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Assigning Triaged Patients to Treatment Rooms in a Hospital Emergency Department

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Abstract

The assigning of new arrivals at a hospital emergency department to treatment rooms was examined. New patients are summarily triaged and assigned to a treatment room based on severity of their symptoms, the grade of a treatment room, and an exponential benefit curve that encourages the solver to schedule the most severe cases early. SAS's OPTMODEL modeling language was employed to build the model and SAS's MILP solver was used to perform the scheduling. Up to thirty patients were optimally assigned to depict the example of a large emergency department.

Keywords: ***Assignment; Binary programming; Work tours***

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Introduction

Consider the emergency department (ED) of a hospital. When a potential patient arrives, he or she is met by a counselor who performs a summary triage and may assign the patient to a treatment room immediately if the symptom is life threatening (for example, chest pain indicating a possible heart attack) or non-life-threatening (for example, flu symptoms). For a small ED, this system is sufficient. However, a large emergency department may have up to 30 patients and up to ten treatment rooms, with rooms ranging from simple examination rooms to well-equipped trauma treatment rooms. An informal, triage-counselor-driven, assignment system may be inadequate for this size ED. In this paper we propose a computer assignment solution that considers severity of a patient's symptoms, a patient's time of arrival, treatment room availability, and treatment room ability to treat the patient's symptoms. Our solution uses binary programming and patient "tours" in assigning patients to appropriate treatment rooms.

Literature Review

To arrive at an optimal decision for both the patient and the hospital, a series of criteria need to be considered. This paper follows Cardoen, Demeulemeester, and Belien [1] framework regarding criteria for scheduling. We take into consideration patient characteristics, performance measures, and decision delineation. In terms of patient characteristics, a procedure can be elective or non-elective according to the status and seriousness of the patient's symptoms. Elective procedures are those that could be delayed

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or treated in a less complex setting, while non-elective procedures are those that demand urgent and immediate action. It is important to understand the main differences among non-elective patients' procedure. Emergencies are to be taken care as soon as possible, whereas urgencies refer to non-elective patients who are stable to the point that their surgery can possibly be postponed for a short period of time [1,2].

Performance measures consider waiting time, patient deferral, utilization, makespan, financial value, preferences, and throughout. Wullink et al. [3] examined the decisions related to advantages in improving responsiveness to emergencies when either reserving a dedicated operating room or to keeping some capacity available in all elective operating rooms. Financial value is also increasingly becoming more of a concern for both patients and hospitals. The operating rooms' (OR) costs have increased over the last few decades. A study by Gordon, Lyles, and Fountain [4] found that in the late 1980's OR costs were about nine percent of hospital's budget but have increased faster than the consumer price index and medical consumer price index [5]. One minute in the OR can cost from $7 to over $100, depending of the location and operating surgeons, with an average of $36 to $37 per minute. Direct costs, such as wages, employee benefits, and direct supplies represent about 55% of the total costs, while indirect costs represent about 45% of the total. Understanding that the cost structure for ORs represents a major cost in the overall hospital bill, and has been increasing over the last few decades, reassures the importance of proper patient allocation to treatment rooms according to the seriousness of their problems. Every minute counts in an OR, for too much time may cost lives and money.

Finally, decision delineation indicates the decision to be made in terms of date, time, room, and capacity. Quality examples of how much improvement can be made in real settings based on scheduling research can be found in the works of Blake, Dexter, and Donald [6] and Blake and Donald [7]. In the first work, the authors conducted a case study looking at block time and how to determine an equitable method of distributing time to different surgical rooms. In the latter work, the authors prepared an integer-programming model and a post-solution heuristic identifying the optimal allocation schedule for different operating rooms in five surgical divisions at a Toronto's Hospital, that according to the authors, have "used this approach for several years and credits it with both administrative savings and the ability to produce quickly an equitable master surgical schedule" [6]. In order to perform our calculations, we organized our data in a way that the treatment rooms can vary in terms of grade, as explained in the following section.

A Small Example Situation

Emergency Department: Consider a hospital with four treatment rooms, Table 1.

Treatment Room	Grade
tr01	1
tr02	3
tr03	4
tr04	4

Table 1: Treatment Rooms.

The grade is the maximum grade of patient symptom that can be handled by the treatment room. tr01 is a simple examination room capable of seeing flu patients, for example. Treatment room tr02 is well-equipped but cannot see full trauma patients. Treatment rooms tr03 and tr04 are equipped to stabilize trauma patients (for example, gunshot wound patients).

Triage Table

Triage symptoms are looked up from the following list of symptoms. See Table 2. A real triage table would have hundreds of symptoms to choose from.

Symptom	Grade	Hours to Treat
flu	1	0.50
chest pain	3	1.75
stroke	3	1.00
gunshot	4	2.00

Table 2: Symptom Lookup Table.

The assigned grade is the severity of the symptom. A grade 1 symptom may be treated in any treatment room. A grade 3 symptom may be treated in a grade 3 or 4 treatment room but not in a grade 1 or 2 treatment room.

Patients

The ED currently has five patients, Table 3.

Patient	Arrival Time	Symptom
pt01	2020159.9	flu
pt02	2020160.5	gunshot
pt03	2020160.5	stroke
pt04	2020160.6	chest pain
pt05	2020160.7	gunshot

Table 3: Arriving patients.

Time 2020160.5 is read as the 160th day of the year 2020 at halfway through the day (0.5), or noon of day 160. We assume the time currently is 2020160.5. Note that patient pt01 arrived the day before but has not yet been treated.

The Problem

Benefit function

The objective is to maximize "benefit" while obeying numerous constraints. The "benefit" is an exponential function of a patient's arrival time and symptom grade.

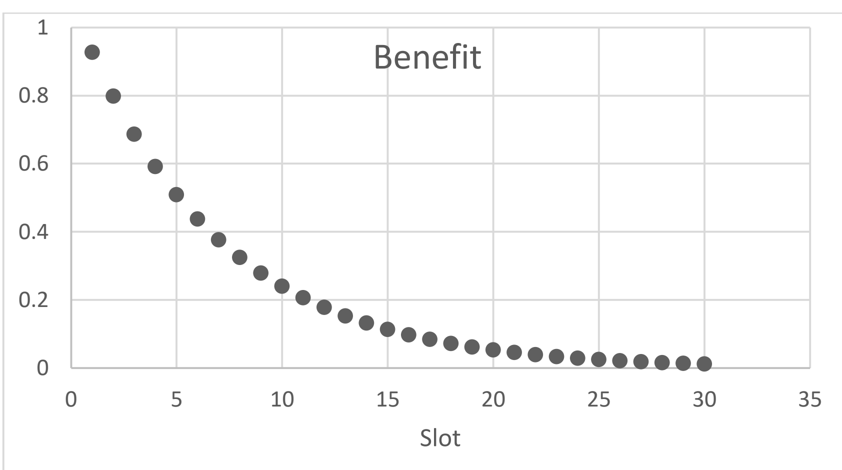

Figure 1: An exponential benefit curve

An exponential form was chosen to emphasize that higher symptom grades should be considered over patients with lower symptom scores. Scheduling a patient in a time slot near the current time should benefit the objective function more than patients arriving later (Figure 1).

Tour

At the heart of this assignment model is a "tour". A tour is turned on or left off by the binary decision variable for a patient and treatment room combination. See Table 4 for an example.

In this table, all values are 0 for patient pt02 (a gunshot victim requiring a grade 4 room), for treatment room tr03, a room that can only accept grades 1, 2, or 3 symptom grades. However, treatment room tr04 can accept a patient with grade 4 trauma symptoms. Tour 1 begins at the current time, 2020160.50 and continues for eight 15-minute periods until time slot 2020160.57. Tour 2 for tr04 begins fifteen minutes later at time 2020160.51. Tour 3 begins fifteen minutes after that, and this pattern continues.

	patient pt02: gunshot wound, grade 4 trauma, requiring eight 15-minute intervals to treat												
	…	treatment room tr03: grade 3 room						treatment room tr04: a grade 4 room					
		tour						tour					
slot		1	2	3	4	5	…	1	2	3	4	5	…
2020160.50		0	0	0	0	0		1	0	0	0	0	
2020160.51		0	0	0	0	0		1	1	0	0	0	
2020160.52		0	0	0	0	0		1	1	1	0	0	
2020160.53		0	0	0	0	0		1	1	1	1	0	
2020160.54		0	0	0	0	0		1	1	1	1	1	
2020160.55		0	0	0	0	0		1	1	1	1	1	
2020160.56		0	0	0	0	0		1	1	1	1	1	
2020160.57		0	0	0	0	0		1	1	1	1	1	
2020160.58		0	0	0	0	0		0	1	1	1	1	
2020160.59		0	0	0	0	0		0	0	1	1	1	
2020160.60		0	0	0	0	0		0	0	0	1	1	
2020160.61		0	0	0	0	0		0	0	0	0	1	
2020160.62		0	0	0	0	0		0	0	0	0	0	
2020160.63		0	0	0	0	0		0	0	0	0	0	
2020160.64		0	0	0	0	0		0	0	0	0	0	
…													

Table 4: Example tours.

Spreading the workload across treatment rooms of the same grade

A perturbation, α, is introduced to encourage the solver to use tr03, for example, for every other time slot and tr04 in the other, Table 5. The perturbation is introduced into the objective function as a multiplier to the decision variable.

Treatment	**Slot**										
Room	0	1	2	3	4	5	6	7	8	9	10
tr01	1.01	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.01	1.00	1.00
tr02	1.00	1.01	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.01	1.00
tr03	1.00	1.00	1.01	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.01
tr04	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.01	1.00	1.00	1.00

Table 5: Perturbation to spread workload across treatment rooms.

Perturbing the benefit to encourage the solver to leave higher grade treatment rooms open

It is desirable to leave higher symptom grade rooms available for those needing such treatment rooms. Although it is permissible to treat a flu patient in a grade 4 trauma treatment room, it is better to keep such a room open for patients who may need the facility of a trauma treatment room.

A simple perturbation is introduced into the objective function (Table 6).

Treatment Room	Patient (with symptom grade)				
(with room grade)	py01 (1)	pt02 (4)	pt03 (3)	pt04 (3)	pt05 (4)
tr01 (1)	1.00	0.00	0.00	0.00	0.00
tr02 (3)	0.98	0.00	1.00	1.00	0.00
tr03 (4)	0.97	1.00	0.99	0.99	1.00
tr04 (4)	0.97	1.00	0.99	0.99	1.00

Table 6: Perturbation to encourage using most appropriate treatment room.

For example, patient pt04, a patient with grade 3 symptoms, cannot be seen in tr01, a grade 1 treatment room. pt04 ideally can be seen in tr02, a grade 3 treatment room. The patient can be treated in tr03 or tr04, but the solver is encouraged to avoid this assignment by degrading the benefit to 99 percent of its value.

The perturbation, β, is 0.99^(room grade – symptom grade). If the result is greater than 1, β is set to 0.

Mathematical Expression of the Problem

Let Z be the objective to be maximized,

α the room perturbation to encourage distributing patients across rooms of same grade,

β the benefit perturbation to encourage assigning patient to appropriate grade room,

B the benefit to be realized for a patient / slot combination,

J a binary variable to assure patient is assigned to a unique room,

K a binary variable to assure patient is assigned to unique tour during treatment,

L a binary variable to assure patient is treated only once,

M the patient symptom grade,

N the room grade, and

x the binary decision variable.

The problem to be solved is:

$$maximize\ Z = \alpha_{rt} \times T_{prst} \times \beta_{pr} \times B_{ps} \times x_{prst} \quad (1)$$

Subject to:

$$\sum_r x_{prst} \leq 1\ \forall\ p, s, t \quad (2)$$

$$M_p \times x_{prts} \leq N_r\ \ \forall p, r, s, t \quad (3)$$

$$\sum_r J_{pr} \leq 1\ \forall p \quad (4a)$$

$$x_{prst} \leq J_{pr}\ \forall\ p, r, s, t \quad (4b)$$

$$\sum_{p,t} K_{prts} \leq 1\ \forall\ t, s \quad (5a)$$

$$x_{prts} \leq K_{prts} \forall p, r, s, t \quad (5b)$$

$$\sum_t L_{pt} \leq 1 \forall p \quad (6a)$$

$$x_{prts} \leq L_{pt} \forall p, r, s, t \quad (6b)$$

(1) Is the objective function.

(2) Places a patient in only one room.

(3) Places a patient in an allowable treatment room.

(4a) and (4b) Place a patient in a unique room.

(5a) and (5b) Assure patient only appears in one tour.

(6a) and (6b) Assure patient stays in one tour.

Optimal Solution to Small Hospital with Five Patients

By Patient Arrival Time: The start slot increments by 15-minute intervals or 0.01 days. See Table 7 and Table 8.

Patient	**pt01**	**pt02**	**pt03**	**pt04**	**pt05**
Treatment Room	**tr01**	**tr03**	**tr02**	**tr03**	**tr03**
2020160.50	1	1	1		
2020160.51	1	1	1		
2020160.52		1	1		
2020160.53		1	1		
2020160.54		1			
2020160.55		1			
2020160.56		1			
2020160.57		1			
2020160.58					
2020160.59					
2020160.60				1	
2020160.61				1	
2020160.62				1	
2020160.63				1	
2020160.64				1	
2020160.65				1	
2020160.66				1	
2020160.67					
2020160.68					
2020160.69					
2020160.70					1
2020160.71					1
2020160.72					1
2020160.73					1
2020160.74					1
2020160.75					1
2020160.76					1
2020160.77					1

Table 7: Five patient solution by patient arrival time

By Treatment Room Usage

Treatment Room	tr01	tr02	tr03		
Patient	pt01	pt03	pt02	pt04	pt05
2020160.50	1	1	1		
2020160.51	1	1	1		
2020160.52		1	1		
2020160.53			1		
2020160.54			1		
2020160.55			1		
2020160.56			1		
2020160.57			1		
2020160.58					
2020160.59					
2020160.60				1	
2020160.61				1	
2020160.62				1	
2020160.63				1	
2020160.64				1	
2020160.65				1	
2020160.66				1	
2020160.67					
2020160.68					
2020160.69					
2020160.70					1
2020160.71					1
2020160.72					1
2020160.73					1
2020160.74					1
2020160.75					1
2020160.76					1
2020160.77					1

Table 8: Five patient solution by treatment room usage.

A Large Hospital with Thirty Patients

Treatment Rooms

Treatment Room	Grade
tr01	1
tr02	1
tr03	2
tr04	2
tr05	3
tr06	3
tr07	3
tr08	3
tr09	4
tr10	4

Table 9: Large hospital treatment rooms.

Symptom List

Symptom	Grade	Hours to Treat
broken digit	1	0.50
flu	1	0.50
laceration	2	0.75
eye trauma	3	1.00
stroke	3	1.00
chest pain	3	1.75
compound fracture	4	1.00
gunshot	4	2.00

Table 10: Large hospital symptom list.

Thirty patients

Patient	Arrival Time	Symptom
pt01	2020160.00	flu
pt02	2020160.25	chest pain
pt03	2020160.25	stroke
pt04	2020160.26	gunshot
pt05	2020160.27	broken digit
pt06	2020160.50	compound fracture
pt07	2020160.51	eye trauma
pt08	2020160.51	laceration
pt09	2020160.52	stroke
pt10	2020160.52	flu
pt11	2020160.53	flu
pt12	2020160.53	flu
pt13	2020160.54	gunshot
pt14	2020160.54	compound fracture
pt15	2020160.55	gunshot
pt16	2020160.55	broken digit
pt17	2020160.56	chest pain
pt18	2020160.56	compound fracture
pt19	2020160.57	chest pain
pt20	2020160.57	laceration
pt21	2020160.58	eye trauma
pt22	2020160.58	broken digit
pt23	2020160.59	compound fracture
pt24	2020160.59	chest pain
pt25	2020160.60	stroke
pt26	2020160.60	flu
pt27	2020160.61	laceration
pt28	2020160.61	chest pain
pt29	2020160.62	chest pain
pt30	2020160.62	stroke

Table 11: Large hospital arriving patients.

Optimal solution for large hospital with thirty patients

Treatment Room	tr01				tr02		tr03			tr04		tr05				tr06			tr07			tr08		tr09			tr10			
Patient	pt01	pt12	pt22	pt26	pt05	pt10	pt11	pt20	pt27	pt08	pt16	pt07	pt17	pt24	pt30	pt02	pt19	pt25	pt09	pt21	pt28	pt03	pt29	pt04	pt13	pt18	pt06	pt14	pt15	pt23
2020160.49	1				1					1		1				1			1			1		1			1			
2020160.50	1				1					1		1				1			1			1		1			1			
2020160.51										1		1				1			1			1		1			1			
2020160.52												1				1			1			1		1			1			
2020160.53																1								1						
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2020160.70			1					1					1				1			1						1		1		
2020160.71			1					1					1				1			1						1		1		
2020160.72								1					1				1			1						1				
2020160.73													1				1			1						1				
2020160.74													1				1													
2020160.75													1				1													
2020160.76													1				1													
2020160.77																														
2020160.78																														
2020160.79																														
2020160.80				1					1					1				1			1		1							
2020160.81				1					1					1				1			1		1							1
2020160.82									1					1				1			1		1							1
2020160.83														1				1			1		1							1
2020160.84														1							1		1							1
2020160.85														1							1		1							
2020160.86														1																
2020160.87																														
2020160.88																														
2020160.89																														

2020160.90																														
2020160.91															1															
2020160.92															1															
2020160.93															1															
2020160.94															1															

Table 12: Optimal solution for large hospital with thirty patients.

Scalability

The problem is of order O(number of patients)^2. The number of patients affects the memory needed and the solution time.

Conclusion

The assigning of patients to treatment rooms in a large-scale emergency department is a challenging task for an informal triage-counselor-driven system. A formal computer assignment system can be more efficient and provide more adequate assignments when an ED has many patients and many treatment rooms. Using binary programming, we develop a computer-centered treatment assignment system that considers several patient characteristics and treatment room attributes to assign patients to appropriate treatment rooms. The optimal outcome is the one that is most beneficial to the patient and most efficient for the ED.

Since large scale EDs have a diverse mix of patients and various types of treatment rooms, we incorporate patient and treatment room attributes in generating patient-treatment room assignments. Upon admission to the ED, a patient is given a symptom grade, ranging from low grade (flu-symptoms), to high grade (full trauma), and assigned an arrival time. Treatment rooms are classified according to which patient symptoms that it is equipped to treat. For example, a low-grade symptom can be treated in any treatment room, however, a high-grade trauma can only be treated in a specialized treatment room. The goal is to assign patients to the most appropriate treatment rooms, while minimizing patient wait time and maximizing use of treatment rooms.

The optimal outcome is to maximize the “benefit” for both the patient and the ED. The benefit is a function of patient wait time and symptom grade, as well as treatment room usage. The benefit will increase when patients have shorter wait time and higher-grade symptoms are treated before lower grade symptoms. The goal is to schedule patients to a treatment room as close to their arrival time as possible, but at the same time, not using an inadequate treatment room. An inadequate treatment room occurs when a high-grade symptom is assigned to low grade symptom room because all high grade symptoms rooms are occupied with low grade symptoms. While patient arrival time and symptom grade are components of the benefit, treatment room usage also contributes to the benefit. For example, EDs prefer to not leave treatment rooms idle while patients are waiting to be assigned to a treatment room. However, the ED also doesn’t want to assign a low grade symptom to a high grade symptom room as a means to reduce patient wait time, because a high grade symptom may arrive and be forced to be treated in an inadequate low grade symptom room because of unavailability of high grade rooms.

Our model provides an optimal solution to assigning patients to ED treatment rooms. The benefit curve is maximized when patients are assigned to an appropriate treatment room based on their symptom grade and in an adequate time frame, while treatment room utilization is maximized. The results suggest that a more formal computer assignment system, relative to an informal triage-counselor-driven system, can generate large gains in ED efficiency and patient benefits.

Reference

1. Cardoen B, Demeulemeester E, Belien J (2010) Operating room planning and scheduling: A literature review. European Journal of Operational Research 201(3): 921-932.
2. Adan IJBF, Vissers JMH (2002) Patient mix optimization in hospital admission planning: A case study. International Journal of Operations and Production Management 22(4): 445-461.
3. Wullink G, Van Houdenhoven M, Hans EW, et al. (2007) Closing emergency operating rooms improves efficiency. Journal of Medical Systems 31: 543-546.
4. Gordon T, Lyles A, Fountain J, et al. (1988) Surgical unit time utilization review: resource utilization and management implications. Journal of Medical Systems 12(3): 169-179
5. Childers CP, Maggard-Gibbons M (2018) Understanding costs of care in the operating room. JAMA Surgery 153(4): e176233-e176233.
6. Blake JT, Donald J (2002) Mount Sinai hospital uses integer programming to allocate operating room time. Interfaces 32(2): 63-73.
7. Blake JT, Dexter F, Donald J (2002) Operating room managers' use of integer programming for assigning block time to surgical groups: a case study. Anesthesia & Analgesia 94(1): 143-148.