Modelling, analysis and simulation of a patient admission problem: A social network approach

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Abstract. Due to pressing demand for the quality of care and to maximize the patient satisfaction, traditional scheduling may not cater the needs of patient's accessibility for mitigating the patient tardiness and social effects. This paper addresses, patient appointment scheduling problem (PASP) in a radiology department in southern India, as a case study. Due to partial precedence constraints between different modalities, the problem is formulated as a static, multi-stage/multi-server system. We proposed a novel social network analysis (SNA) based approach to examine the relationship between identified modalities and their influence with different examination type. To validate the results of SNA model, in a real time environment a simulation analysis is carried out by using FlexSim Healthcare software. Based on the empirical data collected from the radiology department, comparisons between the present condition of the department and the achieved results from proposed approach is performed through discrete event simulation model. The results indicate that the proposed approach has proved its effectiveness on the system performance by reducing the average total completion time of the system by 5% and 38% in patients waiting time.

Keywords: Appointment scheduling problem, social network analysis, Queuing models.

1.Introduction

Recent healthcare services require better quality of care, reducing the cost, and minimizing the patient length of stay by optimal allocation of resources due to a surge in patient volume and increasing awareness for precautionary measures. Subsequently, it is necessary to investigate the patient flow that has been considered as one of the key factors for assessing the performance of a healthcare system [1]. However, patient flow prediction is a difficult errand because of its frequent uncertain nature that prompts the brisk increment in patient volume. An increase in 10% patient's appointments on the same day proved that it leads to 8% reduction of patient satisfaction [2]. In order to take care of the above-mentioned issues and to improve the patient's solace, effective/efficient methodologies and new management techniques must be considered. In India, a noteworthy level of the populace living underneath the national poverty line and their need is a better lifestyle. Catering facilities for such a colossal number surely prompts tremendous workload in the public sector. Hence for improving the patient's comfort by ensuring comprehensive health care modeling, contracts with private service providers have been made under the National health scheme. Despite collaboration with private providers, still patients are suffering from lack of effective treatment. In this context, there is a huge need to reduce the patient's length of stay irrespective of their type of demand, simultaneously costs should be reduced and improving the quality of care.

In the past decade appointment scheduling problem is considered to schedule elective surgeries [3] but in the recent years, it has been widely used for almost all types of diagnosis. Contrary to traditional appointment scheduling problem, it has greater advantages to the patients by providing flexibility in timings, better reachability (patients can priory take their appointments by phone, or other electronic bookings), flexible choices (patients themselves choose their preferable physicians), etc [4-6]. Out of these, the most important factor that majorly affects the patients care is patients flow/delivery process in a hospital system. The patient flow analysis and identification defines how the rate of patient flow can be affected by seasonal and local factors [7]. Statistical models have been developed to predict the patient flow analysis based on patient admission parameters [8]. Waiting time is always a problem in a hospital. Reduction of waiting tine is always a concern. Optimization approach using queuing theory and poisson modelling have effectively reduced the waiting time in the emergency department [9]. Machine learning approaches and data mining techniques are used for the analysis of health records of patients [10].

In this study, we propose a social network analysis based method for a health-care appointment scheduling system to comprehend the process of different modalities such as MRI, CT, RX, OT, PX, and MG and to identify the value-added process thereby removing the components which are actually delaying the process. Consequently, frequencies of each modality, their interactions were investigated and those modalities influencing high that can affect the total system performance has been identified. Thereafter, a single/multi-stage queuing system is designed with total patient’s length of stay and total completion time as performance measures for estimating the current performance of the system. We considered a case study for a radiology department and it has been described in detail with the presented two-dimensional framework.

2. Case Study description

This paper centres around patient admission scheduling problem in a radiology department of a hospital situated in the rural area of southern India. This department offers total six different modalities namely MRI, Computed Tomography (CT), Densitometry (PX), Mammography (MG), Ortho-pan tomography (OT) and RX with varieties of exam types to serve the scheduled patients for ten days working hours. The department is made-out of several humans, physical and technical resources (Administration, Physicians;

Medical assistants; Assistants; Examination rooms; Waiting room; Changing room; and Control rooms) for serving the patients. However, due to the department location and its social environment, at the initial stages of a survey, we found a non-significant amount of delays (downtime). Sometimes, patients arrive much earlier (several hours before) than their actual scheduled time. The detailed workflow of the patient and their information is illustrated in Figure. 1.

Appointments are pre-scheduled by the patients depending on the available slots in the considered hospital and accordingly the processing time for each modality is defined. On the scheduled day, the patient alludes to the hospital and waits until the registry, questionnaire and consent declaration are filled for the admission. Ensuring to admission the patient is then directed to the respective ward for wearing the hospital gown, removing ornaments, watch and any other iron material. In the meanwhile, the equipment is prepared for examination and the necessary resources are made available. The examination process follows patient positioning, image acquisition, contrast administration, image acquisition. The post examination process undergoes wherein the reports are delivered and billing is done, terminating the process. The assistant makes call for examination of the patients and guides them to the dressing rooms which are common for all the modalities and to control the overcrowding of appointments, different technicians are used for assistance.

2.1 Data collection

For a better knowledge on the functioning of the hospital and their resource utilization, 6 different modalities were identified and studied on daily basis for a span of 4 months. The number of patients examined counted was 329. On observation, it was understood that a majority of the appointments fall under MRI category. Henceforth our future research is restricted to MRI modality. A total of 40 different exam types were found in MRI and a major share of 80% is contributed by 4 exam types namely Brain, Joints, Cervical and Lumbar respectively as shown in Fig. 2.

This prompted the constraint of the study to major share contributors. The succeeding phase of study incorporates acquiring discernment time to acquire a sample that would be statistically illustrated. Resource sharing among modalities and rescheduling of patients by the technicians were observed to be the major barriers to the normal workflow. Longer patient waiting and broad working hours are the key impacts of Rescheduling. The final phase includes determining the throughput time of each task involved in the examination procedure.

The analysis of the examinations in the hospital statistically is articulated in Table 1. The average, median and standard deviations of the different tasks involved in the examination are shown in Table 2.

3.MODEL FORMULATION

In this research work, patients follow single stage, multi-stage systems due to their random arrivals. However, registry, questionnaire, consent declaration filling, report delivery and billing falls under multi-stage systems. As the doctor and patient relationship are highly valued in appointment scheduling problem their relationship can be useful to predict the quality of the system, and it can be shown as a single independent queue model. Thus, the problem described within this context considers patients belonging to different types which have been modelled in the form of a static, multi-stage/multi-server system, having estimated processing times belonging to different types of clinical examinations which is further defined as a probability distribution.

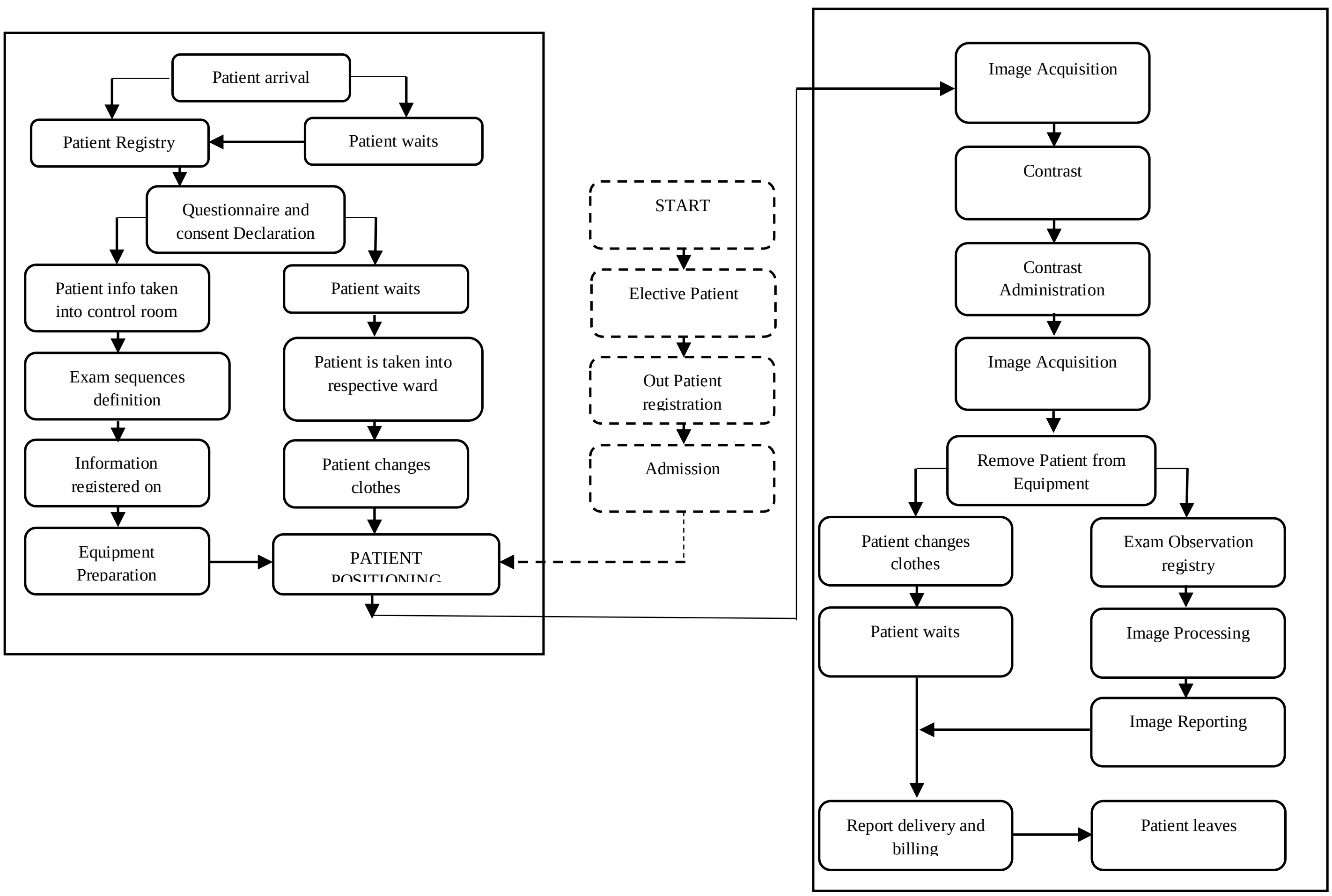

Figure 1. Flowchart of the proposed clinic work flow

3.2*Mathematical model representation*

In this paper, the objective functions that we consider are the minimization of patient length of stay and Minimization of maximum completion time. The objective functions are described as follows:

Equations (1) and (2) stipulates the objectives, i.e. minimization of makespan (total completion of patients) and minimization of the total waiting time of the patients. Constraint (3) articulates all the task for patient's process should be positive in value. The constraint (4) expresses the processing time for a task of the process should be ranging within three-sigma limits.

Decision Variables:

$$\sum_{x,y} = \begin{cases} w \to j_{0_{x,y}} \ge j_{f_{x-1y}} \\ 0 \to j_{0_{x,y}} = j_{f_{x-1y}} \end{cases} \qquad \eta_{x,y} = \begin{cases} zw \to wt_{x,y} = 0 \\ nzw \to wt_{x,y} = j_{0_{x+1y}} - (j_{0_{x,y}} + p_{x,y}) \end{cases}$$

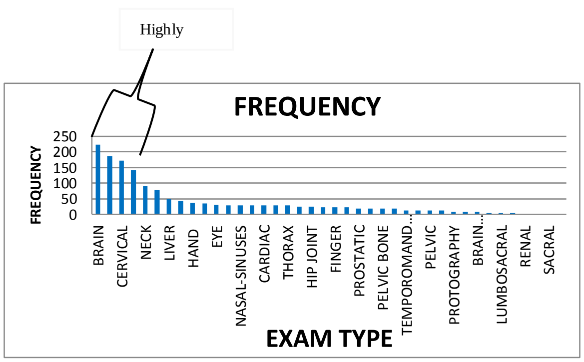

Fig 2: - Frequencies of MRI exam types

Table 2. Statistical Analysis of Image Acquisition Task by Examination Type

Attributes	Exam with contrast			
	Brain (min)	Joints (min)	Cervical (min)	Lumbar (min)
Average	20.42	26.51	26.72	25.92
Median	19.52	25.52	25.17	26.65
Standard deviation	4.48	6.06	8.25	4.91

Table 1. Statistical Analysis of the work flow of hospital

Attributes	Task		
	Initial fabric change (min)	Prepare Equipment (min)	Patient positioning (min)
Average	2.32	0.64	1.98
Median	1.95	0.55	1.81
Standard deviation	0.9	0.31	0.65
	Contrast (min)	Remove patient (min)	Final fabric change (min)
Average	2.09	1.36	1.97
Median	1.94	1.19	1.85
Standard deviation	0.74	0.67	0.9

Minimization of objective functions

$$j_{f_{x,y}} = j_{o_{x,y}} + p_{x,y} + \square wt_{x,y} \tag{1}$$

$$Vwt_{x,y} = t_{o_{x+1_y}} - (t_{0_{x,y}} + p_{x,y}) \tag{2}$$

Subjected to constraints

$$p_{x,y} > 0, \ \forall x \in j_{y,} y \in j \tag{3}$$

$$\mu_{x,y} - 3\sigma_{x,y} \wedge 2 \leq p_{x,y} \leq \mu_{x,y} + 3\sigma_{x,y} \wedge 2 \quad , \forall \ \mathrm{x} \in j_y, y \in j \tag{4}$$

4. Social Network Analysis Method and Flexsim Healthcare Simulation System

In their work, the average distance between patients proved to be better prediction than social network properties such as betweenness and centrality measures for the propagation of disease. According to our knowledge till date, no study has been done on appointment scheduling problem with social network analysis method that can predict patient's frequency on different modalities and their interrelations among them to effectively serve the patient. The point by point depiction of the social network analysis method and execution on the considered problem is as per the following:

4.1 Modelling of collaborative networks

In SNA, network indicates interaction among various nodes linked by ties. In this research, the SNA approach deals with the extraction of hospital data in the form of a network having different nodes. Here, the nodes are modalities while the ties are exam types interconnected with each other to frame a network structure. Using the hospital data as the input parameters for the SNA method, various attributes of the acquired network have been examined. i.e., the SNAM is classified into two stages: (a) modelling of network and (b) network analysis which has been referenced in the accompanying sections:

The network structure begins with, fed the data that has been collected from the survey into an affiliation matrix. The affiliation matrix comprises of Radiology Department attribute information with exam types and modalities as rows and columns. If the interaction of attribute to exam type is 1, they are related and if it is a 0 then they are not related. Here, the interaction articulates the actual material flows on different resources.

Later, the modelling algorithm is performed on the matrix to analyse it for accomplishing the collaborative network as depicted in Figure 3. The collaborative network obtained is more interesting and meaningful in comparison to the simple network with respect to its size, characteristics etc. The arrows here represent interactions between the attributes which is not possible with traditional representation. This proposed approach is repeated for the remaining data for achieving different collaboration network.

Figure 3 gives a detailed view of the influencing exam type in the considered modalities. The complete information about the various exam types performed in the considered modalities is explained. In this paper, the proposed healthcare system's attributes are symbolized by the nodes in the network. The nodes with different colours\label distinguishes each attribute from the other.

For instance, in Figure 3 the nodes having smaller size and blue colour represents various exam types, and the aforementioned nodes stipulates the various modalities present in the system. Although different colours and name has been used to represent each modality nodes and different shapes for each exam type nodes. A preliminary analysis is necessary to be conducted to explain the overall nature of the network. The following section gives a detail explanation about the preliminary analysis and explains about statistical analysis.

4.2Social network analysis for collaborative networks

4.2.1 Network features

The position of the node with respect to the centre of the network can be easily determined using centrality. In this research, betweenness and closeness centrality measures for the network analysis are considered. The below equations (5 and 6) shows the detail calculations of the considered centrality measures.

Closeness is a measure to determine the close connection amongst different nodes in the network. To obtain the values of various centrality measures of each attribute i.e., betweenness and closeness, the input data is entered to the Ucinet software. Table 3 articulates the measures of two centralities of the five modalities for the mentioned cases of the particular work systems.

$$\textit{Closeness Centrality}_i = \frac{n-1}{\sum_{b=1}^{n} k(a,b)} \tag{5}$$

$$\textit{Closeness Centralization} = \frac{\sum_{b=1}^{n} \overline{D} - D_a}{(n-1)(n-2)/(2n-3)} \tag{6}$$

By observing Table 3, a number of conclusions can be extracted based on the obtained collaboration networks. The modalities having higher degree of centrality exhibit emphatically associated, though the modalities with lower degree centrality show very fewer connections. Subsequently, the modalities with a higher degree of centralities have been distinguished so they can act as center points and can serve as key elements or focal elements to the network. The identified key modalities are shown in network diagram as big square nodes and it is shown in Figure.3. These key modalities or hubs have a wide range of connections strength and make it easy to identify the hubs in the health care system by observing the collaborative networks.

Table 3. Centrality measures

Rank	Attribute	Closeness	Betweenness
1	MRI	91.667	44.979
2	CT	91.667	44.979

3	BREAST	50.575	4.548
4	JOINTS	50.575	4.548
5	NECK	50.575	3.7
6	SHOULDER	50.575	0.207
7	TEETH	50.575	0.207
8	CERVICAL	50.575	0.207
9	THIGH	50.575	0.207
10	FINGER	50.575	0.207
.	.	.	.
.	.	.	.
.	.	.	.
43	PX	43.137	0.003
44	MG	33.846	0
45	OT	33.846	0

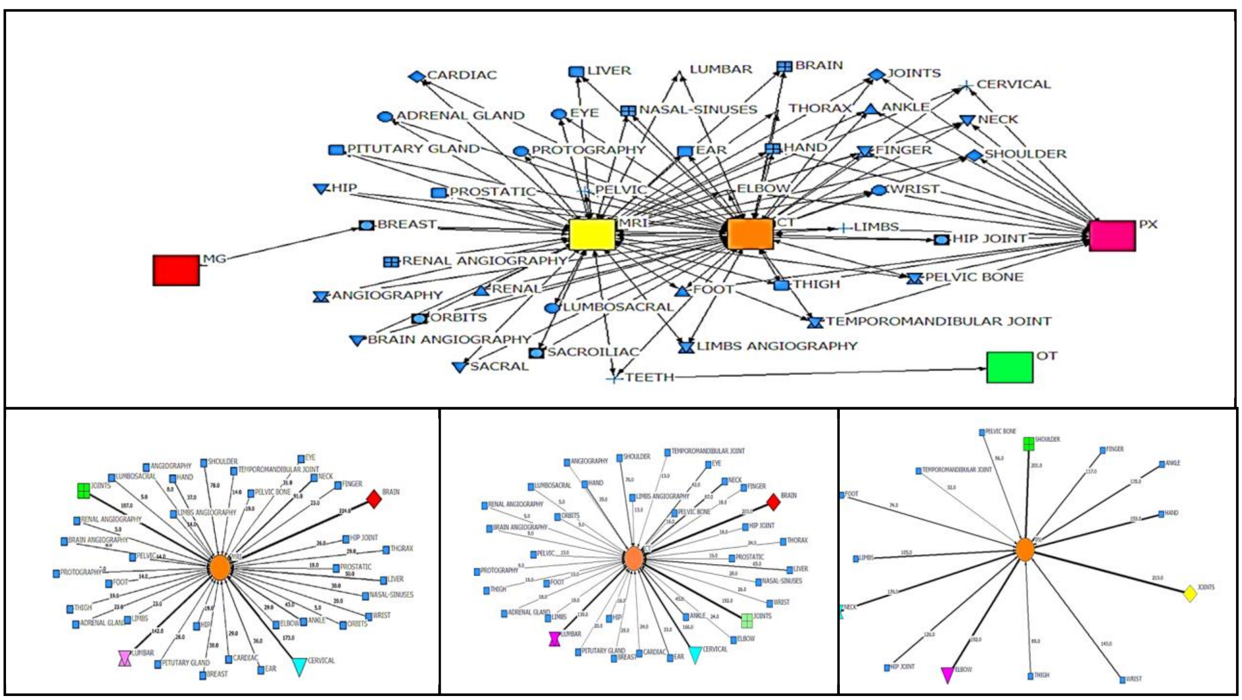

Figure 3. Collaborative Network Diagram of the different modalities and exam type

5.Results and Discussion

The proposed SNAM is implemented on a case study and the distinctive characteristic properties of the network were identified. Later on, the frequencies of the modalities and their interactions in the network were identified by the help of features of every node which were obtained by the analysis of above mentioned data. From the survey data, we identified modality, MRI obtained a higher degree of closeness and betweenness centrality, similarly brain, joints, cervical, and lumbar exam types have higher centralities. The influence of identified modalities and exam types having higher centralities is much higher on the whole network as they act as key hubs of the system. Thereafter, for the considered hospital problem makespan (total completion time) and total waiting time is considered as performance measures that can improve the system performance effectively. After that, to validate the results from SNAM, a simulation is conducted using FlexSim HC simulation tool.

5.1 Validation of SNAM by FlexSim Healthcare simulation

Here in FlexSim, we have considered only the case of patients of MRI, as the percentage of patients for MRI was found to be more. The exam types which are considered are Brain, Joints, Cervical and Lumbar respectively as the percentage of patients for these examinations are found more through SNAM.

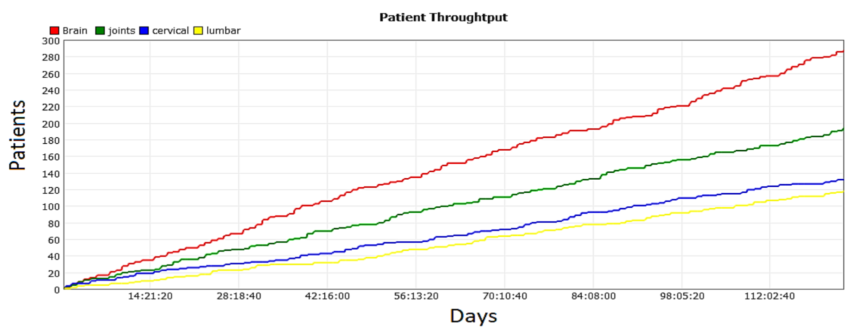

Figure 4. Throughput of the patients through out the simmulation

Figure 4 presents the results for the simulation program that indicates the patient throughput. Here, the graph is plotted between a number of patients with respect to the number of days of observation. From the Figure 4, it is seen that the patient throughput in case of brain examination is more as compared to other examination. To be more specific, for the 4months of observation the number of patients of brain examination were around 277 followed by joints around 189 then cervical 126 and lumbar patients were around 110 which directly reflects the results from SNAM. Figure 5 shows the relation between the average time taken and the number of days for the length of stay of four different groups of patients. The graph is plotted for the length of stay period which has been taken as 123 days. Here, 14:21:20 represents day-14, 21 hrs and 20 minutes respectively. In Figure 5 during the first 14-18 days, it is clearly visible that, there is much fluctuation whereas with the increase in the number of days the graphs tend towards becoming stabilized. In the earlier period lumbar patients stay around 50 to 90 minutes, followed by patients of the brain around 45 to 75 minutes then joints and cervical ranging between 55 to 68 minutes, and as the number of days increases, the length of stay period for all the category patients falls between 45 to 60.

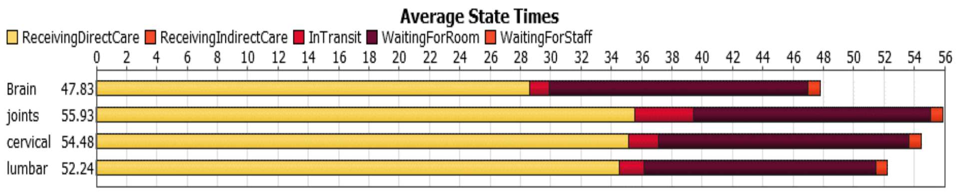

Figure 5. Average length of Stay for the patients for Examination

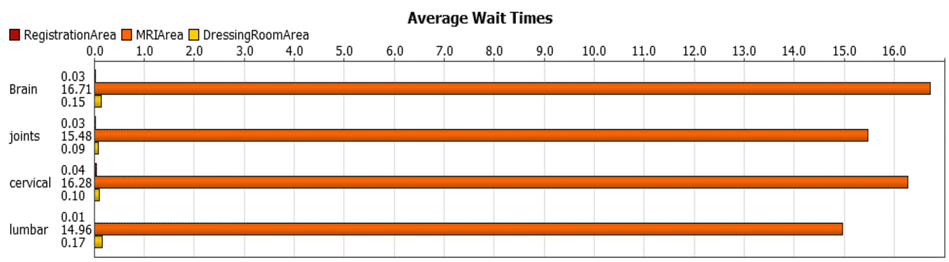

Figure 6. Average state time for patients

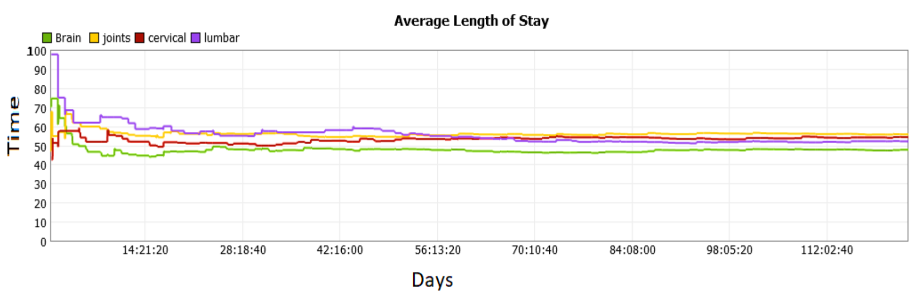

Figure 7. Average waiting times for patients at the following area

Figure 6 shows the Average State Times for the four major examinations. From the above graph, it is observed that the minimum time was spent for the patients of brain examination, followed by the patients of lumbar, cervical and joints examination respectively. Here from the Figure 6, it is clearly visible that most of the time patients of joints achieve direct care followed by cervical then lumbar and Brain. However, this trend in case of the different examination was mainly dependent upon two main factors such as the In Transit time and the Direct Care.

Figure 7 shows the average wait times for the patients of four different examinations which mainly focus on three major areas namely registration area, MRI area and the dressing room area. A difference was observed during the comparison of these four exam types on the basis of the average waiting time. To be more specific, the MRI area was having the highest waiting time i.e. 16.71 for Brain, 15.48 for Joints, 16.28 for Cervical and 1.96 for Lumbar followed by the dressing room area and the registration area. Amongst the four main exam types, the patients of brain examination had to wait for a longer time period especially at the MRI area whereas the average waiting time for the patients of other exam types such as cervical, joints and lumbar were second, third and fourth highest respectively.

6.Conclusions and future work

In this paper, a social network analysis based method integrated with multi-objective optimization approach is developed to solve the patient admission problem for improving the patient's comfort. As a first step, a survey has been conducted in a clinic that is following appointment scheduling to the patients and then identified the different modalities and their exam types individually. Thereafter, with proposed social network analysis method each modalities interaction with each other and their frequency according to patient tasks are identified. From this analysis, we observed that out of 40 different exam types in Radiology department four exam types namely Brain, Joints, Cervical and Lumbar are contributing 80% of the total share. Later, the patient's flow pattern is mapped according to queuing models and this can be useful for formulating the mathematical model. After examining the results and the considered performance measures it is observed that the considered health care system is a case of mixed integer programming model. In this paper, the average total completion time of the system and patients waiting time are considered as objective functions. To solve this, a FlexSim based simulation approach was carried out in which the results were established and validated based upon the patient admission tasks. The results were obtained by running the simulation shows that the average total completion time of patient admission tasks has been minimized. The second objective in this paper, which was the waiting time that indicated the quality of service has also been decreased by 38%.

In future work, it would be interesting to develop a web-based system for improving better communication between patients and the doctors.

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