USING QUEUING ANALYSIS AND COMPUTER SIMULATION MODELING TO REDUCE WAITING TIME IN THE HOSPITAL ADMITTING DEPARTMENT

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ABSTRACT

The Admitting Department is one of the most highly congested hospital services, and faces a great deal of pressure, compared with other components of the health care system. Delays in the AD system may result in difficulties of scheduling services at specialty units and decrease in patient satisfaction. This paper examines the wide-spread problem of extended waiting times for health services, in the context of the Admitting Department (AD) at a regional hospital.

In the first phase of the study, a field observation was conducted to document the current operation of the AD. The authors collected actual data over a one-year period for arrivals, waiting times, and service times. These data were categorized by month, day of the week, and time of day. The data were collected for all patient groups within the AD system: outpatients, inpatients, surgical day care patients and so forth.

Data were recorded for arrival into the system (waiting time 1 (WT1)), and transition from check-in to financial arrangements processing (waiting time 2 (WT2)) followed by departure from the system (to a specialty unit or out of the system). The flow charts for the admission process were developed.

In the second phase of the project, a facility layout analysis provided a proposed redesign of patient flow and changed the number of work stations to alleviate choke points in the system, a proposed scheduling strategy evaluation provided new arrival rate figures, and queuing analysis and queuing simulation were employed by using Quantitative Methods System (QMS) to predict the improvements in waiting times.

The third phase of the study was devoted to the building and validation of a computer simulation model of the AD using the Flexsim™ simulation software for modeling, analysis, visualization, and optimization of the patient flow within the AD. The validity of the model was established by comparison of simulation results with the data obtained during phases 1 and 2 of the study.

In the fourth phase of the study, the model will be utilized to simulate the impacts of different proposed operating strategies on the waiting times and throughput rates for patients in the AD. The objective is to identify those strategies which lead to shorter waits for the patients, and therefore greater throughput rates and higher efficiency for the hospital, but without sacrificing the quality of patient care or significantly increasing costs.

The fifth phase of the project will be to employ the model to gain acceptance by the hospital administration, as well as the health professionals who provide the service for the patients in the AD, that the proposed changes represent actual improvements in the quality of the health care delivery system.

BACKGROUND

From queuing theory standpoint, a hospital admitting department can be viewed as a system of queues and different types of servers. A quantitative analysis of the wait time problem in an admitting department is dependent upon the identification of a methodology which recognizes the structure of the problem as that of a queuing system. Two modes of analysis are generally suggested by the structure of this type of problem: queuing models and discrete event simulations.

Queuing modeling is very useful for supporting the decisions about levels of staff, resource allocation, building layout, and new policies implementation. The use of queuing analysis and simulation of various hospital departments, such as inpatient (Green, 2003), ICU (Kaplan et al, 2003), obstetrics units (Kim et al, 1999) and ED (Green et al, 2005) has been widely discussed in the literature.

In some studies, researchers have generated models that were able to make accurate predictions of quantities such as waiting room times and patient care times. One of such model that was developed by Rossetti et al. (1999) used the Emergency Department at the University of Virginia Medical Center in Charlottesville as a case study model. This model was used to test alternative ED attending physician staffing schedules and their impacts on patient flow and resource utilization. Shift modification was also tested in the McGuire (1997) study (Emergency Services department in a SunHealth Alliance hospital), which allows choosing a solution that reduces average length of stay for patients by up to 50 minutes.

The application of basic queuing principles and models to the hospital inpatient admitting process has been studied by Green (2003). Kaplan, Sprung and Shmueli (2003) used the queuing modeling to analyze the impact of various admissions policies to ICU facilities. Nevertheless, there seems to be a lack of research on using queuing analysis and simulation of the patient flow and service process in the Admitting Department as in an independent queuing system.

Over the past thirty years, a significant amount of research has been done in the area of discrete-event simulation modeling in health care. Resent innovations in object-oriented models enable the construction of large integrated systems that become powerful tools for analysis of and innovations in health care systems (Jun, et al, 1999).

Law and Kelton (2001) proposed an algorithm of a successful computer simulation study. This algorithm includes the following key steps: 1. Problem formulation, 2. Data collection and the conceptual model design, 3. The validation of the model, 4. The constructions of the computer representation of the model, 5. The verification of the model, 6. The design of experiments needed to address the problem, 7. Production runs using the computer model, 8. The statistical analysis of the data obtained from the production runs, and 10. The interpretation of the results.

A number of researchers (Banks and Carson, 1987; Mahachek, 1992; Vissers, 1998; Isken et al., 1999; Eldabi and Paul, 2001; Harper, 2002; Morrison and Bird, 2003; and others) have addressed the core principles for performing a discrete-event simulation study of a healthcare system. Discrete-event simulation models that have been used to analyze healthcare systems have been primarily focused on the Patient flow (PF) analysis and optimization. The primary objective of PF analysis has been to identify the ways to improve patient throughput, reduce waiting time, and optimize resource allocation (for instance, the number of beds and staffing requirements to provide effective and efficient care).

Waiting time in the AD can be reduced through implementation of quantitative methods, understanding of best practices, and commitment to change. For instance, queuing models of admitting department activity have a broad range of potential applications. One of the most promising areas is the study of AD overcrowding. A critical capability afforded by patient flow simulation is the reconstruction of the factors that are responsible for overcrowding. This allows a more detailed understanding of the relationship between the observed conditions and related outcomes that could lead to informed optimization decisions.

GENERAL FEATURES OF THE HOSPITAL AND PROCESS MAP FOR THE AD

The subject of our study is 180-bed Hospital in rural Mississippi which provides the following key services: General medical and surgical care, General intensive care, Cardiac intensive care, Pediatric medical and surgical care, Pediatric intensive care, Physical rehabilitation, Obstetrics, Emergency Department, and Trauma Center.

In terms of patient flow, the Hospital could be viewed from several different perspectives. At the highest level of detail, the hospital includes three general subdivisions: Outpatient, Inpatient and Emergency. The fourth area, the outpatient community clinics associated with the hospital, was not studied in this research.

The Admitting department consists of four major areas: Front desk, Registration desk (booths), Waiting area, and Financial Consulting area (within Business Department). See Figure 1A.

Patient Flow in the AD is very intense, as a result, overcrowding and delays are the major problems in the department. To illustrate patient flow in the AD, flowcharts describing admission process have been developed. The flowcharts are provided in the section “Charts, Tables, and Figures”.

When patient enters the AD she is asked by front-desk clerk to provide name and reason for visit. The clerk also clarifies if patient was pre-registered for this service or not. If the answer is yes, the clerk gets patient’s documentation ready for the admission representative. Then the patient receives an assigned number and is asked to wait in admitting waiting area for admitting representative to call the number. Admitting representative determines if the patient ever receives the service at the hospital and if so, pull up patient’s data from Meditech and verifies patient’s personal information. If the patient is visiting the hospital for the first time, AD clerk creates patient’s profile in the Hospital Information Database system.

Admitting clerk determines patient’s type (Inpatient (IN), Clinical (CLI), Referred (REF), Recurring (RCR), Surgical Day Care (SDC) or Observation (OBS)) and creates new account using Hospital Informational System. AD serves most outpatient and inpatient types, with an exception for: REF, some RCR, OBS and IN.

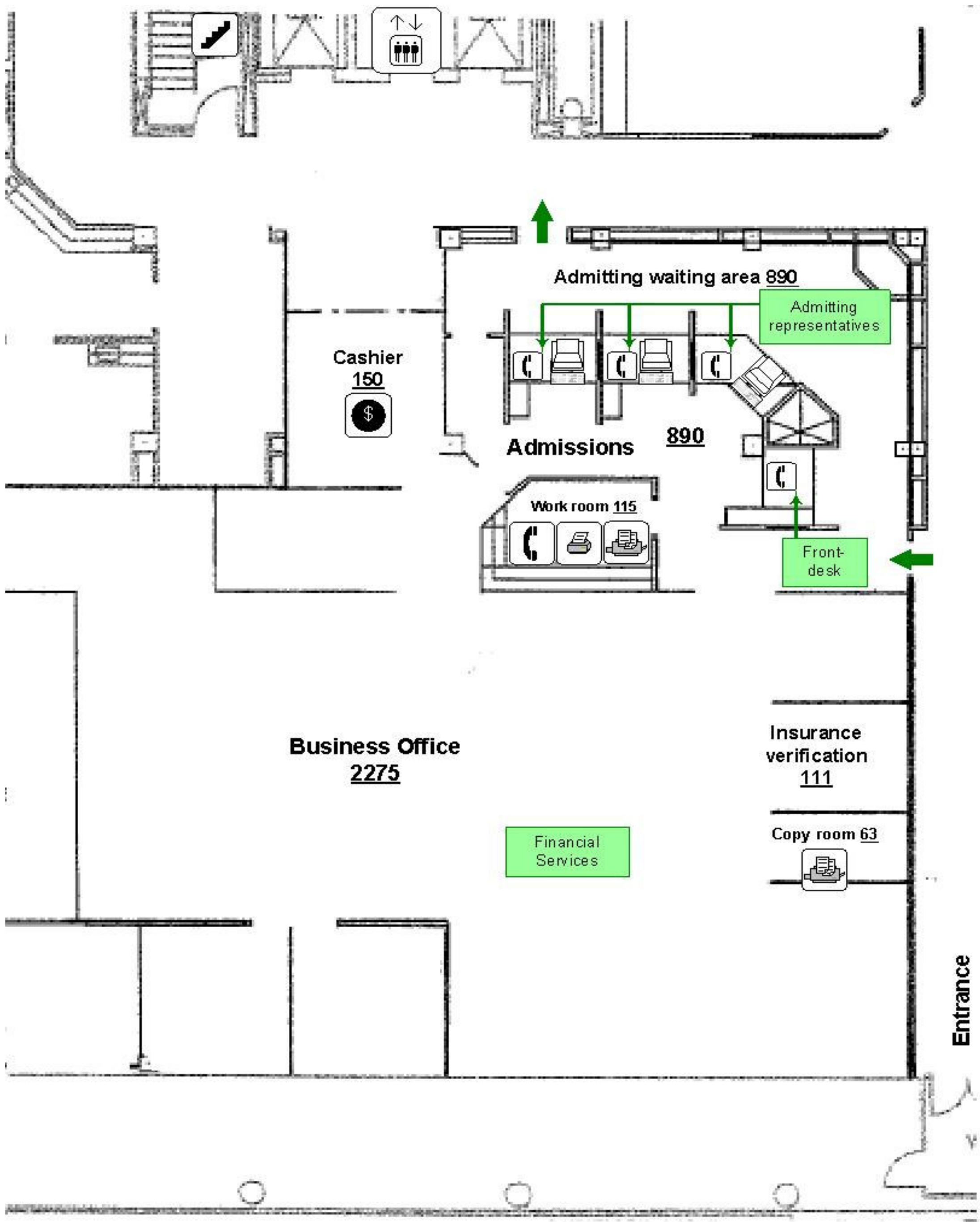

Figure 1A. Admitting Department, main areas

The actual workload within the AD was difficult to measure due to multifunctional role of the Department and lack of the appropriate registration and tracking system designed to control patient flow. Therefore, in order to obtain a reliable figure, the data collected from different sources, such as Admitting Logs, Tracking Forms, Meditech Records, staff surveys, field observation and queuing analysis, were combined. As a result, a unique patient tracking system has been developed. The combination of various computer database reports and paper-based sources yielded reasonably consistent numbers.

EVALUATION OF PATIENT FLOW IN THE AD

In phase 1 of the study, the Admissions process in the regional hospital was examined with the purpose of documenting the existing process and its bottleneck points, determining the waiting time distributions, and developing recommendations for modifying the layout and staffing of the system to reduce waiting times for patients.

Data were recorded for arrival into the system (Source: AD Sign-in log, Tracking Sheets), transition from sign-in to admitting arrangements processing (i.e. waiting in the waiting area), arrival to the registration desk (Source: AD Sign-in log, Tracking Sheets, Hospital Information System (Meditech)), and departure from the system to a specialty unit or out of the system (Tracking Sheets).

The average number of patients who walked through AD on the day of service (true physical arrival rate) was 43 per day (range: 29-60, σ=9.1). The number of servers, the average time in the system, and the average time in the queue for the existing staffing levels are shown in Table 2 and Figure 2 in the section "Charts, Tables, and Figures".

AD visit typically consists of a series of services: registration in Admitting Log (service 1 (ST0), registration in Meditech System (ST1), Financial Consulting (ST2), and insurance verification (ST3), and wait for available server at the corresponding levels (See Table 1 and Figure 1B). AD flowchart with the key service and waiting times marked can be found in the section "Charts, Tables, and Figures".

Waiting Time	**Reason for waiting**	**Range**	**Average time**
WT 0	Waiting for log-in ST0	N/A	N/A
WT1	Waiting for registration ST1	0min- 39min	7min
WT2	Waiting for financial consulting ST2	N/A	N/A
Service Time	**Service Description**	**Range**	**Average time**
ST 0	Registration in "Admitting log"	N/A	N/A
ST1	Registration in Meditech	1min-94min	18min
ST2	Financial consulting	5min-65min	15min

Table 1. Patient Wait time and Service Time in AD
Source: Database analysis

It was determined that the values of service and waiting time tend to reach their maximum during the "busy" hours when the arrival rate is the highest.

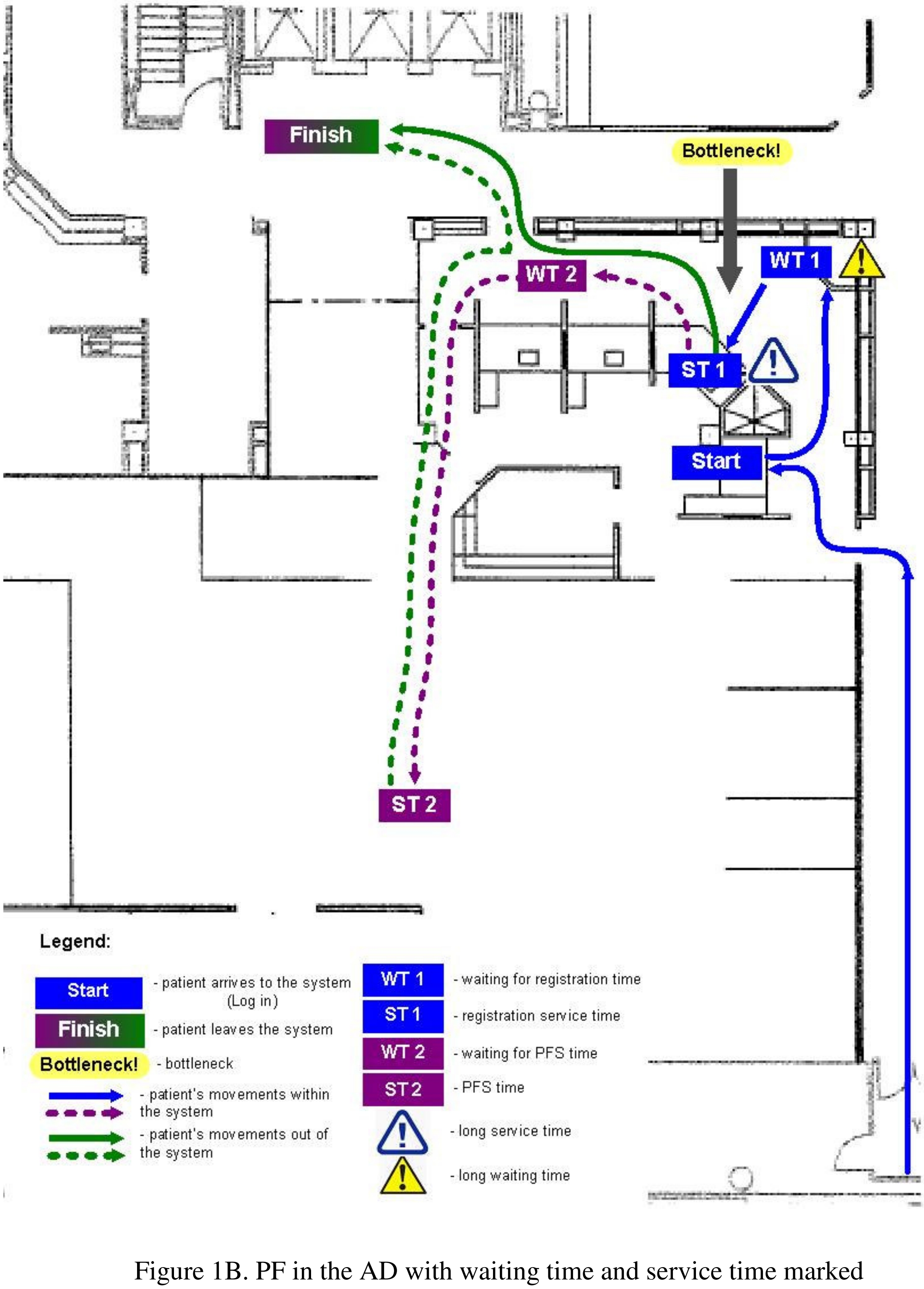

Figure 1B. PF in the AD with waiting time and service time marked

Our observations revealed that the bottleneck in the waiting area occurs when the line starts building up during the time period when the arrival rate reaches its maximum level.

QUEUING STUDY AND COMPUTER SIMULATION MODELING OF PF IN THE AD

In our study, modified M/M/s queuing model was used. A classic M/M/s, or Erlang delay model, assumes a single queue with unlimited waiting room that feeds into s identical servers. Customers arrive according to a Poisson process with a constant rate and the service duration has an exponential distribution (Hall 1990). In healthcare, the Poisson process has been identified as an optimal representation of unscheduled arrivals to various systems (Kim et al 1999, Green et al 2005). Since in our case the majority of out-patient non-emergent visits were not scheduled we used the Poisson distribution for arrival process in the models. After an extensive statistical analysis of the collected data, it was determined that the service rate had a Poisson distribution as well.

Since the M/M/s model assumes that the arrival rate does not change over the day, to model our system (that had a fluctuating arrival rate) we used the M/M/s model as a part of a SIPP (stationary independent period-by-period) approach to determine how to vary staff to meet changing demand. The SIPP approach starts with dividing the day into staffing periods, then a series of M/M/s models are constructed. After that, each of these periods is separately analyzed and solved for optimal number of servers to meet the target service requirements (Green 2006). In our study, the day was divided into 12 periods: 10 1-hour periods and 2 ½-hour periods. This division was used for all models we developed (Table 2).

Queuing analysis revealed a critical congestion in the AD system from 8 am to 11 am when the AD functions in the emergency mode because of unscheduled arrivals (see Table 2 and Figure 2). During this time period, the arrival rate exceeds the capacity of the system and the queue starts building up. To model the line, queuing simulation was performed for each of the 12 periods. It was determined that during the peak hours the developing line reaches the level of 6 patients waiting at the same time which as consistent with the results of our field observation (Figure 3).

The results of Queuing study and simulation were compared with the computer simulation model. For this purpose, industrial simulation software Flexsim™ was used. The software is designed to model, simulate, and visualize industrial processes in the factory settings. As a "what-if" analysis tool, Flexsim™ provides quantitative feedback on a number of proposed solutions, graphical animation and performance report.

For verification and validation of the model, the behaviors of different types of patients were followed through the system. In our model, each unit and member of the AD system was represented by an assigned animated item initially designed by the software developers to simulate industrial factory objects. Each of these items was programmed to simulate the behavior and functional characteristics of the corresponding AD system unit. Thus, the waiting area was represented by the "queue" and "separator", front desk clerk and admitting representatives – by the "processors" of different colors, and exit from the department – by the "conveyor" and "sink" (Figures 8 and 9 illustrate the view of the Simulation Model). The simulation model was run for 20 replications for each of the 12 staffing period. The performance measure, average waiting time, number and time in queue and system were compared with the historical data and the results of the preceding queuing study. The data obtained from the queuing study and computer simulation modeling differed insignificantly and the resulting diagrams had similar shapes. In the light of these observations, we concluded that the simulation model performed adequately well and provided results at the level of accuracy aimed for this project.

REDUCING WAITING TIME

There are several possible ways of improving patient flow, and thereby reducing waiting time for the patients. These include (1) Increasing the number of servers; (2) Managing the arrival rate; and (3) Optimizing the service rate.

The number of servers can be increased by hiring more admitting clerks. This is the most obvious by not necessarily the best decision. Although increasing the number of servers provides immediate results (Table 3 and Figure 4), the most effective approach to improvement should involve optimization of all three variables mentioned above. The arrival rate should be decreased during busy times and increased during “slow” periods. Scheduling arrivals would modify the arrival rate to the necessary degree.

Implementation of an online Appointment Management System would allow scheduling of non-emergency outpatient visits. Radiology was selected to be the first department to test the software. When the hospital starts using the scheduling system to its full extent, the arrival rate in the AD is expected to be stabilized significantly. It was assumed that having implemented appointment software and having been using it for several months, the hospital will be able to schedule over 90% of outpatient Radiology visits. The current arrival rate of the Radiology patients is depicted in Figure 5, along with the impact of this change on the overall arrival rate for the AD (see also Table 5). The impact of combining these modifications in staffing and arrival rate on the average time in the system and the queue are shown in Table 5 and Figures 6 and 7.

The third key variable that can affect system patient flow is service rate. It can be decreased by various means: pre-registering a larger number of patients, introducing a patient member plastic card which would contain patient’s demographic information, using electronic medical forms rather than paper-based, optimizing admitting clerk work place layout (the survey of current operations revealed that on average, each admitting clerk visits the work room 2-4 times while serving a patient to make copies, fax documents and so on; providing personal office equipment will eliminate the need of visiting the work room while serving the patient) and so forth.

RECOMMENDATIONS

This study attempted to analyze actual operations of a hospital and proposed modifications in the system to reduce waiting times for the patients, which should lead to an improved view of the quality of service provided. Three areas of change were recommended: (1) increasing the number and rescheduling the work times of the admissions clerks, (2) adopting an Appointment Management System to spread the arrivals into the system and avoid unacceptable levels of inputs at certain times of the day, and (3) increasing the service rate of the clerks by implementing electronically based systems for pre-registration, re-registration, and document reproduction functions.

Any changes should be evaluated by computer based systems employing queuing analysis and by simulation studies to predict the efficacy of the proposed modifications, prior to their actual implementation. The current study is a first step in that direction.

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CHARTS, TABLES AND FIGURES:

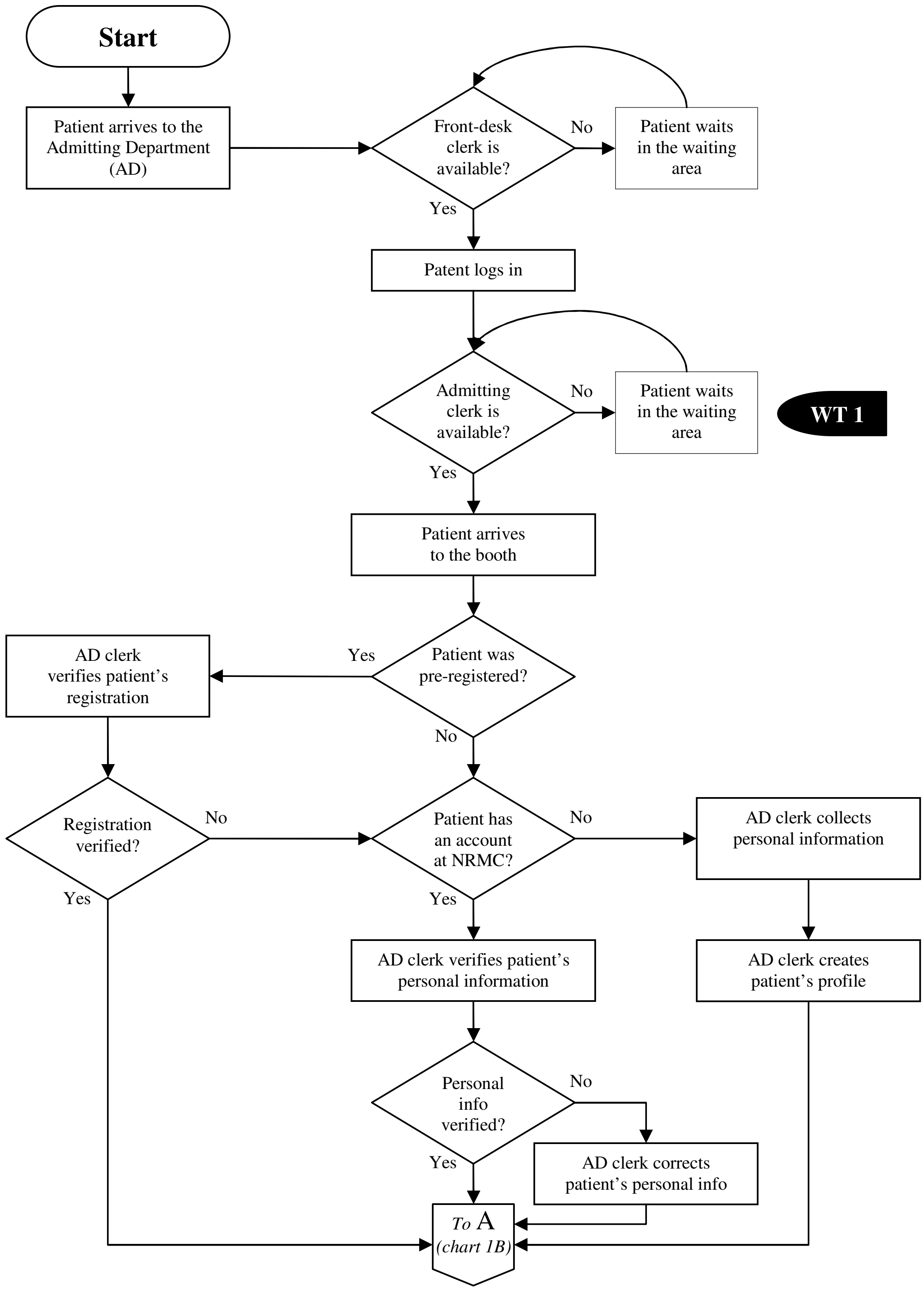

Chart 1A. Patient Flow in the Admitting Department, with Waiting Time

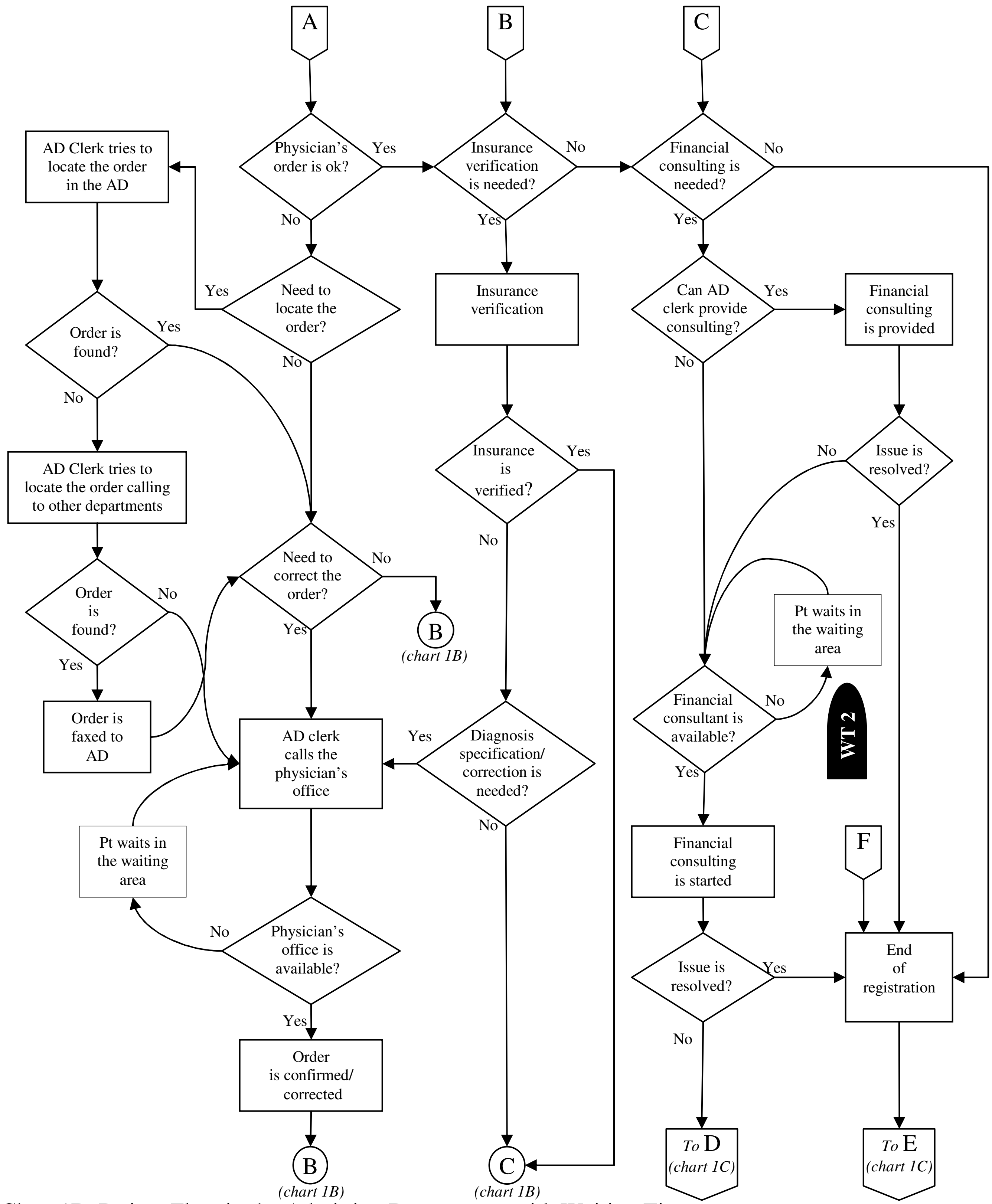

Chart 1B. Patient Flow in the Admitting Department, with Waiting Time

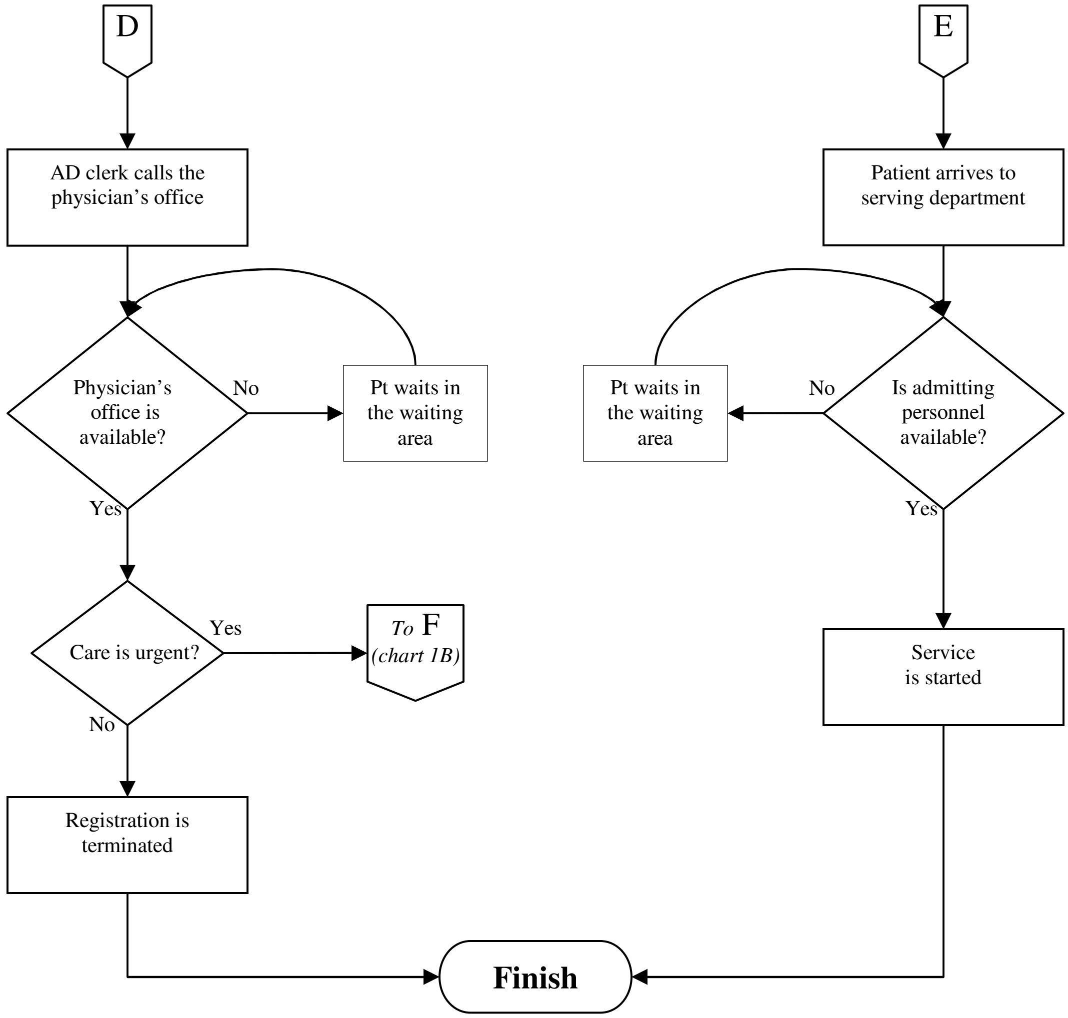

Chart 1C. Patient Flow in the Admitting Department, with Waiting Time

CURRENT MODEL	5:30-6:00AM	6:00-7:00AM	7:00-8:00AM	8:00-9:00AM	9:00-10:00AM	10:00-11:00AM	11:00-12:00PM	12:00-1:00PM	1:00-2:00PM	2:00-3:00PM	3:00-4:00PM	4:00-4:30PM
INPUTS:												
Number of Servers	1	1	1	3	3	3	3	3	3	3	2	2
Arrival Rate (units/hour)	1.0	1.9	5.1	10.1	9.2	7.4	5.7	5.8	5.2	4.1	3.4	2.5
Mean Service Time (min./ server)	18	18	18	18	18	18	18	18	18	18	18	18
OUTPUTS:												
Traffic Density	-	-	na*	na	92.3%	74.1%	57.3%	58.2%	51.5%	40.5%	51.0%	37.5%
Utilization Factor for server	28.8%	55.8%	na	na	-	-	-	-	-	-	-	-
% Idle Time for Server	71.2%	44.2%	na	na	-	-	-	-	-	-	-	-
Average Time in System	25.3	40.7	na	na	84.9	30.8	22.5	22.8	21.1	19.5	24.3	20.9
Aver. Time in Queue	7.3	22.7	na	na	66.9	12.8	4.5	4.8	3.1	1.5	6.3	2.9
Aver. Numb. in System	0.4	1.3	na	na	13.1	3.8	2.2	2.2	1.8	1.3	1.4	0.9
Aver. Numb. in Queue	0.2	0.7	na	na	10.3	1.6	0.4	0.5	0.3	0.1	0.4	0.1
Probability of a wait	.08	.31	na	na	.86	.55	.32	.33	.25	.14	.34	.20

Table 2. Queuing analysis of the system with current number of admitting representatives

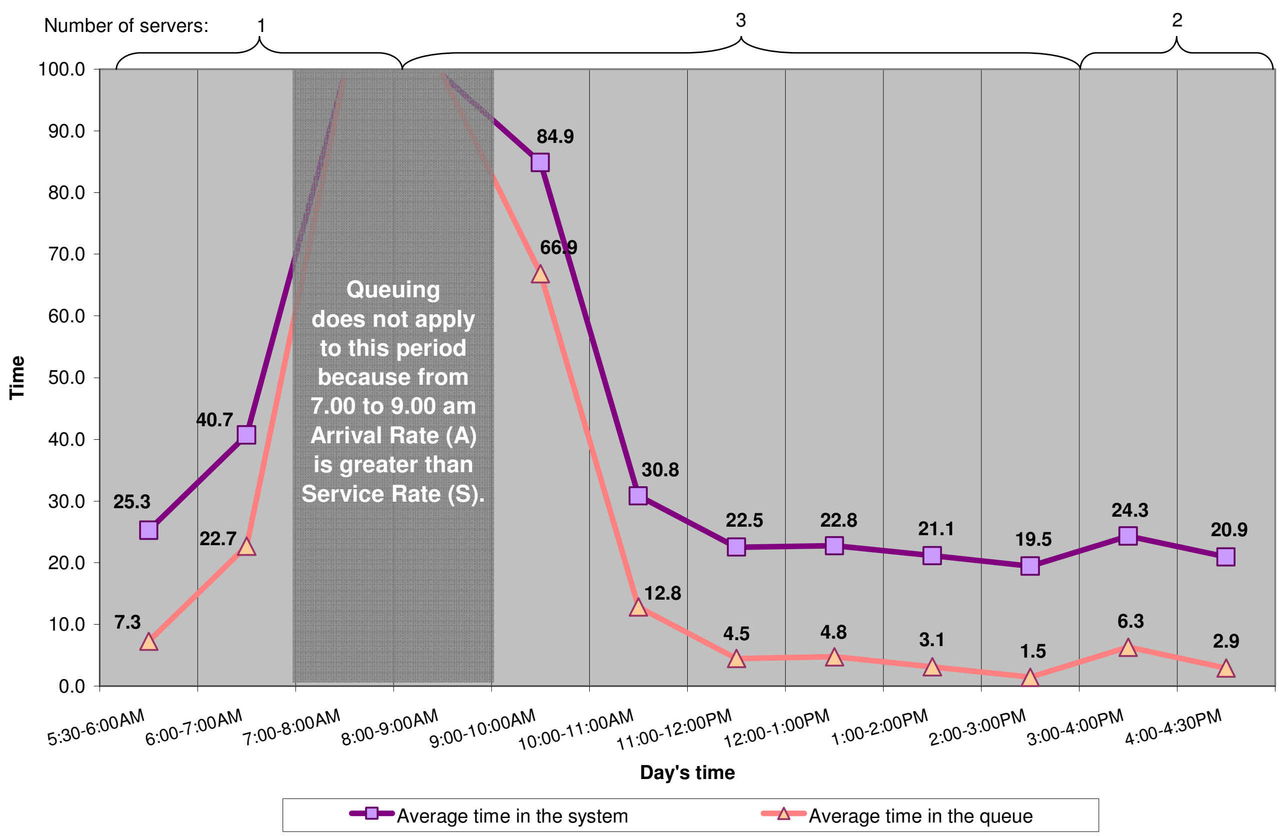

Figure 2. Average Time in System and in the Queue in the AD over the Day with Current Staffing

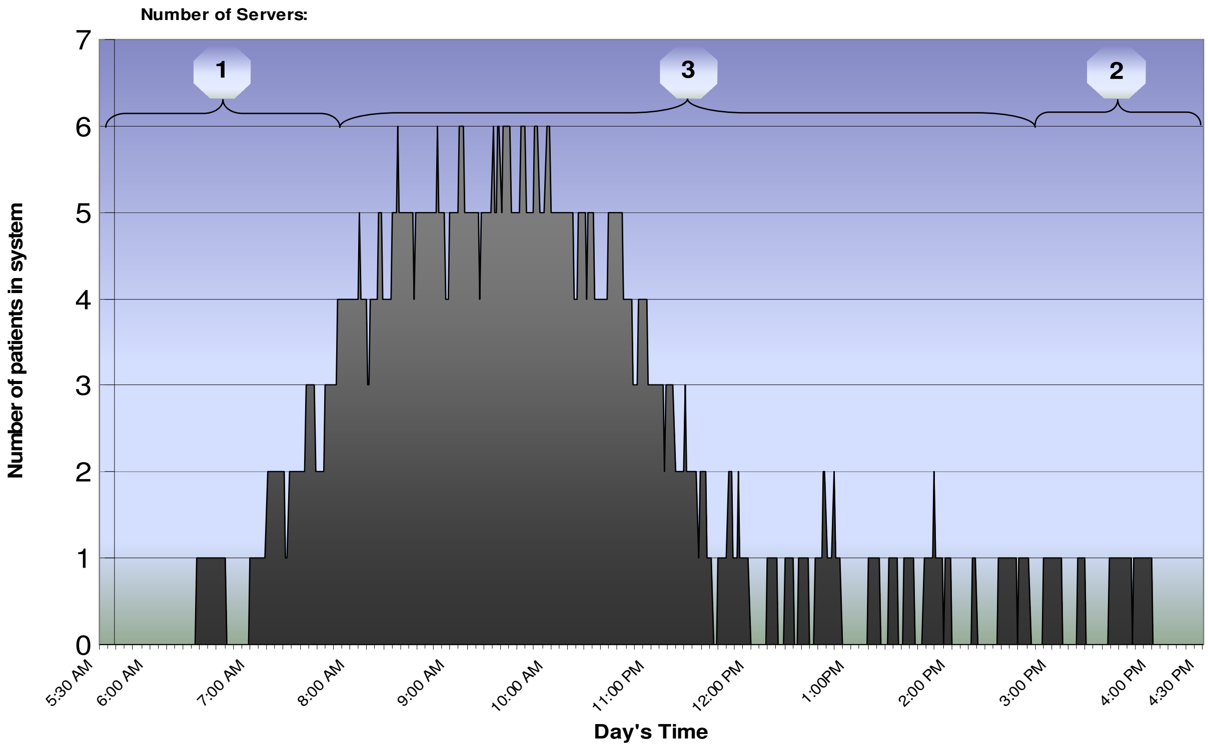

Figure 3. Queuing Simulation of the PF in the AD over the Day with Current Staffing

CURRENT MODEL + Revised Staffing:	**5:30-6:00AM**	**6:00-7:00AM**	**7:00-8:00AM**	**8:00-9:00AM**	**9:00-10:00AM**	**10:00-11:00AM**	**11:00-12:00PM**	**12:00-1:00PM**	**1:00-2:00PM**	**2:00-3:00PM**	**3:00-4:00PM**	**4:00-4:30PM**
INPUTS												
Number of Servers	1	2	3	4	4	3	3	3	3	2	2	2
Arrival Rate (units/hour)	1.0	1.9	5.1	10.1	9.2	7.4	5.7	5.8	5.2	4.1	3.4	2.5
Mean Service Time (minutes/server)	18	18	18	18	18	18	18	18	18	18	18	18
OUTPUTS												
Traffic Density	-	28.5%	51.0%	75.8%	69%	74.1%	57.3%	58.2%	51.5%	61.5%	51.0%	37.5%
Utilization Factor for server	28.8%	-	-	-	-	-	-	-	-	-	-	-
% Idle Time for Server	71.2%	-	-	-	-	-	-	-	-	-	-	-
Average Time in System	25.3	19.6	21	27.7	24	30.8	22.5	22.8	21.1	29.0	24.3	20.9
Average Time in the Queue	7.3	1.6	3	9.7	6	12.8	4.5	4.8	3.1	11.0	6.3	2.9
Average Number in System	0.4	0.6	1.8	4.7	3.7	3.8	2.2	2.2	1.8	2.0	1.4	0.9
Average Number in Queue	0.2	0.1	0.3	1.6	0.9	1.6	0.4	0.5	0.3	0.75	0.4	0.1
Probability of wait	.08	.10	.25	.50	.40	.55	.32	.33	.25	.50	.34	.20

Table 3. Queuing analysis of the system with new number of admitting representatives (Revised Staffing Model)

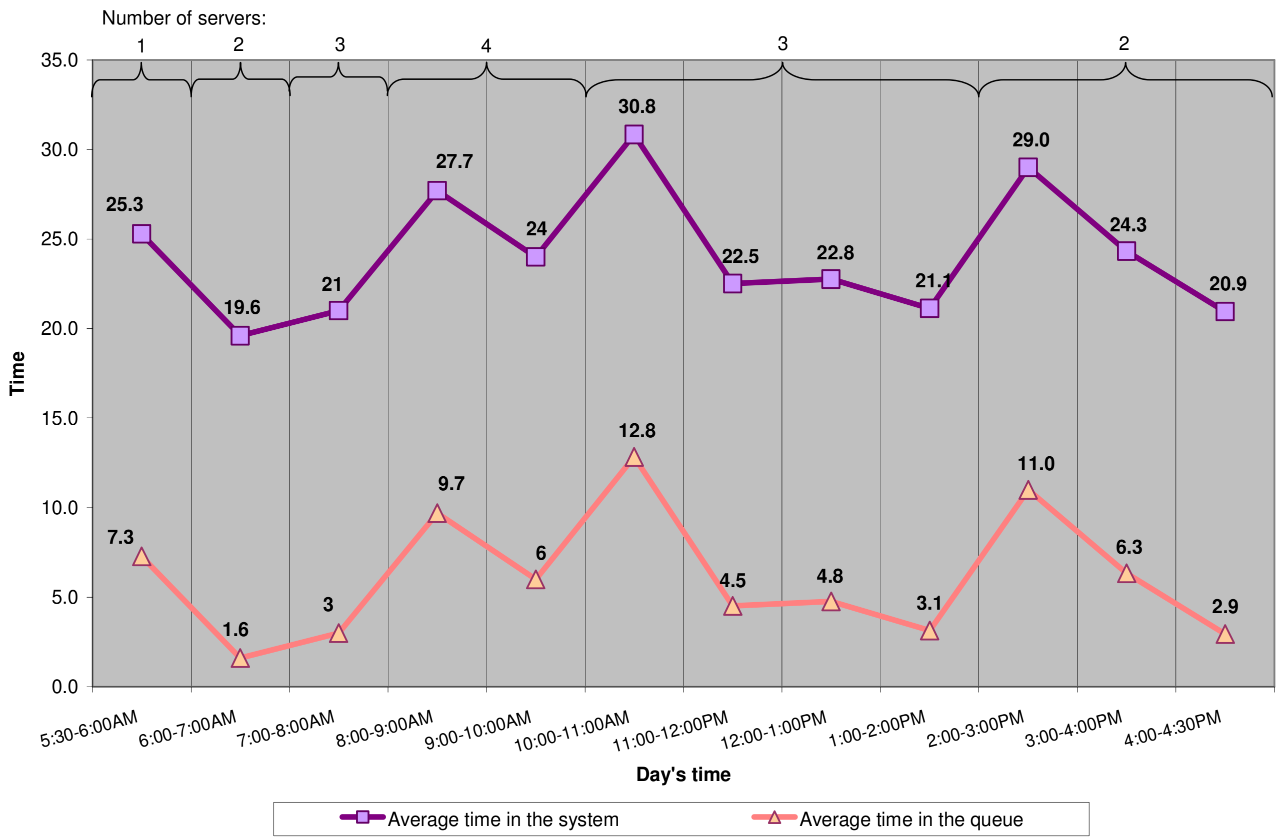

Figure 4. Average Time in the System and in the Queue in the AD over the Day with Revised Staffing

NEW MODEL, Step 1:	**5:30-6:00AM**	**6:00-7:00AM**	**7:00-8:00AM**	**8:00-9:00AM**	**9:00-10:00AM**	**10:00-11:00AM**	**11:00-12:00PM**	**12:00-1:00PM**	**1:00-2:00PM**	**2:00-3:00PM**	**3:00-4:00PM**	**4:00-4:30PM**
Inputs:												
Current Arrival Rate	1.0	1.9	5.1	10.1	9.2	7.4	5.7	5.8	5.2	4.1	3.4	2.5
Steps 1 Target Arrival Rate	0.9	1.7	2.7	7.6	7.6	6.1	5.3	4.7	3.7	3.6	3.2	2.4
Mean Service Time (minutes/server)	18	18	18	18	18	18	18	18	18	18	18	18
Number of Servers	1	1	1	3	3	3	3	3	3	3	2	2
Outputs:												
Traffic Density	-	-	-	76%	76%	61%	53%	47%	37%	36%	48%	36%
Utilization Factor for server	27%	51%	81%	-	-	-	-	-	-	-	-	-
% Idle Time for Server	73%	49%	19%	-	-	-	-	-	-	-	-	-
Average Time in System	24.7	36.7	94.7	32.6	32.6	23.7	21.4	20.3	19.0	18.9	22.4	20.3
Average Time in the Queue	6.7	18.7	76.7	14.6	14.6	5.7	3.4	2.3	1.0	0.9	4.4	2.3
Average Number in System	0.4	1.0	4.3	4.1	4.1	2.4	1.9	1.6	1.2	1.1	1.2	0.8
Average Number in the Queue	0.09	0.53	3.45	1.85	1.85	0.57	0.30	0.18	0.06	0.06	0.23	0.09
Probability of a wait	.07	.26	.66	.58	.58	.37	.27	.20	.10	.10	.25	.16

Table 4. Queuing analysis of the New Model, Step 1 (With Proposed Arrival Rate)

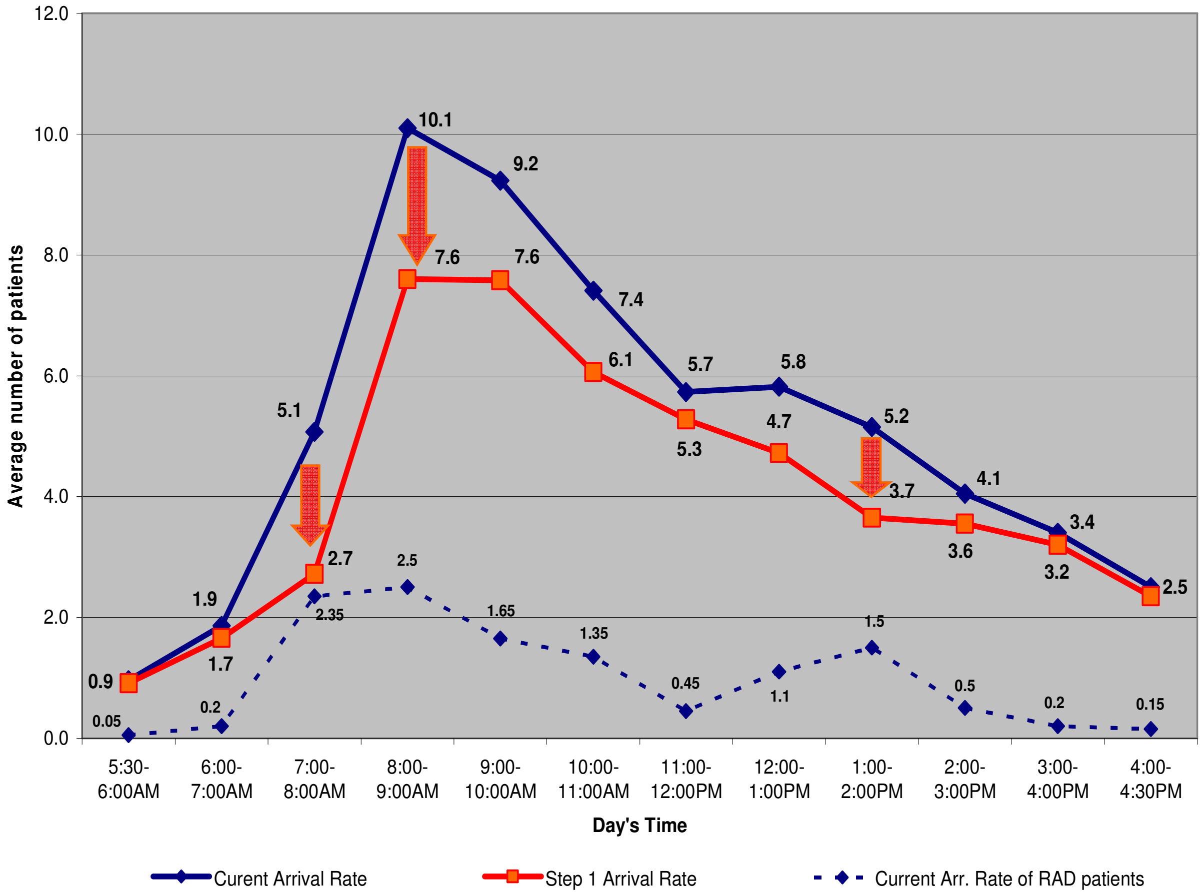

Figure 5. Current Arrival Rate and New Arrival Rate after Implementation of Scheduling System in the Radiology Department

NEW MODEL, Step 2:	**5:30-6:00AM**	**6:00-7:00AM**	**7:00-8:00AM**	**8:00-9:00AM**	**9:00-10:00AM**	**10:00-11:00AM**	**11:00-12:00PM**	**12:00-1:00PM**	**1:00-2:00PM**	**2:00-3:00PM**	**3:00-4:00PM**	**4:00-4:30PM**
Inputs:												
Step 2 Number of Servers	1	1	2	3	3	3	3	3	2	2	2	2
Arrival Rate	0.9	1.7	2.7	7.6	7.6	6.1	5.3	4.7	3.7	3.6	3.2	2.4
Mean Service Time	18	18	18	18	18	18	18	18	18	18	18	18
Outputs:												
Traffic Density	-	-	41%	76%	76%	61%	53%	47%	56%	54%	32%	36%
Utilization Factor for server	27%	51%	-	-	-	-	-	-	-	-	-	-
% Idle Time for Server	63%	49%	-	-	-	-	-	-	-	-	-	-
Average Time in System	24.7	36.7	21.0	29.4	29.4	22.5	21.0	20.0	24.3	23.9	18.6	20.3
Average Time in the Queue	6.7	18.7	3.0	11.4	11.4	4.5	2.9	2.0	6.3	5.9	0.6	2.3
Average Number in the System	0.4	1.0	0.9	3.7	3.7	2.3	1.8	1.6	1.5	1.4	0.9	0.8
Average Number in the Queue	0.1	0.5	0.1	1.4	1.4	0.5	0.2	1.6	0.4	0.4	0.0	0.1
Probability of a wait	.07	.26	.20	.45	.45	.30	.20	.17	.30	.30	.07	.16

Table 5. Queuing analysis of the New Model, Step 2 (With Proposed Arrival Rate and Staffing)

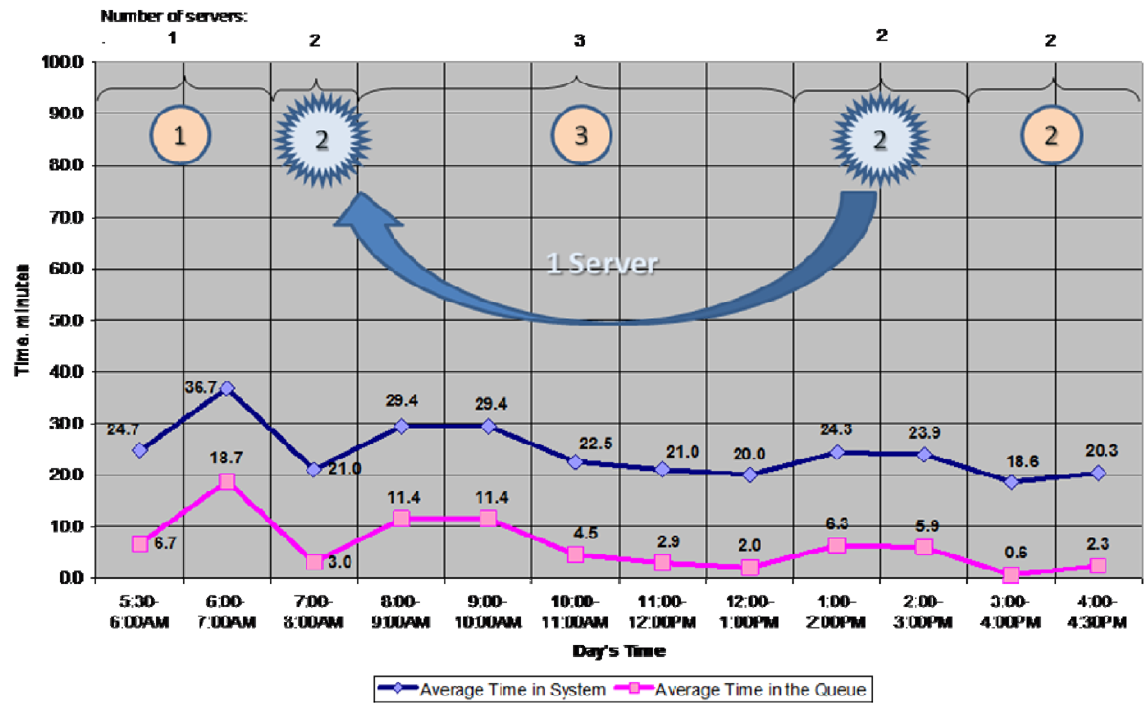

Figure 6. Average Time in System and in the Queue with Proposed Arrival Rate and Staffing

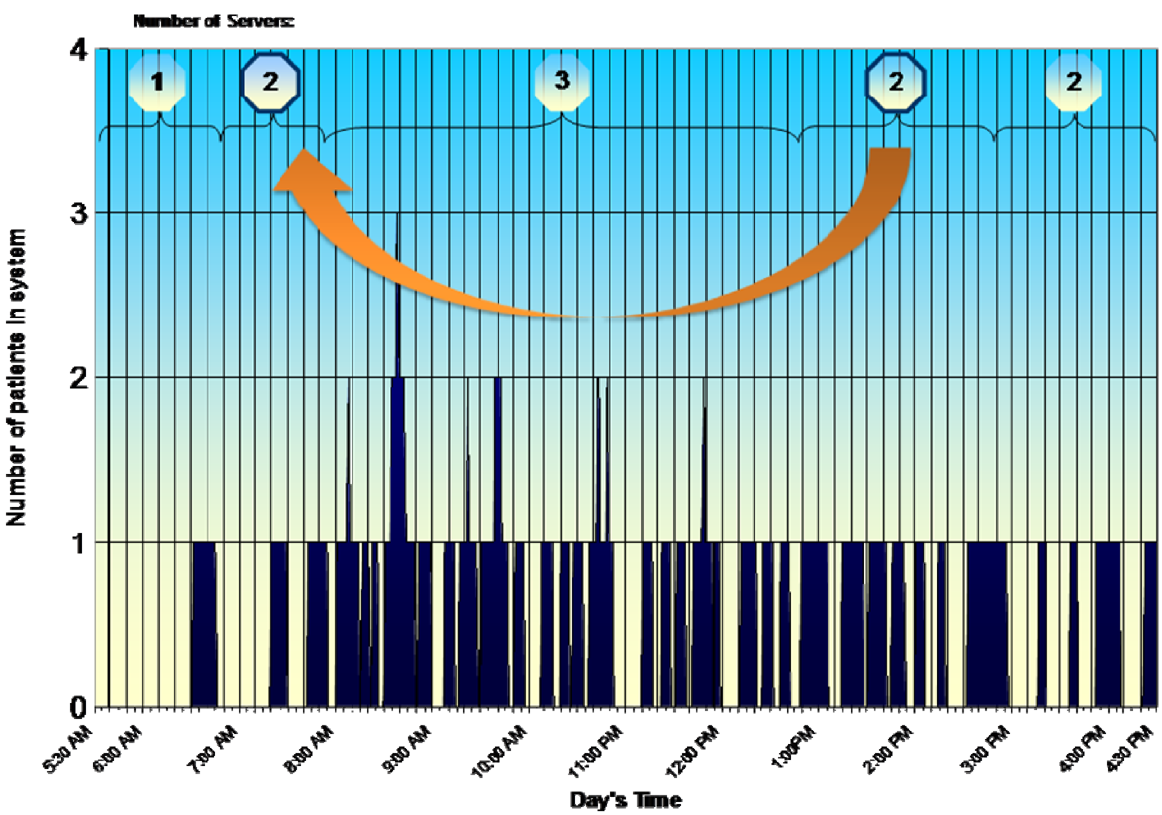

Figure 7. Queuing Simulation of the PF in the AD over the Day with Proposed Arrival Rate and Staffing

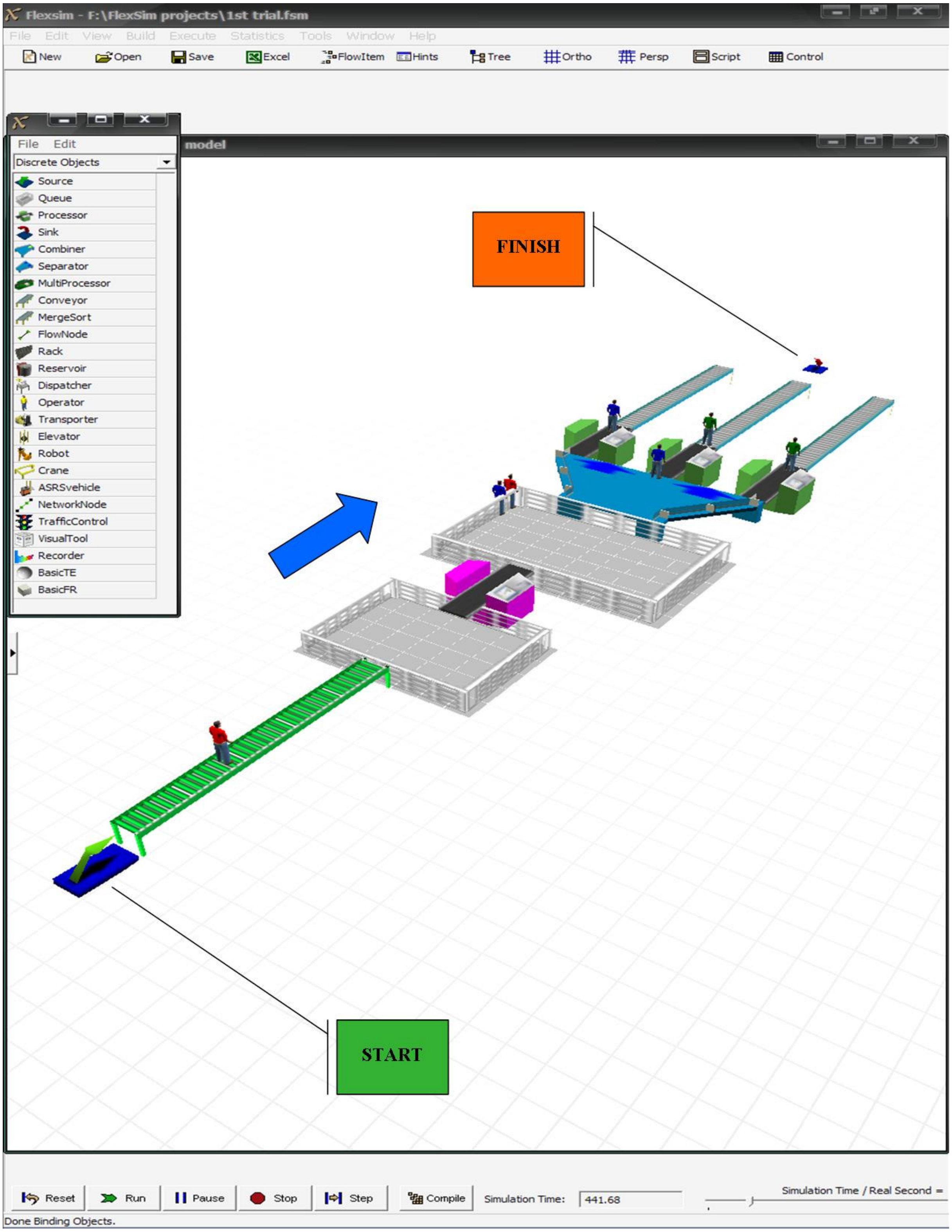

Figure 8. General view of the AD Simulation Model

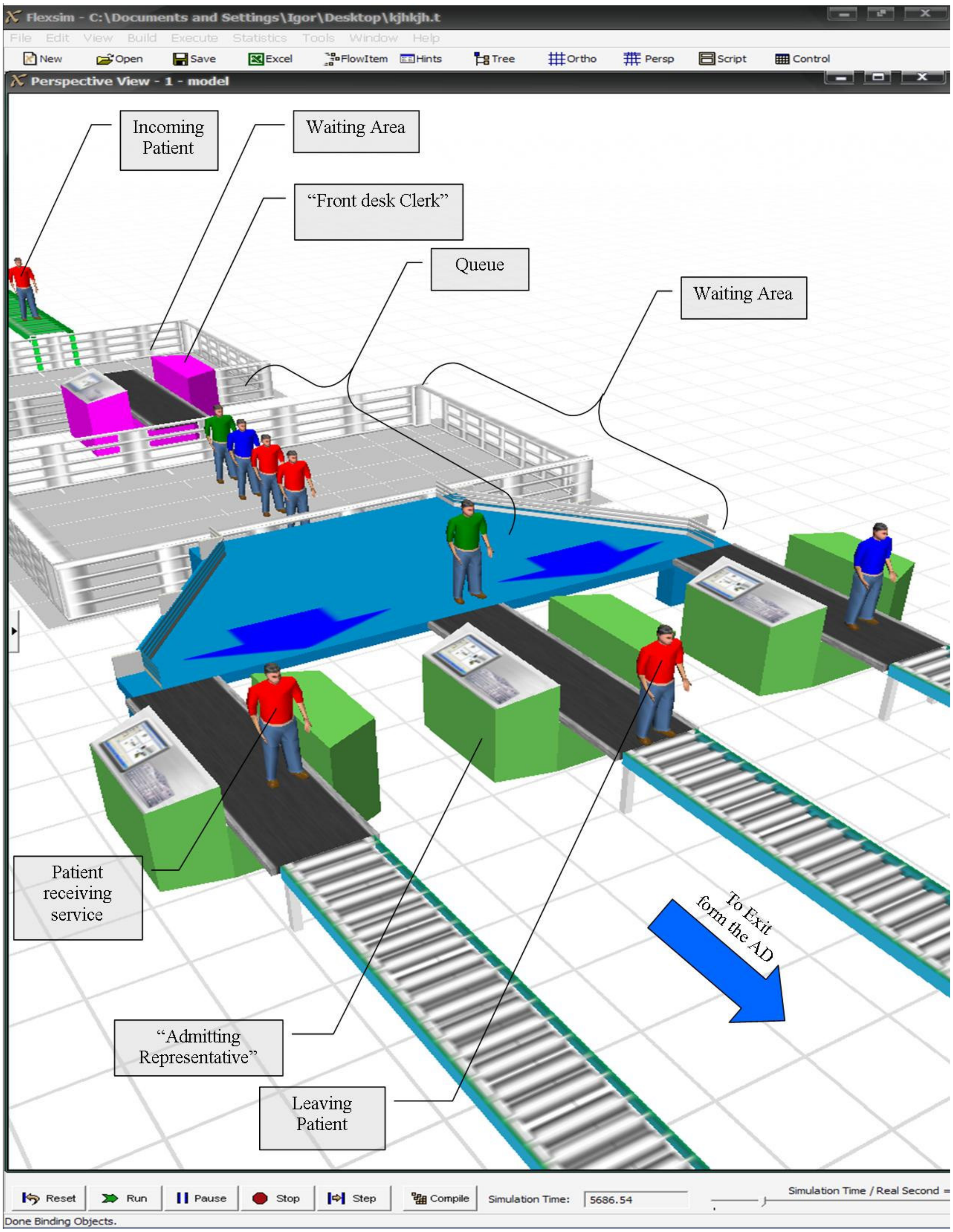

Figure 9. Detailed view of the AD Simulation Model