Decision Support System for the Hospital's Departments: Using Armchairs as Sub-Servers

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Abstract—**The aim of this paper is to present a method and a software program that are designed to help decision makers to plan, reorganize and relocate resources in the hospitals' hospitalization departments. When planning the hospitalization departments layout, the decision maker faces many various problems, that are further emphasized when taking into account budget limitations and space limitations. In this paper we propose a queueing theory-based method for addressing this problem. We deal with a fixed area available for placing resources in the department and consider various scenarios and strategies in order to gain insights that will help the decision makers within this area. A software was written using MATLAB, to generally construct all the balance equations for each scenario, with additional abilities that will allow to decide on the space, available capacity, costs and the specific arrival rates characterizing each department.**

I. INTRODUCTION

Resource allocation in hospitals is a field of operation research (OR) that keep increasing in the last decades [1], while the real-life resource problems have become more acute as hospitals all around the world face a lot of very strict budget limitations. In this paper we present a queueing theory method and tool that can help the decision maker to deal with those limitations. We define a general queueing network of resources that are used by the hospital's patients with arrivals rates and costs for each resource. The resources' costs are not only addressed from budgetary perspective but also from available space perspective. A good example for these both perspectives is the option to add treatment armchairs to the hospitalization department. In many departments and hospitals, decision makers understood that they could improve the patients' efficient arrival rates (i.e., the number of patients that enter the department) by adding treatment armchairs [2]. From queueing theory point of view, those armchairs play the role of sub-servers to the main-servers - the treatment beds. In contrast to the treatment beds, the armchairs are not optimal for all patients, while some patients may prefer them: in terms of functionality beds can be used by all patients while armchairs not. As a result, both servers have different arrival and service rates.

As stated above, the problem of planning and reallocating resources for hospitalization departments is still hard to be addressed optimally in real-life application. To do so, we added another function to our method which is ”additional space” that is made available for the decision maker to add resources to. For example, a department can decide that a specific room (or a new area) can be used as a Fast-Track [3] and filled with armchairs instead of treatment beds that take more space from the department. In the software presented in section III. we give the option to compare different strategies for the benefits of the decision maker. We checked the data and structure from a real department and compared three strategies:

A. *Strict strategy*

In this strategy we have only one opportunity to allocate or reallocate the resources addressed. This strategy is the most common used strategy since most departments were planned to be able to deal with crowding for several years planning range, while the arrival rates increased more than expected. Another reason making this strategy so commonly used is the fact that the addition of a decision maker to the department will induce large costs as well as the resources reallocation costs (transporting of beds/armchairs and renting fees).

B. *Semi-flexible strategy*

This strategy can be observed in many plans for dealing with crisis and emergencies situations. When crisis (as an earthquake, flood or even war) occurs, more resources are transferred to a proper department or area of the hospital. This strategy can also be used for more predictable situations to increase the service quality and the effective patients' arrival rates. For example, when signs of flu epidemics are seen, it is possible to change the structure of the departments in order to get ready for arrival rates that are different from the regular ones and even to assign specific area for patients with flu. When the transportation and renting costs of the resources are low enough, it is possible to use this strategy for periods of weeks, days and even shifts.

C. *Fully-flexible strategy*

For the best of our knowledge, this strategy is not being used in real-life due to the causes mentioned above, as frequent changes will normally cost too much. We check this strategy for different costs in order to achieve insights that eventually can make it feasible for application in real-life departments. As will be discussed in section IV, some special scenarios can make this strategy feasible for real-life application. An example of one optional scenario, for better understanding, is a case where two adjacent departments can help each other so the resources costs will be lower this case makes this strategy feasible.

II. PROBLEM FORMULATION

The structure of the problem is a queueing network where each node, $p_{a,b}$, is the probability of an optional situation of resources being used, in this case armchairs, $a = 1, \ldots, A$, and beds, $b = 1, \ldots, B$. Each arc that is directed away from the beginning of axes contains the arrival rates denoted as λ_a and λ_b for armchairs and beds respectively. As described in Figure 1, at maximal capacity of armchairs their patients will be directed to the same treatment as the beds patients' arrival rate. All arrival rates are considered to be Poisson, as it is a common assumption regarding health-care in OR literature. Opposite to the arrival rates, the service rates (μ_a and μ_b) remain the same as in a common queueing network (Figure 1); the reason why is that we assume that after being assigned to a bed, the patient gets the same treatment as the other patients that were already assigned to beds. This assumption fits most of the real-life scenarios.

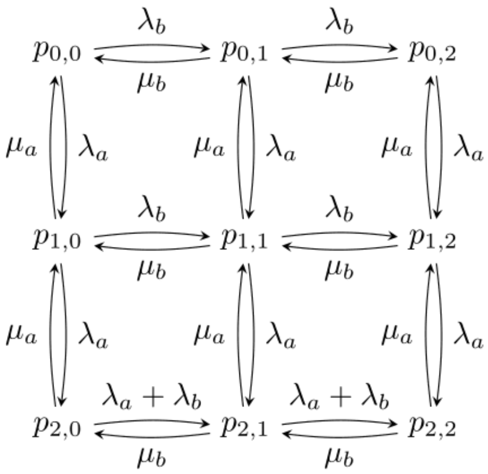

Fig. 1. Arrival (λ) and service (μ) rates for armchairs' patients (a) and for beds' patients (b)

The structure mentioned and shown in Figure 1 can be referred as the basic state. This state fits the strict strategy and is, in fact, a general queueing network for every regular hospitalization department. In addition to the basic state we consider an additional area that expands the area of the department and in which the decision maker can bring more beds or armchairs for treatment. This addition expands the above network and is influenced by the tradeoff between beds and armchairs. In Figure 2 we take the basic state (which describes a department with 2 armchairs and 2 beds) and consider an additional area that can fit for 3 armchairs or 1 bed and 1 armchair (the assumption being in this case that one bed takes the same space as 2 armchairs).

For clearer understanding of how the network expands with the addition of more resources we drew, in Figure 3, the nodes network for 15 beds and 5 armchairs in the basic state with additional area of 7 units (armchairs) with ratio of 2 armchairs per bed. The red nodes represent situations where only beds were added and the blue nodes are situations where only armchairs were added. The green nodes right triangle represents the situations where both beds and armchairs were added to the department area, its right angle arising from the tradeoff between beds and armchairs.

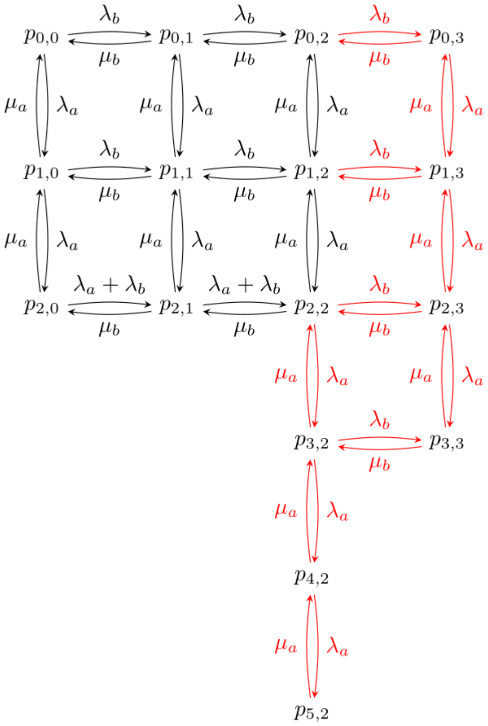

Fig. 2. The expanded state network

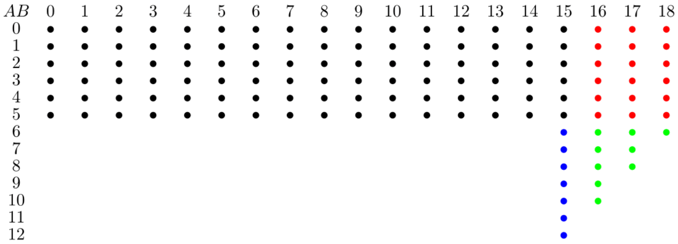

Fig. 3. Nodes network for the expanded state

III. SOFTWARE APPLICATION

In order to provide the decisions makers with an efficient tool, we programmed the above method using a standalone software, written in MATLAB R2013a. MATLAB is a well-known numerical computing environment with a corresponding programing language that allows matrix manipulations, plotting of functions, interfacing with programs written in other languages and finally, built-in user interfaces maker. All the benefits mentioned have made MATLAB the best environment for programing the problem we are dealing with. The main issue we dealt with was the need to keep this problem general. There're many kinds of simulation software that can give insights for this problem with specific settings, but our choice provides the end-user with an easier and faster decision-making support tool.

To keep the problem general, a simple search algorithm was built to find the correct probabilities that will correspond exactly with the balance equations and will keep the total probability of the entire network at 100%. First, we generate matrix of 1 and 0, where the value 1 is given if node a, b is feasible (is part of the basic or expanded states). Then the algorithm rapidly reduces the first node, $p_{0,0}$, and then calculates all the balance equations in a way that goes from the nearest nodes to $p_{0,0}$ to the farthest ones. The pseudo code is shown in Algorithm 1, It is clear from the code that no attempt was made to speed up the running process of the algorithm at this time, since we deal with relatively small numbers that can be quickly calculated by modern computers. After achieving the right probabilities for all the nodes, additional calculations are made to get the effective arrival rate for both types of patients, average time in the department, beds and armchairs efficiency and the additional costs caused by a flexible strategy. Note that strict strategy is on when there is no added space.

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Input: $A$, $B$, $B/A$ ratio, Additional space. $\lambda_a$, $\lambda_b$, $\mu_a$, $\mu_b$, search intervals
Initialization: ($A$+Space) on ($B + \frac{Space}{ratio}$) matrix of zeros
foreach $p_{a,b}$ do
    if node $p_{a,b}$ is in the basic or the expanded state then
        $p_{a,b} = 1$
    end
end
while $\sum P_{a,b} > 1$ do
    $p_{0,0} = p_{0,0}$−Search intervals
    for all feasible nodes part of $p_{0,0}$ do
        Calculate all balance equations in an order that moves away from $p_{0,0}$
    end
end
Output: approximate probabilities for all feasible situations in the department
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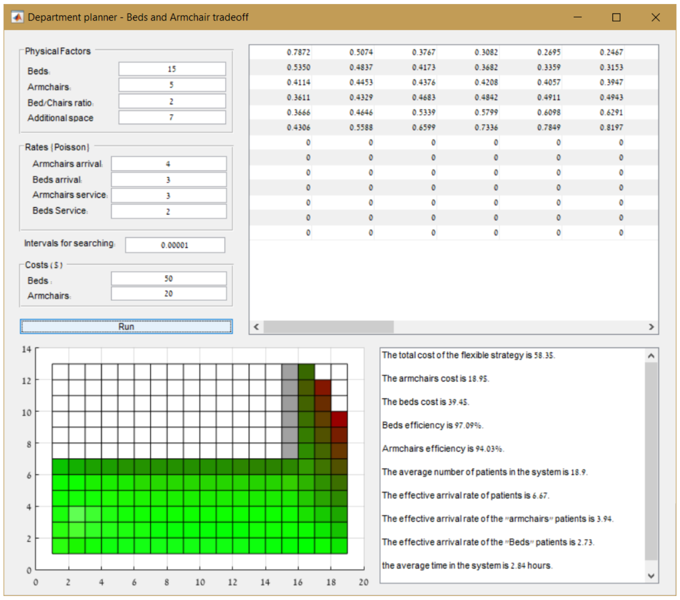
Algorithm 1: Initialize and search for the approximate probabilities of all feasible situations

The user interface was made as simple as possible, as show in Figure 4. On the upper left size there is the user's control panel, where he can type an input for the physical factors (number of beds and armchairs in the department, available added area and the tradeoff between beds and armchairs), the arrival and service rates for both types of patients, the size of the search intervals and the additional costs. On the bottom left there is a probability map, showing in green the situations that are not likely to occur and in red the situations with high probability. On the bottom right there is the output report of the algorithm that includes total and separate costs, resources efficiency, average number of patients in the system and their effective arrival rates (both and separated) and the average time in the system.



Physical Factors
Beds: 15
Armchairs: 5
Bed/Chairs ratio: 2
Additional space 7

Rates (Poisson)
Armchairs arrival: 4
Beds arrival: 3
Armchairs service: 3
Beds Service: 2

Intervals for searching: 0.00001

Costs ($)
Beds : 50
Armchairs: 20

0.7872	0.5074	0.3767	0.3082	0.2695	0.2467
0.5350	0.4837	0.4173	0.3682	0.3359	0.3153
0.4114	0.4453	0.4376	0.4208	0.4057	0.3947
0.3611	0.4329	0.4683	0.4842	0.4911	0.4943
0.3666	0.4646	0.5339	0.5799	0.6098	0.6291
0.4306	0.5588	0.6599	0.7336	0.7849	0.8197
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

The total cost of the flexible strategy is 58.35.

The armchairs cost is 18.95.

The beds cost is 39.45.

Beds efficiency is 97.09%.

Armchairs efficiency is 94.03%.

The average number of patients in the system is 18.9.

The effective arrival rate of patients is 6.67.

The effective arrival rate of the "armchairs" patients is 3.94.

The effective arrival rate of the "Beds" patients is 2.73.

the average time in the system is 2.84 hours.

Fig. 4. The software's user interface

IV. STRATEGIES COMPARISON

In order to applicate our method and software we combined the data regarding the structure of an emergency department from a public hospital in Israel and that from a report published by the Israeli ministry of health [4] that includes values about arrival and service times. Using this data, we built profile of this specific department and run the software in different settings to gain insights about its current situation and the possibilities for improvement. For our purposes, only the acute section of the emergency department is important. As shown on Figure 5 inside the acute section there is a room with additional area available for more beds / armchairs. This area is usually used in times of crisis, similarly to the semi-flexible strategy as mentioned in section I. From the ministry of health's report, we found out that the general arrival rate to the department is 6.58 patients per hour with approximately 60% of non-urgent cases which can be referred to here as armchairs' patients. Service rates were determined with the same method, the general service rate at the department is 4.02 patients per hour.

Our first intention was to see what the added value of more resources will be and ran the program with different sizes of space, from 0 space (the current situation) to 10 armchairs / 5 beds which is the maximal quantity of resources that can be added to the department, the results are shown in Table I. It is clear from the current arrival and service rates that the department works in a very solid manner, nevertheless when using all the available space the average number of patients being treated per hour will increase by 14% from 14.85 to 16.9 patients per hour. Armchairs efficiency remains approximately the same with the addition of more resources while the bed efficiency will rise moderately due to that fact that when armchair's patient is arriving and there is no armchair he will be treated on a bed. The costs in Table I are calculated from the wholesaler prices; in order to see trends for different strategies, we assume that the costs for the departments are lower if there are unused beds / armchairs in other departments at the hospital.

To get an answer to the question, which strategy is the best for this department situation presented here, we need more actual data considering the costs of adding resources. If the

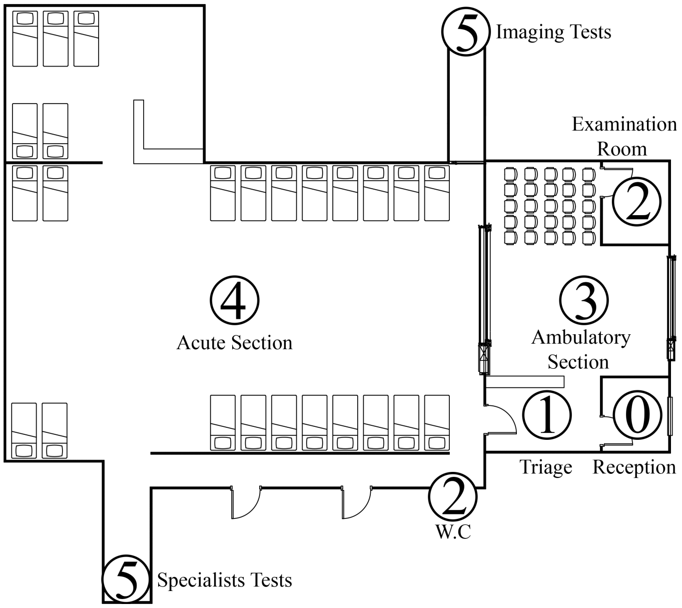


Fig. 5. The department structure

Added resources (units)	0	2	4	6	8	10
Armchairs cost ($)	0	0.24	0.85	1.91	3.41	5.29
Beds cost ($)	0	0.21	0.57	1.03	1.56	2.14
Armchairs efficiancy (%)	98.74	98.76	98.78	98.81	98.78	98.75
Beds efficiancy (%)	94.30	94.44	94.26	94.40	94.45	94.53
Patients in the system	14.85	15.4	15.5	15.9	16.4	16.9

TABLE I. INFLUENCES OF DIFFERENT RATE OF FLEXIBILITY ON THE DEPARTMENT

resources costs are marginal and contain only transportation and no renting costs (as mentioned above), the flexible strategy will yield good results. In that case the only issue is if the medical staff is sufficient for the adding of more patients. If not, semi-flexible strategy will benefit the department, by adding resources when there is enough staff or in time of need (similar to the current situation). The strict strategy is not practiced in this department, but this is not surprising as we deal with emergency department, if it was a hospitalization department, then we would recommend adding more resources in a permanent way.

V. CONCLUSION

We addressed the resource planning and allocation in the hospital's departments from a queueing theory perspective. General network of queues was designed, and a software was programed to quickly solve the network and to give insights to the decision makers. Data about real department was inserted to the software and new insights were made in short time. For a comparison, the construction of a simulation model or the calculations of all the balance equations would take a long time, while our software can do it in seconds. Nevertheless, the software is a basic tool, yet to be further improved and developed. There is still much room for improvement,especially by addition of more types of resources (such as physicians), if not directly to the network, as constraints for the feasible options. Another way to improve is to add more costs and even incomes (from receiving patients etc.). Future research can address this type of improvements, improve the algorithm in the program and even expand this tool to other environments, such as different industries.

ACKNOWLEDGMENT

This research was supported by the Israel National Institute for Health Policy Research NIHP (R/192/2015).

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