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# SIMULATION OF A HOSPITAL PATIENT TRANSPORTATION SYSTEM

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## ABSTRACT

This paper describes a project to improve the patient transportation system (on gurneys and in wheelchairs) at a medium-sized Midwestern hospital. The hospital administration suspected that their use of nurses and technicians for transporting when Nursing Assistants (NA's) were busy was not cost-effective, and wanted to study the implications of several alternatives, including interdepartmental sharing of NA's. The system was modeled as a queueing network, broken into 3 subsystems, some of which were further subdivided by treatment type. Data were collected during a representative week, from which we derived distributions for arrival rates, urgency of cases, number of transporters needed, number of treatments needed, transportation time, and treatment time. We ran the simulation using SIMAN on an AT&T 6300, keeping track of patient time in the system and utilization of NA's, nurses, and technicians for each of the 4 major alternatives. We then presented these basic results to the hospital, along with our own judgments about the trade-offs between quality of patient service and cost for each alternative. The staff found both the basic data and the results of the simulation very useful, have acted upon some of our recommendations, and are utilizing our findings in their decision-making.

## 1. INTRODUCTION

The simulation literature contains many studies involving hospital design, staffing, and operations. For example, Fetter and Thompson (1965) laid some of the theoretical groundwork in his discussion of hospital systems, focusing on maternity wards and surgery departments and considering such factors as admission rate, stay length, waiting times, and scheduled versus walk-in patients, primarily as a planning tool. Schmitz and Kwak (1972) did a hand-simulation to plan the number of beds in a recovery room and the number of surgery stations, then reproduced and enhanced their results using GPSS [Kuzdrall, Kwak, and Schmitz (1974); Kwak, Kuzdrall and Scmitz (1976)], proclaiming the great advantages of computer simulations compared to those done by hand. Rising, Baron, and Averill (1973) did a simulation study to see how scheduling of hospital patients at an outpatient clinic could smooth the patient flow, showing how staff utilization and patient waiting time can both be improved by scheduling appointments countercyclically to walk-in patterns. Mahacek and Knabe (1984) did a time-constrained simple simulation on the effects of combining two OB/GYN clinics, which was an important factor in the decision-making process. And Tunnicliffe Wilson (1981) did a critical analysis of the implementation of simulation projects in hospital decision-making which emphasized such factors as the importance of involving hospital personnel at all stages of the project, putting adequate time and care into verification and validation (again with the hospital staff), and making models that are flexible enough to adapt to changes and give the administration sufficient latitude for judgment and incorporation of factors not in the models.

Despite all of these and many other hospital-oriented simulation studies, there has been virtually no work on the transportation of patients on gurneys and in wheelchairs by hospital staff, an extremely complicated system since it involves interactions between different departments of a hospital. This problem surfaced in discussions between the Assistant Administrator of Elyria Memorial Hospital (EMH) in Elyria, Ohio and the members of the Practicum in Operations Research at Oberlin College. The problem at EMH was that they suspected that their nurses and radiology technicians were spending too much time transporting patients. The staff assigned to do the transporting, called Nursing Assistants (NA's), were often tied up or too far away, forcing the more skilled (and higher paid) staff to do the job. This did not seem cost-effective, as skilled labor was being used for tasks not appropriate to their abilities, so it was believed that the hospital was spending more and providing less service for its patients than it needed to.

In this paper we discuss a model developed to help analyze and solve this problem. We first present some background information about the specific problem at EMH, then discuss the development of the model, including data collection, verification, and validation. We next present the results of the model, and finish with some concluding comments and observations.

## 2. BACKGROUND INFORMATION

We began the project by making several visits to the hospital, talking to the department heads and other staff, visiting the various departments and treatment subunits to get a feel for the physical layout, and following the NA's, technicians, and nurses around to see how the transportation system as it existed then was run. In the rest of this section, we summarize some of the most relevant information pertaining to our project.

Elyria Memorial Hospital is a medium-sized hospital in Elyria, Ohio, about 30 miles southwest of Cleveland. The departments at EMH which involve significant transportation of patients are Radiology (R), Surgery (S), Physical Therapy/Occupational Therapy (PT/OT), and the Outpatient Department (OD). The departments are then broken down into treatment subunits, and the subunits relevant to our study include the following:

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| R: | Main Diagnostic (MD)<br>Special Procedures (SP)<br>Nuclear Medicine (NM)<br>Ulatrasound (US)<br>Computed Tomography (CT)<br>Heart Catheterization Lab (HCL) |
| S: | Surgery (S) |
| PT/OT: | Physical Therapy (PT)<br>Occupational Therapy (OT) |
| OD: | Emergency Room (ER)<br>Emergency X-Ray (EXR) |

Spatially, PT/OT and the OD subunits are not far from each other, and are on the same level, but a significant distance from the upper floor of Radiology, containing MD and SPR. Also on the same level, but rather distant from the others, is Surgery, and HCL is actually in a different building but at the same level. One level below all of these is the lower floor of Radiology (directly below the main floor), with NM, US, and CT. Outpatients register at OD, and inpatients are roomed on floors at levels higher than any of the above subunits.

In determining who gets transported when several patients need to be moved, top priority goes to emergency (Stat) cases (such as severe physical trauma), second priority to urgent cases (such as broken bones), and bottom priority to routine cases (such as scheduled diagnostic tests). Within each priority level, transportation is done on a first-come, first-served basis.

At the time of the project, Surgery and PT/OT each had two full-time NA's (weekdays only) for transporting, who also had other responsibilities, such as washing and shaving patients in preparation for surgery, cleaning whirlpool baths, and changing linen. Radiology had 3.6 full-time equivalent (FTE) NA's with staggered shifts every day of the week. They had two full-time NA's weekdays, with an extra NA weekday mornings and one person weekday evenings, then one NA all day on weekends, with an extra NA on Saturday mornings. All of these were stationed on either the upper floor or the lower floor of Radiology (not at HCL or EXR), giving preference (with only one NA on duty and for extra NA's) to the upper level.

Virtually all transporting in PT/OT and Surgery was done by their respective NA's. Transportation to and from the upper and lower floors of Radiology was done by their NA's whenever possible, but for emergencies, when extra transporters were needed, and when no NA was on duty or when they were too busy, Radiology Technicians (RT's) would help out. EXR was functionally closely tied to Radiology, and could sometimes get help from the Radiology NA's when they were not busy, but most transporting out of EXR was done by technicians. For the rest of the Outpatient Department and for HCL, virtually all transporting (except those cases mentioned above) was done by nurses.

The problem as described to us, then, was that the highly-skilled Radiology Technicians and nurses were spending a lot of their time on transporting, which seemed to be a waste of their training and a waste of money (since they are paid at a much higher rate than NA's). The problem seemed to be especially troublesome in the EXR area (and to a lesser extent in HCL), and mainly on weekdays. Our task was to consider alternative allocations and scheduling of NA's to improve the efficiency of the transportation system and put the hospital's money to better use, balancing cost-effectiveness, quality of patient care, and budget limitations.

## 3. THE MODEL

The system we were studying clearly had a queueing network structure, but its complexity and dynamic nature indicated that an analytical solution was not likely to be tractable, especially since steady-state results would be of no practical value. The problem did seem very well suited for simulation, however.

The project group had access to a version of SIMAN (a descendant of SLAM, for use on microcomputers) to execute the simulation. Unfortunately, our version was limited in the size of the model that could be executed, so we were not able to incorporate all details of the system fully. Perhaps this was a blessing in disguise, for it forced parsimony on the model, and so we had to focus on those aspects of the system that were truly important to the problem at hand.

We were able to streamline our simulation first by restricting our attention to the times that seemed to be causing the greatest problems, weekdays from 7:30am to 4:30pm. We based this decision on both discussions with the staff and the data that we collected later.

Initially, we considered the possiblity of pooling NA's for all of the departments. However, after several discussions with the Assistant Administrator and the department heads, we realized that such a major change was probably not realistic or desirable at EMH at that time. We did still consider some options involving sharing NA's under various circumstances, but decided to maintain the current structure of assigning each NA a home base in one of the departments.

### 3.1 Approach

We first realized that the PT/OT and Surgery departments were virtually self-contained independent systems. In fact, since we had rejected the idea of pooling, other than their potential for sharing NA's, they could be eliminated entirely from our analysis. Still, the possibility of sharing was an important option. We decided to build separate models for PT/OT and Surgery individually first, then calculate the overall inactivity rates of these NA's. If they seemed to have enough time available to help other departments, we could simulate their availability by a simple discrete random variable. For example, if an NA in Surgery was available 20% of the time, then one out of five (randomly generated) requests for assistance would be answered affirmatively. Thus, to model the sharing, we ran the PT/OT and Surgery subsystems first, then incorporated the inactivity information into the third subsystem.

Each of the three subsystems was modeled in the same basic manner. Each consisted of one or more treatment subunits. Patients enter the subsystem when they first need transportation to one of these subunits (usually from a hospital bed on one of the inpatient floors or after arriving from outside the hospital), and remain in it as long as they are being transported to or from (or are waiting or being treated within) one of the subunits. The simulation generates the arrivals of patients and follows each through until they leave the system or until the end of the time horizon, aggregating the subsystem statistical information along the way.

Once an individual patient arrives, the simulation generates attributes such as the number of treatments needed, the sequence of treatment subunits, the urgency (emergent, urgent, or routine), and the number of transporters needed. Before going to each subunit in the sequence, the relevant type of transporter is determined (based on the conventions described above and the particular policy being considered) and the patient joins a queue if necessary, then once the necessary transportation is available, a transportation time is generated, followed by a subunit stay time. At the end of the last subunit, then, the final transportation out of the system is generated similarly (queueing if necessary for the relevant transportation, then generating transportation time). For each queue, priority is by urgency first, then is determined on a first-come, first-served basis within each priority level.

For simplicity, we considered the transportation time to include the total time a transporter is occupied related to a particular patient (e.g., including the time to return to their home department to get their next assignment) before going on to transport another patient, since we were primarily concerned with tracking the transporters' time, not the patients' time. Because of our model size limitations, we chose to aggregate waiting time and treatment time into a single random variable, since modeling waiting time at a subunit would require including all ambulatory outpatients, with whom we were not concerned in this project. This inclusion would have vastly increased the complexity, size, and data requirements of our model, and the possible benefits were not deemed sufficient to justify it.

We should note that the above model has some characteristics of a serial queueing system, but is much more complicated than the ususal version since the number of stations and the sequence required varies for each patient. Arrivals into a queue for transporters can come either from outside or from a patient already in the system completing treatment in a subunit. There are then the added complications of urgency priorities, variable numbers of transporters (servers) needed, and the combining of servers from different queues.

### 3.2 Data

Although quite extensive records are kept for each patient at the hospital and in each department and subunit, it soon became clear that much of the data we needed for this study was not avaiable. We discussed this with the staff, and decided to gather data for a sample week, following all of the patients entering our system as long as they remain in it. We designed a form to collect all of the relevant information from such a patient tour through the system, to stay with the patient (with their charts and other documents) while in the system, and to be filled in by whomever transports them to and from the various subunits.

The most crucial information on these forms included the date, the urgency, the number of transporters needed, the sequence of subunits, the time each transportation was desired, initiated, and completed (as discussed above), and the staff category of each transporter for every transportation. A number of other pieces of ID, location, and time information were collected, to allow for other possible modeling strategies and to help validate the data.

To try to maximize the reliability of the data, we wrote out an instruction sheet for filling out the forms, and went over these in detail with the department heads, who then passed on the information to their staffs. In addition, at the beginning of the first day of the data collection, our project members stationed themselves in each major location to help out and answer questions, and checked back later that day in person and periodically over the week by phone. We were able to catch some problems early this way, saving potential headaches later. Overall, the data we got seemed quite reliable, although there were some gaps and inconsistencies. The major difficulties occurred in areas where many different people were doing the transporting (such as nurses in the Emergency Room), but even then the data was reliable enough to be used effectively.

### 3.3 Derivation of Distributions

**Arrival Rates.** For Surgery and PT/OT, patients tend to be scheduled on the half-hour. For these departments, a Poisson distribution of the number of arrivals each half hour fit the data well. In the third subsystem, Radiology and Outpatient, arrivals were not so patterned, and an exponential distribution of interarrival times provided a good fit. Using the data, we examined patient arrival rates at different times of the day, and determined that it made sense in all of these cases to determine separate distributions for the morning and the afternoon. In all cases, the goodness-of-fit was confirmed by a chi-squared test with a significance level of 5%.

**Number of Transporters.** We assumed this to be constant for a given patient, and simply used the straight empirical distribution from the data collected for each subsystem.

**Sequence of Subunits/Number of Procedures.** The data indicated that almost no patients in PT/OT or Surgery also have other subunits to go to, so in those subsystems we assumed only one subunit. And since PT and OT are in the same physical location, we treated them as a single subunit. In a similar spirit, we did not consider subunits in the Radiology/Outpatient subsystem which never occurred in our data. In some cases, if they occurred only very rarely, we grouped them with similar nearby subunits. After this initial weeding, the first subunit visited by each patient was then generated according to the empirical distribution. Then, depending upon whether that subunit was ER, EXR, or anything else, the occurrence of a second subunit or not was generated by one of three different simple discrete random variables, determined by the data. If a second subunit was called for, it was generated from an empirical distribution which was different from that of the first subunit. But all cases involving a second subunit then used the same simple proportion to determine whether or not there was a third subunit, and the empirical distribution for this third subunit was the same as for the second.

**Urgency.** For PT/OT and Surgery, straight empirical distributions were used to determine urgency. In the Radiology/Outpatient subsystem, the same triage into ER, EXR, and other as described above was used to generate urgency, since these clusters had significantly different empirical distributions.

**Transportation Time.** Transportation times for different subunits turned ou to be remarkably consistent, with one exception: HCL. This is not surprising, since this lab is located in a separate building. We thus used the individual empirical distribution for HCL, and the remaining empirical distribution for the other subunits, to fit gamma distributions individually for the two cases.

**Subunit Treatment Time.** The treatment times at the various subunits varied quite widely in their means and variances, but all could be modeled well with gamma distributions with fitted parameters, so a different gamma distribution was used for each.

### 3.4 The Decision Alternatives

In our discussions with the administration and staff, we arrived at four major policy options to consider, which were not necessarily mutually exclusive. The four are described below.

**The Status Quo.** In this scenario, the baseline for comparison of the other options, NA's are allocated and scheduled as described in section 2. This includes the possibility of EXR asking for help from one of the Radiology NA's, and getting it if any are free, but no other forms of sharing NA's are utilized.

**Alternative 1 - Move a Radiology NA to EXR.** In this scenario, the extra NA weekday mornings on the upper level of Radiology would be moved to EXR, and helps out both EXR and ER with transporting. When this NA is busy, nurses and technicians do the transporting as before.

**Alternative 2 - Limited Sharing of NA'S.** In this scenario, ER/EXR can ask for help from PT/OT and HCL can ask help from Surgery, as described in section 3.1. Otherwise, this is the same as the status quo.

**Alternative 3 - Add an NA to ER/EXR Weekday Mornings.** This is similar to alternative 1, but would keep the extra NA in Radiology.

Notice that only alternative 3 would cost more than the status quo, and that the idea of alternative 2 could conceivably be combined with any of the other approaches.

## 4. RESULTS

The various subsystems and alternatives were run using SIMAN on an AT&T 6300. 1500-5000 runs of a simulated 9-hour weekday (7:30am-4:30pm) were done for each, the exact number depending on the variability of the variables of interest, to achieve sufficiently accurate confidence intervals (normally with a radius of 1-2% or less of the mean, comparable to the reliability of the data).

After running the PT/OT and Surgery subsystems and validating the results with the department heads, the proportions of NA time availability were estimated (taking into consideration their other duties) to be 1/3 and 1/4, respectively. These results were then used to run alternative 2. Interestingly, the potential sharing of Surgery NA's resulted in almost no improvement for the time HCL nurses spend on transporting (less than 3%). However, the potential sharing of the PT/OT NA's by itself was able to reduce EXR technician and ER nurse transporting time by approximately 10%.

For alternatives 1 and 3, the extra NA in EXR had the same effect in both cases: approximately a two-thirds reduction in the time technicians and nurses spend on transporting (approximately .1 FTE of each). In alternative 3, the cost was that of a part-time NA, while in alternative 1 the cost was that of almost doubling the workload of the upper-level Radiology NA on weekday mornings.

Our recommendation to EMH was to add at least a part-time NA to help EXR and ER and perhaps HCL, preferably based in EXR, if this was financially feasible, since the benefit of added technician and nurse time freed up would balance the extra cost. If this was not possible, we recommended moving the extra NA from the upper level of Radiology weekday mornings to EXR, at least on a trial basis, and encouraged them to pursue allowing the PT/OT NA's to help EXR and ER when they could.

From our discussions with the NA's, we also made two independent recommendations to improve the transportation system's efficiency. One related to the fact that often an NA would bring a wheelchair to a room, only to find that the patient required oxygen (for which a special wheelchair is needed), so they would have to make an extra (wasted) round trip to get one. We noted that this could be remedied quite easily in Radiology especially (where the problem was mentioned) because they posted yellow slips on a bulletin board to indicate pending transportation requests, and the oxygen requirement could be written on those slips quite easily. The other recommendation had to do with NA's going to pick up patients who were not yet ready, a problem which we suggested could be solved by having the NA's call ahead to the floor before leaving to pick up a patient.

When we presented a summary of the data, the simulation results, and our recommendations to the staff, they found the information enlightening and interesting. They were surprised at how much transporting goes on every day, and found the results of the simulation illuminating and believable. To date, the hospital has been able to hire an additional NA to help HCL and other nursing subunits, and they have an upper-level Radiology NA go to EXR when possible, so the additional NA is based in Surgery (whose NA's are busier than in PT/OT, as our data and results indicated). Meanwhile, the department heads are discussing more sharing of NA's (such as those in PT/OT) and communication between the floor and NA's. The oxygen information is being written on the yellow slips in Radiology whenever possible, but most of the wheelchairs are now also fitted for oxygen, so the information is less crucial. Despite these improvements, the staff still hope that yet another part-time NA for EXR and ER will be able to be added to the budget or reallocated, since significant pressure and waste of skilled staff time still exist there, and especially since the volume in EXR has been increasing recently.

## 5. CONCLUSIONS

In this paper, we have shown how simulation modeling can be applied to a new area of hospital management: improving the efficiency of the patient transportation system. We have discussed some of the associated problems concerning data collection, modeling, validation, and implementation in this environment, and given some possible solutions. Our major conclusion is that even a relatively small model can capture the essential characteristics of these complex systems, enough to provide a meaningful evaluation of policy alternatives. In addition, the process of collecting data, asking questions, and talking to employees can have intrinsic benefits which go beyond the results of the simulation.

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