Operational Research in the Emergency Medical System of Romania

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The explosive development of the human society in contrast to the limited character of resources determines the need for successful implementation of mathematic models in the decision-making process concerning the use of available resources. One of the critical areas where the need for rigorous criteria for resource allocation is strongly felt is the medical field. This issue appears to be currently affecting the great majority of nations in the world, being considered one of the most important challenges for modern states. The limited amount of resources allocated to the medical system brings forward the importance of optimizing the decision-making process concerning this field using models able to reflect the increasing complexity of the medical system, its interactions with the human society and its dynamics, therefore providing the perturbation control and adjustment instruments. From this point of view, the economical and mathematical modeling of the social phenomena provides strong, elegant and rigorous tools for the description of medical system that appears to be organized as a cybernetic system with a high level of complexity, focused on maximizing the social utility, and allowing the use of cybernetic methods designed for diagnosing, developing automatic medical archives, reducing time consumption and increasing overall efficiency.

Keywords: Markov network, Poisson distribution, cybernetics models, optimal decision, emergency medical system

1 Introduction

The resource allocation issue, especially for key sectors such as the medical one, seems to become more and more of a problem for the great majority of nations in the world. The limited character of resources, those allocated to the medical sector included, points out to the necessity of optimizing the decision-making processes involved in resource allocation based on rigorous methods capable of avoiding unnecessary expense and maximizing social utility.

The high complexity of the medical system and its multiple connections to human society determine the need for careful observation of its functioning and malfunctioning in order to produce the best suitable tools for perturbation control and adjustment.

The use of cybernetic and mathematical models for managing the functionalities of the medical system may lead at first to a mismatch between human expectations and the results achieved by following the path indicated through modeling. However, even these differences may provide useful information for further improvement, so that the medical system may eventually achieve the optimal resource allocation and maximize social utility.

In the pursuit of these goals (optimal utility/resource consumption ratio), cybernetic methods prove their utility for: designing diagnose systems for different clusters of diseases, developing automatic electronic medical archives (capable of minimizing searching times), as well as increasing overall efficiency by limiting waste, while keeping up with the evolution of biocybernetics.

2. The Romanian Medical System in the European Context

Due to Romania joining the European Union, the Romanian medical system started to use the similar structures in the EU as a reference point, which led to the need to increase efficiency by using mathematical methods applied in other European countries. This would be the only way for the Romanian medical system to function as required by the new parameters implied by the efficiency standard implemented by the member states. According to data gathered in order to prove the need for implementing these changes, reforming the medical system using mathematical methods is more than critical, considering that the malfunctioning of the medical systems causes more than 60 000 deaths per year, which is the equivalent population of a small city.

Another challenge for the Romanian medical system is the shortage of medical staff (doctors, dentists, nurses, pharmacists), as compared to the other countries in the EU. Even though in Romania the financial efforts for sustaining almost all types of medical services have recently increased, there is still a general feel of system failure. By comparing the Romanian medical system to those of other European countries, and even by comparing the medical services provided in different regions in Romania, one can easily notice the massive differences in the access to medical services, as well as the gap between the values of most of the medical indicators, all picturing a worrying situation for the health of Romanians.

Romania has the highest mortality rate in the EU for both men and women, and this can be related to the difficult access to medical services of the general population, as well as to the fact that we have the smallest number of doctors, nurses and pharmacists reported to the size of the population. Moreover, in rural areas, where more than half of the population is located, there is even less medical personnel, and almost no functional hospital whatsoever.

According to a study by Ajay Tandon, Christopher JL Murray, Jeremy A. Lauer and David B. Evans in 2000 [0], Romania ranked 99 out of 191 countries in terms of medical system global performance. However, the percentage of the GDP allocated to the health system is not definitory for its efficiency, considering that the USA ranks 37, even if they have the highest percentage of the GDP allocated to health. Still, compared to the European average, Romania allocates to the health system only a third of the amount spent on health by other countries. For instance, in 2010, Romania spent 600 euros per capita, as compared to the 1800 euros per capita which is the European average, and the government only directs 4% of the GDP towards the health system, while in France the percentage is 11% and the European average is around 8%. The difference can be explained by considering the low number of tax payers (only approx. 30% of the total population) and corruption, and it is a direct indicator of the struggle Romania has to put up in order to improve the efficiency of its medical system.

Since 2007, international mobility became even more accessible for Romanians, especially medical staff: almost 10% of the doctors decided to emigrate to countries such as France, Germany or Sweden, allured by the latest medical technologies available there and the high wages, and this percentage is still growing.

Even when it comes to medical equipment, Romania is one of the lowest ranked countries in the EU regarding the use of modern medical technology, being severely underequipped, which brings up even more the necessity to optimize the use of the existing resources, considering the low capacity for budgetary investment in medical technology.

However, almost every nation in the world has yet some challenges to deal with when it comes to the health system: no country has enough resources, money or medical personnel to cover all medical needs. More and more people have to live in fear of getting ill and not being able to access medical care. Therefore, there is a real necessity to improve efficiency of the medical system in order to optimize the use of the existing resources and to meet as

much as possible the demand for medical services.
Beyond the theory of providing public health services and the specific legal frame, a mathematical approach of the issue is also recommended, since the medical system is a good example of a cybernetic system [1], [15], [17], which includes not only complex components, but also dynamic and sensitive interactions that need careful planning.

The Legal Frame For The Functioning Of Emergency Units

Law 95/2006 states that qualified first aid should be provided within:
a) 8 minutes for urban areas, in at least 90% of the cases;
b) 12 minutes for non-urban areas, in at least 75% of the cases.
The emergency medical care service should be organized in such manner that the maximal time for an intervention must not be longer than:
a) **15 minutes**, for emergency and intensive care units in urban areas, in at least 90% of the cases;
b) **20 minutes**, for emergency and intensive care units in rural areas, in at least 75% of the cases.
In order to implement an integrated emergency services management at regional level, all hospitals within the region should be included in a network, each network consisting in one regional first degree emergency hospital and several 2nd and 3rd degree local emergency hospitals. Moreover, the emergency and paramedic services department has to function around the clock in 12 hours shifts.
The mobile intensive care and emergency services provided by **SMURD**[1] have to abide a series of restrictions as well: emergency teams should consist of at least 4 people, including a driver/firefighter and doctor trained in intensive care and traumatology, the rest of the team being supplied by other emergency structures, local authorities and local hospitals, or specially trained volunteers.
Also, according to law, the emergency and first aid structures in charge of the mobile units are responsible for providing functional medical equipment and drugs for the care of at least 20 critical patients.
Order no. 1706/2007 states that:

- County capital cities with less than 500 000 inhabitants have to provide at least one Emergency Unit or Emergency Department within the county hospital. In case there is a regional or county children hospital, it must include a paediatric emergency department.
- Paramedics transporting critical patients have to report the emergency with at least 10 minutes before arriving at the emergency unit and provide all necessary information regarding the medical condition and treatment received by the patient in question.

According to the ***National Triage Protocol***, the medical staff has to evaluate every patient presented to the emergency unit in order to determine the severity of the emergency and the urgency of accessing the medical services of each individual, and the average triage time should be 2 minutes or less. The triage procedure has to take into account two very important parameters:

- The time the patient was registered by the triage personnel;
- The time of the first medical consultation.

Since doctors are tempted to perform thorough examinations, and therefore become unavailable for patients who might need urgent interventions, the triage procedure is performed by other specialized personnel in order to optimize the use of doctors' time.
The National Triage Protocol states that patients registered to the emergency unit have to be sorted in order to be included into one of the following emergency levels:
<u>Level 1 – CPR</u> (code red): special room with life support equipment and defibrillator.

[1] *Mobile Emergency Service for Resuscitation and Extrication*

- The patient requires ***immediate*** life saving intervention.
- Time to be admitted in treatment area: 0 minutes.

<u>Level 2 – Critical</u> (code yellow): first degree emergency room.

- The patient is in severe pain or major disconfort, is of high risk or is in an altered mintal status.
- Time to be admitted in treatment area: 10 minutes.

<u>Level 3 – Urgent</u> (code green): 2nd degree emergency room.

- Stable patient requireing 2 or more of the resources defined in the Triage Protocol.
- Time to be admitted in treatment area: 30 minutes.

In case the time to be taken over by a doctor exceeds 15 minutes or there are changes in the patient's status the triage algorithm is repeated in order to update the procedures necessary for the patient in question.

<u>Level 4</u> – Non-urgent (code blue)

- The patient is stable and requires the use of only one of the resources described in the Triage Protocol.
- Time to be admitted in treatment area: 60 minutes.

<u>Level 5</u> – Consult (code white)

- The patient does not require emergency medical assistance and none of the resources described in the Triage Protocol.
- Includes people coming to the hospital for:
  - ✓ Getting vaccine shots;
  - ✓ Administrative resons such as medical permits, prescriptions etc.;
  - ✓ Social cases without medical complications;
  - ✓ Time to be admitted in treatment area: 120 minutes

In order to avoid overloading the Emergency Unit, the triage area can accommodate some of the medical procedures, so that the time to solve all cases is minimized.

Given all these restrictions and constraints, the need for a resource management algorithm becomes obvious, even more so considering the challenges the Romanian health system has still to deal with.

3. The mathematical model

Since emergency departments always focus on the quality of the medical services they provide, the 4 hour target set for a patient's waiting time is of critical importance, and this raises a problem that still has to be solved properly: how to allocate the human resources in order to meet this target.

The data collected from different emergency departments prove that most of them manage to meet the target and many other are close enough, but considering that lately the number of accidents increased, maintaining this target is still a priority. The so-called staffing algorithm appears to ease the managers' decision-making process regarding the efficient allocation of human resources in order to decrease the waiting intervals.

In all emergency units, the number of patients is a time variable, depending on the time of day, on the day of the week and even on the season (it is expected to have more patients presenting fall-related injuries and broken bones during winter, given the weather conditions). Therefore, the staff allocation differs on various intervals during a day.

The purpose of this research is determining the need for medical personnel (doctors, nurses, lab technicians, triage specialists etc.) for each interval during a day in order to reach the 4 hour target. [0] [0] [0] However, finding the optimal algorithm for such a complex system as the medical one is difficult, since the parameters taken into consideration (especially the patient's arrival time) are not constant. This characteristic was noticed by several specialists and therefore, there are multiple approaches to the matter. Unfortunately, all the approaches so far focused on single service systems, such as call-centers. The allocation of the human resource in an emergency department is much more complex, because of the nature of the medical services: every patient arrived at the emergency unit is submitted to multiple tests, and therefore needs a number of different resources. Moreover, the severity of the case is also an important factor determining the access to certain resources, and resources can be used for more than one patient at a time, which means that, in order to be effective, the allocation algorithm has to take into account all these constraints. The suggested heuristic algorithm uses models based on waiting queues to estimate the amount of resources needed and the loading time for each resource in the system in order to optimize their allocation, while the quality of the medical services is measured through the probability for delays. The model includes a waiting queue M/M/1 with a single serving station [3] [4], with arrivals determined by a Poisson process and an exponential serving time. By using Wolfram Mathematica 9.0, the algorithm is implemented in order to optimize the allocation of doctors, nurses and triage specialists and maximize the number of patients treated.

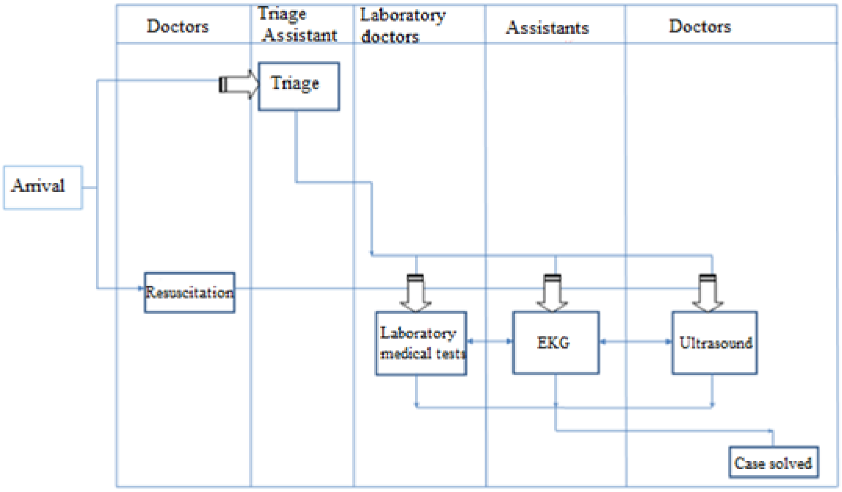


Fig. 1. The possible flow for a patient
(Source: Author prelucration)

According to the Romanian emergency procedures, the patients arrived at the ER are sent to the triage room, where they are sorted (using the National Triage Protocol) by the severity of the case and distributed to the medical disciplines required by their specific situations. This is where the decision regarding further examinations is made, and the patients can be submitted to additional testing, EKG or ultrasound examination. The results of these investigations determines whether the patient will be admitted or discharged. The possible flow for a patient who arrived at the emergency room is represented in Figure 1.

Table 1. *The flow of patients to the emergency room*

	00-04	04-08	08-12	12-16	16-20	20-24	weekly	Percentage per ii		Total / hour
CPR	1	2	3	0	5	4	23	0.02	3	**0.5**
Major emergency 1	64	86	90	60	40	26	374	0.33	53	**8.83**
Major emergency 2	70	42	156	184	164	120	736	0.65	105	**17.5**
Total	**135**	**130**	**257**	**252**	**209**	**150**	**1133**	**1**	**161**	**26.33**

(Source: Author computation)

The table above (table 1) contains data regarding the patient flow at the emergency room within the Bucharest Emergency University Hospital. During the observed interval, the emergency unit registered a total of 1133 patients per week, 161 patients per day and 27 patients per hour, included in three different emergency categories: CPR, Major Emergency type 1 and Major Emergency type 2, in order of decreasing priority. The highest number of patients is registered in the 8-12 interval, followed by the 12-16 interval and the 16-20 interval.

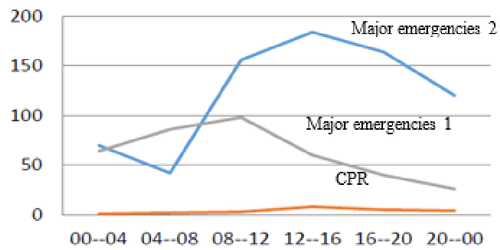
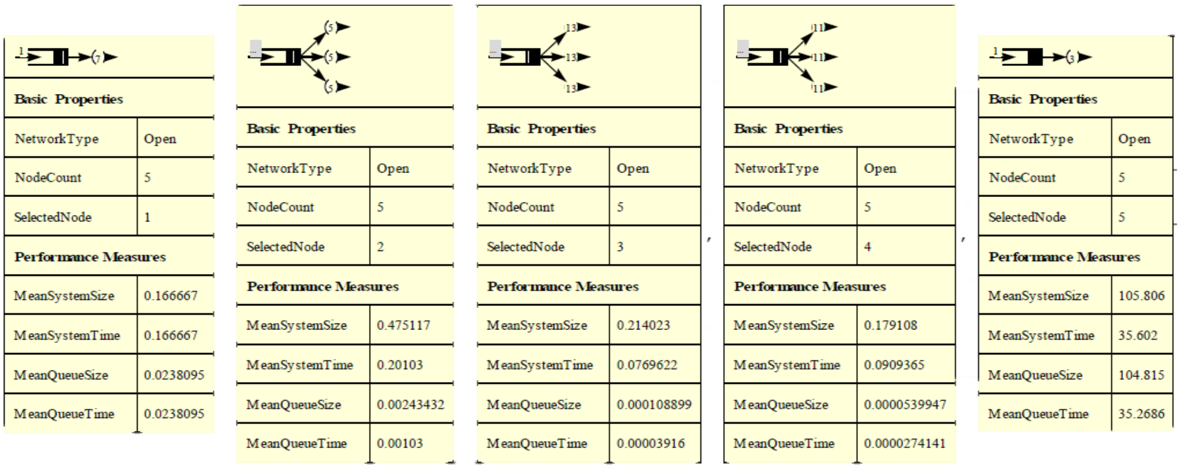


Fig. 2. Variation of the flow of patients by hourly intervals
(Source: Authors computation)

The variation of the patient flow during the 24-hour interval



Basic Properties	
NetworkType	Open
NodeCount	5
SelectedNode	1
Performance Measures	
MeanSystemSize	0.166667
MeanSystemTime	0.166667
MeanQueueSize	0.0238095
MeanQueueTime	0.0238095

Basic Properties	
NetworkType	Open
NodeCount	5
SelectedNode	2
Performance Measures	
MeanSystemSize	0.475117
MeanSystemTime	0.20103
MeanQueueSize	0.00243432
MeanQueueTime	0.00103

Basic Properties	
NetworkType	Open
NodeCount	5
SelectedNode	3
Performance Measures	
MeanSystemSize	0.214023
MeanSystemTime	0.0769622
MeanQueueSize	0.000108899
MeanQueueTime	0.00003916

Basic Properties	
NetworkType	Open
NodeCount	5
SelectedNode	4
Performance Measures	
MeanSystemSize	0.179108
MeanSystemTime	0.0909365
MeanQueueSize	0.0000539947
MeanQueueTime	0.0000274141

Basic Properties	
NetworkType	Open
NodeCount	5
SelectedNode	5
Performance Measures	
MeanSystemSize	105.806
MeanSystemTime	35.602
MeanQueueSize	104.815
MeanQueueTime	35.2686

Fig. 3. Output of Performance Measures using Poisson distribution.
(Source: Author computation)

In Figure 3 it is represented the variation of the patient flow during the 24-hour interval. We calculated the network load by determining MeanSystemSize. In the analysis we also took into account the fact that some of the patients are also admitted, thus diminishing the outputs. Thus, the number of medical interventions is 106/4, for one hour. Also, upon leaving the emergency reception network it is found that 105/4 (for one hour) hours of people / hours are waiting to be consulted at different offices. The average waiting time in the network is about 35 minutes and the number of people waiting is 105/4 hours.Based on the statistic data gathered using weekly reports, the average number of people arriving at the emergency room is 28/hour. The interval considered for simulation is 4 hours, since in Romania, reports are filed every 4 hours.

Considering that the events requiring medical response follow a Poisson distribution with an average of 28 and that serving times are exponentially distributed, a network structure can be identified, leading to the processing of approx. 106 people per simulation cycle. Moreover, there are 105 people waiting in the network, the average time for using a node in the network being of 35 minutes/patient.

Aiming to minimize the probability of delays ($\alpha = [1 + \beta \frac{\Phi(\beta)}{\phi(\beta)}]^{-1}$, where ϕ and Φ are the density function, respectively the normal standard distribution function) and considering that in fact it is approx. 50% (50% of the cases are solved within the system), the resulting loading coefficient is 56%.

In order to determine the number of personnel necessary in an ideal situation, a generic network is considered, characterised by Poisson [7] [9] random entries with exponential serving times and variable number of serving stations for the considered intervals. Once registered, a patient can be transferred to any of the medical specialties or can be discharged (either admitted or case solved and discharged), which means that the Romanian medical system appears to be organized as a Markov chain structure with probabilistic flows between the different medical specialties. [13] [14]
Based on the data gathered at the Bucharest Emergency University Hospital, the state transition matrix is:

$$\begin{pmatrix} 0 & 0{,}5 & 0{,}2 & 0{,}3 & 0 \\ 0 & 0 & 0{,}57 & 0{,}13 & 0{,}3 \\ 0 & 0{,}4 & 0 & 0{,}4 & 0{,}1 \\ 0 & 0{,}2 & 0{,}3 & 0 & 0{,}5 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

The medical emergency network includes three major states: a patient demanding medical care is called a potential patient and is identified when entering the system. Anybody entering the system has no possibility of going through it unless it transitions to one of the following states, which explains the transition probability associated to the first column of the matrix (0). The state corresponding to a person transitioning the stations associated to the specialized medical disciplines is the consultation state. Therefore, a person has a 0,5 probability to access the services of the medical lab, 0,2 to enter the EKG room and 0,3 for getting an ultrasound. Anybody entering the system cannot exit without going through at least one of the specialized consultations.
A patient entering the consultation state leaves the medical lab to enter the EKG room with a probability of 0,57, the ultrasound room with a probability of 0,13 or may get discharged with a probability of 0,3, if the case is considered closed by the emergency system. The patient getting an EKG may return to the lab with a probability of 0,4, be transferred to ultrasound with a probability of 0,4 or be discharged with a probability of 0,1.
Because the path the patient follows within the emergency department is rather complex, this is considered the cause for the queues that affect the efficiency of the Romanian medical system.
A patient sent directly to ultrasound may leave the system with a probability of 0,5, but can return to the lab or EKG with a probability of 0,2, respectively 0,3. A patient reaching the final transition state is considered cured (case solved), with no possibility of going back to any of the prior states, situation that is reflected on the bottom line of the matrix, which only contains 0 valued elements.

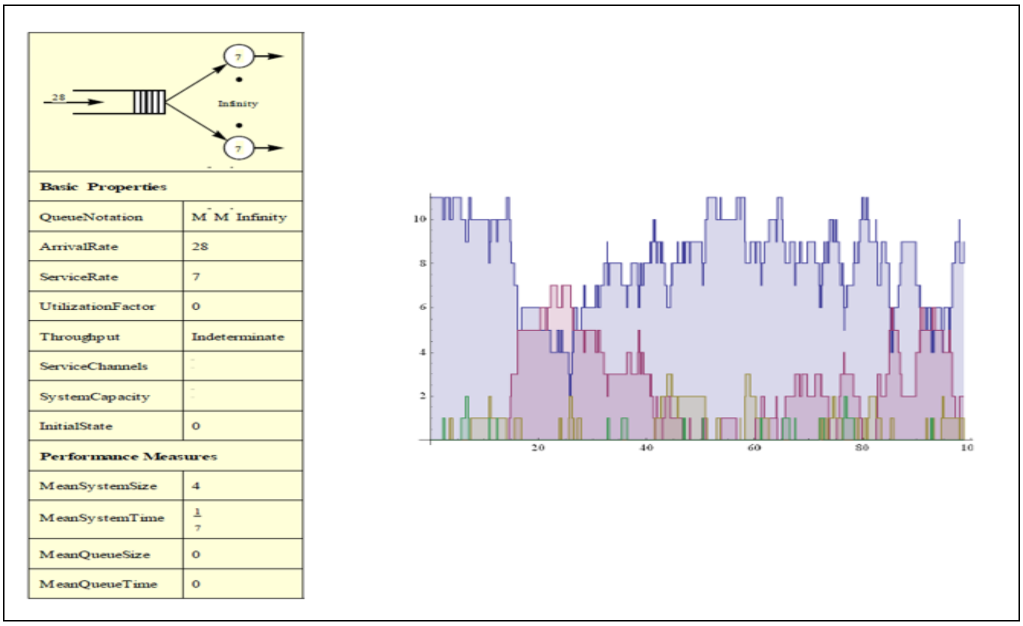


Fig. 4. The distribution of Markov network.
(Source: Author computation)

In Figure 4 s represented the system with infinite number of service stations, the average number of personnel needed is 4. In the graphic representation we simulated on a time horizon of 100 weeks, the allocation of the resources used by the emergency system. The blue line represent the doctors, the purple line are the allocation of the nurses, the yellow line represent the laboratory technicians and the green line is represented by the EKG specialists.As evidenced by a large number of scientific papers and studies, the Markov network structure is generally non-stationary; therefore it can be decomposed in serving networks with deterministic paths, equivalent to the situation of a single serving station with random entries but with unlimited order processing capacity (unlimited number of serving stations).[11] [12] [16]

This is justified by the sorting of patients into groups, by the type of consultation required, which makes the network sequential, with deterministic paths, so that the number of untreated patients is easily calculated by adding up the average unused factor of the station in question.

The ideal allocation of human resources for the emergency system is determined by taking into consideration a queue with an average of 28 entries (patients) per hour, which is equivalent to 112 patients for a 4 hour interval. This way, the system is used to its full capacity, which means that all patients arrived are treated and the average number of specialized consultation rooms in use in the network is 4. Theoretically, within such structure, the number of treated patients is undetermined, this being the ideal situation.

Considering the number of necessary specialists as 4, the model determines the over- and under-load of medical resource for each hour, as a difference between the actual number of doctors existing in the system and the ideal number of doctors necessary at a given time. Over-loading the system leads to an increase of the budgetary costs associated to the system, so this occurrence is penalized with the factor $p^o = 1$. Still, this situation is not that bad, since theoretically a larger number of doctors in the system would consequently mean a larger number of patients treated and an increased efficiency of the medical emergency system. The under-load of the system, on the other hand, means reducing the budgetary costs by reducing the main resource in the system (doctors), which may lead to a diminished efficiency of the system. Therefore, this situation is penalized with the factor $p^u = 2$.

The available human resource is allocated so that the total number of people necessary per shift equals the total number of people allocated on that specific shift. Also, the difference between the variable measuring the overload and the variable measuring the underload should match the difference between the actual situation and the ideal situation resulted from the model. In the specific case of the Romanian medical emergency system, conventionally, the work hours are grouped in three 8-hour shifts. In this particular situation, the differences described above are considered positive (there are more doctors than in the ideal situation), while the maximum value for each resource in the system is considered 100 (maximal number of people available in the ER).

The model considers 49 constraints, the objective function being the minimizing of penalties paid for over- and under-loading the emergency medical system. Considering that the decision variables are whole numbers, the result is a whole number programming case, which can be solved using the Mathematica software. The solution offered by the model is that the first shift should be covered by 23 people, the second by 38 people, while for the third shift, 37 will suffice.

Table 2: *The allocation of the medical staff*

Time frame	00-08	08-16	16-00
Doctors	6	9	8
Nurses	11	25	22
Triage Specialists	4	6	5
Lab Doctors	2	2	2
Total	23	38	37

(Source: Author computation)

Below, we evaluated the number of doctors needed in a system with an infinite number of service stations (equivalent to the ideal emergency system) is 4 doctors if it is considered that the number of patients is 26 per hour.

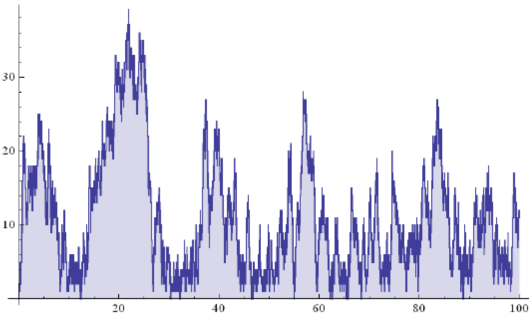


Fig. 5. Evolution of the flow of medical personnel. Simulation of the network in which the number of the patient in 26 and the number of doctors is 4 over a 100 – week horizon.
(Source: Author computation)

The algorithm for determining the necessary human resource consists of 5 steps:

- Step 1: Initialize a = 1;
- Step 2: Calculate parameter P, considering the constraint $= [1 + \beta \frac{\Phi(\beta)}{\phi(\beta)}]^{-1}$, where ϕ and Φ are the density function, respectively the repartition function of the standard normal distribution.
- Step 3: Determine the need for each resource for each specific interval, using the function:
  $s_k(t) = [x + \beta\sqrt{x}]$,
  where $x = m_{\infty}{}^{k}(t)$;
- Step 4: Estimate the percentage of discharged patients based on the resources estimated at step 3.
- Step 5: If the percentage calculated at step 4 is not 98%, a can be increased or decreased and we go back to step 2. Otherwise, STOP and save the solution.

$$\min[p^o \sum_{j=0}^{23} \Delta_j^+ + p^u \sum_{j=0}^{23} \Delta_j^-]$$

$$\sum_{i\in I} p_{ij}x_i = a_j, j = 0,\dots,23$$
$$a_j - s_j = \Delta_j^+ - \Delta_j^-, j = 0,\dots,23$$
$$\sum_{i\in I} y_i \le k$$
$$x_i \le My_i, i \in I$$
$$x_i \ge 0, i \in I$$
$$x_i \ge 0, x_i - integer\ and\ y_i = 0{,}1, i \in I$$
$$\Delta_j^+, \Delta_j^- \ge 0, j = 0,\dots,23$$

$(s_0, s_1, s_2, \dots, s_{23})$ - *levels of resource allocation generated by the algorithm*;

p^o - Penalties paid for each over allocation of the human resource per hour;

p^u - Penalties paid for each underallocation of the human resource per hour;

$\Delta j+$ - overload at hour j, j=0...23;

$\Delta j-$ - underload at hour j, j=0...23;

I - the shift range allowed considering the legal constraints;

xi - the decision variable expressing the number of employees scheduled to work on a shift, $i\varepsilon I$;

$$p_{ij} = \begin{cases} 1 & if\ the\ shift\ i\ includes\ the\ hour\ j\ as\ working\ time \\ 0 & if\ it\ doesn't \end{cases}$$

$$\sum_{i\in I} p_{ij}x_i - the\ total\ number\ of\ employees\ working\ at\ hour\ j, j = 0,\dots,23;$$

M - *A very high number*;

k - The maximal number of shifts;

y_i – Artificial variable - value 1 if at least one employee works on shift i, $i\varepsilon I$;

The suggested heuristic algorithm [8] [10] uses models based on waiting queues to estimate the amount of resources needed and the loading time for each resource in the system in order to optimize their allocation, while the quality of the medical services is measured through the probability for delays.[18]

4. Conclusions

To conclude, by comparing the Romanian emergency system to the British one, the first is found wanting, with a satisfaction level of only 56%, as opposed to 93% for the latter. According to the European standard, a medical emergency system is considered of high quality if it has a 98% quality indicator, which means that it can solve 98 cases out of 100. The Romanian emergency system is also affected by delays, the average time spent by a patient waiting for the different procedures necessary being 35 minutes, as opposed to only 7 minutes which is the European average. Since the main resource used in the emergency system is the human resource, the issue of staff allocation in the emergency departments is a major challenge for many medical systems. In the specific case of the Romanian medical system, it was found, using data gathered in a major Emergency Hospital, that a mathematical model is extremely helpful in determining the necessary human resource per shift, considering multiple factors such as the patient flow per hour and the budgetary constraint.

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