Proceedings of the 1999 Winter Simulation Conference
P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, eds.

THE USE OF SIMULATION FOR PROCESS IMPROVEMENT IN A CANCER TREATMENT CENTER

José A. Sepúlveda
William J. Thompson
Felipe F. Baesler
María I. Alvarez

Industrial Engineering and Management Systems
University of Central Florida
P.O. Box 162450
Orlando, FL 32816-2450, U.S.A.

Lonnie E. Cahoon, III

M.D. Anderson Cancer Center Orlando
85 W. Miller Street
Orlando, FL 32806, U.S.A.

ABSTRACT

This work addresses experience with a simulation model of a full service cancer treatment center. The objective was to analyze patient flow throughout the unit, evaluate the impact of alternative floor layouts, using different scheduling options and to analyze resources and patient flow requirements of a new building. The simulation model provided strong justification to relocate the center's laboratory and pharmacy as well as identifying changes in scheduling procedures that would allow a 30% increase in patient throughput with the same resources. The new building analysis identified a waiting room area that was too small for the increased patient flow.

1 INTRODUCTION

The M. D. Anderson Cancer Center Orlando (MDACCO) is a full-service cancer treatment facility wholly owned by Orlando Regional Health Systems. Currently, there are three buildings involved, one of which is the main hospital which provides in-patient beds for MDACCO patients as well as for any other patients referred by other oncology specialists. The primary focus of this study is the main MDACCO building with four floors that house the facility's medical staff, laboratory, pharmacy and the Ambulatory Treatment Center (ATC). The ATC is where chemotherapy is administered. A third building houses a radiation treatment center and it is located within 300 yards of the main MDACCO building. Services provided in the latter building were not studied but were of interest in planning joint waiting room areas in a new facility.

The study at MDACCO was twofold. The first objective was to model, analyze and improve patient flow processes and increase capacity in the main facility for both the medical oncology practice and the ATC. This involved the formation of a process improvement team of key medical staff supported by UCF and led to the creation of a simulation model for both practices using ARENA. This model allowed the comparison of layout alternatives as well as providing a tool for evaluating the impact of alternate scheduling procedures.

A second and perhaps the primary objective was to translate this model to a new building which was being designed. MDACCO had obtained the funding to build a new wing onto the main hospital that would integrate all of the in-patient and outpatient cancer treatment into one cohesive facility. This new facility was designed to increase capacity by more than 100%. The models developed were scaled to reflect the increased room capacity, staffing and evaluate potential bottlenecks created by the increased volume and combined flow.

2 SYSTEM DESCRIPTION

Cancer treatment occurs in three different facilities in this system. The facilities are located near each other. Figure 1 shows how patients flow through the processes that takes place at each facility and how they are related to each other. The whole system was studied to understand the patients' flow but just one of the facilities, the cancer treatment center, was modeled.

There are two processes that take place there. The first process is referred to as medical oncology. During this process patients go to the facility to consult a medical doctor. This process takes place on the fourth floor of the building. The second process is the ATC process. Patients go through the ATC process to get treatment that lasts less than eight hours. During this process the patients receive chemotherapy sitting in chairs that are located at the first floor of the building.

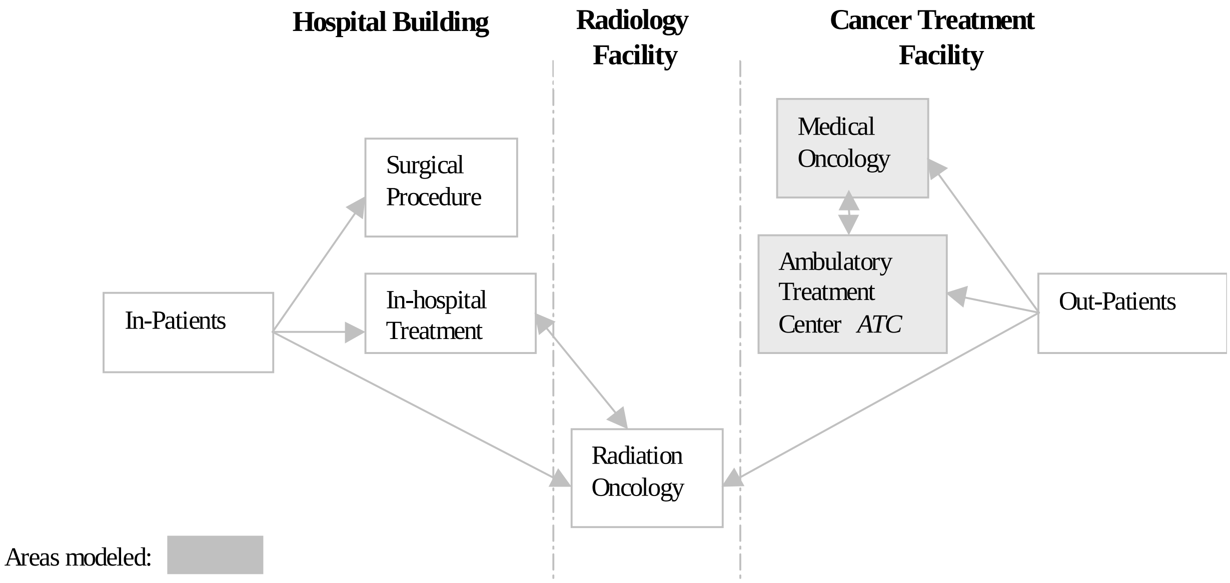

Figure 1: Functional Flow Model

The patients were classified into four types based on the sequence of activities that they go through once they are at the medical facility. These patients are identified as medical oncology, ambulatory treatment center, injection and pre- processed patients.

2.1 Medical Oncology Patients

The flow for medical oncology patients is shown in Figure 2. All patients are scheduled and they arrive to the fourth floor by appointment time. If the patient has a port (device inserted under the skin of the patient by surgical procedure to facilitate the blood drawing process), the port nurse will take him/her to the port room to draw the blood. Otherwise either the lab technician or the nurse will take the patient to the blood draw room. Then the patient will go back to the waiting room until an exam room is available. A doctor's visit could be from fifteen minutes to one hour in length. The patient evaluation can't be completed until the doctor gets the blood results. After the doctor sees the patient, he/she could be sent to the ATC for immediate treatment or could be sent home. All patients go through "check out" to pay for the visit and make future appointments. The process cycle time is between one to two hours and takes between 20 to 70 minutes before the doctor sees the patient. The goal of this project was to reduce this last time to 30 minutes.

2.2 Ambulatory Treatment Center – ATC

Most patients are scheduled and they arrive at ATC by appointment time. The patient will follow the process shown in Figure 3. Treatment is given in chairs that are located in a room on the first floor of the facility. The total cycle time of this process varies significantly because the wide variety of treatment lengths. The total time a patient is in system is between 200 to 300 minutes and the time until treatment is between 40 to 90 minutes.

2.3 Injection Patients

This type of patient goes to ATC just for an injection and stays for about fifteen minutes. They do not use the treatment chairs.

These patients are all scheduled and they arrive by appointment time. The patient goes to the treatment center for either an injection or fifteen-minute treatments. They go directly from the waiting room to the injection chair where the lab technician will take care of them. If the lab technician is busy the patient will go to one of the treatment chairs to be treated by a nurse. The patient leaves ATC after treatment.

2.4 Pre-Processed Patients

Some of the patients that go to ATC have already been seen the day before and they have the blood drawn and analyzed prior to the visit. Because drugs and blood results are available upon arrival, the patient goes directly to treatment chairs after check-in. This streamlined process is

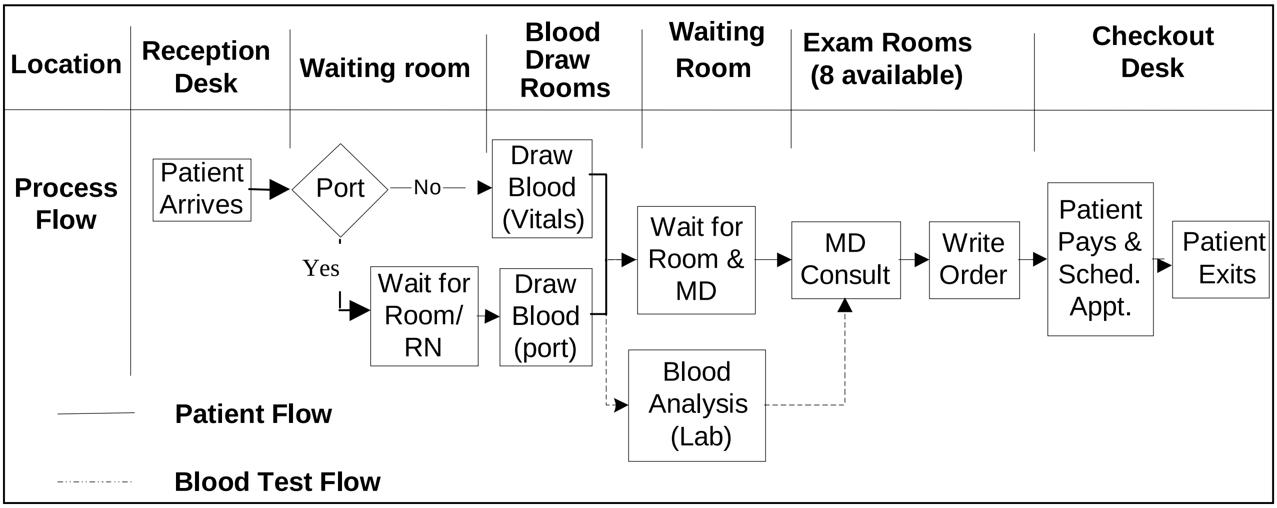

Figure 2: Process Flow in Medical Oncology

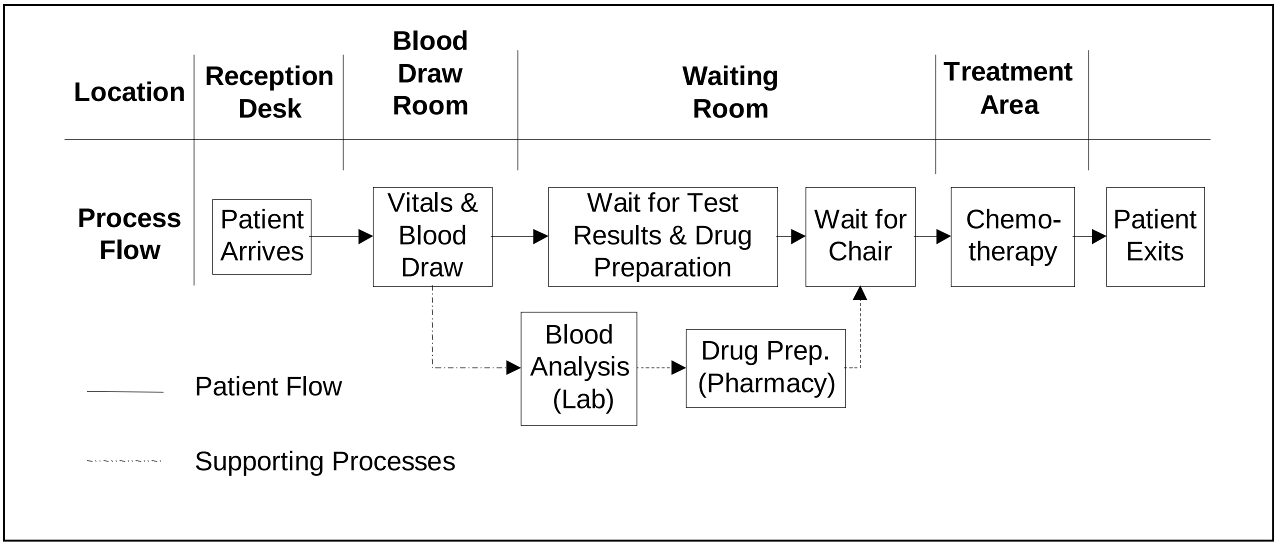

Figure 3: Process Flow in ATC

constrained only by chair availability or unusual circumstances encountered in drug preparation.

3 SIMULATION PROCESS

Simulation is an excellent and flexible tool to model different types of environments. It is possible to find in the literature several simulation experiences in healthcare. For example, Garcia et al. (1995) presents a simulation model focused on reduction of waiting time in the emergency room of Mercy Hospital in Miami. Pitt (1997) presents a simulation system to support strategic resource planning in healthcare. Lowery (1996a) presents an introduction to simulation in healthcare showing some very important considerations and barriers in a simulation project. Baesler et al. (1998) introduces important issues that have to be considered when interacting with healthcare practitioners during a simulation project.

A simulation model for the cancer treatment center was created using the simulation package ARENA, version 3.0. This model represents patient flow within the center, as well as human and physical resources such as physicians, nurses, lab technicians, receptionists, exam rooms, treatment chairs, pharmacy and laboratory. In order to represent the facility layout, a drawing using Visio Technical 5.0 was created and imported to Arena. The drawing was made to scale and considered all features of the facility pertinent to the study.

3.1 Input Analysis

The simulated patient's arrivals were generated from historical data gathered from the hospital personnel in charge of patient scheduling. In this way the simulation model was able to emulate the scheduling patterns used by the hospital personnel, as well as typical variations (lateness, earliness) observed in real life patients. A small number of the medical oncology patients, after doctor examination, required ATC treatment. These patients were considered ATC walk-ins. The model generates two different arrival schedules for Medical Oncology and ATC patients. Input analysis also was performed to determine the duration of the following activities:

- Medical Oncology receptionist time
- Medical Oncology examination time
- Blood analysis time (laboratory)
- Co-pay time
- ATC receptionist time
- ATC treatment time
- Time to draw blood
- Drug preparation time (pharmacy)
- Injection time

Because no historical data was available, the procedure used to determine the duration of these activities was through expert opinion. Hospital personnel in charge of each of these activities were interviewed. The results of these interviews were used to determine the best theoretical distribution to represent each of the processes under study. Uniforms distributions were used in many situations as well as triangular distributions containing as parameters the expert opinions about minimum, maximum and most likely duration of the activity. The most variant activity was the ATC treatment time. This activity represents a very wide range of treatment time that fluctuates between 30 minutes to around 9 hours and varies considerably depending on each patient. Expert opinions, as well as some historical data, were used to build an empirical distribution of chemotherapy treatment time. The amount of data by itself was insufficient to fit a theoretical distribution but was very helpful in order to identify different treatment length ranges.

3.2 Resources

The simulation model was constructed considering the entire healthcare personnel and facilities involved. Types and levels of resources are shown in Tables 1 and 2.

Table 1: Medical Oncology Resources

Resource	***Quantity***
Doctors	3
Nurses	4
Port Nurse	1
Lab Technicians	3
Receptionists	2
Room for Vitals	1
Port-Room	1
Exam Rooms	8

Table 2: ATC Resources

Resource	***Quantity***
Receptionist	1
Nurses	4
LPN	1
Treatment Chairs	14
Port Room	1
Room for Vitals	1

In addition to the personnel listed above, two carriers were included in the model. These carriers are hospital employees in charge of transportation within the hospital. Their role was to transport blood samples from ATC (first floor) to the laboratory (fourth floor) and to transport treatment drugs from the pharmacy (fourth floor) to ATC (first floor).

3.3 Simulation Conditions

The cancer treatment center opens at 8:00 a.m. and closes around 7:00 p.m. when all patients have left. This type of systems requires a simulation approach that replicates as many times as necessary in order to obtain reliable estimates of each system's measures of performance.

A relative precision level of ±10% was used for this study. This level was chosen based on experience and supported in the literature where less than ±15% confidence intervals are recommended (Law and Kelton 1991). The measures of performance used in the analysis are:

- Time until treatment (four types of patients)
- Time in system (four types of patients)
- Number of busy exam rooms at 4:00 p.m.
- Number of busy treatment chairs at 4:00 p.m.

Each simulation run ("replication") focused on the facility's operation for a complete operating day. This means that the simulation starts empty and idle at 8:00 a.m. and runs until the number of patients that have left the center equals the number of patients that arrived that day, e.g., until the last patient has left. The statistical analysis showed that 20 replications were sufficient to obtain reliable estimates of each system's measures of performance.

4 VERIFICATION AND VALIDATION

Verification is determining that the simulation computer program performs as intended, i.e., debugging the computer program. Thus verification checks the translation of the simulation model (e.g., flowcharts and assumptions) into a correctly working program (Law and Kelton 1991). In order to verify our model, we followed the development of the simulation code using the "Trace" option of the ARENA simulation software. This command creates an output file showing every step performed by the simulation model.

Once the model was verified the next step was to validate it. "Validation is the process of raising to an acceptable level of user's confidence that any simulation-derived inference about the system is correct" (Pedgen, Shannon and Sadowski 1995). Sargent (1984) explains some of the techniques used to validate a simulation model. Lowery and Martin (1992) applies validation techniques to a heath care simulation model. Many of these validation approaches make use of statistical analysis. We were not able to apply these techniques due to the lack of sufficient historical data available. For this reason we used other techniques that involve simulated animation and the customer (hospital personnel) directly in the validation process. Kelton Sadowski and Sadowski (1998) explain how animation represents an excellent tool to validate the model when you are working with customers and how sensitive you should be about their feedback, especially related to animation. We applied this strategy by showing the simulation animation and results to the process improvement team and asked them their opinion about different aspects of the system, such as queue length, number of busy exam rooms, number of busy treatment chairs etc. In most cases they agreed with the simulation results.

However, some discrepancies were identified and addressed based on the team's experience. One such case was a blood processing time discrepancy in the laboratory that occurred due to a misunderstanding of equipment operation. Even though the blood analysis machine was loaded with five samples, it processed them sequentially. The initial simulation model assumed that all five samples were processed simultaneously. Consequently the cycle time was one-fifth of the true value. Other minor anomalies were similarly addressed and the model adjusted to approximate reality. A subsequent run yielded a validated model.

5 SCENARIOS

Once the model has been validated the analysis of different system configurations, scenarios, can begin. This paper focuses on three major analyses performed.

1. Layout Scenario
2. Scheduling Alternatives Scenario
3. New Building Scenario

The first scenario is related to a major layout change proposed for the existing cancer treatment center. The second scenario focused on finding alternative patients' arrival schedules in order to obtained a better utilization of hospital resources. The last scenario transferred the results for the existing facility to simulate and analyze the impact of a future building where the cancer treatment center was to be integrated with radiation oncology and in-patient care.

5.1 Layout Scenario

The layout changes considered the transfer of the laboratory and pharmacy areas from the fourth floor, near medical oncology, to the first floor, near the Ambulatory Treatment Center. This layout change was expected to decrease the transportation time between the pharmacy (fourth floor) to ATC (first floor). With this new configuration the pharmacy can deliver drugs to ATC just passing them through a window that separates both stations.

In addition, it was expected that medical oncology patients would spend less time waiting to draw blood since two additional blood drawing rooms were added and additional staff was allocated for this purpose.

Processing the same patients under each operating condition compared the new scenario. Thus, any differences observed between both scenarios will be due to the impact of the scenario themselves, not to the treated patients. The results are summarized in Tables 3 and 4.

Table 3: Time until Treatment

Type of Patient	*Improvement*
ATC	No difference
Medical Oncology	57 %
Injection	70 %
Pre processed	No difference

Table 4: Total Time in System

Type of Patient	*Improvement*
ATC	No difference
Medical Oncology	32 %
Injection	23 %
Pre processed	No difference

These results represent the average system improvement for the new layout. The "No difference" label means that the hypothesis test performed to compare both scenarios reached the conclusion that, for that particular measure of performance, there is no statistically significant difference between both systems.

Medical oncology and injection patients show an important improvement. ATC patients do not present improvements even though drug transportation time was decreased considerably. The reason for this is that, under the new conditions (with laboratory and pharmacy nearby), the treatment chairs became the ATC's bottleneck. Even though drugs were ready sooner to be used by a patient, there still could be no chair available. Therefore, the simulation justified the need for adding more chairs in ATC. Space and staff constraints dictated that no more than 1-2 chairs could be added in the existing facility. The model's predictions were later validated in the best possible form: The pharmacy and laboratory were moved to the first floor and productivity (throughput) increased (as predicted) for Medical Oncology but did not change at the Ambulatory Treatment Center. Occupancy of the new integrated facility will allow at least a 100% increase in chair capacity.

5.2 Scenarios of Scheduling Alternatives

A second objective was to evaluate the system under different scheduling options. Because patients are scheduled, the analysis of alternative schedules offers a powerful tool to optimize the resources utilization and to increase the number of patients served per day. Some experiences where different scheduling systems were used for the patient admission process in healthcare can be found in Manansang and Heim (1996) and Lowery (1996b).

The simulation shows that there are many idle chairs in the morning. A different scheduling technique could be used in order to increase the number of short-term (4 hours or less) patients in the morning to decrease the number of idle chairs. Based on the simulation results, this alternative scheduling technique should lead to increased chair utilization and more patients treated per day.

One of the basic criteria for this alternative was to increase the number of patients during the morning without saturating the system or increasing patients' waiting time. Another important issue was that management did not want to extend operating hours, in other words, closing time was very important. Figures 4 and 5 show the ATC treatment chair utilization profiles. It was concluded that, over time, chairs are busier under the proposed scheduling system when compared with the current one.

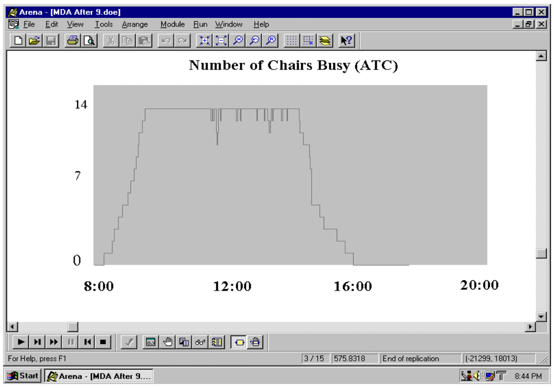

Figure 4: Actual Scheduling Technique

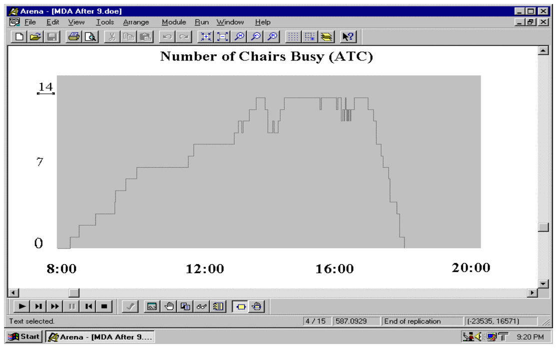

Figure 5: Proposed Scheduling Technique

The proposed scheduling policy should increase chair utilization significantly during the morning with decreasing utilization later in the afternoon. Table 5 shows a comparison of the two alternatives considering the number of busy chairs at 4:00 p.m. and the average closing time.

Table 5: Comparison of Scheduling Approaches

Scheduling	Busy Chairs at 4 PM (average)	Average Closing Time
As Is	11.7	5:52 PM
Alternative	8.4	5:35 PM

The alternative scheduling approach allowed average closing time to be reduced by 18 minutes and have fewer people to service at 4 p.m. However, we are also interested in how many additional patients can be scheduled and still allow the closing time to be no worse than with the existing system.

From the plots and Table 5, it was concluded that new patients could occupy the idle chairs. In other words the number of patients seen per day could be increased. Table 6 shows three new simulations where the number of patients scheduled per day were increased in 10, 20 and 30 percent.

Table 6: Effect of Increasing the Number of Patients Scheduled per Day

Scheduling	**Busy Chairs at 4 PM (average)**	**Average Closing Time**
+10% (3 Pts.)	9.8	5:50 PM
+20% (6 Pts.)	10.0	5:58 PM
+30% (9 Pts.)	10.7	6:13 PM

This table shows that up to 30% more patients could be seen using the proposed scheduling technique. The average number of busy chairs at 4:00 p.m. remains lower than the current system and the average closing time is 23 minutes later. This suggests that an increase of 10-20% in the number of patients scheduled would meet the same closing time as we have today. In all cases there would be fewer patients on average in the system at 4 p.m. It was recommended that staff be scheduled until 6 p.m. and schedule 20% more patients.

5.3 New Building Scenario

This scenario considered the simulation of a future building where the cancer treatment center was to be integrated with radiation oncology and in-patient care. This building was designed for a capacity of over 100% of that existing today. The model was designed to study many issues such as staffing, file movement, patient flow, bottlenecks and operating efficiency. The first step in the development of this model was to import from AutoCAD to ARENA the preliminary layout drawing. The drawing was scaled in order to animate the simulation. This simulation considers three building floors. The first floor were patients draw blood and where the lab is located, second floor where medical oncology is located and fourth floor where ATC and pharmacy will be located. The results of the simulation showed only one area of concern. One waiting room was too small to accommodate the combined flow. Therefore, it was recommended to set aside additional space for waiting areas. Waiting rooms were of particular interest since they were designed to accommodate a concentration of patients from one or more of the treatment areas. Also a factor of 2.5 had to be applied to allow for an average number of friends and family who accompany the patient.

6 SUMMARY AND CONCLUSIONS

This paper shows how decision making in a cancer treatment center or any healthcare facility can be facilitated using simulation. The first model presented in this study evaluated alternative layout configurations. The results obtained from this analysis showed that important improvements in patients' flow time could be achieved. This model was also used to analyze different patient scheduling approaches. This analysis showed that the number of patients seen per day could be increased up to a 20% without materially affecting the closing time of the facility. A second simulation model was developed to analyze a new building where the center was to be moved. This building was designed for a capacity of over 100% of that existing today. The results showed that one of the waiting rooms did not have sufficient capacity to support the flow of patients. In addition to these results all the simulated scenarios were used to identify bottlenecks and to analyze patient flow and operating efficiency.

7 FUTURE RESEARCH

The new building simulation offers important research opportunities. Including potential bottleneck areas such as parking spaces, elevators, etc. as part of this model would offer a more realistic view in terms of overall patient flow capacity. Future research on transition staffing and patient demand would also provide insights into the transition from the existing to the new facilities. Another research area is to determine the maximum patient flow capacities for the new building.

REFERENCES

Baesler, F., Sepúlveda, J.A., Thompson, W., and Kotnour, T. 1998, Working with Healthcare Practitioners to Improve Hospital Operations with Simulation, *In Proceedings of Arena Sphere '98*, pp. 122-130.

Garcia, M.L., Centeno M.A., Rivera, C., DeCario, N. 1995, Reducing Time in an Emergency Room Via a Fast-Track, *In Proceedings of the 1995 Winter Simulation Conference*, Alexopoulus, Kang, Lilegdon & Goldman (eds.), pp. 1048-1053.

Kelton, W.D., Sadowski, R.P., and Sadowski, D.A. 1998, *Simulation with Arena*, McGraw-Hill, New York, NY.

Law, A.M., and Kelton W.D. 1991, *Simulation Modeling and Analysis*, McGraw-Hill, New York, NY.

Lowery, J. C. 1996a, Introduction to Simulation in Health Care. *In Proceedings of the 1996 Winter Simulation Conference, ed.*, J. M. Charnes, D.J. Morrice, D. T. Brunner, and J. J. Swain (eds.), pp. 78-84.

Lowery, J. C. 1996b, Design of Hospital Admissions Scheduling Systems Using Simulation. *In Proceedings of the 1996 Winter Simulation Conference, ed.*, J. M. Charnes, D.J. Morrice, D. T. Brunner, and J. J. Swain (eds.), pp. 78-84.

Lowery, J. C., Martin J. B. 1992, Design and Validation of a Critical Care Simulation Model, *Journal of Society for Health System, 3(3)* pp. 15-36.

Manasang, H., Heim, J. A. 1996, An Online, Simulation-Based Patient Scheduling System. *In Proceedings of the 1996 Winter Simulation Conference, ed.*, J. M. Charnes, D.J. Morrice, D. T. Brunner, and J. J. Swain (eds.), pp. 1170-1175.

Pedgen, C.D., Shannon, R.E., and Sadowski, R.P. 1995, *Introduction to Simulation using SIMAN*, McGraw-Hill, New York, NY.

Pitt, M. 1997, A Generalized Simulation System to Support Strategic Resource Planning in Healthcare. *In Proceedings of the 1997 Winter Simulation Conference,ed.*, S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson, pp. 1155-1162.

Sargent, R. G. 1984, A Tutorial on Validation and Verification of Simulation Models, *in Proceedings of the 1984 Winter Simulation Conference*, pp. 537-555.

Note: This project is part of a Process Improvement/ Innovation Initiative partnership between Orlando Regional Health Systems and the Department of Industrial Engineering and Management Systems at the University of Central Florida (UCF). This process improvement initiative began in May 1997 and involves different areas of health care operations including the emergency department (ED), invasive cardiology procedures laboratory and the M.D. Anderson Cancer Center Orlando.

AUTHOR BIOGRAPHIES

JOSÉ A. SEPÚLVEDA is Associate Professor in the Department of Industrial Engineering and Management Systems Department at the University of Central Florida. He received his Ingeniero Civil Químico degree from the Universidad Santa María, Valparaíso, Chile, in 1970. From the University of Pittsburgh he received a M. S. degree in Industrial Engineering in 1972, a Master in Public Health degree in 1974, and a Ph.D. degree in Industrial Engineering in 1981. Dr. Sepúlveda is a registered Professional Engineer in Florida (1983) and Chile (1975). He is a member of the Institute of Industrial Engineers, the Society for Computer Simulation, the Institute of Management Sciences, the American Public Health Association, and the Hospital Information Management Systems Society.

WILLIAM J. THOMPSON is Assistant Chair in the Industrial Engineering and Management Systems Department at the University of Central Florida. In 1997/98 he was Principal Investigator for a Process Improvement/Innovation Research Project with Orlando Regional Health Systems. He has over 23 years of industrial experience in industrial engineering, process re-engineering and total quality systems. Dr. Thompson received his MSE and Ph. D. in Industrial Engineering from Arizona State University and his BSIE from the University of Texas at Arlington. He is an IIE Fellow and has served at all levels of the IIE chapter organization including Senior Vice-President of Chapter Operations.

FELIPE F. BAESLER is a doctoral student in the Department of Industrial Engineering and Management Systems, University of Central Florida, Orlando, Florida. He received his BS in Industrial Engineering from the Universidad del BioBio, Chile and a MS in IE from the University of Central Florida. During the last two years Mr. Baesler has worked as a research assistant at UCF. He also serves on the Industrial Engineering faculty of the Universidad del Bío-Bío, Chile.

MARIA I. ALVAREZ is a doctoral student in the Industrial Engineering and Management System Department at the University of Central Florida. She has a BS degree in Industrial Engineering from the Catholic University in Venezuela and a Master's degree in Industrial Engineering from UCF. She has been working as a research assistant at UCF for the last two years.

LONNIE E. CAHOON, III is Administrator for M. D. Anderson Cancer Center Orlando. He received his BS in Medical Technology from the University of West Florida in 1986 and his MBA from the University of Central Florida in 1996. He has fourteen years experience in the healthcare arena with his last six years focused in outpatient oncology services. He is an associate member of the American Society of Clinical Pathologists, a delegate to the Association of Community Cancer Centers, and a Board member for the Central Florida Chapter of the American Cancer Society.