided information for the number of admissions and the number of discharges by day. Below is an example of the summary information these charts provided, giving the daily census of the hospital.

Table 7: Example Summary Data from Historical Reports

2/1/07	2/2/07	2/3/07	2/4/07	2/5/07	2/6/07	2/7/07	2/8/07	2/9/07
165	173	145	144	164	176	180	169	180

An analysis of the admissions and discharges was done and the total number was subtracted from the census total from the graph:

$$Census\ Total_i - Discharges_i = Total\ Rooms\ Filled_i$$

$$where\ i = the\ day\ number\ 1, \dots, N$$

This provides the number of rooms filled per day i. This particular data point is important because when one patient is discharged from a room, it is likely another patient will be admitted into that room during the same day. This does not mean the nurse has two rooms to care for as is shown on the census data, rather she has additional work to do for that particular room. After some data analysis, it was that found that there could be +/- 5% error in census using this methodology. Prior to using this technique, the percentage error agreed on with Hospital A administration was 7.5%; therefore, the methodology was validated. This becomes important when building the model.

5.3.2 Direct Nursing Data

Shadowing nurses was 250 hours of the data collection portion of this research at Hospital A. Observing the way nurses interact with the patients, timing nurses on particular tasks, counting the number of times nurses visit each patient during the day, and the purpose of each visit were all data points collected. Below is a table of questions asked during this portion of data collection:

1. Do you have enough time during a regular 7a-7p shift to meet your assigned patients' needs?
2. Do you have sufficient support (from other nurses, LPN's, and CNA's) to complete all tasks during a given shift?
3. During a 7p-7a shift, how much down time do you have when no tasks are being done?
4. In your opinion, what is the one task done daily that takes up the most time?
5. What is one task you do often that should be done by supporting personnel?
6. How often are you called in to work a shift that you were not originally scheduled to work (times per month)?

7. How often (per week) on average do you receive a patient in one of your assigned rooms that you are not properly trained to care for (i.e. a stroke patient, a heart patient, a post-op surgery patient, etc.)? a. (1-2 times) b. (3-4 times) c. (5+ times)

The answers received were anonymous to avoid any indication that a nurse was unhappy with his/her job. During this exercise, 5 inpatient units (wings on specified floor) were given the survey and 36 nurses returned their responses.

The following table summarizes the responses given to each question:

Table 8: Nurse Questionnaire Summary of Results

Question Number	Response/Option 1	Response/Option 2	Response/Option 3	Response/Option 4
1	No: 29	Yes: 7		
2	No: 36	Yes: 0		
3	1 hour: 4	2 hours: 12	3 hours: 14	4+ hours: 6
4	36 Med Passes			
5	Taking Patients to Bathroom: 29	Giving Patients a Bath: 5	Picking Up Trays: 2	
6	1 Time: 6	2 Times: 7	3 Times: 4	4+ Times: 19
7	A: 10	B: 22	C: 4	

This information provided input from those who know the processes best to concentrate on some specific tasks that need to be considered in the system. From the questionnaires, medication passes were chosen as a focus area. After several hours of research focusing on medication passes, admissions and discharges also became a focal point. Nurses working the 7a-7p shift at HA spent 86.2% of their work day performing these tasks. Time studies provided the following results:

Table 9: Results from Medication Pass Time Studies

Medication Passes	Average Time (Minutes)
Easy (3-5 Meds)	12.5
Medium (6-12 Meds)	17.8
Difficult (13+ Meds, procedures, chem sticks	31.6

Table 10: Results from Admission/Discharge Time Studies

Task	Average Time (Minutes)
Admission	50.7
Discharge	60.8

The hospital population over a 120 day time period was broken down into percent of patients receiving each level of med pass. The breakdown is as follows:

Easy – 7%

Medium – 70%

Difficult – 20%

The assumption in the program calculates this to be the same each day, but can be easily changed by the program operator when required.

5.3.3 Administrative Preferences

A questionnaire was distributed to those on the administrative staff who had a stake in the decision making process of the nurse staffing model. This included the hospitals' CMO, CNO, CFO, and CEO. The questionnaire distributed contained the following questions:

1. What is the most important thing you want this nursing tool to do for the hospital?

2. What are three things you view as problems with the current methodology of nurse staffing at Hospital A?
3. What is one thing you would like to see being done differently with the frontline nursing staff?
4. Please provide additional comments in the area below with regards to the nursing effectiveness at Hospital A and the nursing tool.

The responses to each of these questions are summarized in the table below:

Table 11: Administrative Questionnaire Summary of Responses

Question	Response 1	Response 2	Response 3	Response 4
1	Reduced Costs: 2	Assist in Improving Work Environment:2		
2	Effectiveness: 4	Patient Satisfaction: 4	Cost: 2	Nurse Satisfaction: 1
3	Decrease Cost: 2	Decrease Turnover Rate: 2		
4	A way to plan for future staffing levels			
5	Help Decrease Nurse Turnover Rates			
6	Improve Nurse Satisfaction			
7	Improve Patient Satisfaction with Hospital A			

While the results do provide a variety of answers, it is clear that each management employee who has a stake in nursing change has consistent goals in mind. They are interested in reducing costs and increasing patient satisfaction. Most of the management staff mentioned interest with

the tool helping to plan for future staffing levels and increase nurse satisfaction at their hospital. These responses guide the direction of the tool when building and emphasizing the importance of reducing costs and planning for the future.

5.4 Forecasting and Capacity Planning

5.4.1 Day-to-Day Analysis

At hospital A, forecasting from day-to day generated the most accurate results when using historical data as a guide (as mentioned in the methodology section). The equations used for forecasting are shown in the forecasting section of Chapter 4. When applying this to the data collected at Hospital A, the average error is ±1.76 nurses per day shift based on the forecasted census per day. This is calculated based on the formula provided in the Methodology section for converting census to nurses. Below is a summary of the equations used by day for the prediction model:

Table 12 Equations used to Predict the Following Days Census Level when Historical Data is Available

$x_{1jk} = x_{7jk}$
$x_{2jk} = (1 + 0.08235)x_{1jk}$
$x_{3jk} = (1 + 0.020833)x_{2jk}$
$x_{4jk} = (1 - .01)x_{3jk}$
$x_{5jk} = (1 - 0.026086)x_{4jk}$
$x_{6jk} = (1 - 0.0204)x_{5jk}$
$x_{7jk} = (1 - 0.081632)x_{6jk}$

Table 13 Equations used to Predict the Following Days Census Level when Historical Data is not Available

$x_{1jk} = x_{7jk}$
$x_{2jk} = (1 + 0.07)x_{1jk}$
$x_{3jk} = (1 + 0.03)x_{2jk}$
$x_{4jk} = (1 - .005)x_{3jk}$
$x_{5jk} = (1 - 0.0263)x_{4jk}$
$x_{6jk} = (1 - 0.013)x_{5jk}$
$x_{7jk} = (1 - 0.06)x_{6jk}$

These tables show that Saturday is set equal to Sunday in the model and the proceeding days have variables that will predict the census the following day.

5.4.2 Admission and Discharge Forecasting

Forecasting admissions and discharges used exponential smoothing forecasting. The table below shows the alpha values used in the model to predict admissions and discharges for the following week.

Table 14: Alpha Values for Exponential Smoothing Forecast Methodology used for Admissions/Discharges

Day	Alpha
Sunday	0.2
Monday	0.75
Tuesday	0.4
Wednesday	0.85
Thursday	0.8
Friday	0.4
Saturday	0.5

As previously mentioned, following the next week, the admissions and discharges take an average of all data collected by day to estimate the number of admissions and discharges in the future. This is inserted back into the model to increase the nurse workload for each day by approximately one hour per each admission or discharge.

5.4.3 Seasonality Adjustments

Seasonality is also a part of the formulation. Below are charts used to recognize the seasonality trends and create seasonality factors based on prior year trends.

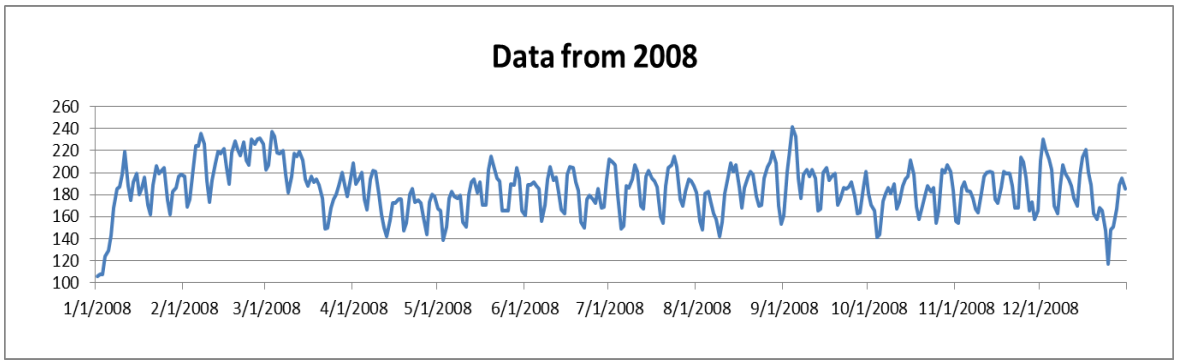

Figure 1: Number of Beds Filled by Day – 2008

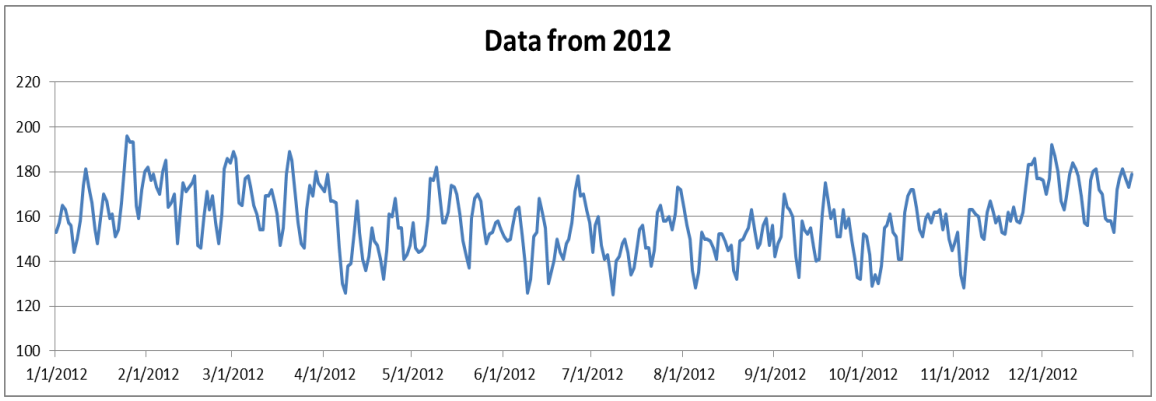

Figure 2: Number of Beds Filled by Day – 2012

This data shows a similar pattern from day to day in both years despite the volume difference. The winter months from December to April are slightly increased from the months in the Summer and Fall. Therefore, there should be a seasonality adjustment for the hospital to accurately predict changes. The methodology used for this change is as follows:

1. Formulas are set up to calculate dates in the following ranges:
    a. Nov – April
    b. February to March
    c. January
    d. October
    e. November
    f. April

    If the date falls within any of these time frames the number one is reflected in that column.
2. The sum of the numbers in the corresponding columns is totaled in the next column for each day.

3. The total column as well as a factor for each of the a-f columns above is then used to adjust the data to reflect the seasonality change for the hospital census. These factors were determined by the average error in that month after other adjustments were made.
4. Once each factor is evaluated, the predicted value is seasonally adjusted based on the information collected.

5.6 Staffing Models

5.6.1 Model Interface

The model interface for this tool is setup to accommodate the desires of HA administration. The interface is simple with few adjustable inputs to avoid misuse of the tool. The graphs and tables provided were those requested by the personnel who would be operating the tool to plan for the future. Each part is discussed in the following sections.

5.6.1.1 Input Data

Inputting data into the model is a very important step. The more data the model has to use for calculations, the more accurate the model will be in the future. The “Data Input” button on the right side of the model interface allows for easy, daily data entry. When the button is pushed, the following form will appear:

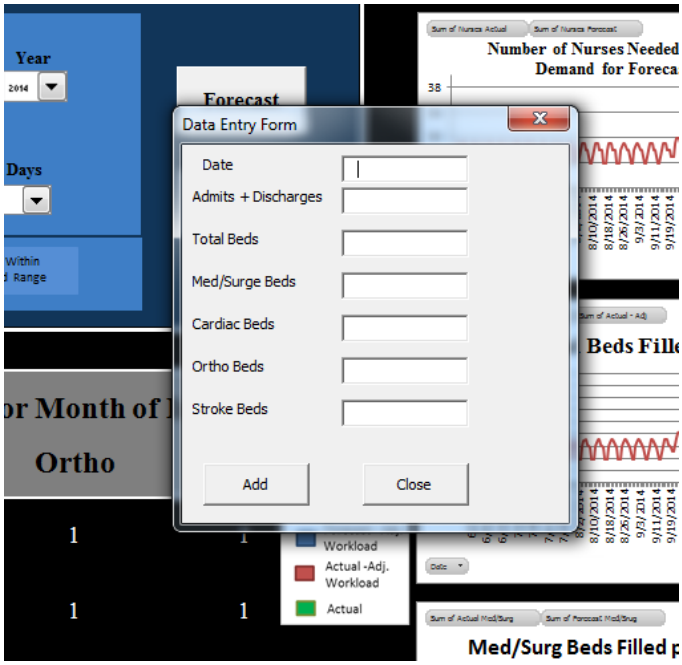

Figure 3: Data Entry Form

It is important to input each data point into this form before pushing “Add”. This form will then populate the model accordingly and the information will be updated after the Forecast button is pressed. Directions for inputting data are further explained in the Work Instruction for this model. Data should only be entered a day at a time using this form. The model’s administrator will have the ability to enter large quantities of data if the need arises.

5.6.1.2 Forecasting

The interface for this model (shown at the end of this section) allows users to input a forecasting period (length of forecast), a forecasting start date, and a month of interest which is a month that more specific information will be provided from the model. The interface also allows for data input by day.

After the start date, forecasting period, and month of interest are entered, the "Forecast" button should be pushed. This will update all graphs and tables to match the time frame of interest. Each time new data is entered into the model, the model should be re-forecasted because numbers could change slightly with any data input. Figure 4 shows the interface of the model.

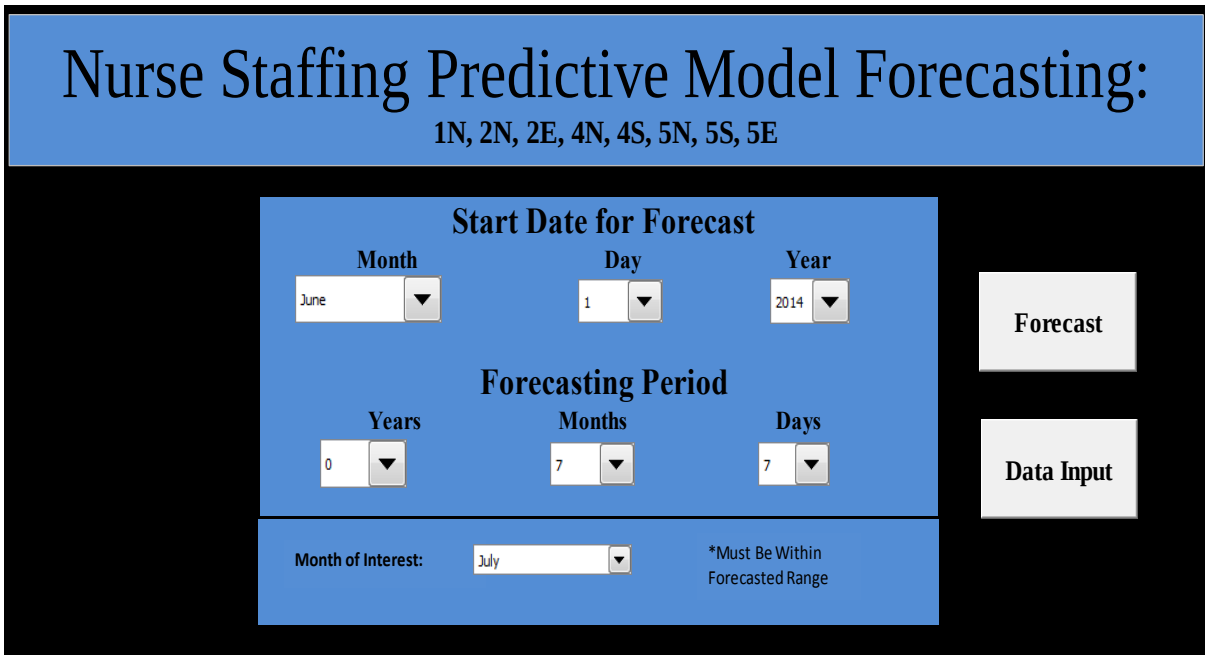

Figure 4: Model Interface

5.6.1.3 Provided Data

Once the desired data is entered and the forecasting time frame has been set, several types of information will be provided from the model. First, the number of nurses by day of week for month of interest is displayed. There is a summary table of this information by day. Additionally, there is a larger pivot table depicting the daily estimate of nurses needed based on

the information provided. The required number of nurses could vary by day from the summary table mentioned previously.

Next, graphs of the number of nurses, total beds filled, and specifically the number of Medical/Surgical beds filled is portrayed. This information is important to notice changing trends that could occur with new data entry. Noticing these trends will help to avoid overstaffing or understaffing in certain situations.

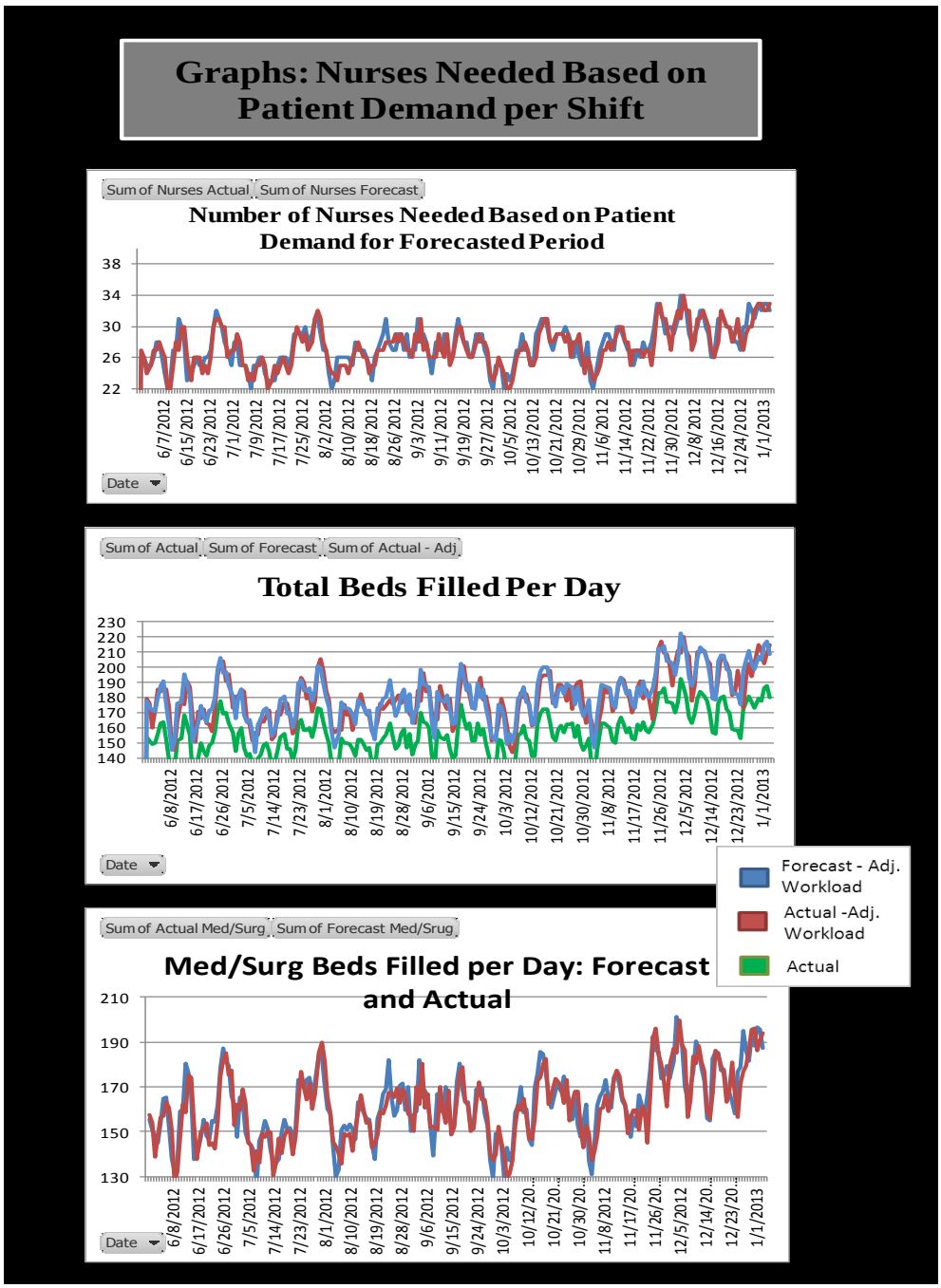

Figure 5: Dashboard Graphs

The additional data that is updated and provided when forecasts are revised is the by day data for the month of interest chosen by the user. This is depicted in pivot table form and shows how many nurses are estimated to be needed on a specific day during the month of interest.

The information provided from the dashboard is chosen based on hospital preference. Each of these items were requested by hospital administration and included for purposes of use at Hospital A. There is no limit to the amount of metrics that could be incorporated for a hospital to make the most use of the tool. Metrics such as Average Length of Stay, Nurses Hours Worked by Day, Admissions and Discharges by Day, etc. are all ideas for different display options.

5.6.2 Model Uses

Since the model provides valuable information about the number of nurses needed based on patient demand, it can be used for multiple tasks. These tasks include using the information to make hiring decisions based on nurse turnover rates, scheduling nurses to work specified shifts, increasing nurse satisfaction by taking nurse workload into account, staggering shifts to decrease hours worked per day, and decreasing overall costs for nursing, etc. The model does not perform all of these tasks, but the output from the model makes it possible to move forward with these improvements. An area of further research could be to incorporate these ideas the model. This will be discussed further in Chapter 7.

Using this model for scheduling shifts will be explained in more detail in the following section. Another use that Hospital A has for the model is illustrated below as an output from their hiring system:

Average Number of Nurses Needed	Number of Nurses	Nurse TO Inpatient	Orientation Process (Months)
27	63	26%	3
January	February	March	April
63+(63*26%)=79			63

Month of Interest
April

Figure 6: Nurse Hiring Tool

As is shown in the above figure, if orientation is a 3 month process and the Nurse Turnover ratio is 26%, the hospital will need to have 79 nurses in January (with 16 of them starting orientation) to have the 63 required to work by April. April would need to have some additional nurses starting orientation to provide the required nurses in July. This is a pattern used to assist the Nurse Staffing Department in making hiring decisions for their inpatient units. The output from the model is necessary to estimate how many nurses are needed in April. The box in bold in the above figure, will be more accurate with use of the forecasting tool.

Another use for the model mentioned is to increase nurse satisfaction. Staffing based on the numbers generated from the model will accelerate the process for improving this issue in hospitals. This model takes into consideration extra work from admissions and discharges as well as time to perform medication passes based on difficulty. Compared to historical staffing levels, this methodology will increase (only slightly) the number of nurses on the inpatient units by day which will allow them to be less overworked. To accommodate the additional employees, a scheduling tool will provide a method to align the employees with the patient demanded work load.

5.6.3 Model Supplement – Short-Term Forecasting in AnyLogic

The many uses of the model have been discussed in previous sections. For purposes of this application, the model is formulated to include a thirty minute lunch break for each nurse plus the amount of time it takse to care for each patient. The model has six patient types: easy medication pass with an admission or discharge, medium medication pass with an admission or discharge, difficult medication pass with admission or discharge, easy medication pass that stays in the hospital all day, medium medication pass that stays in the hospital all day, difficult medication pass that stays in the hospital all day. Each model area is shown in Appendix B.

Once the model runs, the total time to care for patients will be calculated and the number of nurses required can then be decided. Below, is an example of the output provided from this model. The average time to care for each patient type is calculated; then, the total number of nurses necessary can be calculated using this information.

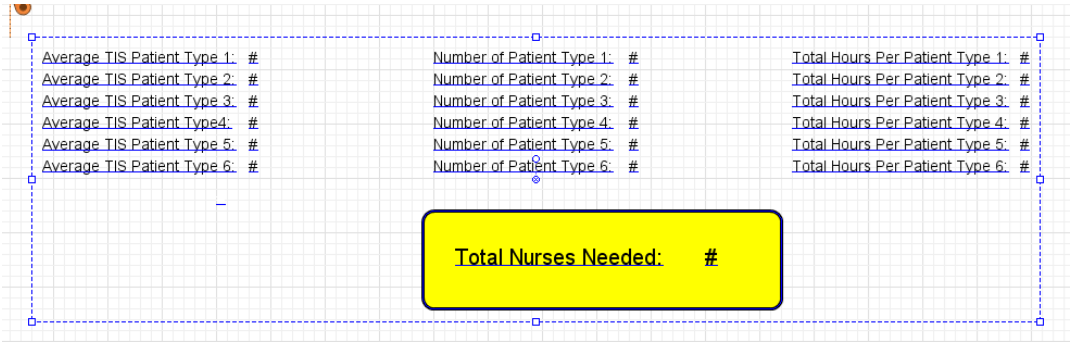

Figure 7: Output from AnyLogic Nurse Staffing Tool

This information can be seen in the AnyLogic tool by going to the “Nurses Needed” view.

The figure below shows the parameter variation portion of this model. This allows for multiple scenarios to be run providing a more accurate estimate of what will happen the following day; therefore, a more accurate staffing methodology can be implemented. In the model, the time it takes to do easy, medium, and difficult medication passes as well as the time to do an admission or discharge are varied based on the triangular distributions collected in the data collection phase (this information can be found in Appendix B). The mean can be found in the upper right hand corner which will likely be the most accurate staffing number for the current conditions at the hospital. This number can also be found on the graph, where the red line falls. The graph at the bottom of the window shows the multiple runs and iterations that were done and the results. This is important because the range of results is noticeable. Nurse staffing employees working with this model can see that the appropriate number of nurses could be slightly different from the average.

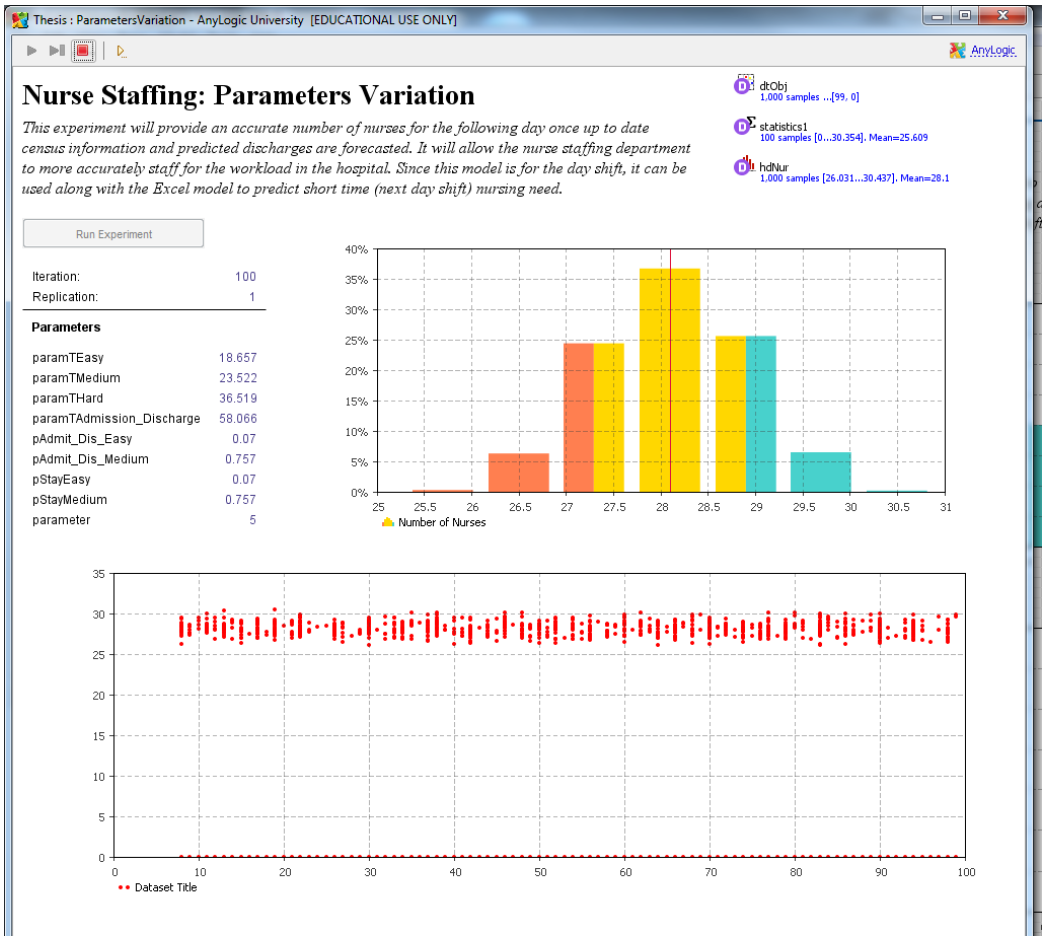

Figure 8: Parameters Variation Window - Nurse Staffing Model

With this information, the nurse staffing office can make an educated decision on the number of nurses needed for the following day shift.

5.7 Scheduling Models

Several additional tools could be created from the implementation of this base model for use in a hospital (explained further in Chapter 7 Further Research). The scheduling tool is one option that is found useful in hospitals. With the combination of the staffing model and the

scheduling tool, there can be increased patient satisfaction, increased nurse satisfaction, and decreased cost for staffing nurses.

5.7.1 The Tool – Excel

The Excel portion of the tool is important. It provides the graphical view of the current situation to inform the interested parties of the problems to be analyzed. The figure below shows the input items required (shaded in yellow) to obtain the graphical data output. These inputs are: time to do an easy med pass, time do a medium med pass, time to do a difficult med pass, the percentage of patients that are easy medication passes, the percentage of patients that are medium medication passes, the percentage of patients that are difficult medication passes, time to do an admission or discharge, admissions by hour, discharges by hour, nurses by hour, percentage of patient receiving medication by hour, and the number of patients. From the output, it is obvious that the shaded purple area which represents available nursing hours is inadequate in some areas (where it goes below the 0 line) and excessive in others (where there are large purple areas with no obvious tasks for nurses to complete).

Level	Time
Easy MP	10
Medium MP	20
Hard MP	35
Adm/Disch	50

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
Admissions	0	0	0	0	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	2	3	2	2	2
Adm Time	*0*	*0*	*0*	*0*	*0.8*	*0.8*	*0.8*	*0.8*	*0.8*	*1.7*	*1.7*	*1.7*	*1.7*	*1.7*	*2.5*	*2.5*	*2.5*	*2.5*	*2.5*	*1.7*	*2.5*	*1.7*	*1.7*	*1.7*
Discharges	0	0	0	0	0	0	0	1	2	2	3	3	3	3	3	3	3	3	3	2	1	1	0	0
Dis Time	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0.8*	*1.7*	*1.7*	*2.5*	*2.5*	*2.5*	*2.5*	*2.5*	*2.5*	*2.5*	*2.5*	*2.5*	*1.7*	*0.8*	*0.8*	*0*	*0*
Nurses	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Med Pass %	10%	3%	0%	0%	0%	3%	15%	50%	10%	75%	25%	50%	5%	15%	10%	0%	50%	10%	25%	0%	30%	60%	10%	0%
Med Passes (time)	*7.8*	*2.4*	*0*	*0*	*0*	*2.4*	*12*	*39*	*7.8*	*59*	*20*	*39*	*3.9*	*12*	*7.8*	*0*	*39*	*7.8*	*20*	*0*	*24*	*47*	*7.8*	*0*

***time in hours

# of Patients
190

Distribution for MP	
Easy	5%
Medium	60%
Hard	35%

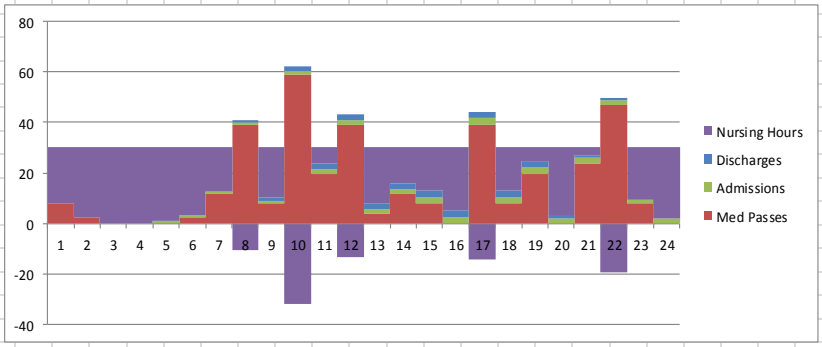

Figure 9: Excel Scheduling Tool

From this tool, an analysis of nursing shifts can be completed. Below in Figure 10 and Figure 11, graphs of the data provided and an alternative nurse scheduling strategy are shown.

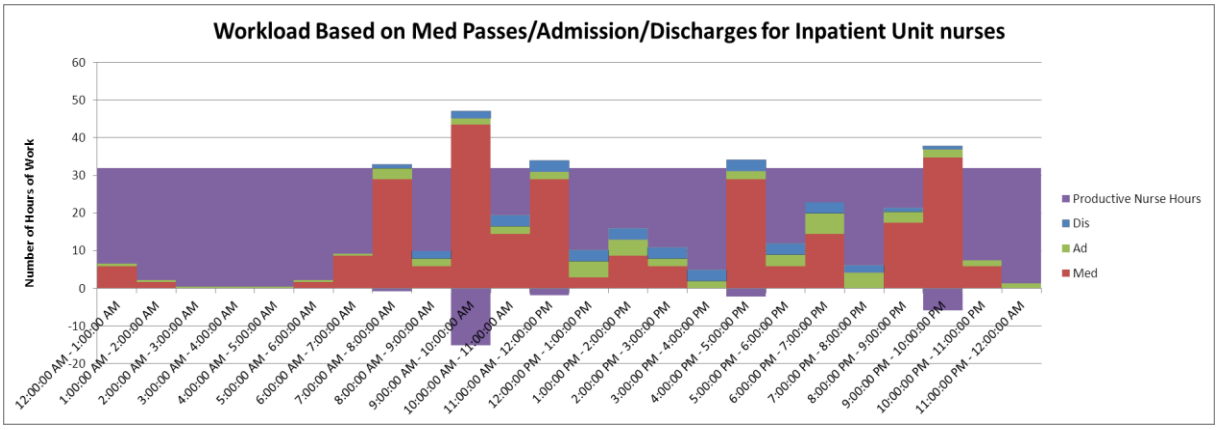

Figure 10: Workload Analysis from Excel Scheduling Tool

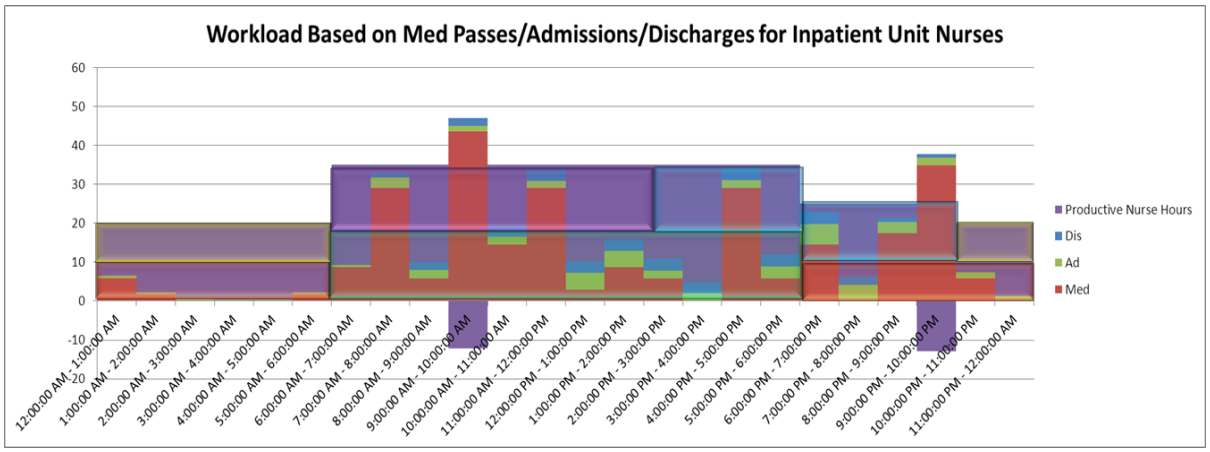

Figure 11: Nursing Shift Analysis Based on Excel Scheduling Tool

The alternative strategy decreases the number of occurrences workload exceeds available nurses and also decreases the number of worked hours. This solution was derived by using a simple analysis method which involved assessing the information and changing nursing shifts to better match patient demand. It would save the hospital 88 nursing hours in a 24 hour period. The

AnyLogic portion of this scheduling tool will provide optimized results based on inputs provided.

5.7.2 The Tool – AnyLogic

Similar to the AnyLogic tool used for nurse scheduling, the AnyLogic model will provide similar information It will optimize the results and provide information for the number of nurses needed. In this model, the work hours by hour are entered into the source schedule. The total hours calculated by hour in the Excel model can be copied and pasted into the AnyLogic source schedule. Below is a screen shot of the scheduling model that has been run for the entire day. Since the hours of work by hour are being introduced into the model at the source, it is assumed that for every hour in the system, one nurse is needed.

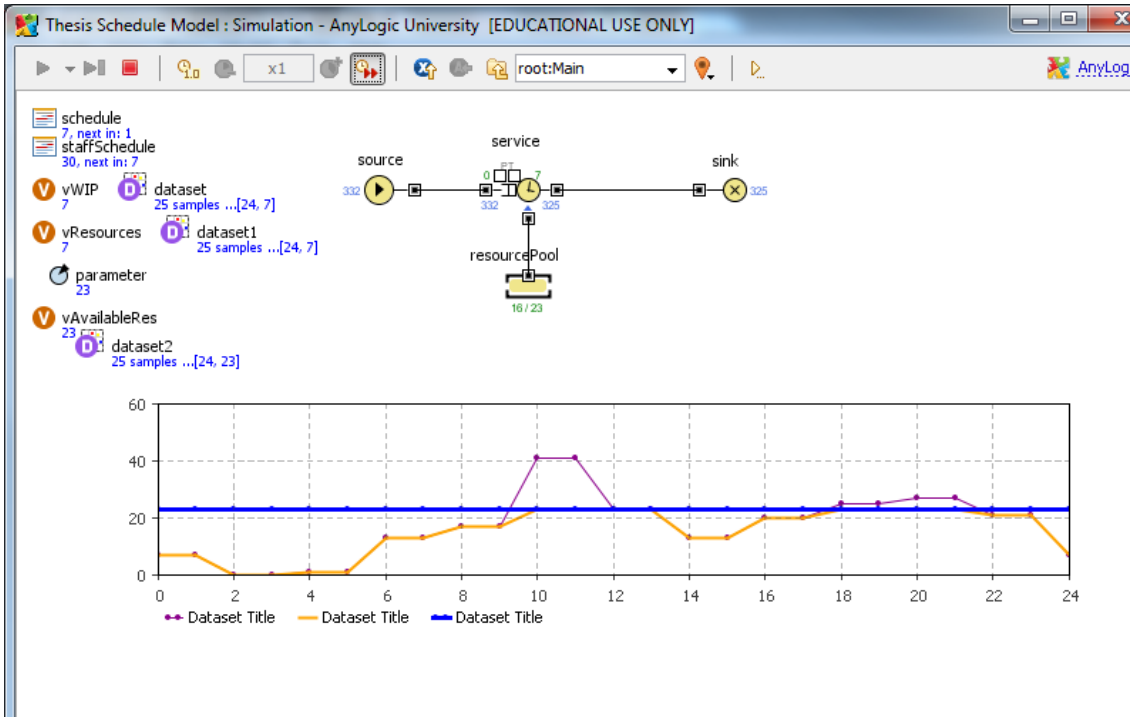

Figure 12: Screenshot of Nurse Scheduling Model

The graph shows three pieces of data. The first is the number of hours that need to be addressed. This is portrayed by the purple line. The second is the number of available nurses which is shown by the blue line. The third is the number of resources being used portrayed by the orange line. This graph highlights the areas where there is more work than nurses available and more nurses than work to complete. The nurses schedule can be changed to fit the line by entering the times a specific number of nurses will work to match the above diagram. When this is done, the model can be re-run to show how well the new model fits the patient demand.

As part of this model, an optimization tool is used. In this tool the number of nurses is the varied parameter. The number of nurses to minimize down time and maximize meeting patient demand is calculated.

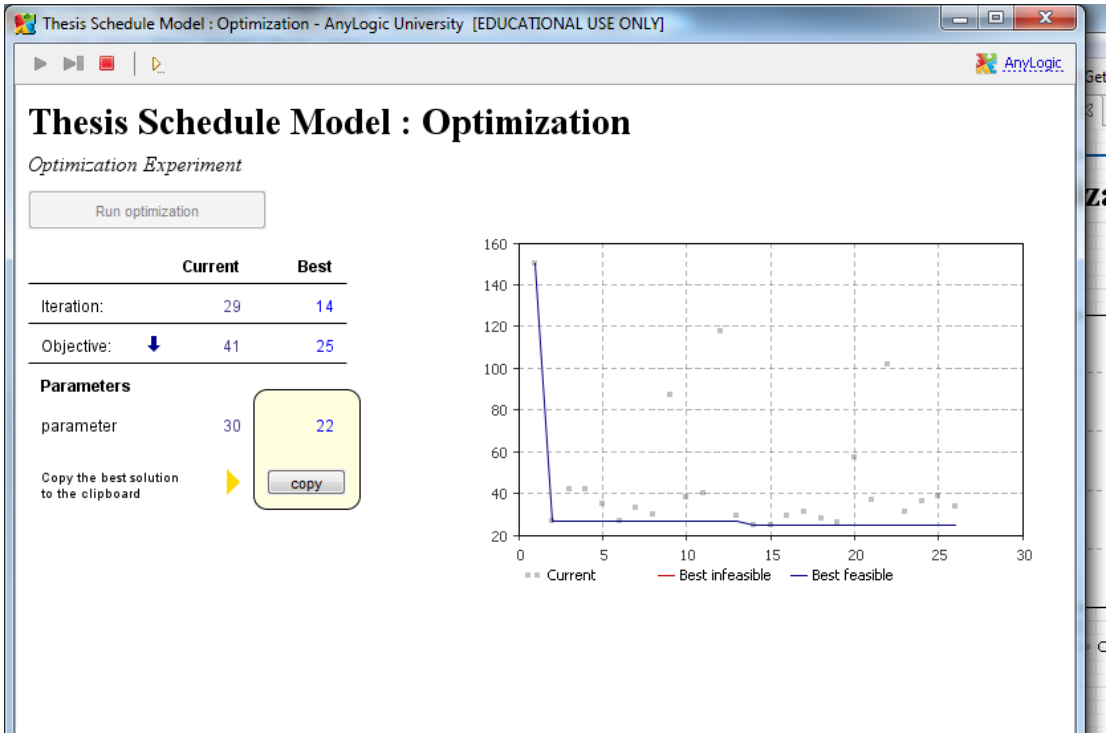

Figure 13: Scheduling Tool - Optimization Output

The optimal solution is provided on the objective line under the “best” column. The gray dots on the graph portray potential numbers in the experiment. When looking at this experiment a few nurses could be added as a cushion factor. This conclusion is based on having a specified number of nurses at any time.

This tool provides the nurse staffing employees a way to quickly identify the areas where scheduling adjustments could be made. Nurse schedules are easily varied to create a better understanding of how patient demand would be affected. Using this tool and the Excel portion described previously adds important insight into nurse staffing.

5.8 Implementation

This section discusses an example process explaining how the predictive modeling tool and the scheduling tools could be implemented into a Hospital using examples from the implementation process at Hospital A. A process flow diagram of the implementation steps at Hospital A is provided below:

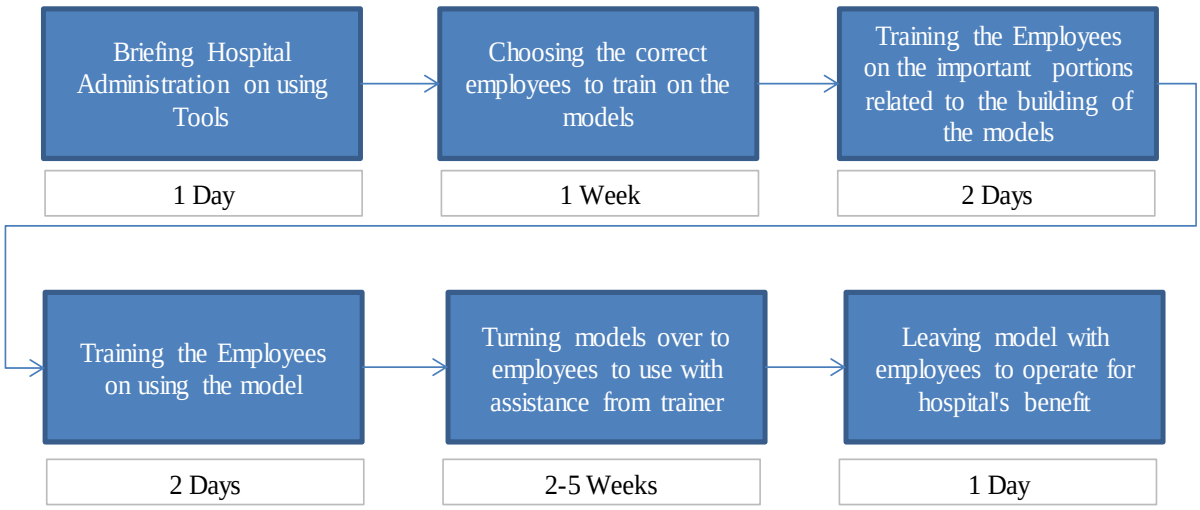

Figure 14: High Level Process Flow Diagram of Implementation Steps at Hospital A

5.8.1 People

Implementation of these processes at Hospital A involved the support and training of several individuals. The administrators at Hospital A including the CNO, CFO, CMO, and CEO discussed the benefits and risks of implementing a new system. Once agreed upon, the Nurse Staffing Department became involved in the decision making process. At this point, a representative from the Nurse Staffing Department, a Management Engineer and a few chosen nurses became involved in the use of the tool. Once the tool was explained and each individual

was trained on the use of the Excel portions and the AnyLogic tools, the team took charge. The people involved in the implementation will vary from hospital to hospital depending on the variation of the tool implemented. Having an understanding of who is affected by the tool and who can have the biggest effect on the tool is very important in determining who to train for use.

There should be one primary administrator who understands how the tool works (calculations, relations, etc.) and have full access to make changes within the tool. A backup for this administrator would be beneficial if something needs to be done when he/she is out of the office. It is imperative to have people (nurses, engineers, etc.) with a complete understanding of the models. This will allow staff to collect and update base data used in the model increasing accuracy in the system. The more data collected from people who understand the model, the more accurate the output. Those using the data from the model should have basic knowledge of how it works to better understand the output provided to the management team. Finally, hospital administration must have a working knowledge of the system in order to accurately incorporate it into future improvement plans.

5.8.2 Using the Data

While implementation of the models into the hospital processes is very important, if the data produced from them is not used effectively the implementation is insignificant. Below are brief explanations of how using the models and data in the short term and long term will make a difference for the hospital's plan for the future

5.8.2.1 Short-Term

In the short term, the AnyLogic models can be used to gain an understanding of current staffing levels for nurses and required staffing levels in the following days. It is important for the people using the output to understand the models and the system make-up. If the AnyLogic model shows that the hospital is overstaffed from 12am to 7am, but there are extenuating circumstances (i.e. paperwork, etc.) as to why extra nurses may be needed during this time; therefore, reasonable assumptions should be used.

The short term tools can be useful for the hospital when used in the appropriate capacity at the appropriate times. This will be model specific as different variations will be used for different purposes. The short term tool could be used the evening before (around 9pm) to verify the Excel models predictions. Another way the short term scheduling tool could be used the previous evening would be to push a nurses start time back an hour or pull it forward to meet patient demand forecasts. This could be a last minute adjustment made to improve patient satisfaction.

5.8.2.2 Long-Term

It is important for the people assessing the data from the Excel models to understand the system from which the models were built. While it is impossible to know that in three months there will be x number of people staying at Hospital A, the models do provide a representation of what the census will be. If the census trends change creating a new pattern, someone must identify the changes to be implemented in the system. It is imperative that multiple nurses understand required data inputs to the model. When changes are identified, they can be provided to the model administrator for updates. Understanding the basis of the calculations will enable nurses to identify hospital census and workload trends. If multiple people are involved, there is a

better chance that changes will be recognized and incorporated for long-term planning. Excess people looking for change will cause the model variables to be altered too often. The appropriate balance should be found

An additional use for the long term data is estimating the total number of nurses to be hired now to start orientation and be prepared in 3 months (or the length of the orientation cycle) for work on the inpatient floors. When a hospital has a lead time after hiring nurses for them to begin working, it confuses the hiring process. For example, if ABC Hospital needs 5 nurses to be staffed according to patient demand and there is no lead time for the nurses to begin work; then, they can hire 5 nurses and meet patient demand immediately. Hospital A has a 3 month lead time for the nurses after hiring. Using the data output from the Excel model, administration can more easily predict how many nurses to hire and when by utilizing baseline estimate workload forecasting three months into the future.

Chapter 6 Conclusions

Nurse Staffing in U.S. hospitals is becoming increasingly more important with the introduction of the Affordable Care Act (ACA). Nurse staffing affects the quality of care provided by the hospital as well as the patient satisfaction with their stay in the hospital. Both play important roles in insurance reimbursement plans under the new ACA. Finding ways to utilize resources in a way that will alleviate negative effects from these changes is at the forefront for hospital administrators.

Using predictive modeling techniques to help prepare for patient demand shifts and avoid negative patient satisfaction scores is one very important route a hospital can take. There are many ways to use predictive modeling and other mathematical approaches to forecast the number of nurses required. With the combination of Excel and AnyLogic tools as well as predictive modeling and optimization, the information in this paper provides hospital administrators with important planning methodologies.

This combination provides a dynamic approach for planning near term (based on real-time data) and long term (based on historical and real time data) for nurse staffing levels. Management can use "What-If" analysis by changing tool parameters to see the effects of different scenarios on their nurse staffing levels. This will provide a basis for decision making and reasons for hiring additional staff to prepare for upcoming census surges. On the other hand, when nurses leave and the predicted census is decreasing, there will be no reason to hire back every position.

In summary, the tools will allow appropriate staffing levels to be kept depending on time of year and nurse turnover. Several benefits will be recognized: it will help decrease nursing costs because additional nurses will no longer be hired if the nursing staff is sufficient to meet

patient demand, administration will be able to hire nurses in advance so that they will have time to complete their 3 months (length of time orientation lasts at HA) of orientation making them better prepared to take on patients, doctors at the hospital will have sufficient support from nursing staff which will improve the hospitals' reputation and make the hospital more likely to recruit top doctors, and patients will be satisfied with their nursing care because nurses will be less overwhelmed and have more time to spend with patients each day.

The dashboards provided in the models are customizable and easy to change to meet hospital needs. Without understanding the needs of the hospital or healthcare facility (step 1), it will be difficult to provide a product that is useful. This paper provides one way to use important hospital data to increase staffing efficacy and meet the needs of administrators. There are several ways explained in the following section that could change and improve this methodology with further research.

Chapter 7 Further Research

There are multiple directions that further research from this particular project could continue. Since the dashboard is built for a specified hospital's request, continued research could alter this dashboard based on what a majority of hospitals would like to see in order to create a system that would be readily available for use. This research would need to use further data collection as well as additional surveys to Nurse Staffing Departments at different hospital locations. Alterations to the programming of the dashboard would be necessary once the variables were chosen to meet the demand of the Nurse Staffing Departments.

The scheduling tool (which was not part of the original project) has the potential for much more research and development. The provided Excel and AnyLogic programs are simplified to meet the needs of Hospital A. This could be a vital tool for hospitals, to consider. At Hospital A, this tool was made simple because three main categories (Admissions, Discharges, and Medication Passes) combined to take 86.2% of a nurses work day. Since this is far more than the majority of the work day, those are the activities included. There is little basis to show why the 86.2% is enough for the model other than agreement from the CMO and CNO at Hospital A. The additional 13.8% of the workday is added into the model as an adjustment factor which could play a small role in the models variability. Further research on the percentage of the workday to be considered a majority (at most hospitals) and the tasks nurses do to take up that time, would be essential pieces of information to improve the tool to accommodate the needs of multiple hospitals. Creating an interface that would allow for either of these things to be changed easily to fit hospital preference would be even more beneficial. Currently the scheduling tool, there is no way to optimize the nurse schedules using Excel rather than an estimation. Creating an interface in Excel would make the tool more useful in the healthcare industry

because most hospitals have access to the Microsoft software. Additionally, a more efficient version where the two interfaces (Nurse Staffing and Scheduling) work together would increase the use of the tools in order to verify the importance of each.

Alternative research could be used for more specific information the tool could provide to hospital administration. Using real time data from the hospital data system could help to increase the accuracy of the tool and provide further knowledge to the Nurse Staffing Department. The connection to the real time data system used at the hospital would have to be integrated into the Excel dashboard where data would be imported at certain intervals. At the current time of this project at Hospital A, this could not be done without extensive programming knowledge. This tool could be very useful to hospitals in making decisions both within the day and in a three month time period.

Additional areas of research extending from this paper include: obtaining a better understanding of how this information could be used to assign nurses to particular rooms, understanding more of the dynamics of what makes a patient difficult to care for and how those can be forecasted, integrating information that would show how many nurses to hire now to prepare for the future based on nurse turnover rates into the model, incorporating the 7pm – 7am shift into the predictive modeling tool, changing the predictive modeling tools that shifts can be chosen base on the scheduling tools, etc.

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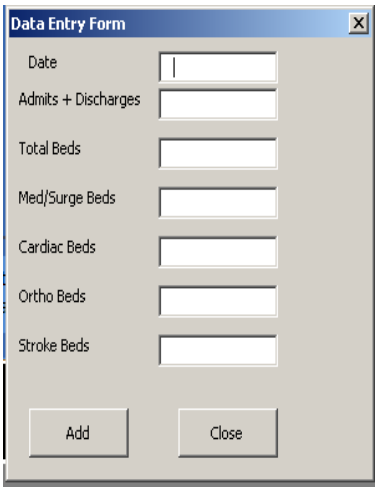
Appendix

Work Instruction

Work Instruction for Staffing Dashboard

Inputting Data

1. When the Dashboard is open, push "Data Input" button. A form will pop up with blank fields to input needed data.

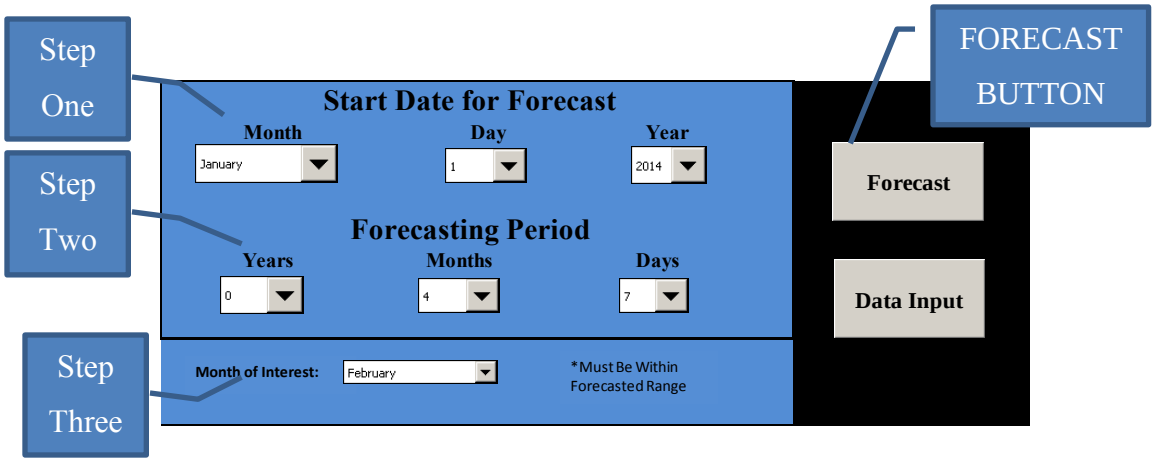


2. The date must be put in the form in the following way:
   - If the month is a single digit, type in a single digit month. *(i.e. 1/1/2012)*
   - If the month is a two digit month, type in both digits. *(i.e. 10/1/2012)*
   - If the day is a single digit day, type in the single digit. *(i.e. 1/1/2012)*
   - If the day is a double digit day, type in two digits. *(i.e. 1/14/2012)*
   - The year must always have 4 digits. *(i.e. 1/14/2012)*

   If the date is typed in incorrectly, an error will show up. The data will not be imported into the file in this case and must be re-entered again.
3. Each data field should be filled before pressing "Add".
4. Once the data is in the form and confirmed correct, push "Add". The data will then be part of the model.
5. Press "Close" once the form has emptied to get back to the model.
6. If the data is entered with an error, please call Brian Canfield or Thomas Florian to correct the data input.

Please remember, each time data is entered the forecast button must be pressed in order to update the data output.

Using the Dashboard



1. Choose a date to start the forecasting period you wish to see.

   For example: If the forecasting period you wish to see is January 2015, the start date would be January 1, 2015.

2. Choose a length for the forecast. This can be based on number of days weeks or months.

   For example: If the forecasting period you wish to see is January 2015, choose either 1 month or 31 days.

3. Once the data is updated choose the "Month of Interest". This month must be included in the time period within the length of forecast.

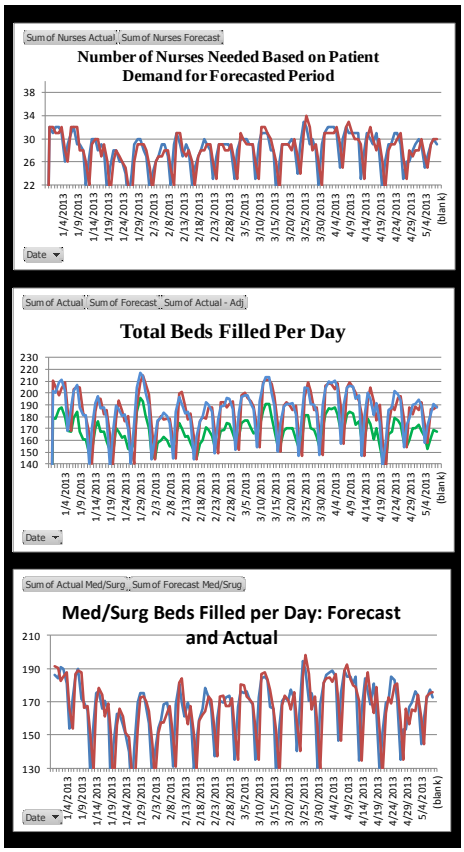
   For example: If the forecasting start date is January 1, 2015 and the forecasting period is 3 months then the month of interest can either be January, February, or March. No other months of interest would be appropriate for these dates.

4. Once all fields are filled in, press the "Forecast" button. All information will update accordingly with data filled in to the most recent entries.

5. If a box pops up with a message, push "Yes" and the updates will complete.

Forecasted Number of Med/Surg Nurses by Day for Month of Interest		By Day for Month of Interest		
		Cardiac	Ortho	Stroke
Sunday	22	3	1	2
Monday	29	3	1	2
Tuesday	29	3	1	2
Vednesda	28	3	1	2
Thursday	28	3	1	2
Friday	29	3	1	2
Saturday	26	3	1	2

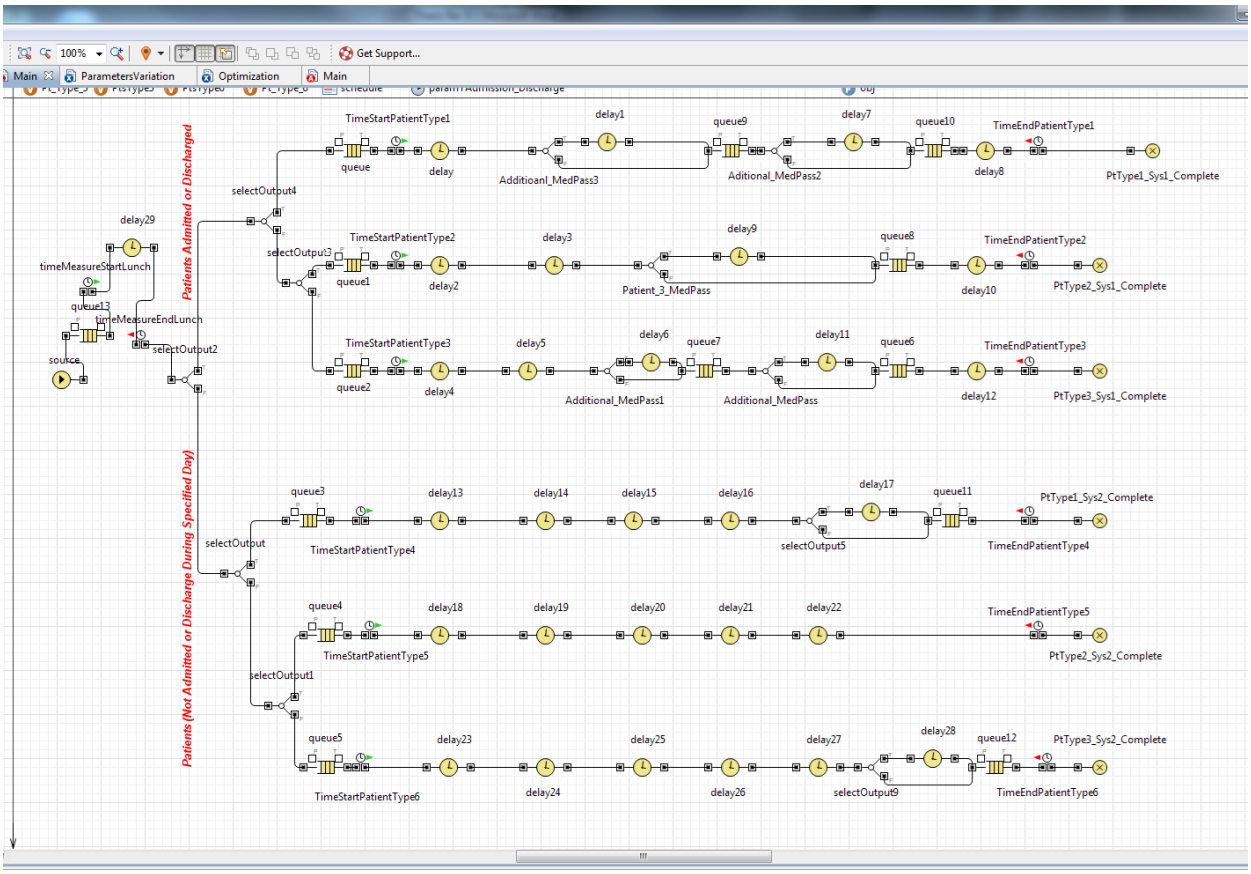
6. Above is a picture of the data listed below the Dashboard area. This information provides averages by day for the Med/Surg units as well as Stroke, Cardiac, and Ortho trained nurses needed by day.
7. To the right of this information are three graphs providing more specific data. These graphs will show trends that could occur based on data that has been input into the system. These graphs are shown at right.
8. Under the average data section is a pivot table that will provide specific numbers for the "Month of Interest" by day for each patient category. These could differ slightly from the averages based on historical information.



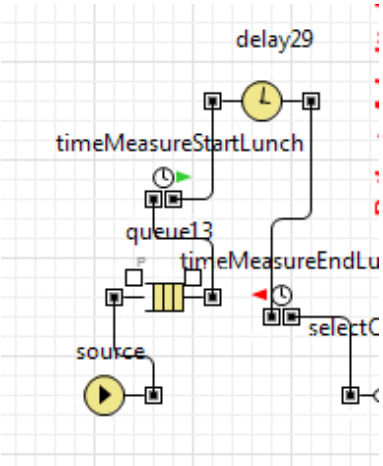
If there are any questions about the operations of this system, please contact the program administrator for assistance.

Nurse Scheduling AnyLogic Tool Model Overview

Below is an image of the whole Nurse Scheduling model in AnyLogic. This shows how each patient type is separated. The top portion represents those patients who are either admitted or discharged from the hospital in a given day. The bottom portion represents the work required for those patient who stay in the hospital for the entire day.



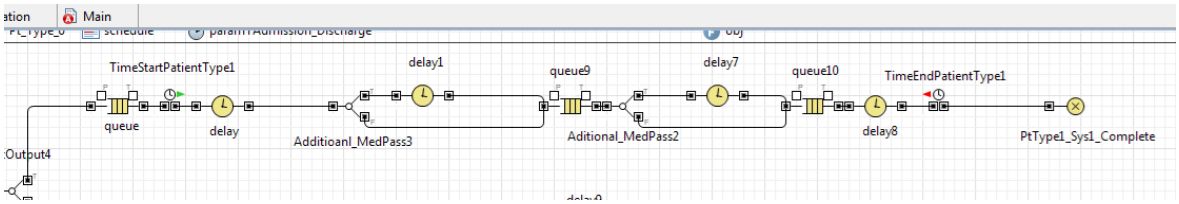
Next, the beginning of the model is shown in more detail. This is where the patients enter the system and go through delay29 which represents nurses' lunch breaks. This time is added to the total time to calculate the number of nurses needed.



The following diagrams represent each patient type and the work accompanied with each. The delays represent medication passes.

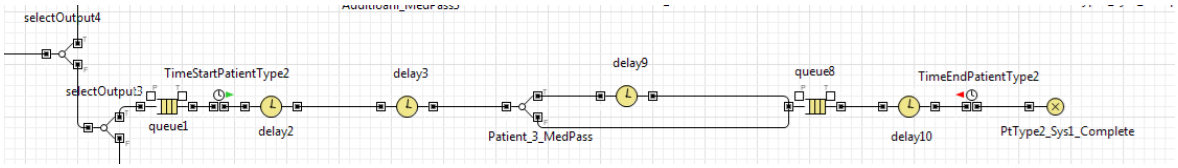
Easy Medication Pass, Admission, Discharge:

In this diagram, dealy8 represents an admission or discharge.



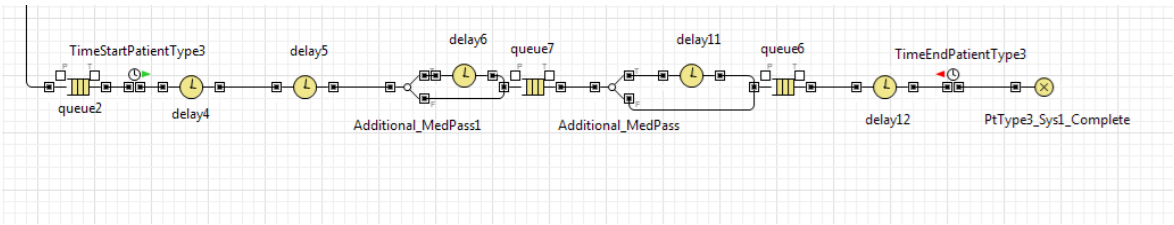
Medium Medication Pass, Admission, Discharge:

In this diagram, dealy10 represents an admission or discharge.

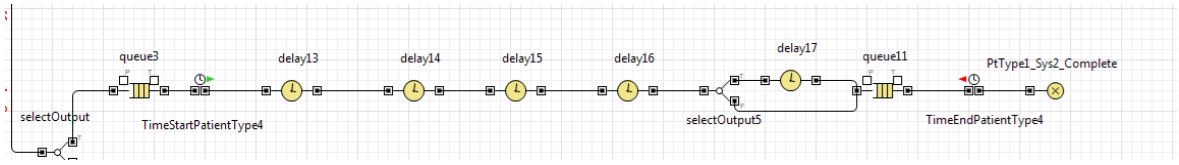


Difficult Medication Pass, Admission, Discharge:

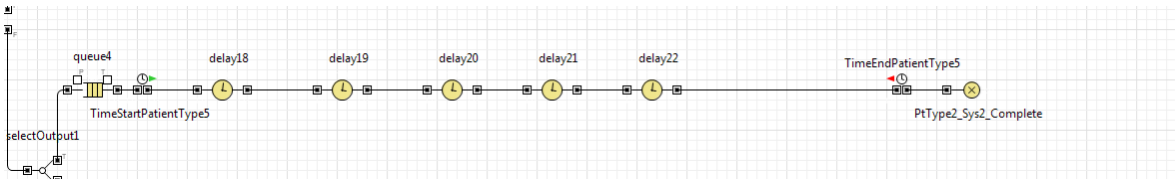
In this diagram, dealy12 represents an admission or discharge.



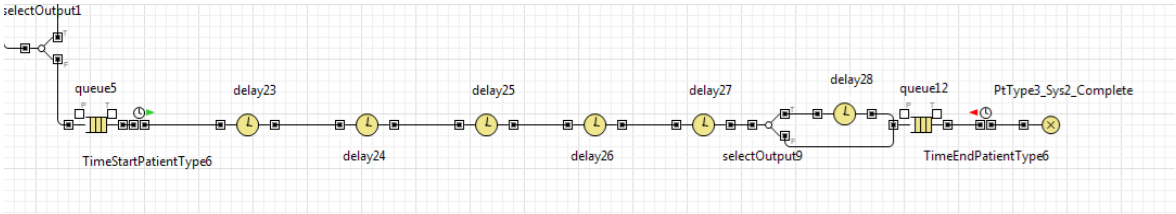
Easy Medication Pass, stays in hospital



Medium Medication Pass, stays in hospital



Difficult Medication Pass, stays in hospital



Each patient type has a start time and end time in the system. These calculate the amount of time it takes a nurse to care for one patient throughout the day regarding medication passes (and admissions/discharges if applicable). As explained in the AnyLogic Nurse Staffing section of this paper, the is a formula to calculate total nurses needed from this information. The formula is as follows:

$$[Total\ Time\ for\ Patient\ Type\ 1 + Total\ Time\ for\ Patient\ Type\ 2 + Total\ Time\ for\ Patient\ Type\ 3 + Total\ Time\ for\ Patient\ Type\ 4 + Total\ Time\ for\ Patient\ Type\ 5 + Total\ Time\ for\ Patient\ Type\ 6 + Total\ Time\ for\ Nurse\ Lunch\ Breaks] \div 60 \div 12 + 3$$

This will add the total time calculated for patients going through the system and divide those minutes into hours then into 12 hour shifts The additional three nurses are added because the processes accounted for in this model only add up to 85% of nurse work during the day. The three is used as a buffer for this. This number is subject to change based on hospital administration preference.

Vita

Kelcee Ramsey Elfstrom was born in Oak Ridge, TN to the parents of Dale and Linda Ramsey. She has an older brother, Tyson Ramsey. She attended Woodland Elementary School, Jefferson Middle School, and Oak Ridge High School. After graduating, Kelcee enrolled at the University of Tennessee, Knoxville, to study Industrial Engineering. She obtained her Bachelors of Science in May 2012 in Industrial Engineering from UT. The following semester she enrolled in the dual MBA/MS Industrial Engineering program at the University of Tennessee, Knoxville. She took a graduate assistantship position at Y-12 National Security Complex and held two internship positions. One of the internships was in the summer of 2013 at East Tennessee Children's Hospital. The other position spanned the summer of 2013 to December 2013 at Blount Memorial Hospital. At the beginning of 2014, Kelcee accepted a job with Ascension Health as a Senior Analyst for the Operations Resource Group. Kelcee will graduate with her MBA and MS in Industrial Engineering in May 2014.