Proceedings of the 1987 Winter Simulation Conference
A. Thesen, H. Grant, W. David Kelton (eds.)

IMPACT POINTS IN PATIENT FLOWS THROUGH A RADIOLOGY DEPARTMENT PROVIDED THROUGH SIMULATION

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ABSTRACT

Concern existed for the flow of the daily non-admission patients through the radiology department of a large midwestern acute care hospital. Their stay from time of entry to time of departure was deemed to be longer than was desirable. The flow of non-admission patients was complicated by the fact that the radiology department also provided services to all the in-house patients on a daily basis. A simulation model was built to trace the flow of patients through the system, to observe where waiting lines existed, and to determine the length of time individuals spent waiting for the scarce resources. Several different scenarios, represented by the number of available radiologists, were tried in an attempt to reduce the length of stay a non-admission patient remained in the hospital. The simulated runs indicated that the addition of one more radiologist to the existing five provided a reduction in the length of stay of non-admission patients.

1. INTRODUCTION

Timken Mercy Medical Center, a 500-bed acute care hospital in Canton, Ohio, had a growing concern for the flow of non-admission patients, which included Same Day Surgery Patients (SDS), Pre-Admission Testing Patients (PAT), Regular Outpatients, and Clinic Patients, through their Radiology Department. In an attempt to determine where difficulties might exist in the system, it was deemed that the construction of a simulation model to depict the flow of patients through the system would be beneficial. In addition to these four types of patients using the radiological facilities, consideration had to be given to four other types of patients: In-house Ambulatory Patients, In-house Portable Patients, Emergency Patients, and Emergency Portable Patients. These latter four types of patients in essence created interference with the basic flow of the former four types of patients. For the past several years, the hospital has maintained a scheduling procedure that was designed to maintain an orderly flow of all types of patients through the system. The difficulty that arises is in the arrival of four of the types of patients thus far indicated. These are the two types of Emergency Patients, the Regular Outpatients, and the Clinic Patients. These types of patients are not scheduled into the system except as they arrive and, therefore, create pressures on the system that cause backups to arise.

At the present time, the hospital employs five radiologists. Their basic tasks include the reading of processed x-rays and making a diagnosis, dictating this diagnosis on tape for later transcription, reviewing transcriptions and signing the permanent record, and being present for all or part of the time or for immediate reading of results in fluroscopy, radioisotopes, cat scan, and ultrasound. The total number of technicians available during the week is 17 with 2 additional technicians available in the AM when patient flows are the heaviest. The specific breakdown of technicians by radiological specialty is shown in Table 1. Although the prime responsibility of the two technicians assigned to the portable machines was to do all the emergency and in-house x-rays for the non-ambulatory patients, they also assisted the technicians responsible for the Head, Chest, etc. type x-rays. Since there were three rooms available for these types of x-rays, it was easy for them to step in and assist.

Table 1: Technician Assignment by Radiological Specialty

Radiological Specialty	# of Technicians
Special Exams	3
Urological	2
Fluroscopy	3
Head, Chest, Spine, etc.	2
Radioisotopes	2
Cat Scan	1
Ultrasound	2
Portable Machines	2
Total	17

2. GATHERING DATA FOR THE MODEL

The arrival rate of the eight types of patients as well as the total number of each type of patient that had to be serviced by the radiology department had to be created from the day sheets, a daily log of the type of patient together with the type of procedure the patient was to receive. A total of six months of daily log sheets was made available to the model builder to create the appropriate functions that would help to create the proper number of patients for each day, as well as the total number of patients of each type. Since the flow of patients and the type of procedure varied by the day of the week, it was necessary to look at specific days as these distributions were built. It was agreed that a random sample of specific days from each of the six months would be representative of the actual flows when these samples were averaged together for the specific days. It was not necessary to randomly select for each of the patient types as each day's daily log recorded information for all eight categories of patients. When all this information was gathered, distributions were built for the varying number of patients occurring per day, as well as the probable occurrence of the types of procedures to be performed.

The time necessary to perform a specific procedure was taken from information gathered by the hospital over a period of time and was provided directly to the model builder. Interviews with technicians provided additional information regarding timing of specific procedures. This information enabled the construction of some additional distributions with respect to the timing of the procedure. The technicians were particularly helpful in providing information with respect to the necessity of having a radiologist present for a particular procedure and the duration of the radiologist's presence. Lastly, information was gathered with regard to the time it takes to log a patient into the radiology department and send that individual on to have the procedure performed.

3. BUILDING THE SIMULATION MODEL

The model was constructed using General Purpose Simulation System (GPSS) language and was constructed sector by sector. Before any patient flows were completed, all the necessary distributions were constructed. Two such distributions are depicted in Figures I and II. For use in the simulation program, these distributions are reconstructed to be cumulative distributions. Figure I represents the determination of the number of patients for any

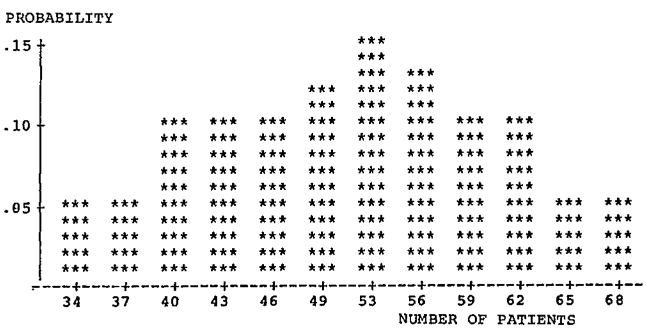

Figure 1: The Probability Distribution of the Daily Count of the In-House Patients for a Typical Monday

given day, and Figure II depicts the occurrence of the type of procedure to be assigned to a specified patient for that day. It should be noted that the type of procedure was coded. This coding system enabled the construction of yet another function that matched the procedure to the time necessary to perform that procedure. A total of 112 functions were created to enable the program to operate.

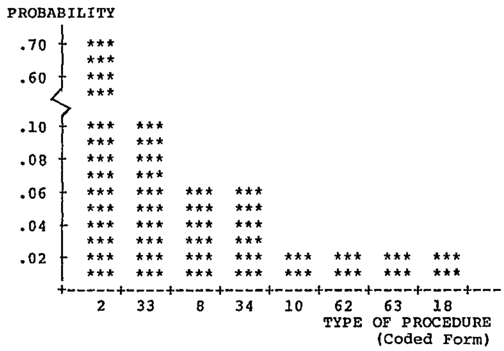

Figure 2: The Probability Distribution for the Type of Radiological Procedure by Patient Type

The first portion of the model was the creation of the eight types of patients. Since the hospital scheduled its In-house Ambulatory and Portable patients, as well as the SDS and PAT patients, the arrival patterns were created to emulate the scheduling concept. The creation of Emergency patients was strictly random throughout the day with various time intervals between arrivals. Regular Outpatients generally arrived throughout the day, although it was known that 60% of them came before noontime. Clinic Patients arrived anywhere between 9:00 a.m. and 3:00 p.m.

The main portion of the model was the creation of the specific procedural areas so that patients could be traced through the system and that information regarding the time the patient was in the system could be gathered. Queues were incorporated into the model wherever scarce resources were to be used. Observing the length of these queues and the length of time that patients spent waiting was deemed to be an integral part of the model.

Since the simulation model was to depict a time period beginning at 7:30 a.m., it was not necessary to pre-load the model as the basic activities depicted by the model would begin at that time. Thus, the initialization of the model required only that tapes, ready for transcription, be available for the transcribers when the model began.

4. VERIFICATION OF THE MODEL

The model was run for a period of four days, and two observations were made regarding the output. The first observation is related to the number of patients that went through the system, and the second is related to the length of time it took to perform each radiological procedure. Table 2 shows the number of patients, by type, that were generated by the model for the four day period. The model provides a variability in numbers for each type of patient that is indicative of what actually happens at the hospital. In Table 3, average times to execute a specific procedure are shown for the simulation, as well as the average actual time provided by the hospital

Table 2: Patients Generated by Type for a Four Day Period

Day	Type of Patient 1	2	3	4	5	6	7	8
1	36	36	16	3	10	7	61	6
2	54	30	21	2	9	7	57	4
3	33	26	21	3	7	7	54	6
4	56	17	23	4	9	7	57	2

1 In-House Ambulatory
2 In-House Portable
3 Emergency Ambulatory
4 Emergency Portable
5 Same Day Surgery
6 Pre-Admission Testing
7 Regular Outpatient
8 Clinic

Table 3: Comparison of Radiological Procedure Times

PROCEDURE	SIMULATED AVG TIME	HOSPITAL AVG TIME
Fluroscopy	81.0	85.3
Head, Chest etc.	16.6	19.1
Urology	82.2	77.8
Special Exams	43.8	35.0
Radioisotopes	95.6	67.5
Ultrasound	79.6	43.0
Cat Scan	43.1	62.5

from their records. Although the times are not identical, it can be concluded that, with respect to the first four procedures, they do not differ significantly when a test of medians is performed. For the remaining three categories, the significant increase in time for radioisotopes and ultrasound was attributed to the manner of reporting. In both instances, the patient oftentimes needed to have the procedure repeated. The hospital time is based on procedure time whereas the model time is based on patient time. The significant difference in times for cat scan has not been resolved at this time. However, considering the number of patients (45 representing 7% of the total) during the four day simulation, it was deemed that the difference does not greatly affect the reported results. This information was verified by the Assistant Director of Radiology and provided the level of approval that was necessary to indicate the model was accomplishing what it had been created to do.

5. RESULTS OF THE SIMULATED RUN

The basic observation to be made from the simulated results was concerned primarily with the radiologists. Because of the variety of tasks incumbent upon them, their utilization time was quite high and the number of patients having to wait for their services was also quite high. The information with respect to radiological workload and utilization is shown in Table 4. The waiting line information is

Table 4: Radiologist Workload and Utilization

DAY ONE Load	Util.	DAY TWO Load	Util.	DAY THREE Load	Util.	DAY FOUR Load	Util.
50	.804	44	.802	67	.720	82	.720
84	.776	79	.886	44	.823	71	.870
69	.804	74	.845	77	.816	61	.864
92	.772	79	.769	44	.771	57	.851
83	.855	110	.819	108	.720	84	.863

shown in Table 5. Since the model was run in minutes, some of the waiting times depict averages greater than a 2 hour wait for the radiologist to become available. The time for

Table 5: Waiting Line Information for Five Radiologists

MAXIMUM WAITING	AVERAGE WAITING	TOTAL ENTRIES	NO WAIT ENTRIES	AVERAGE TIME FOR THOSE WAITING
Data relative to the fluroscopy area.				
5	1.980	18	7	92.00
3	1.001	21	14	73.14
3	1.019	13	7	86.83
6	2.033	23	10	79.92
Data relative to the radioisotopes area.				
3	1.336	6	1	136.60
2	.771	6	2	98.50
3	1.090	19	2	79.57
3	1.219	10	4	103.83
Data relative to the cat scan area.				
3	1.221	9	2	89.14
4	1.342	13	8	61.69
2	.542	10	8	138.50
3	1.213	9	3	103.33
Data relative to the ultra-sound area.				
2	.882	14	9	90.20
2	1.232	9	4	126.00
2	1.025	8	5	174.67
2	.831	8	5	141.67
Data relative to the reading of processed x-rays.				
18	5.547	126	22	27.26
19	6.982	125	19	33.66
15	4.131	99	24	28.15
13	3.909	109	12	20.60
Data relative to the reading of transcribed x-ray reports.				
54	26.240	221	2	61.22
63	30.549	238	5	67.00
51	24.590	238	8	54.63
50	24.300	195	4	65.02

each specific area represents the average of the four day period. Table 6 represents the length of time it took each of the specific types of non-admission patients to move through

Table 6: The Processing Time in the Radiology Area for the Four Types of Non-Admission Patients: Five Radiologists

Same Day Surgery Patients NO. OF PATIENTS	AVG. TIME	TOTAL TIME	Pre-Admission Testing Patients NO. OF PATIENTS	AVG. TIME	TOTAL TIME
10	110.80	1108	6	119.33	716
9	77.78	700	7	125.86	881
7	36.00	252	7	106.00	742
9	78.78	709	7	74.57	471
SUM 35		2769	27		2810
AVERAGE	79.11			104.07	

Regular Out Patients NO. OF PATIENTS	AVG. TIME	TOTAL TIME	Clinic Patients NO. OF PATIENTS	AVG. TIME	TOTAL TIME
47	105.74	4970	4	143.00	572
47	96.23	4523	2	48.50	97
39	99.00	3861	3	51.00	153
43	104.56	4496	1	240.00	240
SUM 176		17850	10		1062
AVERAGE	101.42			106.20	

the system. In this table, the four simulated days are shown for each type in addition to an overall average. This was done so that the variability in the number of patients and the variability in times could be noted. All the information presented thus far could be represented as the basic model or scenario one. Because of the lengthy waiting lines and the waiting times themselves, it was deemed that the addition of another radiologist would help reduce the time it took for a patient to get through the system. Tables 7, 8, and 9 are comparable tables to Tables 4, 5, and 6 but with six radiologists. We first note that the

Table 7: Radiologist Workload and Utilization

DAY ONE		DAY TWO		DAY THREE		DAY FOUR	
Load	Util.	Load	Util.	Load	Util.	Load	Util.
64	.745	56	.780	85	.782	32	.847
67	.751	67	.857	70	.802	69	.645
114	.718	57	.802	85	.765	47	.667
64	.708	79	.747	88	.780	83	.661
61	.714	77	.745	46	.761	74	.690
72	.704	85	.743	80	.804	85	.792

utilization time of the radiologists has been reduced. This might cause some alarm, but it should be noted that for both the first scenario (5 radiologists) and the second scenario (6 radiologists), there was no built in lunch time or break time. Thus, the reduction in utilization was not as critical as may first be concluded. The results shown in Table 8 are indicative of what the addition of one more radiologist does to the waiting line information. The overall waiting time of patients or records that had to wait was

Table 8: Waiting Line Information for Six Radiologists

MAXIMUM WAITING	AVERAGE WAITING	TOTAL ENTRIES	NO WAIT ENTRIES	AVERAGE TIME FOR THOSE WAITING
Data relative to the fluroscopy area.				
3	.438	19	15	56.00
4	.849	19	13	72.33
3	.763	18	11	55.71
3	.412	17	15	105.50
Data relative to the radioisotopes area.				
3	.698	6	1	71.40
2	.381	7	4	65.00
3	.448	11	5	38.17
1	.070	10	9	36.00
Data relative to the cat scan area.				
1	.248	5	3	63.50
3	.998	9	5	127.50
2	.223	9	6	38.00
2	.522	9	6	89.00
Data relative to the ultra-sound area.				
2	.718	12	7	73.40
2	.223	11	9	57.00
1	.144	16	14	37.00
2	.808	9	4	86.60
Data relative to the reading of processed x-rays.				
7	1.906	142	44	9.94
14	5.602	128	26	28.07
7	1.841	128	38	10.46
7	1.244	101	35	9.64
Data relative to the reading of transcribed x-ray reports.				
35	15.632	248	8	33.28
69	24.608	248	9	52.62
61	19.162	265	10	38.40
48	18.309	235	6	40.86

diminished. In addition, the number of individuals who were able to be serviced without having to wait at all was increased for all categories. A review of the information shown in Table 9 and a comparison of it with Table 6 show that the length of time a non-admission patient took to pass through the radiological department was reduced for all four of the categories of non-admission patients with the reduction being significant at the .10 level using the Mann-Whitney U Test.

Table 9: The Processing Time in the Radiology Area for the Four Types of Non-Admission Patients: Six Radiologists

	Same Day Surgery Patients			Pre-Admission Testing Patients		
	NO. OF PATIENTS	AVG. TIME	TOTAL TIME	NO. OF PATIENTS	AVG. TIME	TOTAL TIME
	12	74.67	896	6	97.33	584
	5	65.00	325	2	53.50	107
	9	44.22	398	7	54.71	383
	9	55.22	470	2	85.00	170
SUM	35		2079	17		1244
AVERAGE		59.40			73.18	

	Regular Out Patients			Clinic Patients		
	NO. OF PATIENTS	AVG. TIME	TOTAL TIME	NO. OF PATIENTS	AVG. TIME	TOTAL TIME
	52	99.88	5194	5	68.40	342
	44	74.25	3267	1	21.00	21
	46	88.50	4071	3	60.00	180
	47	89.17	4191	1	79.00	79
SUM	189		16723	10		622
AVERAGE		88.48			62.20	

Considering the dramatic reduction when a sixth radiologist was added to the system, it seemed appropriate to investigate what would happen if a seventh radiologist were added to the model. The results of that run are not presented in this paper. Although there was again a decrease in the waiting lines and a reduction of the overall waiting times of the patients, the one critical component that was not diminished was the length of stay of the four non-admission types of patients when the system was viewed in total. Further investigation of the model through the third scenario (7 radiologists) indicated that patients now were subject to wait as a result of the need for technicians to perform the procedure or, because of the duration of the procedure, there would be a wait anyway. For instance, in fluroscopy the average number of patients undergoing this procedure is 20, and the average time to complete the procedure is 81 minutes, indicating a requirement of 1620 minutes for the day. If there are 3 technicians available, then each is working 540 minutes. We can see from the utilizations of the technicians in fluroscopy that there is not much idle time available.

6. CONCLUSIONS

In reviewing the results of the model, we see that the addition of one more radiologist to the existing staff would have a dramatic effect on the time non-admission patients were in the system. However, the addition of two radiologists to the system was not beneficial. Any further reductions in the time a patient remains in the system must be a result of an increase in the reduction of the time it takes to complete a procedure or through the duplication of the specific facilities so multiple procedures can be done at the same time. One basic limitation to the results presented in this paper is the number of days that were simulated. The evidence provided by four simulated days would seem to indicate that the addition of another radiologist is appropriate. Simulating a larger time period would enable a more conclusive statistical analysis.

There was one last consideration given to providing availability of radiologists during the peak periods of the day and that was to have the radiologist review transcriptions of dictated diagnoses at the end of the day rather than periodically during the day. In the model, this task was allotted 1 minute of time for each review and, considering that each doctor averaged 44 reviews during the day, that is a total of 220 minutes or almost 4 hours devoted to the reading of transcriptions. Admittedly it is a task that must be done because the transcription becomes a part of the patient's permanent record, but the review of transcripts takes time from the more immediate task of on the scene involvement of the radiologist.

The use of a GPSS simulation model proved to be very beneficial to the hospital in attempting to determine where changes could be made to help alleviate the length of time a non-admission patient remained in the system. The worth of such a model is centered around how well that model depicts the reality of the system. The building of this model was checked at each point along the way to ensure that what was being done did, in fact, parallel what occurred on a typical day. If the model does indeed represents what is actually happening, then the "what if" questions can be looked at one by one. Incorporating additional radiologists represent "what if" questions in the model. Further work continues with this model as other scenarios are being investigated.

AUTHOR'S BIOGRAPHY

KEITH A. KLAFEHN is a Professor of Management and Health Care Systems in the College of Business Administration at The University of Akron. He received a B.S. in Industrial Distribution and a M.S. in Industrial Management from Clarkson University in 1961 and 1968 respectively, and a DBA from Kent State University in 1973. He has been involved in various material flow simulation projects with the Firestone Tire and Rubber Company, Joseph Sedlak and Associates, and James Keough & Associates. In addition, simulation models have been built for Akron General Medical Center, Childrens' Hospital Medical Center of Akron, and Timken Mercy Medical Center to assist in the management decision making process. His current research interests include the building of simulation models for health care administration purposes, nursing acuity systems, and forecasting patient loads. He is a member of the Academy of Management, ORSA, TIMS, and DSI.

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