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THE USE OF SIMULATION AND DESIGN OF EXPERIMENTS FOR ESTIMATING MAXIMUM CAPACITY IN AN EMERGENCY ROOM

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ABSTRACT

This work presents the results obtained after using a simulation model for estimating the maximum possible demand increment in an emergency room of a private hospital in Chile. To achieve this objective the first step was to create a simulation model of the system under study. This model was used to create a curve for predicting the behavior of the variable patient's time in system and estimate the maximum possible demand that the system can absorb. Finally, a design of experiments was conducted in order to define the minimum number of physical and human resources required to serve this demand.

1 INTRODUCTION

The *Hospital del Trabajador* in Concepción city in Chile is an institution that offers a wide variety of healthcare services. The hospital is mainly oriented to serve patients that are workers in local companies who have had work accidents or diseases developed from their professional activities. The companies have contracts with the hospital in order to get treatment for their workers. For this reason the most important part of the demand is controlled by the hospital based on the number of companies affiliated to them. In other words, if more companies were affiliated to the hospital it could be said that they were incrementing their demand. The hospital interest is to estimate the amount of extra demand that they are able to absorb considering two main issues, maintain the patients' waiting time standard and to consider some physical and human resources limitations.

2 BACKGROUND

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, in the area of emergency rooms simulation it is possible to highlight Garcia et al. (1995). They present a simulation model focused on reduction of waiting time in the emergency room of Mercy Hospital in Miami. A similar application is presented in Baesler et al. (1998) where important issues that have to be considered when interacting with healthcare practitioners during a simulation project are presented. Other cases not related to emergency rooms can be found in Pitt (1997). They present a simulation system to support strategic resource planning in healthcare. Lowery (1996) presents an introduction to simulation in healthcare showing very important considerations and barriers in a simulation project. Sepulveda et al. (1999) shows how simulation is used to understand and improve patient flow in an ambulatory cancer treatment center. This same study is complemented in Baesler & Sepulveda (2001) where a multi-objective optimization analysis is performed.

3 SYSTEM DESCRIPTION

The emergency department of the hospital is open 24 hours a day and receives an average of 1560 patients a year. Besides their internal capacity the emergency department shares resources with other hospital services such as, X rays, Scanner, MRI, clinical laboratory, blood bank, pharmacy, and surgery. The human resources work in shifts, but at every moment three physicians are available, one nurse, and two or three paramedics depending on the time of the day. The patients get their examination and general treatment in five rooms, three of them for general use, the other two for specific cases. The general patient´s process is presented in Figure 1.

When the patient arrives to the hospital, a receptionist collects their personal information. After this, the patient waits for availability of a treatment room and a paramedic. When this occurs the patient is walked to the room where

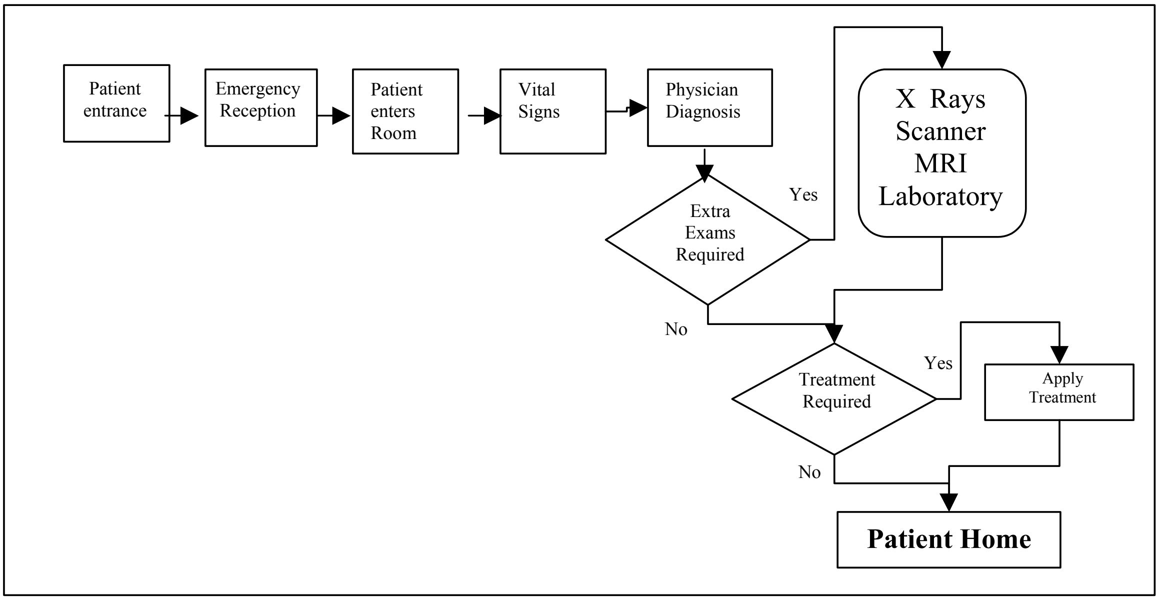

Figure 1: Patient Flow

the paramedic takes their vital signs. Then the physician is informed that a patient is waiting for treatment. If the physician is available goes to see the patient and performs the examination. After the physician evaluates the patient he could conclude that additional exams are required. In this case the patient is transported to the corresponding test area, such as X rays, scanner, MRI, etc. Finally the patient returns to the exam room and the physician concludes the treatment and the patient is sent home.

4 THE SIMULATION MODEL

The simulation model was constructed using the simulation package Arena 4.0. The information required as input for the model was collected from the hospital databases, such as inter arrival rates, type of diagnosis, type and duration of treatments. A replication/deletion approach was used in order to run the model for a length of 1 month and a warm-up period of 4 days. A total of 57 replication were necessary in order to obtain the statistical precision required. The results obtained after running the as-is scenario were validated using hospital data.

The objective of this project was to predict the maximum demand that the emergency room is able to afford without increasing the waiting time over an acceptable level. The response variable "time in system", that represents the total time a patient spends inside the emergency room, was used as a service level parameter. Currently, patients spend an average of approximately 70 minutes inside the system. The management is willing to increase the time up to 100 minutes in order to increment their demand.

At the same time they are willing to expand their resources within a range that offers feasibility to this project, this means, add one receptionist, two physicians, two paramedics and build one extra room. The question that arises is "which is the maximum demand that the emergency room can afford without going over 100 minutes of patient average time in system with this new configuration of resources. In order to answer this question it was necessary to understand the behavior of the variable time in system versus changes in demand. This was done running the simulation model with the new configuration of resources in 5 different levels of demand. Table 1 shows the percentage of demand increased and the number of patients associated to that level of demand.

Table 1: Changes in Demand

% Demand Increase	Patients per day	Patients per month
As-Is	52	1560
21	63	1890
44	75	2250
70	88	2640
100	106	3180
150	131	3930

The results obtained after running these five scenarios as well as a polynomial curve that fits the behavior of the time in system is presented in Figure 2.

Interpolating this curve it is possible to estimate that the level of demand that generates an average time in system of 100 minutes corresponds to a 130% increase of demand. The question now is to determine the minimum number of resources required to achieve this level of demand. The simulation scenarios were carried out using the maximum feasible hospital capacity, but it could be possible that one or more resources of this configuration were

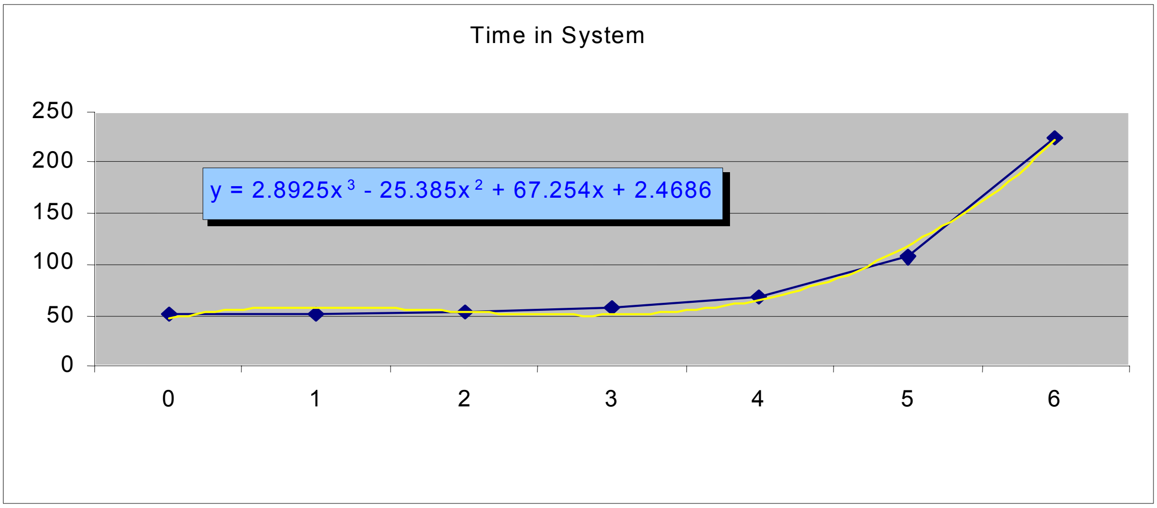

Figure 2 : Demand Curve

under utilized. In this case the same level of demand could be satisfied using less resources. To do this it is necessary to determine which resources could be decreased without altering the system's performance. In order to answer this question it was decided to perform an experimental design analysis.

5 DESIGN OF EXPERIMENTS

In order to determine the significance of the resources in the system's behavior, a design of experiments was performed. The experiments considered a fixed level of demand (130%) and four factors, physicians, paramedics, exam rooms and receptionists. Table 2 shows the settings of this experiment.

Table 2: Factor Levels

Level	Receptionist	Physician	Paramedic	Room
-	1	3	3	5
+	2	5	5	6

A fractional factorial design with resolution IV was conducted. This requires a total of $2^{4-1} = 8$ simulation scenarios. With this resolution it is possible to determine the significance of the main effects, but the two-way interactions are confounded. The results obtained after performing the experiments are presented in the pareto chart shown in Figure 3.

This chart shows that the main effects receptionist and paramedics as well as the confounded interactions AC+BD are significant. Since it is not possible to determine which one of the interactions AC or BD is the significant one, it is necessary to conduct additional experiments that permit to understand the significance of the interaction AC (Physicians- Rooms). The design selected was a full factorial

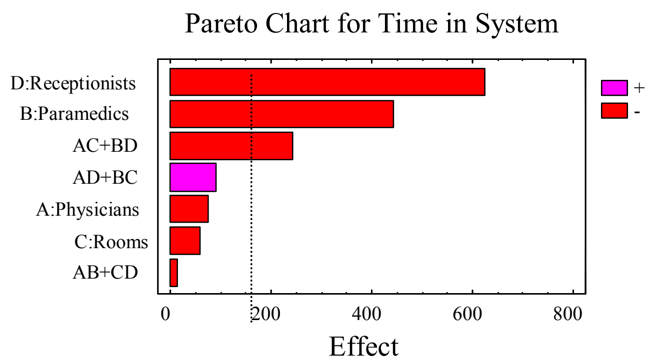

Figure 3: Pareto Chart

design considering two factors, Physicians and Rooms. Since the main factors receptionists and paramedics resulted to be significant from the previous experiment, it was decided to fix these factors in the high level, this means, two receptionists and five paramedics and a level of demand of 130% increase.

The experiments were performed and it was concluded that the two factors were significant, so they have to be set in a high level. Figure 4 presents a response surface plot of the two factors.

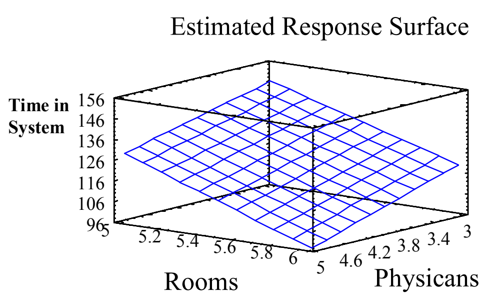

Figure 4: Response Surface Plot of Rooms vs Physicians

The response surface plot indicates that in order to decrease the time in system it is necessary to set the two factors in a high level, six rooms and five physicians. Even though it is clear that the two factors are significant, the plot shows that the maximum time in system allowed (100 minutes) is reached before the level of five physicians. A contour map can explained better this issue and it is presented in Figure 5.

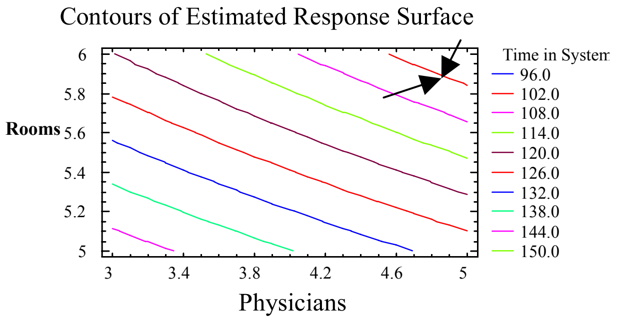

Figure 5: Contour Map

The contour line highlighted with the two arrows represents the level of resources required to reach a time in system of 102 minutes, very close to 100 minutes. It can be concluded that fixing the factor physicians in a level of 4.5, it is possible to maintain the time in system in 100 minutes. This interesting result could be interpreted as a requirement of four fulltime physicians plus one halftime physician.

6 CONCLUSIONS

This study showed how simulation could be used to estimate the maximum level of demand that an emergency room is able to absorb and which is the configuration of resources required to maintain a quality of service. The results showed that the resources required to reach this level of demand are close to the feasible maximum level. For example, the hospital layout permits to build just one extra exam room. Probably the most important conclusion of this study is that 4.5 physician are required (four fulltime and one halftime). Of course, this means important saving to the hospital.

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