Application of Simulation to Facility Planning Utilizing an Organization's Forecasted Growth Strategy

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Abstract

This study proposes simulation as a tool for transforming forecasted data into information that leaders can use to make strategic decisions. This study focuses on a health system's strategic decision to meet future demand by either expanding an existing hospital or developing a new 700,000-square-foot, $500M-plus facility. The researcher extracted data from forecasting reports, translated the data into scenarios, and used a simulation package to test, modify, and retest each until a best-suited scenario was identified. Simulation indicated that existing facilities could not accommodate projected demand, delineated structural and financial requirements for a replacement facility, and projected profitability of the new site by service line, program of excellence, and facility. Results of the simulation were used to secure support from the Board of Trustees and funding from financial institutions. The organization initiated construction of the 365-bed facility in late 2008 with occupancy scheduled for early 2011.

Key words: simulation, forecasting, hospital construction, growth, facility planning, strategic growth

Introduction

Healthcare organizations are challenged to transform massive amounts of data into actionable information that leaders can use to make long-term strategic decisions. This need is highlighted when organizations face critical decisions of facility planning and revenue optimization in the midst of unprecedented industry uncertainty driven by issues of access to affordable care, escalating utilization rates, restrained hospital finances, and looming healthcare reform. Health systems require comprehensive, flexible tools to assist in managing such imperatives by gauging the impact of multiple variables and decisions on a health system. Discrete stochastic simulation permits users to transform data into scenarios that can be systematically tested, modified, and retested in a reliable, repeatable process until a best-suited scenario is identified. Health systems can use simulation outcomes to make informed, data-driven, strategic decisions that maximize their ability to meet forecasted demand while not placing capital at undue risk.

Background

Simulation is the process of developing a model of an entity that can then be altered and analyzed to determine the impact of changes in key variables.[1, 2] Simulation can be used for process improvement, scenario planning, and resource utilization. It is one of the most powerful tools available for analyzing new system design, retrofits to existing systems, redesign of system components, and proposed changes to operational processes.[3] Simulation models enable the user to visualize how an entire system can be altered by changing an individual piece of the system; test hunches and risk-prone decisions and then remove risk when implementing simulated decisions;[4] discover solutions to operational problems; mimic the dynamic behavior of a system regardless of its complexity;[5] experiment with a system at little or no risk to patients;[6] analyze allocation of scarce resources; assess future optimization initiatives; and improve efficiency and efficacy of any process.

Two general categories of simulation are deterministic simulation and discrete stochastic simulation.[7] Discrete stochastic simulation is a process-oriented estimation approach that measures the performance of a system and its responses to varying conditions. This form of simulation is most often used in healthcare because it has the ability to model events that trigger activities, as well as both predictable and nonpredictable processes, over specified, discrete time periods. Its capabilities are applied easily to distinct clinical settings and operational situations. It can be used to identify opportunities for change, to design alternative business processes, and to execute them. For example, it allows users to forecast the impact of change on a specific patient pattern or flow. It is equally beneficial in allocating and scheduling resources for specified processes. Lastly, it allows users to examine how resources are utilized.[8] Simulation has been more frequently applied to healthcare settings where appropriate resource consumption and excellent service delivery are critical: emergency departments and mobile intensive care units,[9–18] inpatient areas such as operating rooms[19–21] and labor and delivery,[22] and outpatient services.[23]

This article introduces the concept of simulation and its applicability to hospital facility planning for the purpose of meeting projected demand. The following sections present a statement of purpose for the research conducted, the methodology, data analysis, results of the study, limitations of simulation and this study, and suggestions for areas of future study.

Research Purpose

This study assesses the applicability of simulation to strategic decision making at a health system evaluating the decision to expand an existing facility or construct a new facility on an undeveloped site to accommodate future growth. Using actual and forecasted data, the researcher hypothesized that simulation would generate multiple scenarios and assist leaders in identifying a best-suited scenario that would indicate facility requirements, assess the system's existing ability to meet those requirements, and evaluate the financial implications of a strategic decision to construct a new hospital.

Methods

Setting

Virtua is a multihospital healthcare system headquartered in Marlton, New Jersey. It is a not-for-profit, tax-exempt entity and the largest healthcare provider in south New Jersey. Virtua consists of five acute care hospitals, two rehabilitation hospitals, multiple ambulatory sites, physician-owned practices, mobile intensive care units, and a fitness center. Virtua's product portfolio is composed of programs of excellence (POEs) and product lines typically offered by a community teaching hospital. They are cardiovascular services, neurosciences, orthopedics, pediatrics, oncology, women's and children's (W&C) services, surgical services, and geriatrics. It is the largest employer in south New Jersey with more than 8,000 employees, 1,800 physicians, and 350 nonphysician clinical professionals. Virtua serves a suburban community spanning three counties that have a combined population of approximately 1.2 million.

Study Design

This quantitative study implemented a simulation approach to organizing, testing, and analyzing data for the purpose of understanding the organization's capacity to meet projected growth in demand. Using a stochastic discrete-event simulation package, the researcher built a model of the healthcare system's existing structure to demonstrate each component's position within the system, its relation to other components, and the impact that changing one component would have on other components. The researcher reviewed the organization's strategic and operating plans for their content, designs, and growth specifications. Additionally, the researcher assessed the organization's forecasting reports to understand projected demand and evaluate how that data would impact the organization's growth, facility, and resource plans. The researcher extracted from these sources existing organizational data and forecasted data related to product lines, volume, length of stay (LOS), and utilization. These data were integrated into the predictive model to create multiple scenarios that were tested, modified, and retested in a systematic process to yield a best-suited scenario indicating how the health system could meet projected demand without unnecessarily risking capital.

Data Collection

The researcher collected data from the 2005–2012 forecasted growth plan, whose methodology incorporates a statistical approach capable of manipulating multivariate events with characteristic seasonality. The researcher reviewed the facility and major capital plan (a five-year plan including a technology adoption strategy, an infrastructure replacement plan, a building expansion and renovation plan, and a major plant and equipment acquisitions plan); data specific to each facility's capacity; and data specific to POEs and the remaining products and services in the acute, post-acute, inpatient (IP), and outpatient arenas. During 2006 and 2007, the researcher collected and sorted data from 2003 through 2005 related to strategic, capital, and resource planning; financial information; market share information; and other relevant hospital statistics. This information was culled from the organization's long-term strategic plan and multiple one-year operational plans. Each operational plan covers a one-year prospective period and contains the following information: marketing strategy, volume strategy, financial projections, workforce needs, investment requirements, intended venue of services (e.g., inpatient or outpatient), revenue projections, LOS projections, expected expenses, and medical staff needs.

Data Analysis

Simulation Model

The researcher employed the Arena 10.0 simulation software to model the current state of the organization and future-state scenarios using data from the organization's forecasted growth plan. First, the researcher determined that the simulation model characteristics for this study would be the variables that impacted expected bed utilization by program and service line (see Table 1). Second, the researcher developed the simulation programming model to depict model flow and input using a three-stage approach. The process-oriented software stratified models into three panels, each containing a collection of templates: (1) basic process, (2) advanced process, and (3) advanced transfers.

The basic process panel in Arena contains multiple modules reflecting basic simulation processes, including arrivals, departures, and services. The researcher used the basic process template to model the patient arrival time by POE, service line, mode of admission (e.g., emergency department admits or direct admits), and discharge (see Figure 1). This model described the variability and seasonality of patient arrival by service line. (Historically, capacity needs were determined through a linear process of identifying discrete needs by product line—a process that failed to capture peak census, opportunities to redistribute patient mix among available capacity, and effective utilization of a universal room concept.)

The advanced process panel provides a collection of modules with lower-level operations from which users may create more complex operations such as pickup and drop-off. These modules allowed the researcher to perform specific logical functions to create and manage a queue when multiple services are being processed to determine bed availability as a function of volume, wait time, and LOS (see Figure 2).

The advanced transfer module is used to model the flow of entities through the system. In this study, the advanced transfer module was used to depict the transfer of patients from one area of the system to another. This module plotted patient flow within and across inpatient units, distance between units, and total travel time for each service line to create a critical pathway model that visually depicted the relationships between multiple inpatient units from various departments categorized by service line.

After developing these three templates, the researcher identified key variables to consider when testing scenarios, including variables that impact expected bed utilization by POE and service line (e.g., patient arrival mode, patient treatment times by product line, and units). The researcher also described assumptions made during the creation of these templates. The assumptions reflected how data were collected and reported by the organization. For example, neonates and newborns arrive independent of the labor and delivery (L&D) unit visits; patients from the emergency department are given preference for admission to a bed; and admission locations do not change once patients are assigned a bed.

The researcher then estimated the duration of a warm-up period. Specifying a warm-up period eliminates the bias of data generated by a previously empty system, which would permit accelerated movement and transfers. As the system's volume increases over time, it reaches a more accurate steady-state performance that the initial data returns do not accurately reflect; therefore, initial data returns need to be excluded from analysis. The parameter driving bed utilization and capacity needs in this study was LOS—a nonterminating steady-state parameter because it does not depend on a specific duration of operations. To capture the nonterminating nature, the model ideally would run for an infinite time. The same effect can be achieved by running the model over a long period and discarding the values of throughput generated during the transient or warm-up period.

The researcher applied the Welch graphical method whereby LOS values from multiple replications are averaged and plotted against time. At a certain point, the LOS plot stabilizes and becomes parallel to the time axis. The segment prior to this consistency is regarded as the warm-up period. The researcher followed Law's suggested warm-up period of 84 days based on 20 replications of a 365-day simulation.[24] Following this process, a baseline model accurately describing the current state of the system was in place.

Current-State Scenario

The current-state scenario was tested using 2005 actual and 2012 projected volumes per POE and other service lines to determine the ability of the existing facility's bed capacity to absorb expected growth for 2012. The researcher then conducted specific product portfolio analyses by POE. Emphasis was placed on product mix, expected volume, and market position for each POE. The researcher identified planned bed requirements by POE utilizing specific volume and LOS expectations and determined that facility bed capacity should be capped at 396 beds.

The current-state model analysis revealed that existing facilities could not accommodate projected capacity demand; therefore, executives decided to pursue the construction of a new facility. Following a review of the organization's debt capacity and equity, as well as stipulations specified by the Finance Committee of the Board of Trustees, executives determined that the recommended construction of a 396-bed hospital was cost prohibitive. Executives thus requested that the researcher test the potential of building a 365-bed hospital on an undeveloped site.

Future-State Scenarios

The researcher modeled six scenarios in simulation to identify a best-suited future-state scenario:

1. The Ideal Scenario modeled infinite capacity. It was tested to determine the average number of beds busy per unit and the distribution of beds by POE or service line, given the organization's forecasted growth.
2. The Variable Scenario accounted for seasonal trends and variable time series utilization based on historical arrival patterns and 2012 projected volume. The model assumed unequal distribution and thus permitted sensitivity to the variable nature of patient arrival times, LOS, and bed utilization.
3. The Desired Utilization Rate Scenario modeled utilization levels of 85 percent for noncritical beds and 75 percent for critical or intensive care beds—per the recommendation of the architectural firm Hammel, Green, and Abrahamson (personal communication, May 9, 2006)—to determine the number of beds utilized and the number of beds left idle.
4. The Idle Bed Allocation Scenario involved the development of a model that suggested potential allocation strategies for the idle beds.

5. The Arrival Rate Scenario tested the arrival rate necessary to achieve the suggested utilization rate, given specific allocations of the idle beds.
6. The Revenue Growth Scenario depicted potential revenue growth, assuming achievement of the desired bed utilization rates described in the previous scenarios.

Results

The current-state model and future-state scenarios yielded outcomes that allowed the team to draw several conclusions.

The **Current-State Model** demonstrated that current bed capacity could not meet future demand (see Figure 3). The organization's decision to pursue a growth plan tempered by the constraints considered by the Finance Committee of the Board of Trustees moved the bed capacity target from 396 to 365. A baseline model depicting current-state bed capacity revealed a licensed bed capacity of 288 beds, of which only 271 are maintained and available for patient occupancy. The current bed capacity (271) fell short of the bed capacity requirements of the forecasted growth plan (396) and the recommended target capacity (365) by 125 and 94 beds, respectively.

The **Ideal Scenario** suggested specific bed allocations (see Figure 4). The Ideal Scenario was tested assuming infinite capacity to determine the average number of beds busy per unit per POE or service line. The analysis did not assume equal distribution of the growth pattern; instead, it considered POE-specific variability and seasonality. The result of this analysis indicated allocation of the 365-bed target capacity should be 52.6 percent (192 beds) to W&Cs and Pediatrics—the fastest-growing programs with the largest volumes—and 47.4 percent (173 beds) to all other services.

The **Variable Scenario** determined that current utilization rates fell short of the recommended utilization rates (see Figure 5). Simulation revealed utilization of inpatient units ranging from 55 to 78 percent in W&C's services and pediatrics and from 62 to 68 percent in all other programs. These utilization rates fell short of the recommended rates.

The **Desired Utilization Rate Scenario** identified the increased utilization needed to address the utilization shortfall (see Figure 6). The results of this particular scenario indicated that bed utilization fell short of the recommended rates by as much as 30 percent. Attaining the recommended utilization rates would require increasing bed utilization at the 365-bed facility to 291 beds, leaving 74 beds idle or available for other use.

The **Idle Bed Allocation Scenario** suggested that idle beds be assigned to W&C's services and Pediatrics (see Table 2). Simulation identified several uses for the 74 beds, such as accommodating the 23.5 observation patients usually grouped with outpatient statistics or growth beyond what was already projected. Researchers determined that a better allocation would be to the system's fastest-growing POEs: women's and children's services and pediatrics. These two POEs could absorb the additional 74 beds across their subspecialties, particularly in the neonatal intensive care unit (NICU), postpartum unit, and women's and children's medical/surgical (med/surg) unit.

The **Arrival Rate Scenario** identified rates at which arrivals for W&C's services and Pediatrics needed to increase in order to meet the desired utilization rates (see Figure 7). Increasing the arrival rate for W&C's services by a factor of 1.53 and Pediatrics by a factor of 1.6 augmented utilization to the desired rate.

The **Revenue Growth Scenario** demonstrated opportunity for significant increases in operating income. Results of the simulation showed an 86 percent increase in operating income, assuming W&C's services and Pediatrics reached desired utilization rates.

Discussion

The findings of this study advocate an integrated approach to developing an organization's strategy. Coupling a statistical forecasting model with simulation creates a well-balanced, strategic approach to profitably meet growth in demand. Several salient messages emerged from this study.

Scenario Development and Testing

The development of multiple scenarios was integral to understanding how the forecasted growth plan could be used to make decisions in support of the organization's strategic plan. Multiple runs of the models produced a best-suited scenario where utilization of the 365-bed hospital was at 85 percent for noncritical beds and 75 percent for critical or intensive beds. These utilization levels translated into an average daily census of 291 patients and an occupancy rate of 80 percent.

Facility Planning for the New Site

Data from the simulation-tested scenarios were used to determine the ideal scope and size for a new facility. The volume projections, patient arrival rates, and LOS for each POE and service line provided the information required to proceed with the allocation of available beds. Of the 291 available beds, 66 percent were assigned to the W&C's and Pediatrics POEs. The remaining 34 percent were allocated to all other POEs and service lines. This is particularly significant because the W&C's and Pediatrics POEs are the fastest-growing programs in the marketplace.

Strategic Decision Making

In 2008, health system leaders used the results of this simulation study to propose construction of a new 700,000-square-foot hospital at a cost of more than $500M. The Board of Trustees considered the findings from the study and made the strategic decision to move forward with the project. The study was also used during discussions with financial institutions and was considered integral to securing funding. In 2008 the system initiated construction of the new facility, which will be ready for occupancy in early 2011. System leaders assert that, given the current financial standing of the healthcare industry, the support of both the Board of Trustees and the financial institution would have been difficult to obtain without the use of simulation, its rigorous analysis of existing and forecasted data, and its ability to inform such a critical strategic decision.

Limitations

Limitations to the study include the following:

- Constructing a simulation model can be an expensive, time-consuming process. It is also resource intensive as analysts must sort volumes of irrelevant data from relevant data archived in information systems that may not be sensitive to the simulation's data requirements.[25] In addition, accurate results depend on the depiction of scenarios that precisely mimic the real system. Furthermore, the computer model used in simulation is encrypted in complex mathematical terms, requiring a sound understanding of simulation statistics.[26] Lastly, solutions derived from simulation may not be optimized. The output of a simulation model depends on how the scenarios have been defined and configured. The output is a function of the variables that have been entered and may not be the optimized solution for the system.[27]
- The model does not take into account possible changes in Medicare, Medicaid, and private health insurance reimbursement rates. The largest growth pattern in the plan is directed toward women's and children's services and pediatrics—programs that enjoy the highest reimbursement rates in the market. A positive or negative change in reimbursement can directly impact the expected revenue stream.
- This study does not consider the possibility of mergers or acquisitions. A horizontal integration strategy could alter the organization's product offerings, facility size, and scope of services.
- Operational efficiency, specifically increased productivity, was not addressed in this study. Although the facility size was calculated from the anticipated throughput based on expected patient days multiplied by the current LOS, efficiencies that could be gained by improving LOS were not evaluated.

Future Study

The researcher offers the following suggestions for future study:

1. Explore how the techniques for manipulating data used in this study can facilitate the planning, blocking, and stacking of a new facility utilizing the simulation model and critical pathway analysis in this study.
2. Pursue the application of the methods and models used in this study to developing strategy and facility plans for an ambulatory healthcare entity.
3. Replicate the study but consider different input points, sensitivity analyses related to various reimbursement models, and product and services targeting ambulatory settings instead of the inpatient arena.

Conclusion

An organization's ability to harness historic and forecasted data related to volume, utilization, and solution strategies is critical to making strategic decisions about facilities and corresponding capital plans. The ability to model existing and forecasted data permits organizations to test multiple options and quantify relationships and values in a laboratory setting with minimal risk to the organization. Scarcity of resources compels organizations to test and validate a variety of scenarios before strategic decisions are made and plans are executed. Simulation offers what conventional analytical techniques do not—a comprehensive, precise, flexible way to test, modify, and retest processes until a best-suited scenario is identified. Simulation allows organizations to make informed, data-driven strategic decisions that minimize the possibility of placing capital at undue risk, strengthen the organization's market position, and improve the organization's financial viability.

Ninfa M. Saunders, MSN, MBA, PhD, is the president and chief operating officer at Virtua in Marlton, NJ.

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Notes

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Table 1

Simulation Model Characteristics

Entity	Patient
System type	Steady-state nonterminating
Attributes	Patient arrival mode Patient product line Patient pathway by product line Patient treatment times by product line and units (intensive care unit [ICU], progressive care unit [PCU], pediatric intensive care unit [PICU], etc.) Net operating income per patient by product line
System parameters	Replication length: 365 days Replication number: 20 Warm-up period: 84 days
Resources	Beds
Inputs	Interarrival times Treatment times Product-line volume projections for 2012 Current facility’s bed capacity and scope New facility’s bed capacity and scope
Outputs	Patient LOS by product line Utilization of beds by bed types Total net operating income by product line Total bed capacity and scope

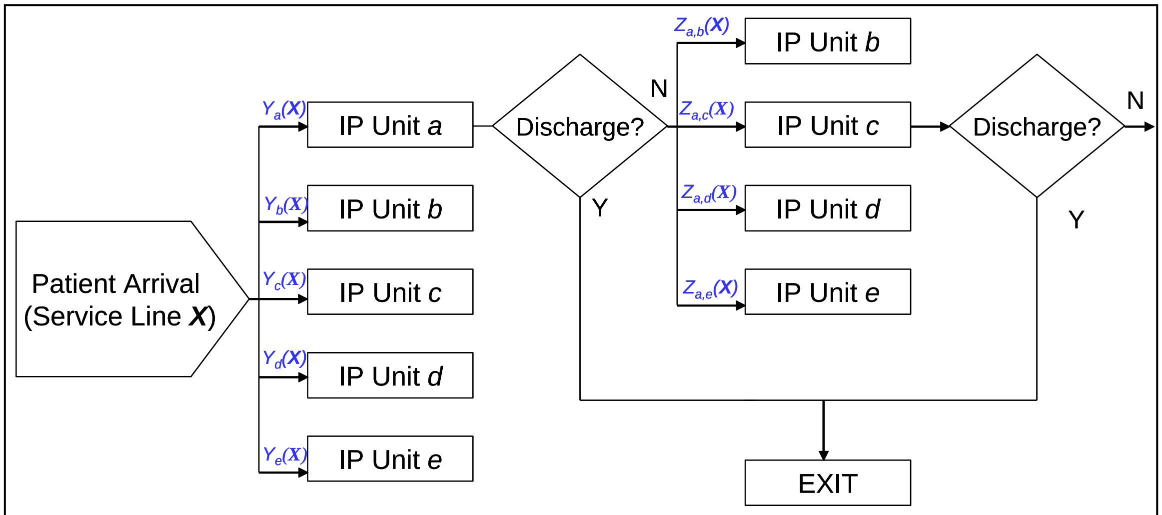
Table 2

Idle Bed Allocation Scenario

Bed Capacity for Desired Utilization			Allocation of 74 Remaining Beds	
Inpatient Unit	**No. of Beds**		**Inpatient Unit**	**No. of Beds**
Antepartum	18	Increase over volume-based factor (Antepartum through PICU)	Antepartum	27
Postpartum	33		Postpartum	49
Mother Baby	18		Mother Baby	27
W&C Med/Surg	29		W&C Med/Surg	43
Pediatrics	13		Pediatrics	20
NICU	37		NICU	55
PICU	3		PICU	4
Med/Surg/Oncology	49		Med/Surg/Oncology	49
Telemetry	47		Telemetry	47
PCU	21		PCU	21
ICU	23		ICU	23

Figure 1

Simulation Programming Model for Patient Arrival



$Y_i(\boldsymbol{X}) = P$(Patient of Service Line ***X*** admitted to IP Unit *i*)

$Z_{i,j}(\boldsymbol{X}) = P$(Patient of Service Line ***X*** in IP Unit *i* is transferred to IP Unit *j*)

Figure 2

Simulation Programming Model with Input and Output Points

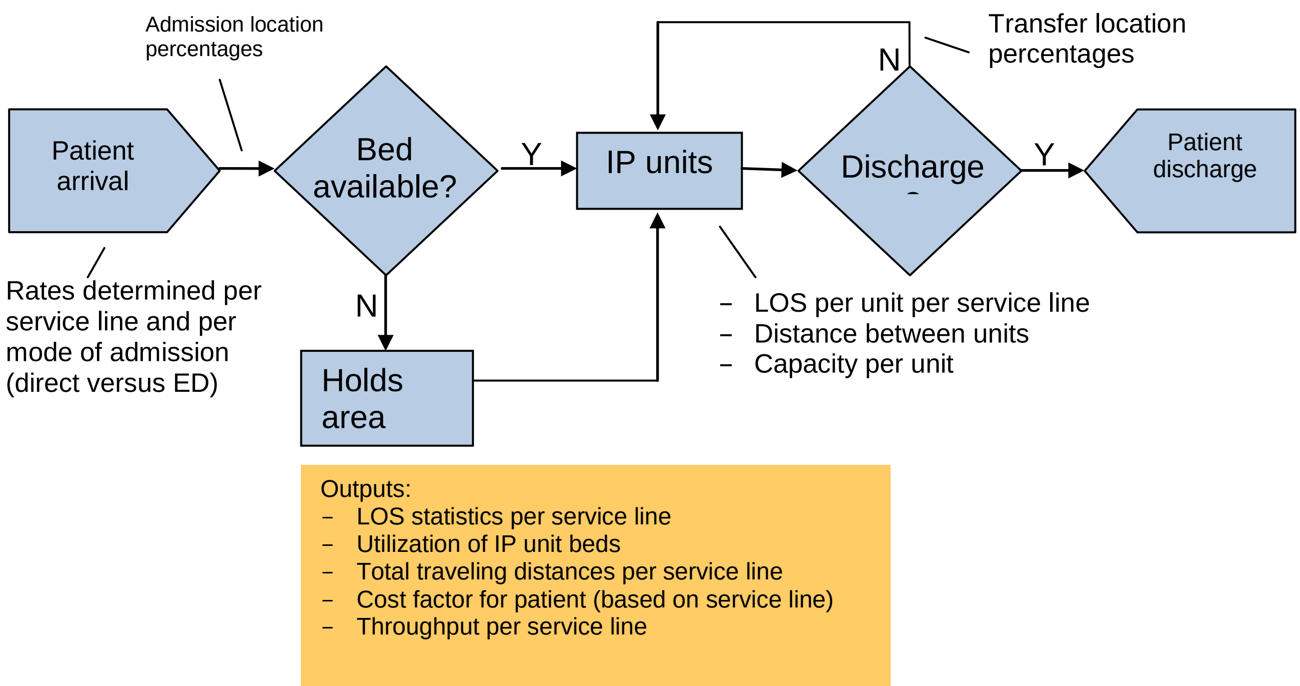


Figure 3

Current-State Model Capacity to Accommodate 2012 Forecasted Growth

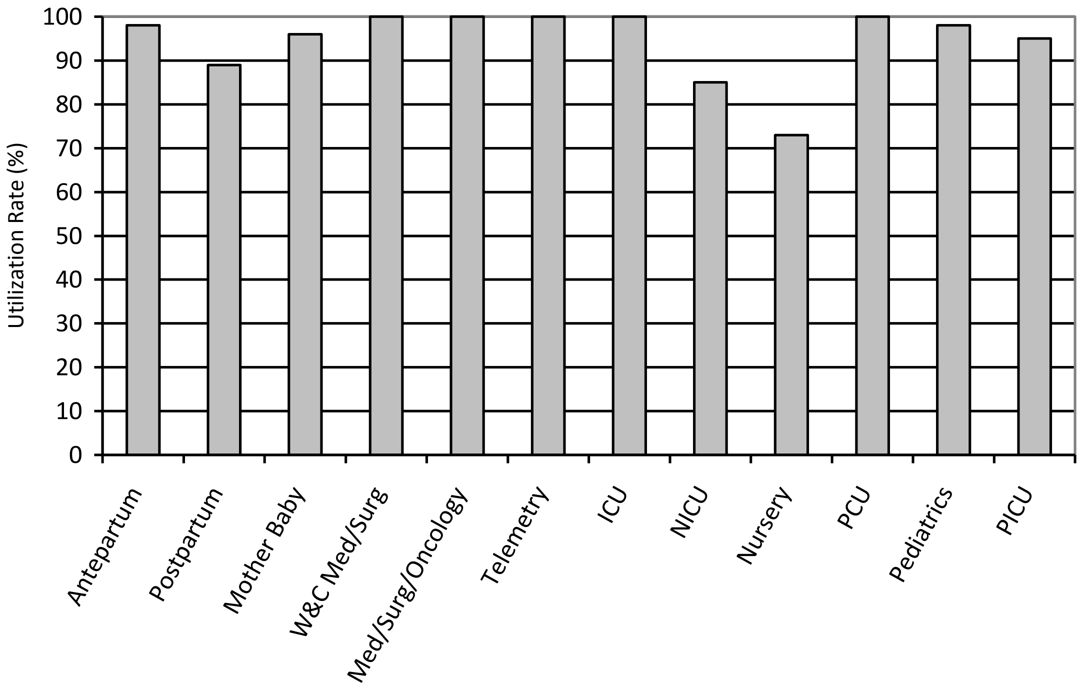


Figure 4

Ideal Scenario with Infinite Capacity to Accommodate 2012 Forecasted Growth

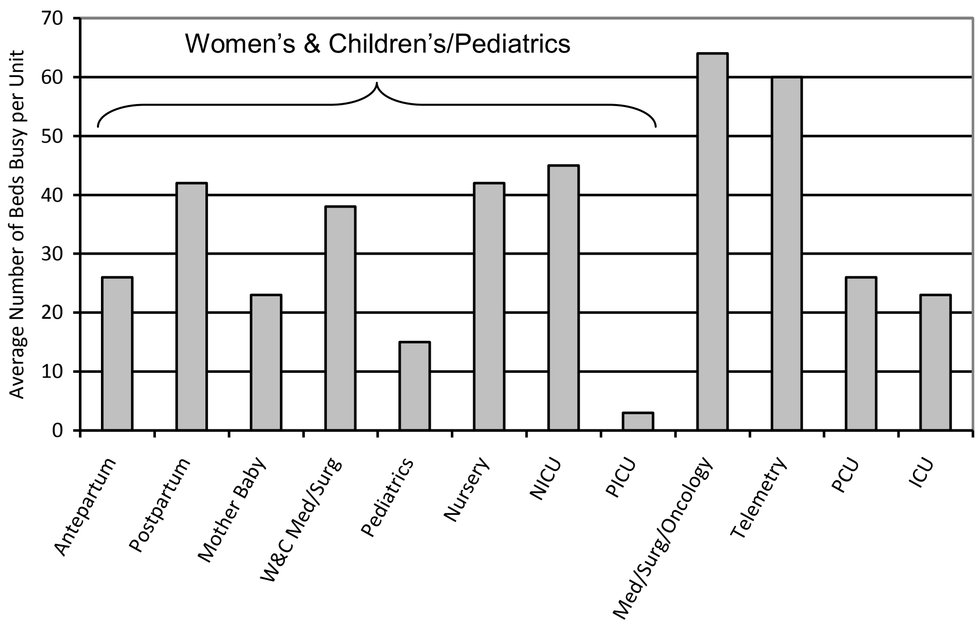
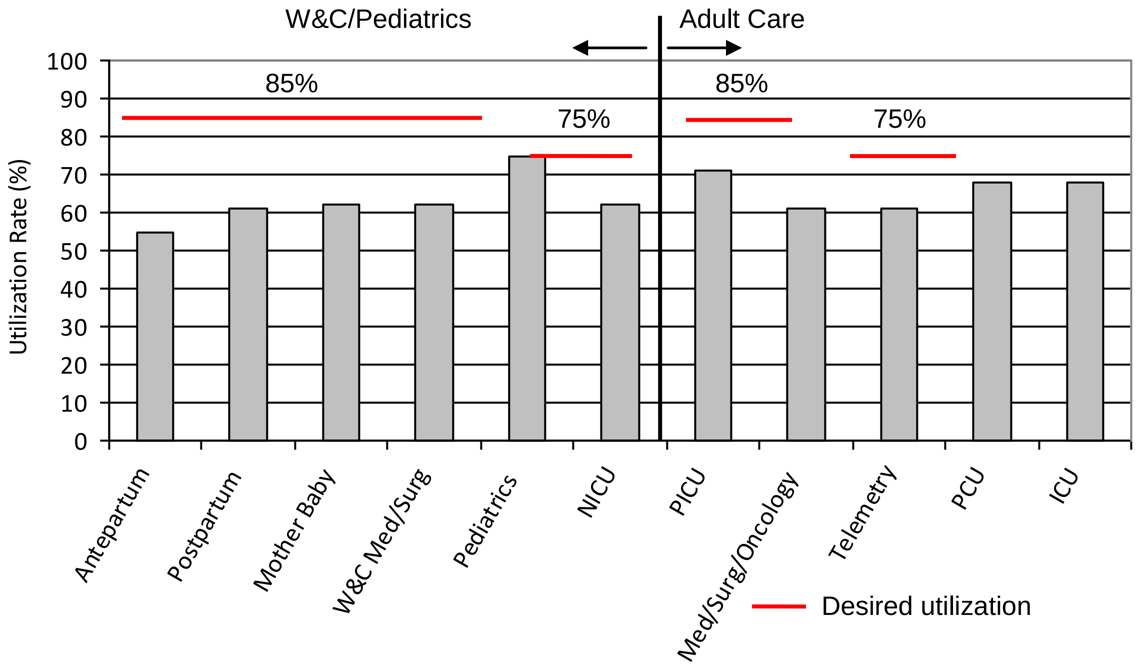


Figure 5

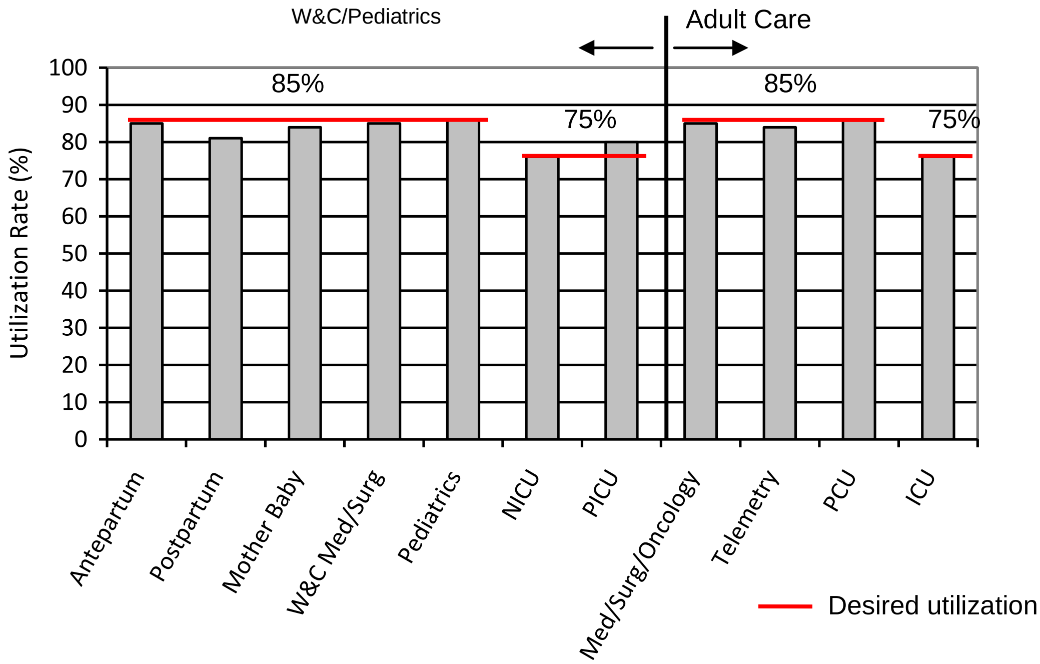
Variable Scenario: 2012 Utilization Rates with Adjusted Bed Capacities



Notes: Number of runs: 30. Run length: 365 days.

Figure 6

Desired Utilization Rate Scenario: 2012 Utilization Rates with Optimal Bed Capacities



W&C/ Pediatrics Total Beds: **151**

Inpatient Units	No. of Beds
Antepartum	18
Postpartum	33
Mother Baby	18
W&C Med/Surg	29
Pediatrics	13
NICU	37
PICU	3

Adult Care Total Beds: **140**

Inpatient Units	No. of Beds
Med/Surg/Oncology	49
Telemetry	47
PCU	21
ICU	23

Total beds required for optimal utilization: 291
New facility beds remaining: 74

Figure 7

Arrival Rate Scenario (with Incremental Volume)