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A SIMULATION STUDY OF THE RADIOLOGY DEPARTMENT AT JMH

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ABSTRACT

This paper discusses a study of the Radiology department at Jackson Memorial Hospital. The animated simulation model was fed data from the operations database. Several inefficiencies were identified, and suggestions for improvement were explored. These adjustments included six scenarios: 1) Current system, 2) Modeling each procedure to take place with the assistance of only one technologist, 3) Modeling each procedure to take place with the assistance of two technologists, 4) Addition of a new Neurological operating room, 5) Addition of a designated preholding area for the patients' comfort, and 6) One-day extension in the weekly operating schedule. It was identified that under scenario 2 (one technologist) the total time in the system was significantly lower than the current system and scenario 3 (two technologists). However, this scenario also gave the lowest utilization rate for the eight technologists and the lowest utilization rate for the operating rooms. To increase efficiency, other recommendations were made.

1 INTRODUCTION

Jackson Memorial Hospital (JMH) is a licensed and accredited public, not for profit, teaching hospital that maintains a symbiotic relationship with the University of Miami School of Medicine. Since its inception, the hospital attained national and international recognition for the outstanding quality of its clinical programs, comprehensive public mission and unique structure of governance. In 1986, the hospital was identified as one of the top 25 medical centers in the nation. Ten years later, the hospital received the highest accreditation score of any hospital in the public sector in the United States. The hospital is licensed to operate 1,576 inpatient beds, making it Florida's single largest hospital facility. Due to the hospital's large size, it is necessary to maintain close control of all of operations and processes that take place in the facilities. It is the duty of the Department of Management Systems Engineering to maintain such control, and to provide methods that will increase efficiency within the hospital.

This project represents one of a set of initial efforts to implement the usage of simulation modeling as a modeling and analysis tool at JMH; in particular, the Radiology Department has been modeled and studied. The main goal of this project was to provide means to increase efficiency and improve the processes within the Radiology Department. Specifically, this study sought to determine the most adequate number of technologists to be used per operation, while maximizing the utilization of OR's and staff. A simulation model of the department was built to explore current conditions as well as five additional scenarios.

Section 2 provides a summary of the analysis done on the data coming out of the JMH operational database. Section 3 discusses the various costs involved with the Radiology Department. Section 4 describes the model itself and the experiments that were conducted. Section 5 discusses the results. Finally, Section 6 summarizes our conclusions and offers some additional recommendations.

2 STATISTICAL ANALYSIS OF INPUTS

JMH has an extensive database describing the various activities within the Radiology Department. Records from this database were extracted and analyzed to establish probabilistic models for the inputs of the simulation model. A first hurdle that had to be resolved was the quality of the data. It was found that some records were incomplete or incoherent; thus, these records were filtered out.

The analysis included explaining why the data values varied so much, and establishing percentages for special and neuro procedures, the various times for these procedures, the probability of cancellation, the arrival pattern, and the percentage of patients that are returning patients. It was found that the data vary significantly due to the subjective nature of the procedures. Some physicians take longer than others and may have different methods of

performing the procedures. Furthermore, physicians rotate every week; therefore, the data may contain weekly patterns depending on the attending physician in charge. Some of the variability is rooted in the educational mission of the hospital since some doctors like to teach while performing procedures.

It was determined that 87% of the procedures are special procedures (SP) and 13% are Neuro procedures (NR). The actual time it takes to perform a procedure on a patient is given in Table 1. Times were also established for other activities and procedures that take place prior and posterior to an operation (Table 2). These include waiting time prior to operation, operating room pre-op waiting time, post procedure time in operating room, and post operation rehabilitation.

Once a patient has a scheduled appointment, there is a chance that the procedure gets cancelled. There are two types of cancellation: 1) Type A: when the procedure gets cancelled once the patient has arrived to the Radiology Department, and 2) Type B: when the procedure gets cancelled prior to his/her arrival. From the data available, it was possible to determine the probability of cancellation for cancellations type B only since the information system does not include activities outside Radiology (Table 3).

The arrivals to the Radiology Department vary from day of the week to time of the day. Therefore, the information in the database was grouped in days, and then further broken down into segments of 1 hour from seven a clock in the morning to ten at night (Table 4).

Many patients that come for operations must return for additional procedures. These are denominated as *returning* patients. They constitute 45% of all patients. On the average, these patients return within four weeks.

Table 1: Procedure Time (SP)

Procedure Type	Time Range	Probability	Procedure Time (min)
NR	0 - ∝	1.00	Erlang(49.7,2)
SP	<15	0.04	Uniform (4.5, 15.5)
SP	15-30	0.1	Uniform (15.5,30.5)
SP	30-60	0.31	Uniform (30.5,60.5)
SP	60-120	0.36	Uniform (60.5,121)
SP	120-180	0.12	121+Weib(26.8,1.41)
SP	180-240	0.04	Uniform (181,241)
SP	>240	0.03	245 + Expo(58.7)

Table 2: Events Time

Events	Distribution
Transportation to Radiology	Gamma (13.3, 3.26)
Waiting Time prior to Op.	Exponential (31.9)
OR Pre-op Waiting Time	Exponential (23.5)
Post Procedure Time in OR	Normal (19.1, 15.2)
Post Op Rehabilitation	Uniform (30,60)
Cleaning/Setup Time	Triangular (10,15,30)

Table 3: Probability of Cancellation

Cancellations	Probability
Prior to arrival to Radiology	0.257
At Radiology	0.027

3 COST ANALYSIS

The cost analysis included personnel salaries, equipment, and supplies. These costs were added to each individual patient as they traversed the simulated system. The costs had to be converted in order for them to be introduced into

Table 4: Arrival Pattern

	Quantity	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22
Monday	32	12	82	33	61	46	52	40	40	49	36	18	25	9	4	3
Tuesday	32	6	101	38	65	60	40	52	51	38	44	12	22	10	3	2
Wednesday	32	8	103	30	65	47	61	53	40	50	28	20	23	10	4	3
Thursday	32	8	73	56	45	71	46	51	45	54	41	22	18	13	2	3
Friday	33	7	106	37	55	57	50	40	47	57	45	28	21	12	4	6
Saturday	29	1	3	9	6	6	5	6	11	6	11	3	4	1	1	1
Sunday	22	0	3	4	3	3	6	8	2	1	3	1	0	0	4	0
Monday	Arrival Ratio	0.024	0.161	0.065	0.120	0.090	0.102	0.078	0.078	0.096	0.071	0.035	0.049	0.018	0.008	0.006
Tuesday	Arrival Ratio	0.011	0.186	0.070	0.119	0.110	0.074	0.096	0.094	0.070	0.081	0.022	0.040	0.018	0.006	0.004
Wednesday	Arrival Ratio	0.015	0.189	0.055	0.119	0.086	0.112	0.097	0.073	0.092	0.051	0.037	0.042	0.018	0.007	0.006
Thursday	Arrival Ratio	0.015	0.133	0.102	0.082	0.130	0.084	0.093	0.082	0.099	0.075	0.040	0.033	0.024	0.004	0.005
Friday	Arrival Ratio	0.012	0.185	0.065	0.096	0.100	0.087	0.070	0.082	0.100	0.079	0.049	0.037	0.021	0.007	0.010
Saturday	Arrival Ratio	0.014	0.041	0.122	0.081	0.081	0.068	0.081	0.149	0.081	0.149	0.041	0.054	0.014	0.014	0.014
Sunday	Arrival Ratio	0.000	0.079	0.105	0.079	0.079	0.158	0.211	0.053	0.026	0.079	0.026	0.000	0.000	0.105	0.000

the model. Salaries and supplies were changed from an annual base into a per operation base. For the equipment, a straight-line depreciation method was utilized to find out the annual cost per machine and from it the cost of usage of a machine per operation.

Attendings, Fellows and Residents were not included in the final costing of the model since they work based on a rotational schedule, which was not provided for the study. Hence, the cost per patient that was calculated in the model only includes Nurses, Technologists, and equipment costs.

4 DESCRIPTION OF THE SYSTEM

Patients arrive at a designated rate for each weekday (Figure 1). Transportation from an outside department brings the patients to the radiology area in which a scheduler takes proper action to attend the patients as soon as possible. Room assignment takes place immediately and the necessary staff is arranged accordingly. Neuro angio procedures take place at the OR labeled NR18, while the other angio procedures take place in SP25, SP26 and SP27. The remaining angio room, SP24, is only used to perform simple procedures. SP24 is equipped with less sophisticated apparatus satisfying only the simple procedures equipment requirement.

In every simulation model, certain tradeoffs exist between model complexity and realism. The key is to identify the factors that influence the system the most and concentrate the efforts in achieving a higher degree of realism in those areas. Hence, the success and accuracy of the simulation study performed is cohesively related to the assumptions made. Thus, the following assumptions were made.

- The hours of operation range from 8:00am to 10:00pm plus the additional time to process the remaining patients in radiology and recovery area.
- Emergencies during the night shift are not modeled since the study focuses on the normal operating hours of the facility.
- The attending doctor in the model does not impose nor become a constraint for the model at any time, except for the neuro procedures where he/she is modeled as an integral part of the necessary staff. This design resolution was forced by the lack of statistical data on the attending.
- Transportation time is measured only from the elevator location to the waiting area. Transportation times and delays are embedded in the statistical distribution used to compute the time between arrivals to radiology.

5 THE SIMULATION MODEL

The model was developed using MedModel. Layouts, locations for the entities to stand on, and path networks for the resources to move around in the system were developed. Once all these graphical and logic factors were completed and coordinated the model was first verified and later validated. Validation is the process of insuring that the model truly represents the real world. This was done by observing the behavior of the model through animation, and by looking at the results and ensuring that the processing times, waiting times, number of patients per day, etc. gave reasonable results.

The model was set up to gather data about the desired measures of performance. The measures of performance that were used in this study were:

- Idle time of the operating rooms
- Number of daily procedures

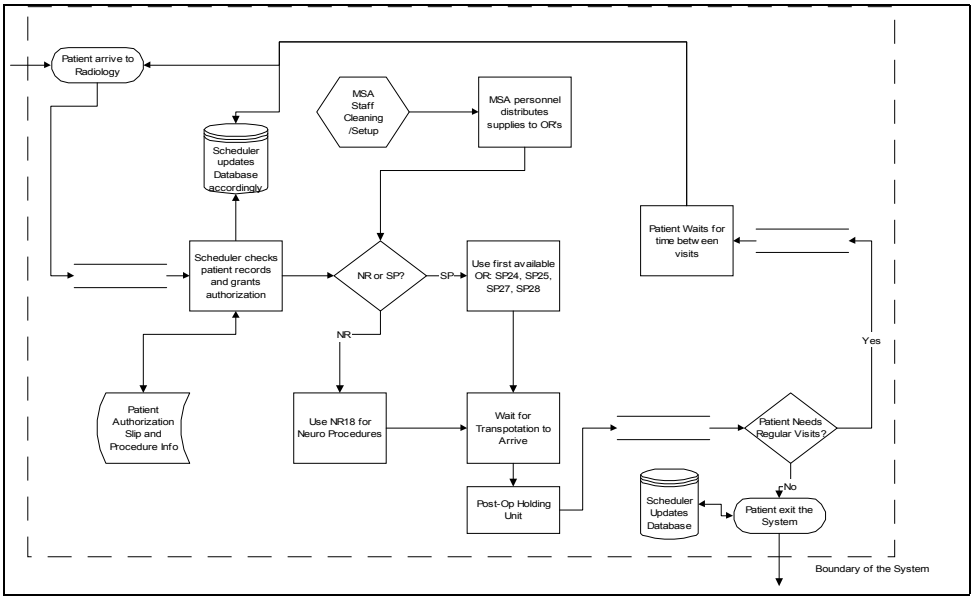

Figure 1: Schematic Representation of the Model

- Waiting time to access the operating rooms
- Technologists' utilization rate
- Staffing costs
- Turnover time of the operating rooms
- Starting and final procedure time for each day.

The model was executed for a period of 86 working days and results were collected. This initial model represents the Radiology Department under current conditions.

6 SCENARIOS

The main concern of the department of Management Systems Engineering at Jackson was the number of technologists assisting during operations. Studies carried by this department demonstrate that many hospitals in the United Stated perform these procedures with only one technologist. However, doctors at Jackson claim that they need two technologists per procedure. Thus, a total of six scenarios were modeled. The first three account for the main concerns of the department, depicting the operational differences between the current system and the system with configurations of strictly one and two technologists per procedure. Currently, procedures are performed 46% of the times with one technologist and 54% of the times with two technologists. The scenarios are as follows:

1. Current system.
2. Using one technologist per procedure.
3. Using two technologists per procedure.
4. Introducing another neurological operating room.
5. Using a 6-day weekly schedule.
6. Re-opening the pre-holding area to have better access to the radiology.

7 COMPARATIVE ANALYSIS

By comparing the outputs of the six scenarios, we were able to draw several conclusions. As originally suspected, the processing time significantly decreases by using only one technologist per procedure. Figure 2 to Figure 7 compare the scenarios in terms of utilization, costs, and processing time.

Table 5 shows that scenario 2 yields the lowest cost, and it is certainly a competitive alternative to the current configuration. The procedure time does not vary significantly between the alternatives making them equally attractive in that regard.

Table 6 gives an overview of patient throughput. Except for the 6-Day service, there are no significant differences between the different scenarios in patient throughput. The lesser throughput for angio procedures on the 1 tech scenario can be attributed to inherit variation in the system or noise and it is not significant enough to draw conclusions.

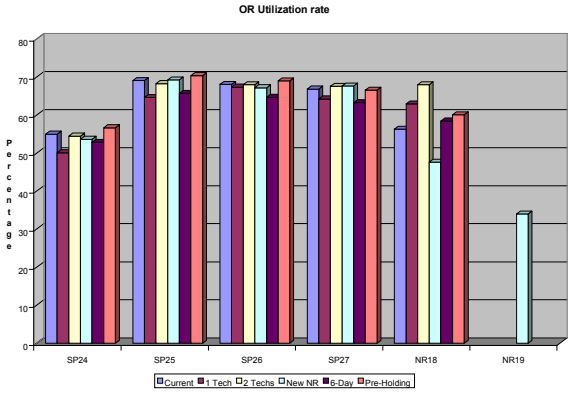

Figure 2: OR Percent Utilization

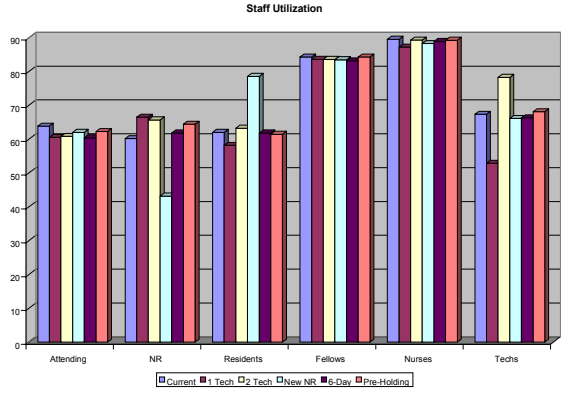

Figure 3: Staff Utilization

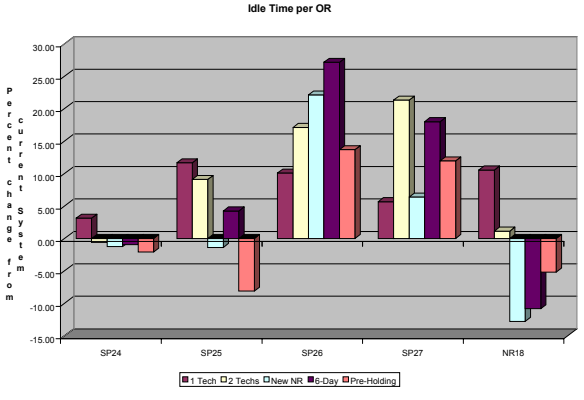

Figure 4: OR Idle Time

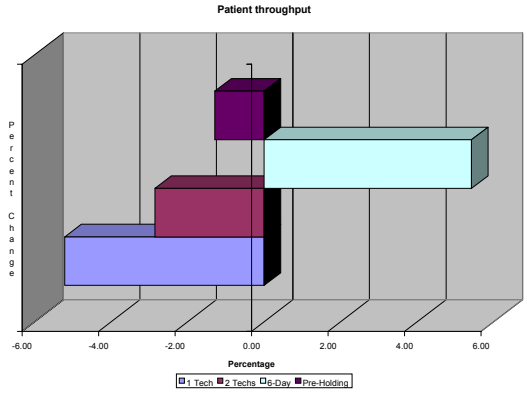

Figure 5: Throughput

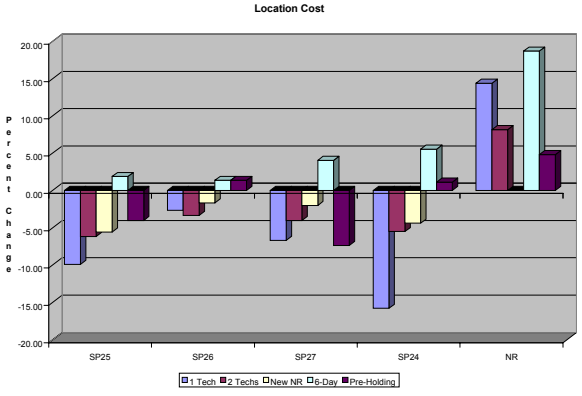

Figure 6: Location Cost

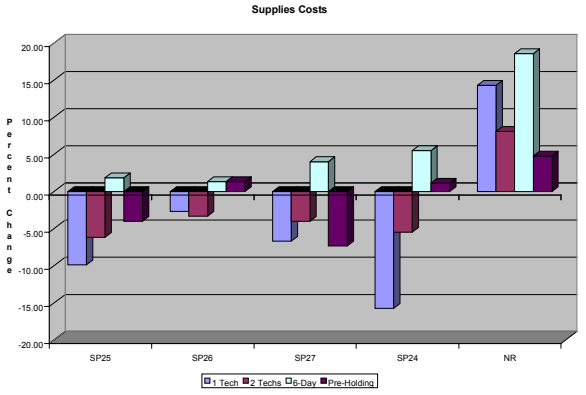

Figure 7: Supplies Costs

The addition of a new neuro operating room alleviates the demand for the old neurological operating room as much as 30%, leaving enough breathing room for significant growth and throughput increase. These results were evaluated using a 12-hour shift for the locations and summarized in Table 7.

Table 8 summarizes the results for staff utilization. The percent utilization is expressed as a percentage of the shift, *excluding* all breaks and allowances which can account for as much as one-fourth of a resource. With a few notable exceptions, utilization rates are fairly stable across the scenarios. As expected, the utilization of the technologists varies significantly between the first three scenarios. The utilization of the technologists ranges from

Table 5: Outputs Summary

Logs	**Scenarios**					
	Current	**1 Tech**	**2 Techs**	**New NR**	**6-Day**	**Pre-Holding**
Waiting for NR	32.15	39.52	39.18	5.07	34.58	40.41
Waiting for SP	20.65	21.19	19.54	26.63	15.79	26.01
Time Angio	123.6	125.59	131.65	128.17	123.87	129.53
Time C-Arm	94.45	94.69	100.57	94.46	92.52	98.14
Time Neuro	132.44	142.54	146.6	135.49	130.91	141.05
Recovery	24.27	24.08	24.28	24.26	24.78	24.37
Costs	Represents staff wages for nurses and tech per procedure ($)					
Angio	139.91	122	165.18	N/A	141.81	146.42
C-Arm	96.4	86.42	109.57	N/A	96.23	95.53
Neuro	159.51	150.61	199.01	N/A	158.9	172.43

Table 6: Patient Throughput

Throughput	**Scenarios**					
	Current	**1 Tech**	**2 Techs**	**New NR**	**6-Day**	**Pre-Holding**
SP24	323	291	303	305	329	310
SP25	299	291	289	294	303	303
SP26	298	278	286	292	310	276
SP27	272	229	257	260	287	275
NR18	209	239	226	155	248	219
NR19	N/A	N/A	N/A	54	N/A	N/A
Total Patients	1401	1328	1361	1360	1477	1383

Table 7: Location Statistics

Location Statistics	Scenarios					
	Current		1 Tech		2 Techs	
OR's	Scheduled Hours	% Utilization	Scheduled Hours	% Utilization	Scheduled Hours	% Utilization
SP24	1638.527	54.96	1649.23	50.05	1658.26	54.43
SP25	1638.415	69	1649.23	64.54	1657.74	68.21
SP26	1638.415	67.99	1649.37	67.31	1657.74	67.91
SP27	1638.555	66.8	1649.23	64.2	1657.74	67.51
NR18	1638.577	56.21	1650.54	62.87	1658.51	67.91
Location Statistics	Scenarios					
	New NR		6-Day		Pre-Holding	
OR's	Scheduled Hours	% Utilization	Scheduled Hours	% Utilization	Scheduled Hours	% Utilization
SP24	1638.08	53.58	1839.54	52.82	1639.14	56.6
SP25	1638.56	69.21	1839.54	65.66	1639.54	70.33
SP26	1638.2	67.15	1839.88	64.61	1639.26	68.94
SP27	1638.06	67.62	1839.7	63.2	1639.14	66.47
NR18	1638.06	47.59	1840.15	58.4	1639.39	60
NR19	1638.06	33.93				

Table 8: Resources Statistics

Resources Statistics		Scenarios								
		Current			1 Tech			2 Techs		
Resources	Quantity	Hours	Time per use	% Utilization	Hours	Time per use	% Utilization	Hours	Time per use	% Utilization
Attending	5	1046.52	26.22	63.83	1045.68	25.35	60.54	1063.67	24.73	60.79
NR	1	996.89	99.58	60.16	1042.76	107.59	66.51	1024.17	109.53	65.68
Residents	3	2736.68	67.25	61.98	2750.79	70.73	58.18	2794.48	73.19	63.22
Fellows	3	2828.75	69.82	84.3	2870.86	73.68	83.59	2933.36	74.63	83.56
Nurses	6	5102.49	101.44	89.53	5173.93	106.46	87.19	529829	108.95	89.31
Techs	8	6018.13	68.81	67.33	5950.03	73.73	52.87	6308.05	72.81	78.28
Resources Statistics		Scenarios								
		New NR			6-Day			Pre-Holding		
Resources	Quantity	Hours	Time per use	% Utilization	Hours	Time per use	% Utilization	Hours	Time per use	% Utilization
Attending	5	1055.74	26.26	62.02	1144.76	24.44	60.37	1060.12	25.2	62.23
NR	1	1944.33	100.29	43.16	1124.53	99.13	61.83	1005.2	107.5	64.41
Residents	3	2735.38	71.02	78.55	2976.94	68.62	61.79	2795.85	70.6	61.41
Fellows	3	2868.28	72.46	83.47	3054.48	70.13	83.12	2893.65	72.21	84.26
Nurses	6	5168.81	103.15	88.25	5437	102.47	88.85	5227.09	106.39	89.24
Techs	8	6061.06	70.97	66.1	6470	69.78	66.31	6071.65	72.54	68.12

53% to 78% for scenarios 2 and 3. Scenario 1 exhibits an utilization of 67%, which was expected since the current configuration is a combination of the two extremes tested. Interestingly, the addition of a new operating room makes the utilization of residents higher, even with the same demand. This is an important factor to consider when the aggregate operating room begins its operations somewhere in the year 2001 as projected.

In addition, room turnover time was studied and proved to be consistent with the department's operational goals and current operating conditions (Table 9). The confidence intervals show a tight spread and therefore there is no need to alter the current operating conditions of the MSA procedures at the radiology area. The efficiency is high and the current staff level (2) is appropriate.

8 CONCLUSIONS AND RECOMMENDATIONS

Based on the extensive analysis performed on the Radiology Department, along with the outputs collected from the simulation study, it can be concluded that performing procedures with only one technologist is a cost effective solution and will reduce the need for more staff, at least in the short run. The slightly reduced throughput using this

Table 9: OR's Turnover time

	Operating Rooms Turnover Time (Minutes) 95% Confidence Intervals					
	Current	**1 Tech**	**2 Techs**	**New NR**	**6-Day**	**Pre-Holding**
SP24	15.89 +/- .61	15.49 +/- .59	15.88 +/- .59	15.78 +/- .59	15.76 +/- .61	15.66 +/- .58
SP25	15.27 +/- .53	15.13 +/- .55	15.41 +/- .54	15.5 +/- .64	15.26 +/- .53	15.57 +/- .56
SP26	15.53 +/- .58	15.15 +/- .53	15.75 +/- .55	15.33 +/- .54	15.33 +/- .58	15.02 +/- .53
SP27	14.59 +/- .51	14.51 +/- .51	14.56 +/- .51	14.28 +/- .50	14.51 +/- .51	14.5 +/- .54
NR18	15.25 +/- .53	15.71 +/- .68	15.99 +/- .68	14.90 +/- .42	15.32 +/- .53	15.53 +/- .54
NR19				16.37 +/- .57		

configuration is not significant enough to exclude this configuration from the feasible alternatives. Moreover, this scenario gives the possibility of reducing staff, and it allows the department the flexibility to schedule more daily procedures if needed.

A few additional recommendations may improve the process and service of the Radiology Department.

1. *Provide a waiting area*. Currently there is a waiting area, however, it is not being utilized because there is deficiency of nurses in the department. As with any service industry, if the hospital provides its patients with a better service, the probability of returning will significantly increase.
2. *Provide a more suitable lunch/break area*. While doing the process of interviewing staff members, several remarks were made regarding the current lunch/break area. If staff members were given a more spacious and comfortable area to take their breaks they would probably feel more appreciated and would work with greater enthusiasm and more efficiency.
3. *Create a field in the database that will enable the identification of emergency cases*. This will allow better record keeping, hence providing greater control of the events. Additionally, better results can be obtained from future studies if the data are more accurate and complete.

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