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ALLOCATING OUTPATIENT CLINIC SERVICES USING SIMULATION AND LINEAR PROGRAMMING

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ABSTRACT

A large number of operational tools exist to help researchers determine business solutions for their customers. Each individual tool serves a distinct purpose for specific types of problems. Deciding which tool to use requires knowledge and experience. Sometimes, the researcher should integrate several tools because each tool may get too complex or not form a complete solution. This paper discusses how simulation, linear programming and spreadsheet analysis were integrated to help a new hospital determine ideal space assignments, schedule configurations and throughput targets for numerous clinic services.

1 INTRODUCTION

1.1 Hospital Background

1.1.1 History

The current LAC+USC Medical Center functions as Los Angeles County's largest health care facility and is the single largest provider of trauma and emergency services in the County with a full spectrum of emergency, inpatient and outpatient services. The General Hospital provides medical, surgical and emergency/trauma services. The nearby Women's and Children's Hospital provides obstetrical, gynecological, pediatric and specialized neonatal intensive care services. Psychiatric inpatient services are provided offsite at Ingleside Hospital and Hawkins. The existing facility is licensed for 1,395 beds and is currently budgeted to staff 685 beds. LAC+USC has over 6,900 employees.

1.1.2 New Construction

The Department of Health Services (DHS) is constructing a 600-bed hospital to replace the existing General Hospital and Women's and Children's Hospital while maintaining their 50 off-site psychiatric beds. A key planning objective of the County and DHS is to ensure that the replacement facility continues its core mission to function as the backbone of the County's safety net and as a major regional and community emergency/trauma and critical care provider.

The site of the replacement facility is located in the southeast area of the hospital campus. Construction excavation and other activities began in March 2003 and construction is scheduled to complete in June 2008. The new facility is expected to be fully operational in Fall 2008.

1.1.3 Vision for the Future

The new 600-bed facility will operate as a Level I Trauma teaching hospital accommodating an average of 570 inpatients per day in addition to 49 Psychiatric inpatients. This is a reduction from their current average daily census of 640 but an occupancy of 95%. The facility will have a higher proportion of ICU beds than the present hospital, resulting in an overall higher patient acuity.

The new facility will operate as a tertiary-level medical center in four (4) buildings with a 600-bed inpatient tower, a diagnostic and treatment services center, an outpatient specialty services clinic, and a central plant. The current space allocation for the replacement facility is 1.47 million square feet.

1.2 Process Challenges

1.2.1 Current Services

LAC+USC provides services not available at other County or private hospitals. In Fiscal Year 2005-06, emergency visits exceeded 150,000 patients and outpatient visits exceeded 530,000 patients. LAC+USC provides the following services:

- Operates one of three burn centers in the County
- Operates one of the few Level III Neonatal Intensive Care Units in Southern California

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- Cares for half of the AIDS patients and half of the sickle cell anemia patients in Southern California
- Maintains inpatient and outpatient services for the most acute cases of mental illnesses

The hospital trains approximately 1,500 medical professionals per day, including more than 860 medical residents in nearly all medical specialties. It also trains 160 students for nursing and other health professions such as pharmacists, midwives, occupational, speech and respiratory therapists, dieticians, podiatrists, and laboratory and radiology technicians.

The following factors require the facility to maximize the new Outpatient building utilization and capacity across the network:

- Maintain a very large number of specialty and sub-specialty outpatient services designed to meet community needs in the current campus.
- Significantly less space to house these services in the new facility.
- Meet complex scheduling requirements, both clinically and operationally, due to teaching requirements.

1.2.2 Future Configuration

The complexity and broad scope of this project require highly analytical expertise in service allocation methodologies and information technology. Table 1 shows the constraints which the hospital must operate.

Table 1: Operational constraints on building design.

Basis of Building Design	Operational Constraints
Excluded Primary Care (Internal Medicine Clinic)	Primary Care is on Campus today, with highest volume of all Clinic Groups
Designed to accommodate up to 350,000 Annual Visits	Must maintain current visits of over 500,000 annual visits. (42% increase)
Designed to accommodate Infusion Therapy Services for 22 patients in one location (Adult and Peds combined)	Current Infusion Therapy Services accommodates over 54 Infusion patients in one location (trending upwards)
Total # Exam Rooms in New Building: 171	Total # Exam Room in Existing Buildings: 340 (50% reduction)

The main objective of this project was to enable LAC+USC to strategically enhance its ability to meet the community's needs while minimizing space requirements and optimizing space utilization. Also, the project sought to identify the best operating model given the building constraints, while:

- Accommodating current Service volumes
- Minimizing the move of services to the Community Health Centers
- Not adding evening/off-hours sessions due to staffing limitations
- Minimizing session/schedule change to the extent possible
- Minimizing session over-time
- Optimizing space utilization of the new facility

1.3 Toolset Capabilities

1.3.1 Process Modeling

A process can be defined as a set of activities or tasks in sequence or in parallel working together to achieve a common purpose, such as a beginning-to-end workflow. A process model therefore is a simply a structured and documented representation (e.g. drawing, flow diagram, etc.) of an As-Is or To-Be process. The 'actual process of creating' a good process model promotes a better, more complete, and more in-depth understanding of the process. Good process models often include the following characteristics:

- Ensures effective communication between users and modelers about what is being modeled
- Defines the process completely
- Provides a mechanism (medium) to evaluate current performance and identify improvement opportunities
- Establishes a common vocabulary that enables effective communication

The primary type of process modeling utilized for this project was "static" process mapping. The process maps are said to be "static" representations because neither real-world uncertainty (i.e., probability distributions) of the elements of the process nor the cause-effect behavior of the process over time are taken into account. Therefore, such static process maps and documentation are not inherently analytical techniques.

1.3.2 Spreadsheets

Spreadsheets are one of the most common tools that people of all ages, demographics, and employment use. And though spreadsheets may be one of the most common and flexible computer applications available today, often times they are not powerful or sophisticated enough to solve complex analytical models by themselves. However, this does not diminish the tremendous power and capability spreadsheets offer as part of solving complex dynamic models (such as this paper describes). Specific capabilities of this project included:

- Manipulation and organization of complex data sets
- Analysis of data sets (i.e. descriptive statistics, graphical analysis)
- Exporting capabilities (both for the Linear Program & Simulation models)
- Setting up of What If scenarios to perform multiple "runs"
- Importing capabilities (repository for outputs / scenarios)
- Post-Processor (ability to perform additional analysis as needed)
- Reporting capabilities
- Macro capabilities

1.3.3 Integer Programming

Linear programming is a tool for solving optimization problems in which we do the following:

- Attempt to maximize or minimize a linear function of the decision variables (the function that is to be maximized of minimized is called the objective function).
- The values of the decision variable must satisfy a set of constraints. Each constraint must be a linear equation or linear inequality
- A sign restriction is associated with each variable
- Integer programming is a specific type of linear program in which some or all of the variables are required to be nonnegative integers.

As part of this application, Premium Solver 7.0® by Frontline Systems™ was used as the linear programming application for this engagement. However, due to its full compatibility with Microsoft™ Excel®, the model was set-up, executed, verified, and validated through the use of the spreadsheet interface. This provided multiple benefits not the least was the ability to quickly communicate and train concepts to the extended project & customer team.

1.3.4 Discrete Event Simulation

Modeling a business process in a flowchart gives a good overview of the steps in the process but does not tell how that process behaves over time. Likewise, finding an optimal solution for a linear programming model, although valuable, does not predict how a system may behave over time either. Thus complex business processes, characterized by numerous activities, business rules, resources and entity flow may therefore benefit from the "dynamic" process analysis provided by discrete event simulation (Crosslin 1995). This is done though the testing of all assumptions and data in one comprehensive model, including:

- People, Technology, Process
- Workload
- Business rules that control the process

It is also done by quantifying the key elements of the process being modeled, such as:

- Resource utilization - e.g., % busy, % idle,, # of resources required
- Queue behavior - e.g., number and time waiting in queue(s)
- Performance metrics - e.g., cycle time, throughput, activity based costs, value-added time, rework

This allows an analyst to predict the effects that various changes will have on a process in order to identify and minimize risk. Thus, discrete event simulation adds the elements of real-world uncertainty and variability of process elements and the dimension of time (e.g., to accomplish activities, queuing, etc.) to analyze and predict the behavior of the process (Law and Kelton 1991).

2 PROJECT APPROACH

2.1 Project Objectives

The objectives of this project were to maximize the hospital's ability to meet their community's needs by offering high-value-added clinics designed for the community. Additional objectives included minimizing space requirements and optimizing space utilization. These objectives were met by building a sophisticated computer model capable of analyzing clinic needs and evaluating alternative configurations. This model employed best practice scheduling techniques learned in operating rooms and clinics around the country. The project took six months to complete.

2.2 Modeling the Clinic

2.2.1 Modeling Detail

One of the first steps of model design is to determine how much detail and complexity to include. Adding more complexity to a simulation model doesn't always add value to the final analysis (Miller, Ferrin and Messer 2004). In fact, too much complexity is counterproductive because more time and effort are involved with ensuring the model behaves like the real system (see Figure 1). Also, the data available may not apply to the level of model detail. For example, order completion data may only contain begin and end times but not for activities within the process. As a result, the process model should reflect a single activity for completing orders. The goal is to find the right level of complexity which allows you to meet project goals.

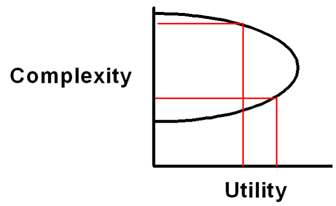

Figure 1: Utility Curve For Model Complexity

Project goals required two levels of model detail, although, both levels achieved the same objective of placing services into appropriate clinic space. A high-level model groups services together, holding these groups constant, while assigning attributes, preferences and priorities to these groups. The high-level model then places these groups into any clinic space (pods) such that it maximizes the entire building according to specified constraints. The high-level model had 13 pods and 13 clinic groups. By contrast, a low-level model examines one pod at a time by varying the services in a group to find a good fit. This service configuration is checked with the simulation model to determine clinic performance.

2.2.2 Workshops

One of the main steps of model design is gather information about the process (Miller et al. 2006). The project team met with the Clinic Redesign Committee on a semi-weekly basis to gather information about the hospital's processes. The team gathered the information through Process Modeling Workshops, one-on-one interviews with staff and data collection. The Process Modeling Workshops mapped the patient experience from beginning to end. The team interviewed personnel, when necessary, to discuss their role. The majority of information was gathered through a formal data collection effort. This involved gathering existing documentation, observing process events, conducting time and motion studies, and database queries which provided insight to the process.

2.2.3 Process Maps

Process maps provide design guidance to a simulation model similar to how a blueprint provides design guidance to building construction. The clinic process map involved all routing and activities for patients from arrival to departure (see figure 2). Subject Matter Experts described their process, identified who does what, when and for how long. The clinic process proved less complex than Emergency Department and Operating Room processes (Miller, Ferrin and Szymanski 2003). Typically, the patient arrives, registers at the front desk and waits in a waiting room until staff call them back to an exam room. Once in the exam room, staff will prep the patient and then a physician will examine the patients. Upon completion, the patient leaves the exam room, sometimes makes a follow up appointment, then departs the clinic.

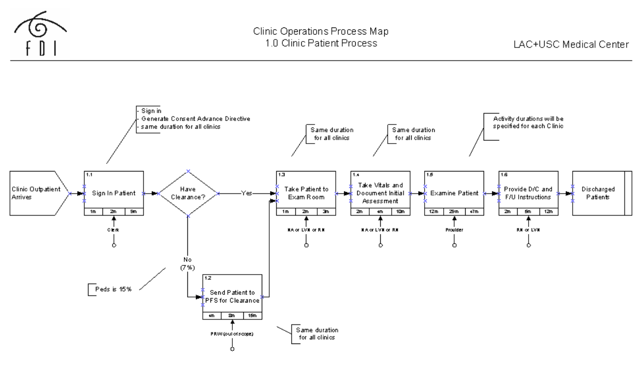

Figure 2: Map of a Clinic Patient Process

2.2.4 Parameters

The team designed control variables for both levels of the model. These control variables were centrally placed in an easy to read format. This enabled the team to efficiently experiment with alternative scenarios. An experimenter could make a single variable change and moments later begin the application software that computes the results.

Several types of control variables exist. Some variables simply store the quantity of a given resource, such as the number of exam rooms in a clinic location. Other variables express a value within a range that indicates how likely an event should occur. For example, a patient may have a given probability for scheduling a follow up appointment. Another example includes a clinic service that may have a high preference for a particular location and it may store a nine on a scale between zero and ten.

Control parameters for this model include the number of exam rooms per pod, clinic preferences for a pod, weighted preferences for various quantitative results, activity durations for patients during their clinic visit, when a service will have a session, etc. This project stored control parameters in three files: the linear program model, a preprocessor spreadsheet and a simulation input spreadsheet. Each of these files will be discussed later.

2.2.5 Assumptions and Constraints

Computer models are never perfect and always require simplifications to help govern them. Modelers make assumptions about the real system so they can program it into the software. For example, the logic and reasoning that an Emergency Department patient considers while waiting to see a doctor before they give up and leave can become complex. A patient's patience can vary greatly. The modeler may assume that no patient waits more than 24 hours to see a doctor. Once a modeler makes an assumption, he or she must document it and seek consensus from Subject Matter Experts.

Making valid assumptions simplifies the model and allows the project team to control scope and proceed efficiently. Typical clinic assumptions may include

- Clinic is open 8 AM until 4 PM
- Clinic staff will work overtime if necessary.
- Equipment (e.g., IT system) does not breakdown
- No catastrophic events occur (e.g., terrorist attack)
- Sufficient parking space available for all patient arrivals
- Sufficient waiting space available for patient's family

2.3 Data Collection

A valid model requires valid data which project team members must collect (Miller et al. 2007). Data may come from information systems databases, observations, paper-based charts, and estimates from subject matter experts. This project gathered data using each of these methods in addition to statistical reports from clinic management.

The project team analyzed clinic data as they obtained it. Data analysis involves reformatting, formulating equations, summarizing, and graphing. An analyst should stay objective about the data and seek ways to ensure it is reliable. Data may require reformatting to make it more useable. For example, an analyst records handwritten data into a spreadsheet. Often, an analyst will formulate equations to gain more insights into the original data. For example, which days of the week do patients arrive to the hospital? The analysis would convert 05/23/2008 to Friday.

2.4 Software Development

2.4.1 Software Strategy

In order to accomplish the key objectives of this project, it was decided that a multi-faceted approach that combines process modeling, spreadsheet analysis, linear programming, and discrete event simulation would be needed to accurately predict and forecast future behavior of the model. A brief summary of these four capabilities are listed below.

The project team employed a mature software development strategy by dividing completing three major components in parallel (Miller, Pulgar-Vidal and Ferrin 2002). This included the linear program, the simulation model and spreadsheet processors. Once the team understood how these components would interface their data, the team could then develop components simultaneously. After the components were coded and tested individually, the team integrated them and performed system tests to ensure they still worked properly. Experimentation begins upon completion of this system test milestone.

2.4.2 Linear Programming Model

The high-level model, which featured the LP and simulation models, controlled the size of clinic groups, pod space and the desired placement of groups. Software developers divided the LP model into distinct sections:

- Definitions
- Preferences
- Constraints
- Engine

The software user has the ability to update model definitions, preferences and constraints (see figure 3). The model engine performs calculations which determines the optimal clinic configuration.

Model Definitions allow the user to define the clinic names, the number of exam rooms in each clinic pod, available sessions, and the clinic group relationship to pod space and session times. Model Preferences determine the objective function for the system. The objective function is simply the mechanism for the LP model to choose the optimal solution.

Table A: USED IN OBJECTIVE FUNCTION
Value to Pod (rank from lowest to highest)
- *(Priority Matrix to "maximize which Pods get filled first)*

	Ped1-Pod2A	Ped2-Pod2B	ENT-Pod2C	Womens1-Pod3A	Womens2-Pod3B	Dental-Pod3C	Ortho-Pod3D	MedSurg1-Pod4A	MedSurg2-Pod4B	Ophth-Pod4C	MedSurg3-Pod5A	PreOp-Pod5B	MedSurg4-Pod5C
Pod Value	1	2	3	4	5	6	7	8	9	10	11	12	13

Table B: USED IN OBJECTIVE FUNCTION
Pod Preference (1=first choice, 13=last choice)
- *(Priority Matrix to "try to match Clinic to Pod:)*

	Ped1-Pod2A	Ped2-Pod2B	ENT-Pod2C	Womens1-Pod3A	Womens2-Pod3B	Dental-Pod3C	Ortho-Pod3D	MedSurg1-Pod4A	MedSurg2-Pod4B	Ophth-Pod4C	MedSurg3-Pod5A	PreOp-Pod5B	MedSurg4-Pod5C
Peds Clinic 1	1	2	13	3	4	13	13	5	6	13	7	8	13
Peds Clinic 2	2	1	13	4	3	13	13	6	5	13	8	7	13
ENT/Audio/Speech	9	9	1	9	9	13	2	9	9	3	9	4	5
Womens Clinic 1	3	4	13	1	2	13	13	5	6	13	7	8	13
Womens Clinic 2	4	3	13	2	1	13	13	6	5	13	8	7	13
Dental	9	9	5	9	9	1	5	9	9	5	9	9	5
Orthopedic	5	5	3	5	5	13	1	5	5	3	5	5	13
Med/Surg Clinic 1	7	8	12	10	11	13	12	1	2	12	3	12	4
Med/Surg Clinic 2	8	7	12	11	10	13	12	2	1	12	4	12	3
Ophthamology	6	6	2	6	6	13	3	6	6	1	6	6	9
Med/Surge Clinic 3	7	7	11	7	7	13	11	3	4	11	1	5	2
PreOp Test Clinic	13	13	13	13	13	13	13	9	9	9	3	1	3
Med/Surge Clinic 4	8	8	11	8	8	13	5	4	3	5	2	5	1

Table C: USED IN OBJECTIVE FUNCTION
Session Preference (1=first choice, 10=last choice)
- *(Priority Matrix to "try to match Clinic to Session:)*

	Mon AM	Mon PM	Tue AM	Tue PM	Wed AM	Wed PM	Thur AM	Thur PM	Fri AM	Fri PM
Peds Clinic 1	1	1	1	1	1	1	1	1	1	1
Peds Clinic 2	1	1	1	1	1	1	1	1	1	1
ENT/Audio/Speech	1	1	1	1	1	1	1	1	1	1
Womens Clinic 1	1	1	1	1	1	1	1	1	1	1
Womens Clinic 2	1	1	1	1	1	1	1	1	1	1
Dental	1	1	1	1	1	1	1	1	1	1
Orthopedic	1	1	1	1	1	1	1	1	1	1
Med/Surg Clinic 1	1	1	1	1	1	1	1	1	1	1
Med/Surg Clinic 2	1	1	1	1	1	1	1	1	1	1
Ophthamology	1	1	1	1	1	1	1	1	1	1
Med/Surge Clinic 3	1	1	1	1	1	1	1	1	1	1
PreOp Test Clinic	1	1	1	1	1	1	1	1	1	1
Med/Surge Clinic 4	1	1	1	1	1	1	1	1	1	1

Figure 3: LP Model for User Input Parameters

The software user can update several tables which set the magnitude for where and when clinic services prefer to operate. The first is a priority matrix that attempts to maximize which Pods get filled first. The next table is a priority matrix that attempts to match a clinic to a pod based on user preference. Another table is a priority matrix that attempts to match a clinic to a session based on user preference. For all tables, the lower the value entered, the more important the preference.

Model Constraints determine strict boundaries which the LP model must abide. These constraints control which pods and sessions a clinic group must go, must not go, the minimum number of sessions for each clinic group, and which clinic groups cannot locate near another clinic group. For example, a pediatrics clinic group cannot locate next to a psychiatric clinic group.

2.4.3 Spreadsheet Model

The low-level model featured a spreadsheet, or preprocessor, that controlled the selection of individual clinic services into a single clinic group. This preprocessor listed parameters for each service, such as:

- Annual number of patient visits
- Current throughput
- Current session schedule
- Service priority

The software user has the ability to update patient throughput, session schedule and service priority (see figure 4). The user manually selects the services to include with the clinic group. The preprocessor instantly predicts expected performance by using average capacity and throughput values, calibrated with previous simulation results. For example, the user can immediately recognize if a given session has too much patient volume. The user may then decide to move clinic services to another session. Once the user finishes configuring the clinic pod, these parameters then feed the simulation model which will predict the clinic's long-term performance.

RF Plan	Clinical Service (Dept-Division)	Clinic Name	MON AM	MON PM	TUE AM	TUE PM	WED AM	WED PM	THU AM	THU PM	FRI AM	FRI PM	time/pt (throughput)
Ortho	Orthopedics	Ortho-Adult: ORTHO FOOT							x				85.6
Ortho	Orthopedics	Ortho-Adult: ORTHO HAND			x	x			x	x			61.2
Ortho	Orthopedics	Ortho-Adult: ORTHO INFECTION BONE/SOFT									x		233
Ortho	Orthopedics	Ortho-Adult: ORTHO SPINE					x						48.7
Ortho	Orthopedics	Ortho-Adult: ORTHO SPORTS MEDICINE	x	x									124
Ortho	Orthopedics	Ortho-Adult: ORTHO TRAUMA & Ortho Fracture	x	x			x	x			x	x	66.3
Ortho	Orthopedics	Ortho-Adult: ORTHO TRAUMA COMPLICA				x							180
Ortho	Orthopedics	Ortho-Adult: ORTHO TUMOR									x		67.5
Ortho	Orthopedics	Ortho-Peds: CHILDREN'S HAND			x	x			x				4645
Ortho	Orthopedics	Ortho-Peds: ORTHOPEDIC EVALUATION					x						1091
Ortho	Orthopedics	Ortho-Peds: ORTHOPEDIC FOOT							x				738
Ortho	Orthopedics	Ortho-Peds: ORTHOPEDIC GENERAL (Ortho Trauma)			x	x	x	x	x	x	x		55.2
Ortho	Orthopedics	Ortho-Peds: ORTHOPEDIC PRE-OP- Surgical Referal					x						4000
Ortho	Orthopedics	Ortho-Peds: ORTHOPEDIC TUMOR				x							495
Med/Surg	Dermatology	PH DERM HANSEN'S	x				x						176
Med/Surg	Podiatry	PODIATRY	x	x	x	x	x	x	x	x	x	x	90.6

Figure 4: Preprocessor for User Input Parameters

Another spreadsheet, or postprocessor, will extract simulation results and summarize them into an easy to understand format (see figure 5). The postprocessor classifies results into the following types:

- Unscheduled patients
- Session on-time rate
- Patient time to exam room
- Patient length of stay
- Session overtime
- Utilization

The postprocessor also computes an overall, numeric score for each scenario. It does this by multiplying result values against weighted user preferences for each result classification.

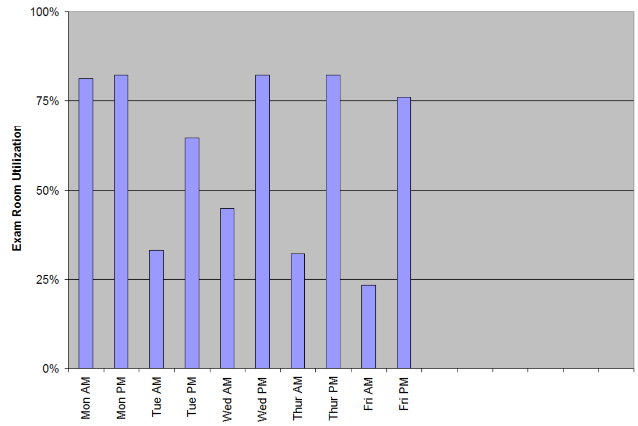

Figure 5: Exam room utilization for sessions within a clinic pod.

2.4.4 Simulation Model

The simulation model, developed in Extend™, imports parameters from each of the previously discussed sources, configuring the model to run a given scenario (see figure 6).

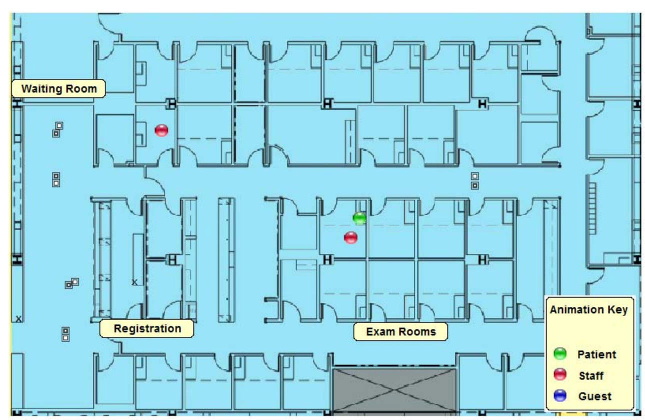

Figure 6: Animation Layout for Simulation Model

The simulation determines the long-term behavior for the clinic on both levels of details. At the high-level detail, the simulation determines feasibility for the entire clinic tower, with all service groups in each identified clinic pod, as directed by the LP model. The simulation model accounts for variability of patient volume in a given week, patient duration in the exam room and resource availability, such as staff and space.

At the low-level detail, the simulation determines performance for a given week in selected clinic pod. The model returns key performance indicators for each session, such as overtime and utilization. The simulation model shows the expected performance for each scenario, which enables the software user to make adjustments to previous control parameters.

3 EXPERIMENTATION RESULTS

3.1 Model Validation

The software developers needed to ensure the models would behave similar to the real system. They validated this model by creating a specific scenario with known outcomes to see if the model would yield results close to reality. For example, a Neurology Clinic may currently hold a session on Wednesday mornings in a pod with ten exam rooms. This clinic will also have known patient volumes and throughput. If this session normally ends at 11:30 AM, then the simulation should show similar end times. If not, then the developers may need to adjust the model for accuracy. Adjustments may include changes to activity durations that subject matter experts estimated during process modeling workshops. Analysts must always discuss these adjustments with the same subject matter experts and secure their approval. Also, analysts should document these baseline adjustments, along with their purpose, to ensure the client and business partners don't misunderstand these changes while auditing project deliverables.

3.2 Clinic Service Acceptance

The software users ran hundreds of scenarios to test various clinic service configurations. Some clinic groups and pods were easily determined because the nature of the services, such as Dental or ENT (Ear, Nose and Throat). These clinic groups must keeps their services together and reside in specific pods which are specially equipped. Other clinic groups were more flexible with their configuration and location.

The team ran several iterations of the model to determine optimal service groupings and pod placement. The team presented these proposed results to the service departments to see if they could accommodate recommended changes. Several times, however, the services could not make session changes, so the team reran the model with new constraints. Eventually, the service departments reached consensus with the proposed changes. These change were not mathematically optimal, but realistically the most practical. The project team learned that involving service departments with low-level scenario setup using the preprocessor reduced the necessary number of scenarios because it more clearly defined the solution space.

4 CONCLUSION

This solution, with both high-level and low-level model capabilities, enabled the hospital to better meet the community's needs while optimizing space utilization. The team provided key stakeholders the ability to make improved decisions with clinic assignments in the new hospital before it opened. The complexity and broad scope of this problem required highly analytical expertise in service allocation methodologies and information technologies. The team achieved this by integrating several distinct types of quantitative tools, each serving their distinct purpose.

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