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A Novel Approach based on PSO and Coloured Petri Net for improving Services in the Emergency Department

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Abstract

Congestion in the Emergency Department (ED) is a major problem in the hospital for patients and staff, due to the increased waiting times, length of stay, and medical errors, thus causing great losses to the hospital. Emergency services are essential in society, given the human need for them at any stage of life. The emergency department is characterized by the complex nature of its resources, as it consists of different parts. Many solutions are being proposed in order to solve the numerous problems in the ED, and to improve the quality of service. Researchers rely on many techniques such as optimization algorithms, simulations, data mining, and other methods to solve congestion. In this research, an approach based on PSO algorithm and coloured Petri net has been proposed. The emergency department is modelled using a coloured Petri net, and PSO algorithm is used to determine the human resources. Based on the results, the simulation model is modified, restarted, and the results are compared with the Benchmark model. This research helps decision makers in the ED to find appropriate solutions for human resources.

Keywords: Emergency department, Coloured Petri Net, PSO, simulation, optimization.

1. Introduction

The Emergency Department (ED) plays a major role in healthcare, as it treats most patients from their arrival to their discharge or transfer to another department. Recently, the increase in emergency cases has led to overcrowding, which has caused great pressure on emergency departments and has made the task of medical staff difficult. In addition, a number of patients with non-critical conditions are heading to the ED [11]. The problem of overcrowding is a common problem in the ED, resulting in several reasons, including the lack of material and human resources. Among the solutions that the ED may rely on is the raise in

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the number of resources, but this solution remains expensive, and other ways must be sought to improve the quality of services in the ED [10]. Simulation is an effective tool for modeling and optimizing ED operations and complex systems. For good control of resources, a methodology that includes the simulation of discrete events is used. These methodologies greatly support the decision-making process [7].

This research presents an approach based on Coloured Petri net and PSO algorithm, and the objective of this work is to model and improve the processes that occur in the ED. To determine the appropriate number of resources, genetically modified algorithms are relied on. Using this approach, decision makers are given several nearly ideal solutions, through which the Length of Stay (LOS) and waiting time of patients are reduced. The rest of this article is ordered as follows. In section 2, some research that have been done on ED are listed. Section 3 contains the suggested approach, and the final section summarizes the conclusion and future solutions.

2. Literature Review

The field of healthcare has received intense attention in the past decades, especially in cases of ED [13]. Medical service in the ED is an emerging specialty in the field of modern medicine, but research in it remains under qualitative analysis [9]. Interest in simulation and improvement in the field of healthcare systems is not new [8], as many researchers have focused on solving many problems in the ED [2]. Improving and supporting the decision-making process in EDs is very important for hospitals and patients [5]. To reduce congestion in the ED, [16] suggested a algorithmic approach based on the "floating patients" method, in which some patients are sent to other hospital departments instead of being treated in the ED. The decision-making process in the emergency department is rather difficult, and for this reason, Fábio [14] suggested an approach based on the Decision-Making Trial and Evaluation Laboratory method. The aim was to raise the level of services provided by the emergency department management.

Another approach proposed by Elpidio[15] was based on simulation based on dynamic and continuous logics, and the aim of which was to provide a decision support tool that contributes significantly to the improvement process. The simulation method has a major role in the process of improvement in the ED, hence Muhammet [6] made a presentation that explained the importance of simulation and its role in finding solutions. In light of the lack of real information for the ED, some researchers resort to other methods. In this context, Zheng

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[12] proposed an agent-based model, the aim of which was to obtain data, through which the best values for the model parameters are deduced. Reducing the waiting time for the patient is very important, but the optimal use of the material and human resources of the ED must be taken into account. For this purpose, Fabio [4] proposed an approach based on simulation and an ant colony algorithm, the aim of which was to strike a balance between staff working times and optimal use of medical facilities.

3. The proposed approach

3.1 ED mathematical model

In this research, a mathematical model is proposed to solve the problem of the length of stay of the patient in the ED and reduce the waiting time. Firstly, the parameters used in the mathematical model are defined and then used in the proposed algorithms. The objective function is constructed to determine the relationship between available resources and time spent in the ED.

3.1.1 Parameters:

Table 1. Mathematical Model Parameters

PARAMETER	DESCRIPTION
P	No. of patients
k	Index of a patient; k = 1, 2,…, P;
T[k]	A table containing the time each patient spends at the resource Rr
R	Resources available to the patient (Triage, medical consultation, nursing consultation, etc.), for example: R[r] =R[1]=3 means there are 3 nurses.
r	Index of a resource; k = 1, 2,…., P; (r=1(Triage), r=2(medical consultation), etc.).
Dr	The duration the patient Tk spends in resource Ri.
Dk	The duration the patient Tk spends on the Ri resource, including waiting time (Dk+1= Dk+Dr).
S	Total time for all patients relative to resource Rr (S=SOME (Dk)).
Mr	The average length of stay for a patient in the resource Rr (Mr=S/k).

3.1.2. The proposed TIME_Rr algorithm

The TIME_Rr algorithm calculates the average amount of time spent by the patient in a certain stage, and the algorithm takes two inputs: the number of resources in each stage of ED (Rr), and the duration the patient spends in each resource (Dr).

Algorithm TIME_Rr

```
Input: Rr, Dr
For k = 1: (P divide Rr)
      Dk = Dk +Dr
            For k = 1: Rr
                    T[k]= Dk
                    k=k+1
           END
  END
  if P mod Rr ≠ 0
        Dk = Dk +Dr
  END IF
  For k = 1: (P mod Rr)
        T[k]= Dk
        k=k+1
  END
  For j = 1: P
       S = S+ T[j]
  END
  Mr = S/P
Output the Mr
Output: Mr (average length of stay for a patient in resource Rr)
```

3.1.3. Objective function:

Many researchers focus on many solutions for the improvement process in the ED, and most of these work to reduce the duration of the patient's stay in the ED. In this research, the following objective function is proposed.

$$Min\ LOS = \sum_{r=1}^{R} \text{TIME\_Rr}(\text{Rr}, \text{Dr})$$

The objective of the objective function is to find the lowest value for LOS, taking into account the available resources.

3.2. ED simulation model

Simulation contributes greatly to improving processes in ED. Thus, creating a simulation model for the ED will be very useful for evaluating various scenarios. Simulation models have been frequently used to model operations in EDs [3]. In this work, the ED is modeled using coloured Petri net. The simulation model was created after a good study of the behavior of the system, and with the help of the medical and administrative staff. The coloured Petri net is used to model complex and simultaneous systems. By using the coloured Petri net, an executable version of the system can be obtained. The simulation model is represented in Figure 1. The model includes all the basic stages of triage, reception, and medical observation. In the model, all possible places where the patient might be, according to the condition in which he is, are noted. It is noticed in the model that places are characterized by the PATIENT colour set. The last one contains attributes needed to calculate the duration of operations in the most important stages, in addition to waiting times and the total length of stay. It is also explained in the form the functions of the transitions. Figures 2 and 3 show the subpages for critical and non-critical state, respectively.

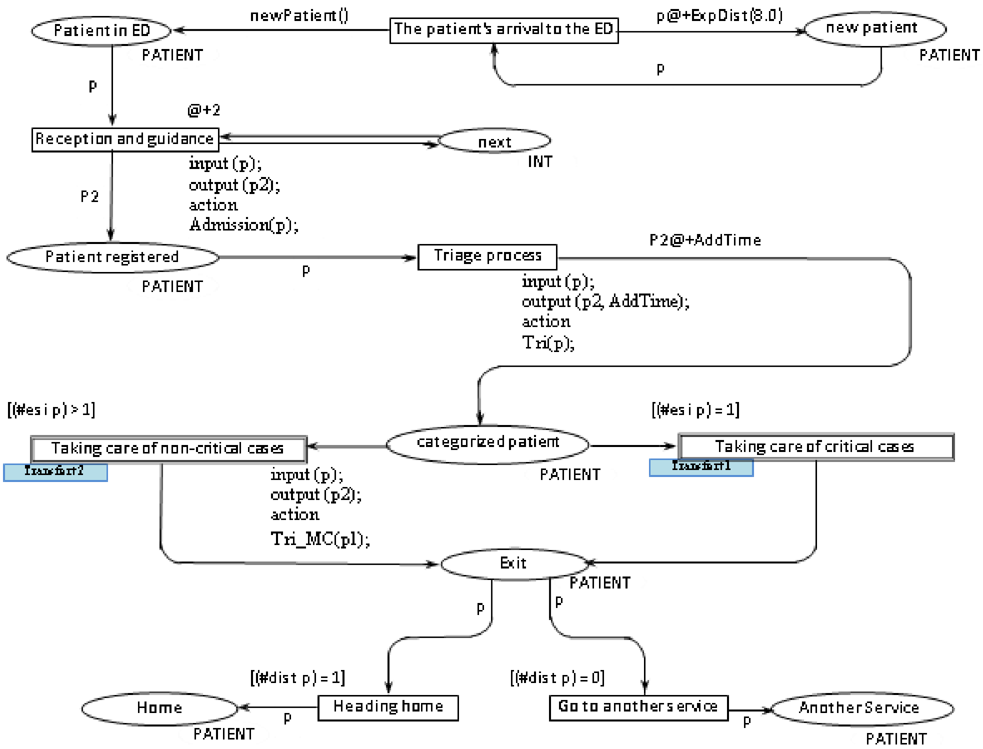

Figure 1. Main page of ED simulation model using coloured petri net

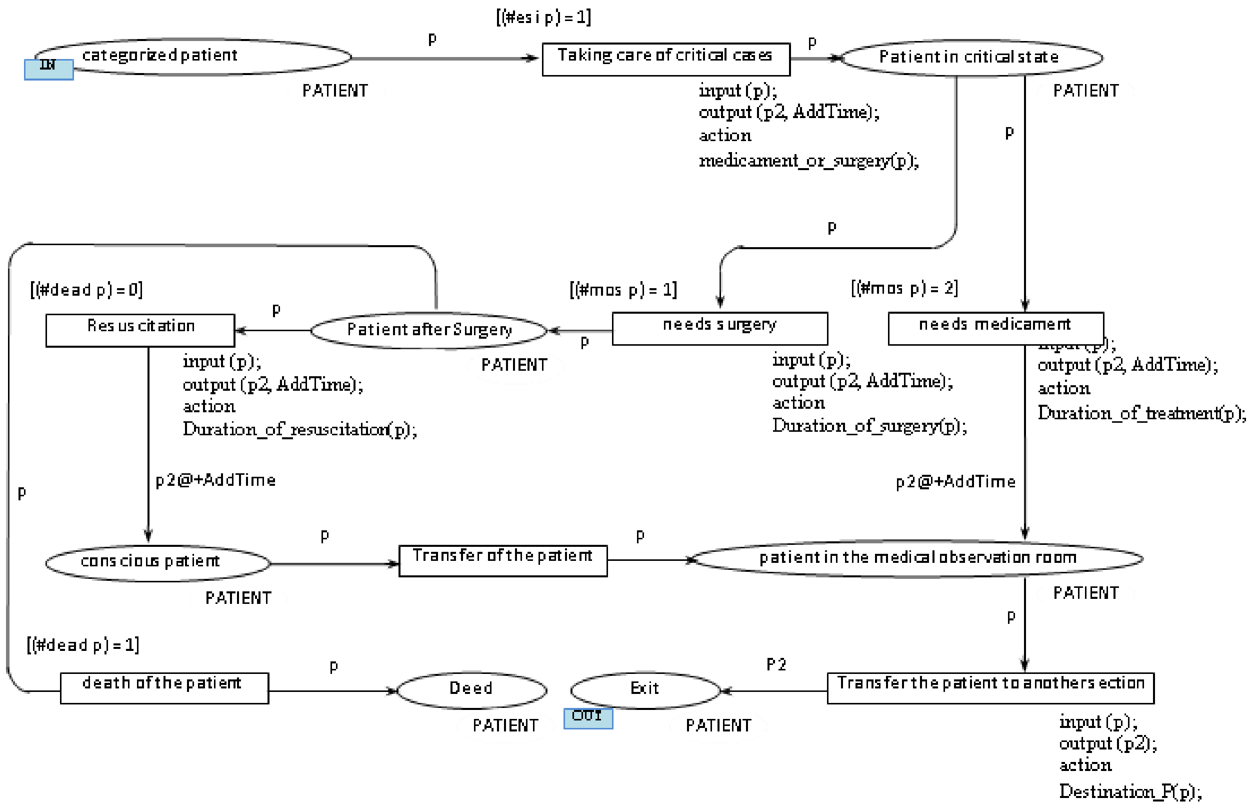

Figure 2. Subpage of the substitution transition (Transfert 1)

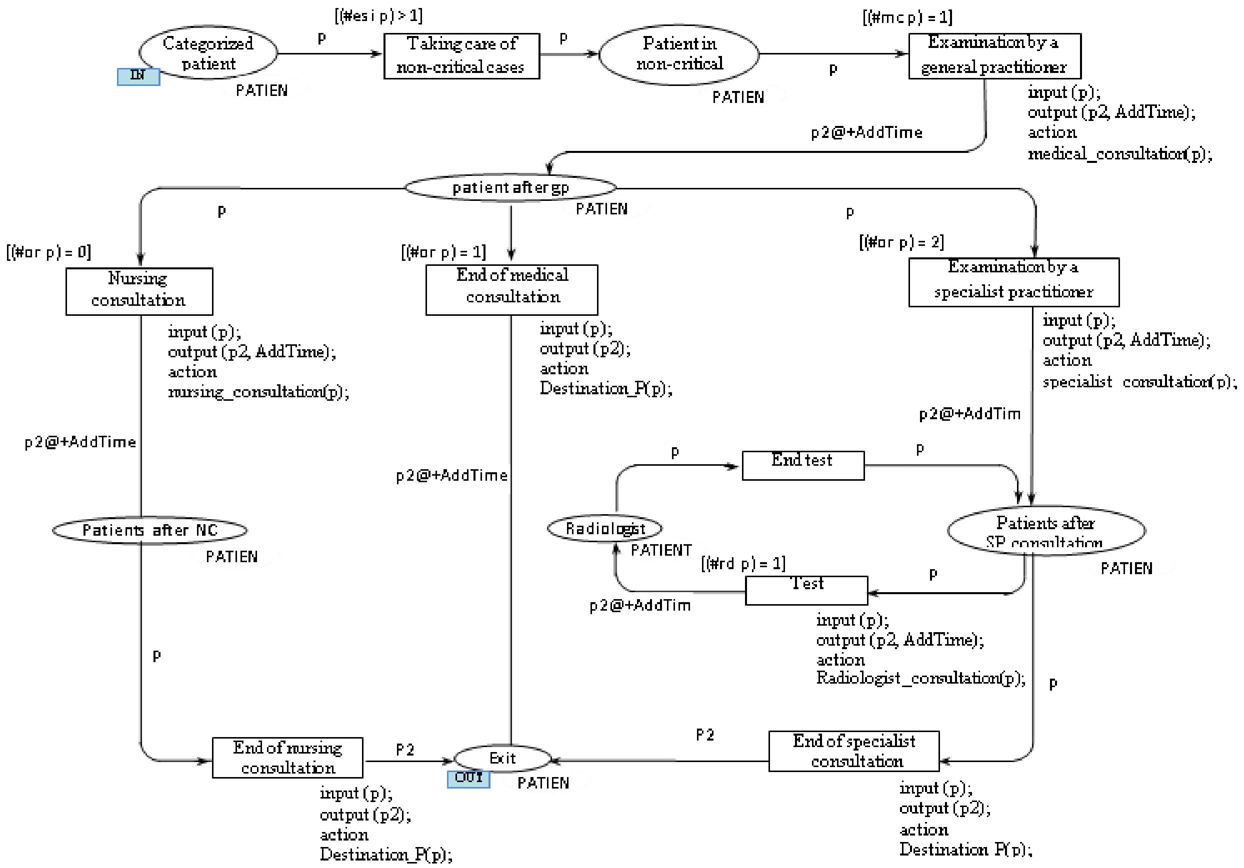

Figure 3. Subpage of the substitution transition (Transfert 2)

3.3. PSO algorithm

3.3.1. Definition

PSO is a swarm intelligence algorithm that is simple, easy to use, flexible, easy to implement, and easy to integrate with other algorithms. The PSO is based on the rules of behavior of a group of birds, in order to solve optimization problems. The algorithm simulates the bird group behavior. The set of solutions in a PSO is called a particles and the entire population is denoted by a swarm. The swarm consists of N particles in a search space of M dimensions. The swarm is initially initialized by random solutions.

The velocity as well as the position values are indicated for individual swarm particle falling into the range [Xmin, Xmax] and [Vmin, Vmax]. Individual particle successively set its position based on its own experience and the experience of the particles nearby, utilizing the optimal position found by the individual and its neighbor. Every swarm particle has an objective value that is evaluated using the fitness function, to be optimized.

The position as well as the velocity of the jth particle is represented as,

$$Vj(tt + 1) = w * Vj(tt) + C1 * r1*(pbest - Xj(tt)) + C2 * r2*(gbest - Xj(tt)) \quad (1)$$

$$Xj(tt+1) = Xj(tt) + (1 - w) Vj(tt + 1) \quad (2)$$

Where, C1 and C2 are constant factors, w is the inertia weight. r1 and r2 are random numbers in [0,1], pbest refers to the optimal particle position, and gbest is the global optimal positioning of the swarm.

PSO algorithm is presented below:

• Step 1: Initialize the swarm: swarm size, position, velocity for individual particle, and the random parameters.

• Step 2: Calculate the individual particle objective value. pbest and gbest are evaluated, the position and the velocity are updated by the particles based on the equations 1 and 2.

• Step 3: Exit on conditions for discontinuation or go-back to Step 2.

• Step4: Find the global best solution that provides the newest gbest.

3.3.2. Determine resources using the PSO algorithm

The optimal selection of resources in the emergency department is very important, so the good use of resources leads to improving the quality of service and patient satisfaction [1]. The use of resources in the ED varies according to the need, and the duration the patient spends in each resource. The most important resources that the patient goes through are:

- Nursing consultation (10 to 20 minutes)

- General Practitioner (10 to 15 minutes)

- Specialist practitioner (10 to 20 minutes)

- Radiologist (10 to 15 minutes)

In PSO algorithms, the minimum values and maximum values are entered for each resource along with the time spent by that resource. Each variable x in the algorithm represents the number of resources available in each stage, for example, x = 3 in the medical consultation stage means there are three doctors in this stage.

The PSO algorithm is modified, where in the objective function, the proposed TIME_Rr algorithm is used in order to calculate the average time spent by the patient on each resource. The PSO algorithm is run several times, and each time the number of available human resources is obtained, in addition to the minimum value of LOS. The simulation model is modified based on the results obtained by running the PSO algorithm. Then the simulation is run again and the results are compared with the benchmark model.

3.4. Simulation Results and Discussion

The aim of this research is to reduce waiting times in the most important stages in the ED, and to reduce the length of stay of the patient. At first, a simulation model is created, and after running it, the preliminary results are obtained. The PSO algorithm has been implemented several times. Table 2 shows the results obtained each time, and in each execution, the results are different and a new number of HR, with new values for LOS are obtained.

Table 2. Results of executing the PSO algorithm

Nurse	General Practitioner	Specialist Practitioner	Radiologist	Min_LOS
3,41142046	3,68257408	3,742865071	3,931240032	162,3
2,927031712	3,206051346	2,654724191	3,537776772	184,7
2,662088656	3,74586834	4	2,803601184	164
3,7	3,037543257	3,823881538	3,893472739	161,05
2,785013439	2,872661756	3,731443321	2,895002426	185,1
3,787190893	2,910382903	2,651693222	2,946061297	191,95

The first four columns of Table 2 represent the resources obtained by running the PSO algorithm, and the last column represents the results of the obtained Min LOS objective function. Three new simulation models are built based on the resources obtained in Table 2; for example, the first model is based on resources (the third line of Table 2), the second model based on resources (the fifth line of Table 2), the third model based on resources (the sixth line of Table 2).

Table 3 represents the results obtained by running the three models compared to the Benchmark model. In the Benchmark model, at each stage of ED, there are two Resources; for example, in the stage of medical consultation, there are two doctors.

Table 3. Simulation results for the proposed models

	Benchmark model	First model	Second model	Third model
Waiting time for a nursing consultation	80.5	60.5	61.2	50.8
Waiting time for a medical consultation	61.8	40.8	50.75	55.4
Waiting time for a specialist consultation	85.5	50.5	52	61.3
Waiting time for radiologist consultation	59	40	43.3	50.2
Nursing consultation	18,6	16.3	17,8	16,3
Medical consultation	12.4	12.5	13.7	14.8

Specialist consultation	16.2	18.7	17.6	15.5
Radiologist consultation	14.1	14.3	13.2	13.2
Length of Stay (LOS)	310.4	220.6	229.65	217.7
Door-to-Doctor Time (DTDT)	87	70.2	69.6	55

The above table shows the decrease in LOS and DTDT for the three models compared to the Benchmark model. For the first model, the LOS decreased by 28.93% compared to the Benchmark model, and the DTDT decreased by 19.31%. As for the second model, the LOS decreased by 26.01% compared to the Benchmark model, and the DTDT decreased by 20%. For the third model, the LOS decreased by 29.86% compared to the Benchmark model, and the DTDT decreased by 36.78%. The values of LOS and DTDT differ from one model to another, as a result of the different values of the waiting periods in the different stages, which greatly affect the values of LOS and DTDT, due to the different resources available in each stage. As for the duration of operations in each stage, it changes slightly among the three models.

4. Conclusion and future work

With the increase in population density and the emergence of new diseases, the management of EDs has become very difficult, especially in terms of material and human resources. Determining human resources in EDs is very important, considering the limited budget of hospitals. This study has proposed a new approach based on simulation and PSO algorithm. A good and accurate study of the various operations that take place at the level of the emergency department is done. The emergency department is modeled using coloured Petri net, which is a mathematical model used to model complex systems. A Benchmark model is built to monitor the behavior of the system. PSO algorithm is used for HR identification with LOS calculation. Based on the results obtained using the PSO algorithm, three different simulation models are built, each model according to its own resources. The simulation is run for the three models and the obtained results are compared with the Benchmark model. This approach yielded good results, with the latter reducing both LOS and DTDT, while determining the appropriate amount of resources. This study gives an insight to decision makers about the optimal use of resources. The main problem remains to find a way to calculate LOS and DTDT accurately, so that it facilitates the use of optimization algorithms.

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