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SIMULATION OF THE QUESTON PHYSICIAN NETWORK

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ABSTRACT

This paper examines the construction and implementation of a simulation model that supports the design and development of the Queston Physician Network. Queston seeks to partner with health care professionals to provide high quality, cost-effective medical care. Towards this end, a simulation model encompassing both the operations of a Queston clinic and a Queston Information Center has been developed. This model is built in an object-oriented, visual manner utilizing the Visual Simulation Environment (VSE). Application of the object-oriented paradigm (OOP) allows simulation objects in the Queston model to be easily reused. The simulation model incorporates this reusability with traditional modeling and simulation techniques, including for example, the acceptance-rejection method (Law and Kelton 1991) to describe the arrival of walk-in patients to the clinic and the use of thinning (Lewis and Shedler 1979) to create a nonhomogeneous Poisson process that describes the arrival of incoming phone calls to the Information Center. The Queston model provides a means for risk-free implementation and evaluation of operating policies in both the clinical and telephony environments.

1 INTRODUCTION

With increased governmental and insurance regulations, today's physician devotes less and less time to patient care. The Queston Physician Network, a division of Biological & Popular Culture, Inc. (Biopop), seeks to alleviate the physician of burdensome administrative, clerical and scheduling work. Physicians who partner with Queston receive advanced business technologies, as well as access to a wealth of professional expertise. Queston aims to manage office operations and handle all routine, but essential, interactions between the physician's office and managed care organizations and insurance companies.

The Queston Network will be composed of clinics located throughout the United States. These clinics will rely on the Queston Information Center to manage their non-medical operations. Operations such as patient scheduling and billing which are typically handled at individual clinics will be processed by the Queston Information Center, allowing the physician to focus solely on the practice of medicine. Queston also serves as a business consultant to its member clinics and aims to increase patient flow and customer satisfaction in the clinical environment.

To assist Biopop in evaluating potential operating procedures both at Queston clinics and at the Queston Information Center, a discrete-event simulation model has been developed. The model was built using Orca Computer, Inc.'s object-oriented, domain independent visual simulation software, the Visual Simulation Environment (VSE). The use of visual simulation has been acknowledged as beneficial (Bell and O'Keefe 1994) and the use of the object-oriented paradigm (OOP) provides the added benefits of model reusability and maintainability.

2 LITERATURE SURVEY

A great deal of work has been done in the simulation of clinical environments. Jun, Jacobson and Swisher (1997) provide an extensive taxonomy of the literature on the simulation of single and multi-facility health care clinics. The focus of previous simulation studies has ranged from scheduling and admissions to the operations of individual outpatient facilities.

Many simulation studies have been published in the area of health care scheduling and admissions. Rising, Baron and Averill (1973) were among the earliest to publish research in this area. They show that alternative decision rules for scheduling appointments can increase patient throughput and staff utilization. Hancock and Walter (1979) present similar results from a simulation study attempting to increase patient throughput in a hospital setting. Unfortunately, they were unable to implement the revised scheduling rules because of staff resistance. Since this article's appearance, numerous papers have detailed simulation studies focused on patient scheduling. The common conclusion drawn among these papers is that patient throughput can be increased by altering scheduling and admissions rules.

In addition to research on health care scheduling, many researchers have also attempted to model the entire operation of an outpatient facility. Fetter and Thompson (1965) present one of the first simulation studies conducted on the operations of an individual clinic. They identify several important variables in assessing physician utilization, including early and late patient arrivals, patient no-show rates, walk-in patient arrival rates, appointment intervals and physician lunch breaks. Since the Fetter and Thompson article first appeared, researchers have experimented in various areas such as clinic queueing and patient flow, clinic staffing and facility sizing.

Although a great deal of work on individual health facility simulation has been published over the past thirty years, Jun, Jacobson and Swisher (1997) note that the literature lacks a significant amount of research in the area of complex multi-facility health care systems. Stafford (1976) and Stafford and Aggarwal (1976) present the results of a multi-facility simulation study based upon a university health center. No work, however, has been published on the operation of several independent health care facilities relying on a common scheduling and information center. Although the Queston model can currently be classified as a single-facility simulation, the authors plan to expand the model to simulate the operation of and interactions between several clinics, thus filling this void in the literature. The final Queston model will be a visual simulation of a multi-facility health care system.

3 OVERVIEW OF THE QUESTON SIMULATION MODEL

The overall goal of the Queston simulation study is to design the optimal patient-physician encounter by maximizing patient throughput and minimizing cost per patient while still providing quality care. The Queston model developed uses the discrete-event world view in its implementation. It also takes advantage of OOP as implemented by VSE. OOP allows model components to be specified as objects that can be instantiated multiple times throughout a model. Object reusability is a major benefit of OOP and proved beneficial in building flexibility into the Queston model. For example, instead of building a fixed number of examination rooms into the Queston clinic, the user simply inputs the desired number of examination rooms in VSE's 'Constants' panel (see Figure 1). At run time, the model instantiates the number of examination rooms the user has specified. This approach is taken throughout the model, allowing the user to define many of the key components by simply changing a single number prior to run time.

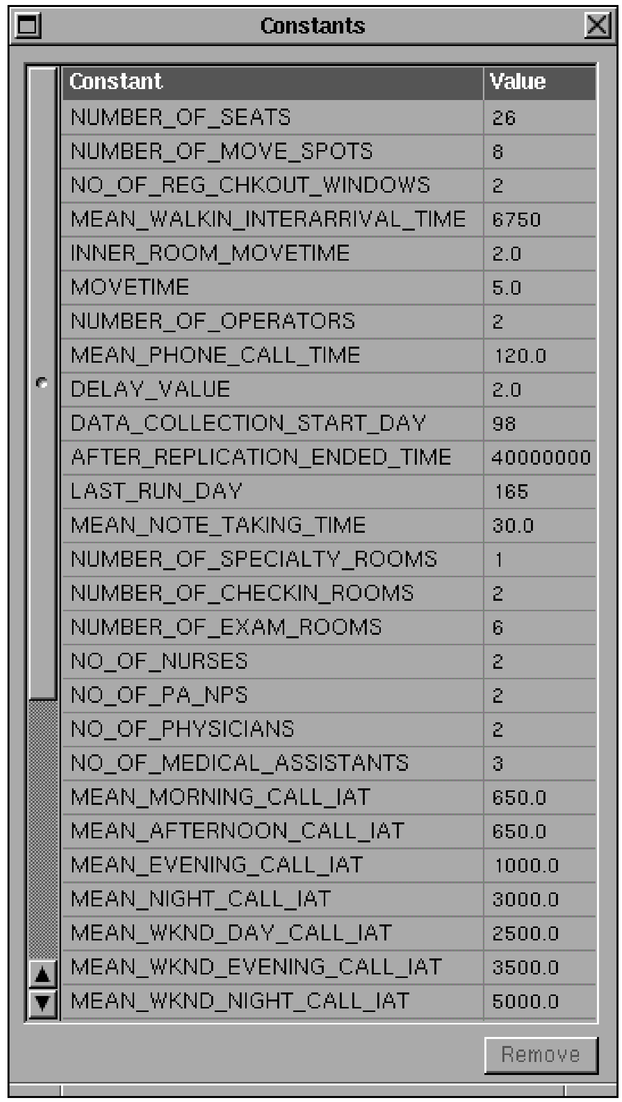

Figure 1: The Queston Model's Constants Panel

The model is built in a hierarchical fashion, with the top level representing the continental United States of America (see Figure 2). On this level exist two objects: the Queston Information Center and a Queston clinic.

The Queston Information Center is composed of operators capable of receiving calls from the geographic area of the clinic and scheduling appointments for patients. Note that the number of operators in the Information Center is a user-defined variable.

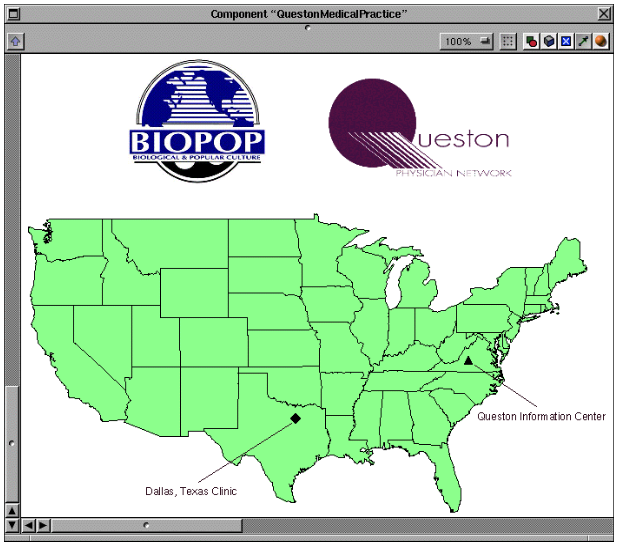

Figure 2: The Top Level of the Queston Model

The Queston clinic is a completely scaleable physician clinic with several user-defined parameters, such as:

- composition of the medical staff
- number of registration windows
- number of examination rooms
- number of check-in rooms
- number of specialty rooms

The model is designed to run for a fifteen month period. The first three months act as a warm-up period and the final twelve months represent the steady-state for the system. During the steady-state period, statistics are collected on medical staff utilization, facility utilization, patient throughput, staffing costs (including overtime), revenue generated by patients and patient time in system.

By carefully analyzing the output of different model configurations, Queston assists its member clinics in striking a balance between maximizing revenues and providing fast and accurate care for their patients.

4 MODEL BUILDING

The first steps in any modeling study are the investigation of the real-world system and the definition of scope for the model based upon the study objectives. This process was greatly aided by a team of medical professionals assembled by Biopop. Together, the modelers and the medical experts developed a generic clinic model fashioned around a family practice. This model includes a standard clinic layout, standard medical personnel and standard patient types. The modelers also developed a template for the Queston Information Center, which acts as the scheduling and information center for all Queston clinics.

4.1 Clinic Layout

Physically, the clinic is laid out in six major areas (see Figure 3):

- registration
- waiting room
- medical area
- internal waiting area
- physician office area
- medical staff area

The registration area houses the clerical staff who service patients as they enter and exit the clinic. Patients wait in the waiting room until a check-in room becomes available or if there is no available registration window.

The medical area (see Figure 4) is composed of the check-in, examination and specialty rooms. A check-in room, as defined in the model, is not typically a room in most clinics. It is the area in which medical staff gather initial information on a patient prior to entering an examination room (e.g., weight measurement). An examination room, as the name implies, is where the patient undergoes a medical examination or procedure. A specialty room houses any special equipment a clinic may have (e.g., an x-ray machine). The clinic may have an infinite number of each of these room types.

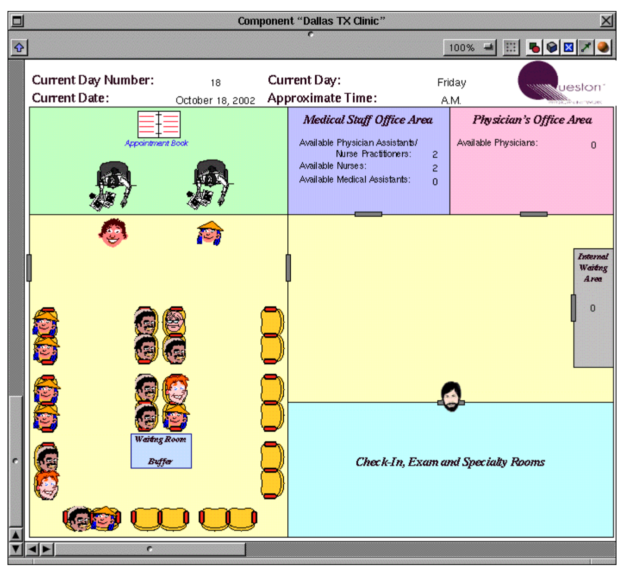

Figure 3: The Queston Model's Clinic

The internal waiting area is for patients who have been admitted to the medical area, but are awaiting the availability of an exam or specialty room. For example, a patient may complete service in an examination room and need to move to a specialty room for an x-ray. If the specialty room is already occupied by another patient, the first patient will move to the internal waiting area. One of the key concepts of the Queston philosophy is the *maximum utilization of resources*. Instead of allowing the patient to wait in the examination room, occupying a valuable service area, the patient waits in the internal waiting area.

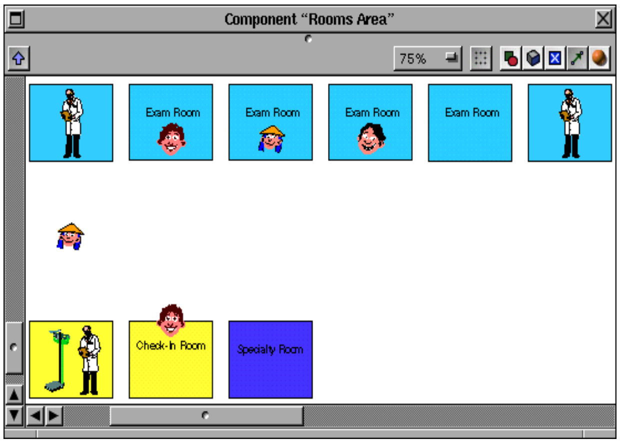

Figure 4: The Queston Model's Medical Area

The physician office area and medical staff area house the physicians and medical staff while they are either taking notes on a patient or are idle. After servicing a patient, the physician returns to his/her office and records information about the encounter for an exponentially distributed amount of time. Likewise, each medical staff member returns to the medical staff area after servicing a patient. The medical staff members, however, record information and perform services related to the patient for an amount of time that varies as a linear function of the length of the patient-staff encounter. The medical staff member spends twice the amount of the patient interaction time (face-to-face time) working in the medical staff area on services related to the patient.

The differentiation between the physician's post-service office time and the other medical staff's post-service office time stems from the modelers' observation of an actual clinic in Christiansburg, Virginia. While observing the clinic, the modelers noted that although the nurse practitioners, nurses and medical assistants spent only a short amount of time with the patient, they spent, on average, twice that amount of time performing patient-related tasks outside of the examination room. The physicians, however, spent a significantly greater amount of time with patient and performed very little patient-related work after an examination.

4.2 Clinic Human Resource Definition

The key human resources in a clinical environment, as identified by the team of medical experts, are:

- physicians
- physician assistants
- nurse practitioners
- nurses
- medical assistants
- lab technicians
- clerical staff

Consultation with the team of medical experts allowed the modelers to combine the physician assistant and nurse practitioner categories into a single category (PA/NP) on the assumption that the typical physician practice only staffs one or the other of these personnel types, but not both. The model allows the user to choose the clinic's staffing in terms of physicians, PA/NPs and medical assistants. The number of lab technicians is determined by the number of specialty rooms selected in the model (one technician per specialty room). Likewise, the number of clerical staff is determined by the number of registration windows selected (one clerk per registration window).

4.3 Patient Definition and Development

The identification of patients for the clinic proved more complex than the identification of the medical staff. The team of medical experts identified general categories of patients. Through an iterative process of presentation and review with the modelers, the medical experts agreed upon ten distinct categories of patients. These categories have their basis in the American Medical Association's codification of patient evaluation and management services provided in a physician's office. The *Physicians' Current Procedural Terminology* (American Medical Association 1996) defines five general patient levels which require an increasing amount of the physician's time and decision-making abilities. The patient categories defined for the Queston model act in a similar manner, increasing in services required as the category number increases. For example, a Category 1 patient may only require a blood pressure check, while a Category 5 patient may require immediate medical attention for a life-threatening ailment. Also included in this patient breakdown are categories for patients who come for pre-visit tests and patients who are new to the clinic. Table 1 provides a listing of the patient categories with samples of patient ailments and/or medical services required.

The next step in the modeling process was to examine the clinic's patient flow. The modelers and medical experts identified seven distinct processes in the patient-physician encounter (see Figure 5):

- registration
- check-in
- pre-examination
- examination
- post-examination
- exit interview
- check-out.

Registration is the time a patient spends interacting with clerical staff prior to treatment. Check-in is the time spent with a medical staff member collecting initial medical information prior to an examination. A pre-exam covers time spent in an exam room or specialty room collecting more extensive medical information prior to an examination. An examination is the time spent with a medical staff member either undergoing medical services used to make an ailment diagnosis or undergoing treatment for an ailment. A post-exam is the same as a pre-exam, except that it occurs after an examination. An exit interview is the time the patient spends with a medical staff member for final consultation and diagnoses. Check-out is the time spent interacting with clerical staff prior to exiting the clinic. The only required processes for each patient are registration, at least one type of examination, and check-out.

Table 1: Queston Model Patient Categories and Associated Examples of Ailments or Service Performed

Patient Category	Example of Ailment or Service
1 A	Blood Pressure Check, Tuberculosis Test Reading
1 B	Immunization, Phlebotomy
1 C	Dressing Change
2	Sore Throat, Fever, Fatigue, Headache
2 PV	Category 2, Pre-Visit
3	Hypertension, Diabetes, Asthma, Flu
3 PV	Category 3, Pre-Visit
4 A	New Patient
4 B	Rheumatoid Arthritis
5	Chronic Ailment Complication

With an understanding of the medical processes and the breakdown of patients, the modelers developed a standard form for each patient category. This form required the medical experts to identify all key aspects of a patient category:

- probability of occurrence
- distribution of scheduling lead time (number of days between a patient's call and the appointment date)
- distribution of cost and revenue
- scheduling rule (e.g., appointment must be in the morning hours)
- probability of undergoing a process (pre-exam, examination, post-exam, etc.)
- probability of requiring a particular medical staff type for a process (e.g., probability of 0.50 that a patient requires a physician for an examination)
- distribution of the time to undergo a process

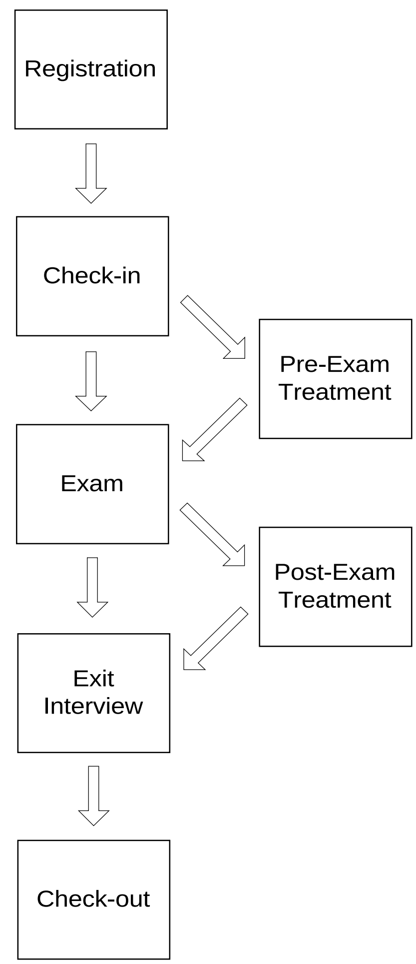

Figure 5: Diagram of Patient Service Flow

The thorough definition of the aspects of the patient categories proved to be a formidable task. The data collection effort required to obtain the needed patient information was deemed both too costly and too time-consuming. Some data collection was performed at a nearby clinic, though the modelers relied primarily upon existing data sources and the medical experts' clinical knowledge.

For example, anecdotal evidence from the minimal data collection effort suggests that the time to undergo a medical process is distributed exponentially. Since this data is not explicitly available, the modelers asked the medical experts to estimate the minimum, maximum and modal times for a process. In this manner, a triangular distribution was built for each patient category in each process with each medical staff member. The distributions built are typically positively skewed, thereby capturing the essence of the exponential distribution while still providing a simple format for the medical experts to provide the distribution data.

In this case and others, the medical experts relied upon their own clinical experiences and published medical information. After a great deal of consultation and reformulation between the modelers and the medical experts, the group as a whole felt comfortable with its definition of the patient population.

The modelers had only to define one last type of patient: the walk-in patient. Walk-ins are drawn from the overall population of patients and arrive at the clinic throughout the day at a user-defined exponential rate. The modelers use the acceptance-rejection technique (Law and Kelton 1991) to ensure that walk-ins only arrive at the clinic during business hours. Walk-ins who are scheduled to arrive outside of clinic hours are simply destroyed after scheduling the next walk-in arrival. The modelers also reschedule the arrival of walk-ins who are scheduled to arrive during the clinic's lunch hour. In this manner, walk-ins who arrive while the clinic is closed for lunch simply wait for service until the clinic reopens.

Although a comprehensive definition of patient types was developed, the modelers had to create one additional class of humans for the model to be complete: the companion. A companion is a person who accompanies the patient to the clinic (e.g., the patient's husband/wife). A patient may arrive with 0, 1, 2, 3 or 4 companions. Although companions do not utilize the clinic's medical resources, they do utilize its waiting room space. The modelers felt that not including companions in the Queston simulation could provide misleading results on the appropriate size for a clinic's waiting room.

4.4 Queston Information Center

Definition of components for the Queston Information Center was less cumbersome than component definition for the clinic. The Queston Information Center consists of a user-defined number of operators who answer calls. A portion of these calls are simply questions relating to billing, appointment times and the like. The remaining calls are patients who call wishing to schedule an appointment in a Queston clinic. The operator determines the appropriate clinic and schedules an appointment for the patient based upon the patient's needs. The center accepts calls twenty-four hours a day.

The arrival of calls to the Queston Information Center is modeled as a nonhomogeneous Poisson process. Calls arrive at a greater rate during the morning and afternoon hours than in the evening and night hours. Calls also arrive less frequently on weekends than on weekdays. Note that all call arrival rates are user-defined inputs. Arrival thinning (Lewis and Shedler 1979) is used to generate the calls. Employing this method, the model generates calls at the maximum rate throughout the day and simply accepts calls with a probability based upon the call rate for the given time period. For example, if the maximum call rate is 1 call per 500 seconds and the current rate for call arrival is 1 call per 1000 seconds, the model will accept calls with a probability of 0.50 ((1/1000) / (1/500)). During the time period when the call arrival rate is at its maximum, all calls are accepted. This scheme was readily implemented using OOP by assigning each call a state attribute of "thinned" or "accepted." "Thinned" calls are destroyed, while "accepted" calls are received by the operators at the Queston Information Center.

5 VERIFICATION, VALIDATION AND TESTING (VV&T)

Throughout the development and implementation of the Queston model, the modelers employed informal, static and dynamic verification, validation and testing techniques (VV&T) as described by Balci (1997).

Although informal VV&T techniques do not rely on stringent mathematical formalism, they are among the most commonly used. Balci (1997) states that well structured informal VV&T techniques applied under formal guidelines can be very effective. Examples of informal VV&T techniques employed in the Queston modeling effort include desk checking, face validation and the Turing Test.

The most significant informal VV&T result came from the Turing Test, in which Biopop's team of medical experts were presented with output from the simulation model and output from an actual clinic. The experts inability to distinguish between the data sets increased the modelers confidence in the model's validity.

Static VV&T techniques are concerned with assessing the accuracy of a model based upon characteristics of the static model design and source code. Static techniques do not require machine execution of the model (Balci 1997). Examples of static VV&T techniques employed in the Queston modeling effort include calling structure analysis, fault/failure analysis, syntax analysis and traceability assessment.

The most significant static VV&T result came from the fault/failure analysis. Fault/Failure analysis examines the model design specification to determine under what conditions the model might logically fail. Fault/Failure analysis identified logic problems in the definition of patient flow and allowed the modelers to better define the possible paths a patient may take through the system.

Dynamic VV&T techniques require model execution and are intended to evaluate the model based on its execution behavior (Balci 1997). Examples of dynamic VV&T techniques employed in the Queston modeling effort include assertion checking, debugging, execution tracing, fault/failure insertion testing, functional testing, object flow testing , special input testing and sensitivity analysis.

The most significant dynamic VV&T results came from assertion checking, functional testing and object-flow testing. Both assertion checking and object-flow testing were aided by the design of the Visual Simulation Environment. VSE allows the modeler to insert specific assertion checks within each object method. This allows the model to constantly monitor critical state variables to assure that their values are not infeasible. For example, an assertion in the medical area assures that a person in a medical room is not a member of the companion class.

Object-flow testing was aided by both VSE's visual nature and its implementation of the object-oriented paradigm. Tracing the life of an object in VSE is as elementary as physically viewing the object in question as it moves through the model during execution.

Functional testing is used to assess the accuracy of a model based upon its outputs, given a specific set of inputs (Balci 1997). Although it is impossible to test all input-output combinations, the modelers tested the Queston model with a large variety of input parameter variations. For example, the model was tested with a wide range of incoming call rates to the Queston Information Center. For those runs in which very few calls were placed, such model outputs as clinic overtime and medical staff utilization were minimal. Conversely, for those runs in which many calls were placed, clinic overtime and medical staff utilization were much greater.

Based upon the results of the VV&T techniques utilized in testing the Queston model, the modelers concluded that the Queston model provides a sufficiently valid representation of the clinical environment.

6 EXPERIMENTATION AND RESULTS

Experimentation with the Queston model has shown the clinical environment to be highly sensitive to patient mix and patient scheduling. Model experimentation also shows that under certain conditions staffing reductions can be made without sacrificing patient throughput or increasing staff overtime. Table 2 provides the key input parameters for the baseline experiment upon which these results are based.

Table 2: Key Initial Experiment Input Parameters

Input Parameter	Input Value
Number of Physicians	2
Number of PA/NPs	2
Number of Nurses	2
Number of Medical Assistants	3
Number of Examination Rooms	6
Number of Check-In Rooms	2
Number of Specialty Rooms	1
Number of Registration Windows	2

After making an initial model run to establish a baseline (Model I), the modelers tested the clinic's sensitivity to patient mix. A change was made to the model to slightly decrease the number of patients requiring extensive physician interaction (Model II). The probabilities that a patient is a category 4B or category 5 patient were decreased while the probabilities that a patient is a category 2 or category 3 patient were increased. Table 3 provides the probability of occurrence for each patient category in Model I and Model II.

Table 3: Probability of Occurrence for Patient Categories in Model I and Model II

Patient Category	Model I P(Occurrence)	Model II P(Occurrence)
1 A	0.10	0.10
1 B	0.10	0.13
1 C	0.02	0.05
2	0.30	0.30
3	0.28	0.28
4 A	0.04	0.04
4 B	0.08	0.05
5	0.08	0.05

The change in patient mix reduced physician utilization from 0.68 to 0.61 while significantly reducing the average daily overtime of the clinic. Clinic overtime is defined as the length of time the clinic remains open serving patients after 5:00 PM. Table 4 lists the mean clinic overtime per day of operation for the original model (Model I) and the revised model (Model II).

The modelers next tested the effect of changing the time of day a patient category is scheduled. Model I schedules 20% of category 5 patients in the morning hours (9 AM to 11:30 AM) and 80% in the afternoon

(1:00 PM to 4:15 PM). The category 5 scheduling rule was altered to schedule 50% of patients in the morning and 50% in the afternoon. A model run reflecting both this change in scheduling rule and the previous changes in patient mix was performed (Model III). Table 4 provides the clinic overtime results for Model III.

Table 4: Mean Daily Clinic Overtime for Model I, Model II and Model III

Day of Operation	Model I Clinic Overtime (minutes)	Model II Clinic Overtime (minutes)	Model III Clinic Overtime (minutes)
Monday	36.9	14.9	4.2
Tuesday	25.2	12.5	0.0
Wednesday	16.7	9.9	4.5
Thursday	17.1	10.2	0.0
Friday	25.7	3.3	8.6
Mean	24.3	10.2	3.5

The modelers were not only interested in the effects of patient mix and scheduling changes, but were also interested in determining the effect of staffing changes. The modelers performed two model runs with reductions in the number of medical assistants in the clinic. The first run was made with two medical assistants (Model IV) while the second was made with one medical assistant (Model V). The base model for these experiments, Model III, utilizes three medical assistants.

Neither Model IV nor Model V show significant changes to clinic overtime, physician utilization or mean patient visit length. Table 5 displays the similarities in mean patient visit length for the three models.

Table 5: Mean Visit Length per Patient Category for a Clinic with 1 (Model III), 2 (Model IV) and 3 (Model V) Medical Assistants

Patient Category	Model III Mean Visit Length (minutes)	Model IV Mean Visit Length (minutes)	Model V Mean Visit Length (minutes)
1 A	25.6	25.5	24.5
1 B	25.9	26.3	25.9
1 C	31.9	33.2	35.1
2	61.7	60.2	62.2
2 PV	27.5	27.8	27.8
3	60.3	60.8	64.9
3 PV	21.5	21.7	22.3
4 A	48.5	46.5	48.4
4 B	65.6	65.0	68.8
5	82.2	83.6	85.2

As a whole, the experiments performed on the Queston model show the clinical environment to be very sensitive to small changes in patient mix and patient scheduling rules. Experiments show that clinics treating a greater percentage of category 5 patients can expect a more heavily utilized physician and a greater amount of clinic overtime. Experimentation with the system also reveals that staffing reductions can be made, under certain conditions, which do not cause significant negative impacts on patient service time or clinic overtime. Data such as this could prove invaluable to Queston physicians who hope to reduce costs while still providing fast, efficient patient care.

7 SUMMARY AND FUTURE RESEARCH DIRECTIONS

In a world of high quality, efficient service operations, health care consumers expect no less from their physicians. Efficient health care in the 21st century will be vital to the success of physician clinics. The Queston Physician Network aims to gain efficiencies through the use of state-of-the-art information systems and well-planned physician clinics. The simulation model described herein allows physicians who partner with Queston to perform risk-free what-if analyses on staffing levels and facility design, as well as experimentation on scheduling policies and operating hours. The model also allows Queston to determine appropriate staffing for its Information Center. Biopop believes that Queston has the potential to set new standards for efficiency and excellence in health care.

Although the modeling team is pleased with its results thus far, it plans to continue to revise and experiment with the model. The key future research issue is the system’s response to the addition of several more Queston clinics. The modelers plan to expand the single clinic model to a multiple clinic model and study the effects upon the Queston Information Center. Once again, OOP will play a major role in expanding the model. The modelers expect only minor changes to allow an entire clinic to be instantiated as any other object in the model.

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