A hybrid algorithm to size the hospital resources in the case of a massive influx of victims

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ABSTRACT

Disaster situations either natural or made-man caused a large number of deaths and injured people. Morocco has experienced several disasters recently, the last one was the railway accident on 16 October 2018, which caused 127 serious injuries and 7 deaths. This large number was a big problem for the hospital to manage the received victims in right direction, which caused lives lost and disability. In this article, in collaboration with Mohammed (V) hospital in Casablanca city in Morocco, we suggested a solution that saves lives and eliminates number of disability by using a hybrid algorithm to size the hospital resources in the case of a massive influx of victims. We also suggested a support decision tool that is called Emergency Support Decision Tool. This helpful tool gives an idea about the needed resources that support these emergencies according to the victim's number. The proposed solution consisted in making a hybrid algorithm that mixed the theoretical simulation process and the experience feedback by developing hybrid genetic and hybrid heuristic algorithms. These algorithms using as an input the matrix solutions that generated under ARENA software and the solution generated by neural networks that based on experiences feedback. The objective was to provide a solution based on available resources. In fact, the results showed that the hybrid heuristic algorithm is more performant than the hybrid genetic algorithm.

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1. INTRODUCTION

Every year Thousands of people in the world are affected by natural or human-made disasters. These disasters often have dramatically effected the human health and causing hundreds thousands deaths and cause victims with different gravity degrees [1]. That is why it is necessary for hospital managers to make effective decisions under very tight time constraints in order to save many lives as possible. In this context, several countries require their hospitals to establish a disaster management plan in order to be able in responding effectively to disaster situations. In Morocco, the disaster management plan is called the Emergency Hospital Plan (EHP) [2].

The main challenges in the Moroccan hospitals is the lack of human and material resources that helps them to treat these situations. In addition, the EHP describes only the organization process from the arrival of victims and do not allocate the necessary resources according to the victim's number. This can lead to under sizing or oversizing resources. Therefore, the hospital is unable to treat all victims in the right direction.

The aim of this article is to propose a decision support tool that helps hospital managers to organize and allocate the needs of human and material resources according to the number of victims. Sizing the needed resources is frequently encountered in hospitals in order to optimize critical resources such as operating rooms, beds, etc. [3]. Research studies interested in sizing hospital resources used different solving approaches. Kadri et al [4] proposed a decision support system for the management of tension situations, which allows the proactive steering of the Emergency Department (ED). Kao [5] used Markov's chains to analyze the different patient flows in the care units and estimated their stay times at the hospital to calculate the needed resources in care staff and hospital beds. Nouaouri et al [6] also proposed two integer linear programming models to provide first the optimal number of operating rooms that allow the treatment of all the victims, and then to determine the latest ready dates of surgical staffs. Lamiri et al [7] proposed a stochastic model for operating room planning with two classes of patients: elective patients and emergency patients. Cochran [8] used queuing theory to propose a model based on patient flows to size the emergency department surface according to certain pre-established criteria. The simulation is also used in the ED to adjust the number of medical teams by sizing the number of beds needed to accommodate patients [9]. Ridge et al [10] used simulation model for bed capacity planning in intensive care. John et al [11] described a set of models for allocating the surgical resources in hospitals. Hans et al [12] proposed various constructive heuristics and local search methods that use statistical information on surgery durations to exploit the portfolio effect, and thereby to minimize the required slack. Fiedrich et al [13] introduced a dynamic optimization model that detailed descriptions of both the operational areas and the available resources to calculate the resource performance and efficiency for different tasks related to the response after earthquake disasters.

Although a lot of tasks concerning the sizing of the hospital resources have appeared in the literature, we have noticed that little of them have focused on resources sizing in disaster situations generating a massive influx of victims who require urgent care [6]. Also, most of them interested in two material resources: (operating rooms and beds). One exception is the study of Berquedich et al [14] which used the artificial immune system as a decision support tool to manage the allocation of necessary resources during a tension situation. This method is based on the affinity of each case with respect to the available solutions to assign the most suitable one.

Our research aim is to suggest a solution for the decision maker in the Moroccan hospital to save lives and eliminate disability in natural and human disasters situations using the following:

a. Reorganize the management process of victims.
b. Estimate the hospital human’s resources (doctors, nurses,) and material resources (beds, operating rooms...) according to the number of victims and the available resources.
c. Make a decision support tool for the hospital managers.

In addition, this article will address the problem of lack of resources and propose solutions for resizing emergency departments. These solutions consist in suggesting a hybrid heuristic algorithm that improve another hybrid genetic algorithm (GA). These algorithms use two inputs:

a. The matrix of solutions proposed by simulation using OptQuest ARENA as theoretical needs according the new proposed process.
b. The solution proposed by Neural Networks (NN) based on experiences feedback.

This study and simulations of our tasks was in collaboration with Mohammed (V) hospital in Casablanca city in Morocco.

2. RESEARCH METHOD

The methodology used is a hybrid algorithms (GA and HA). This method is a blending between the simulation (ARENA) and machine learning using NN. The simulation of our proposed process contributed a matrix of theory solutions. This matrix is the first input for the hybrid algorithms. The machine learning using NN is the tool with which we generate a solution that based on experiences feedback. This solution is the second input as an evaluation vector for the hybrid algorithms. The choice of these algorithms aims to have a best solution between the theoretical needs and the experiences feedback that reflects the available resources, which applied in similar cases. The idea is to suggest a realistic solution based on the available resources. This method have been recommended by Mohamed (V) hospital managers because it combines theory and real practice (feedback) to produce a feasible and effective solution in order to save the maximum number of victims within a reasonable time.

3. THE DIFFERENT LEVELS OF EXCEPTIONAL SITUATIONS

The massive influx of victims is the arrival of a large number of victims for the same cause, or following different causes, except that in the first case the ED is supposed to receive in addition to the victims, their families, the medias and of course the authorities. When there is a massive influx of victims in a HC, the normal situation of the ED is transformed into a tension or a crisis. These levels of situations are classified according to the charge/capacity ratio of the HC which defines the need in human and material resources necessary to return to the normal situation [15].

The main factors that can affect the charge /capacity ratio are:

a. The factors related to the number of victims received by the HC.
b. The factors related to the skills of human resources (feedback on experiences, training and so on).
c. Internal and external transfer capacity (availability of downstream care services) [16].

4. PROCESS MANAGEMENT IN THE CASE OF A MASSIVE INFLUX OF VICTIMS

4.1. Current process management within the Mohammed V HPC

At the occurrence of a tension or exceptional situation, the plan called the Hospital Emergency Plan (HEP) of Mohammed V HC consists to create a coordination and command team, led by the prefectural authority. At the arrival of the victims, the team members start to receive, guide and register the victims. Then, they begin the triage and orientation operation of victims for treatment according to their emergency degrees (relative emergency, absolute emergency). Death Cases are placed in the morgue [2]. The Figure 1 summarizes the processes organization in the event of a massive influx of victims.

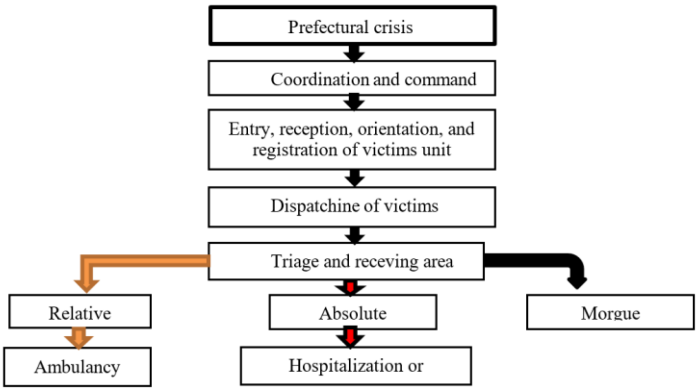

Figure 1. Organization chart with victim's circuit applicable to crisis situations at CH Mohammed 5

Depending on the catastrophic (exceptional) situation, type and number of victims, the HEP envisages two major scenarios:

a. Plan A is the case when the center receives either more than twenty victims in a serious case or fifty victims of any severity.
b. Plan B is the case when the center receives either five serious victims requiring immediate treatment (Such as surgical cases or respiratory distress) or ten victims of any severity.

According to these two scenarios, we noticed that the triage is done at the HC. In addition, there are two levels of triage which the relative emergency and the absolute emergency, also there is no vision to predict the needed resources according to the victim's number.

4.2. Proposed process organization

4.2.1. Proposed triage of victims

The triage operation is a key step to better manage the victims handling, it identifies the order in which victims should be evacuated and treated following the emergency degrees to save a maximum number of victims. This operation determines:

a. The condition and the emergency degrees of victims.
b. The evacuation priority to the HC.
c. The degree of the treatment priority that should follow.
d. For this purpose, there are several scales and models for classifying victims [17].

Taking into account these different triage scales [18-20] and in consultation with CH managers, we proposed a five emergency levels model. At each level we have associated a color from the most urgent case (red) to the less urgent case (blue), in order to save a large number of victims as possible and to save time for the available resources. Our proposition suggests that the triage should be conducted at the incident site to avoid prioritizing less urgent case [15]. The Table 1 summarizes the proposed triage model.

Table 1. Emergency levels from 1 to 5

Emergency levels	Colors	Status	Recommended time frame
Dead victims	Black	Neurological Death impairment (coma, bilateral mydriasis)	Morgue
1 : Immediate	Red	Failure of one vital function at least (neurological, cardiac, respiratory)	Immediate
2 : Very urgent	Orange	Unstable victim (hemorrhage, CT, visceral damage, burns, gas poisoning)	5 Munites max
3 : Urgent	Yellow	Victim with a wound Musculoskeletal injury (fractures)	20 Munites
4 :Less urgent	Green	Stable victim no emergency but requires an assessment	60 Munites
5 : No-urgent	Blue	Can be treated on the accident site	Treatment outside HC

4.2.2. Process organization

At the occurrence of an exceptional situation, the HC creates a local regulation post whose mission is to communicate the information received to the Delegate, the Director of the HC and the heads of departments (nursing, medical, administrative), also of the city's other HC. When a tension/ crisis situation occurs, it is essential for us to applicate the EHP in order to reconfigure the HC before the arrival of the first victims (possibly families, the media and the authorities). At the accident site, the triage operation starts, it is done by an emergency doctor and emergency or state nurses. The goal is to identify first the most urgent cases that need an immediate treatment and at the last time those that are less urgent. Non-urgent cases will be handled on the accident site to do not clutter up the CH. If the capacity of the HC is reached, the remaining victims must be oriented to the nearest HC.

The different step to manage an exceptional situation are as follows:

1) On the accident site:
   a. Framing and distribution of the accident site.
   b. Consulting and triage of victims according to the five levels proposed to better orient them.
   c. Identifying the victims by the labels that indicate their emergency level.
   d. Less urgent and non-urgent victims should be monitored.
2) Before the arrival of the victims at the HC:
   a. The HC must be evacuated.
   b. Prepare the operating rooms, beds, equipment and necessary materials to treat victims.
3) At the arrival of the victims at the HC:
   a. Treat them following their emergency levels.
   b. Allocate the necessary human and material resources for each case.
4) Communicate information in real time to the local regulation post in all steps of the process.

The Figure 2 summarizes the proposed process management:

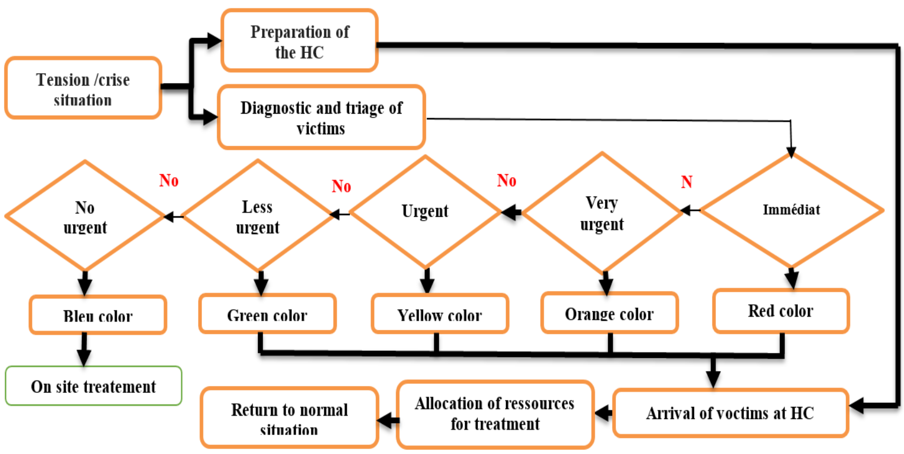

Figure 1. Victim's process management

5. IMPLEMENTATION AND RESULTS

Sizing of human and material resources is the second step after the triage operation, in this stage, the HC managers should have a decision support tool that give them an idea about the number of resources needed to treat victims. To this end, we proposed a three hybrid algorithms that combine between simulation and experience feedback.

5.1. Sizing the hospital resources based on a simulation by ARENA software

The simulation is one of most used solution to solve sizing problems. In this regard, we used ARENA software because it makes it possible to get a structure of the software model same to that of the real system to be simulated. In addition, it has Opt Quest tool that gives us the opportunity for sizing resources. The Figure 3 represents the ARENA model of our management process of victims.

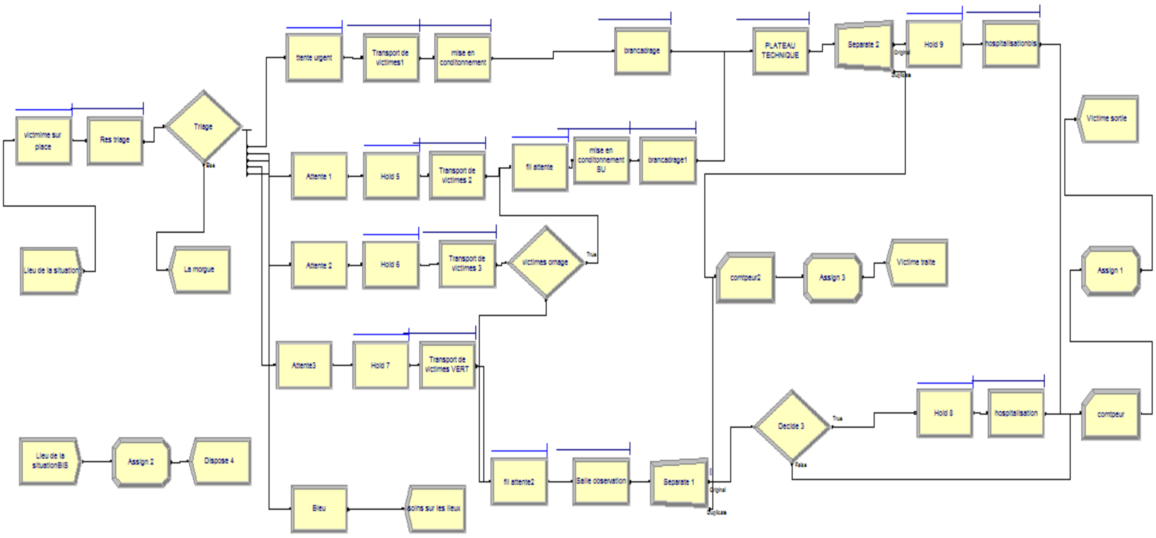

Figure 2. The ARENA model of our proposed process management of victims

The configuration of the different block parameters was carried out in consultation with the HC managers in order to capitalize on their experiences. So that, we used Arena software version 11, the Capacity resources of the HC as a constraints and the number of victims as an input. The sizing of the resources provided the results in Table 2. To get the best matrix of solution, we made many simulations. The best solution is the line in blue. In order to improve these results, we used them as the input matrix of our tow hybrid algorithms proposed in this article.

Table 2. Results of simulation by ARENA software

			Best Solutions											
Simulation	Objective	Status	Ambulances	Surgicals	Nurses	Nurses BIS	Nurses SR	Beds	S Do	E Do	E DoBIS	Radiologos	Reanimators	Surgical Rooms
28	112.00000	Feasible	17	4	2	13	12	95	18	1	3	3	3	3
31	112.00000	Feasible	10	4	1	7	16	12	7	2	1	1	3	3
32	112.00000	Feasible	15	6	1	13	20	56	10	2	1	2	4	4
34	112.00000	Feasible	11	7	1	19	12	43	17	2	2	4	3	4
39	112.00000	Feasible	15	6	1	13	16	55	10	2	1	3	4	4
40	112.00000	Feasible	19	6	1	12	24	60	10	2	1	2	4	4
42	112.00000	Feasible	6	6	1	17	8	43	10	2	2	3	2	4
43	112.00000	Feasible	15	6	1	13	4	56	10	2	1	2	4	4
45	112.00000	Feasible	18	6	1	12	24	60	10	2	1	2	5	4
46	112.00000	Feasible	14	6	1	12	20	51	10	2	1	2	4	4
47	112.00000	Feasible	15	5	1	13	16	68	12	2	1	2	4	4
48	112.00000	Feasible	15	6	1	13	20	46	10	2	1	2	4	4

5.2. Sizing the hospital resources based on neural networks

In order to propose an effectiveness decision support tool, we used NN as tool of machine learning to produce a solution based on experience feedback, this idea aims to refer to resources used in the real experiences.

5.2.1. Algorithm architecture

Figure 4 shown the neural network architecture.

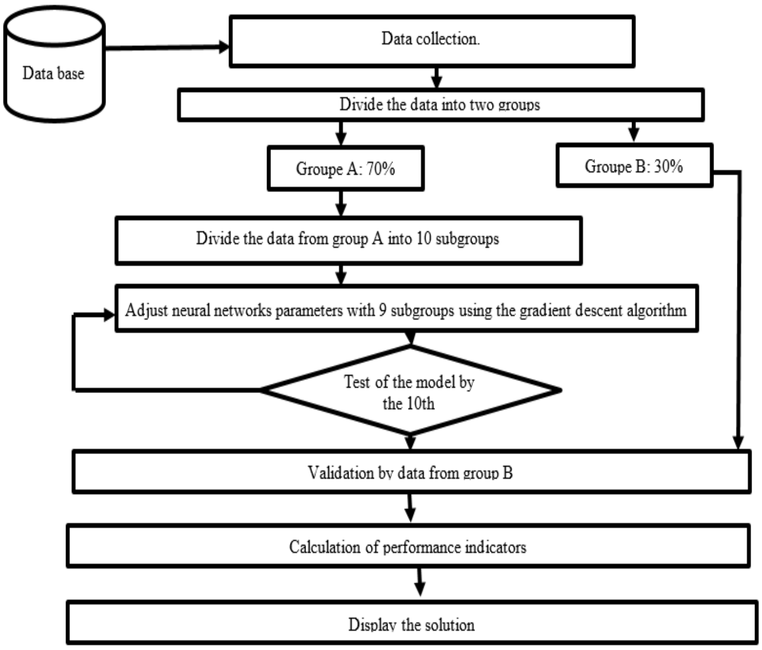

Figure 4. Neural network architecture

5.2.2. Description of our algorithm

1. Collecting data from experience feedback.
2. Dividing the data into two groups, group A contains 70% of the data and group B contains 30% of the data, this choice has been validated after several tests to help the NN to train well on the data.
3. Learning of NN in three steps, training step, test step and validation step.
4. In this proposition, the training and test phases were done by the group A data, for this we used the algorithm of the gradient descent and the procedure of the K-FOLD cross validation [21]
5. Calculating of the performance indicators of the algorithm.
6. Displaying the solution.

The sizing of the resources contributed the following result in Table 3. The obtained result constitute the evaluation vector for our three hybrid algorithms.

Table 3. Result of NN

Neural network solution (NN)								
Ambulances	Surgicals	Nurses	Nurses SR	Beds	Doctors	Radiologs	Reanimators	Surgical rooms
13	13	13	10	102	19	5	5	4

5.3. Hybrid algorithms to size hospital resources

A hybrid algorithm is an algorithm that combines two or more other algorithms that solve the same problem. The hybridization using GA used by a lot of researches to get the best optimal solution [22-26]. Although GA's are effective complete search algorithms with crossover and mutation operators, GA can be improved using local search methods and they can be made competitive with others when the search space is too large to explore. So if one uses some local optimization algorithm for making good blending between global exploration and local exploitation.

The proposed solution consists in making a hybrid algorithm that mixes the theoretical simulation process and the experience feedback by developing hybrid genetic and hybrid heuristic algorithms. These algorithms using as an input the matrix solutions that generated under ARENA software and the solution generated by neural networks that based on experiences feedback. We used the Manhattan distance to measure of the similarity between these two inputs solutions, as we suggest one of the best solution.

5.3.1. Choice of Manhattan disatance

Manhattan distance is a function that measures the similarity between two vectors, Xi =[xi1, xi2, ..., .., xi N] and Xj =[xj1, xj2, ..., xjD], producing a non-negative real number, representing the degree of divergence between the two data points. It is the sum of the differences of their corresponding components. The distance between a point x = (x1, x2... xn) and a point y = (y1, y2,... yn) is:

$$MD_{(x,y)} = \sum_{i=1}^{n} |x_i - y_i| \quad (1)$$

The choice of Manhattan distance for the analysis of our data is based on the literature which shows through the results obtained that Manhattan distance is the best the in terms of efficiency [27-29]. This is what prompted us to adopt this distance metric. In this article, we used the Manhattan distance to measure the distance between the solutions simulated under ARENA and the evaluation vector calculated under NN. The objective is to reproduce a new solution that has a minimum distance to approach between theory and experience feedback.

5.3.2. Hybrid GA

GA have been developed by John Holland and his team. The goals of their research have been twofold: (1) to abstract and rigorously explain the adaptive processes of natural systems, and (2) to design artificial systems software that retains the important mechanisms of natural systems. This approach has lead to important discoveries in both natural and artificial systems sciences [30].

a. Algorithm architecture

Figure 5 show hybrid genetic algorithm architecture.

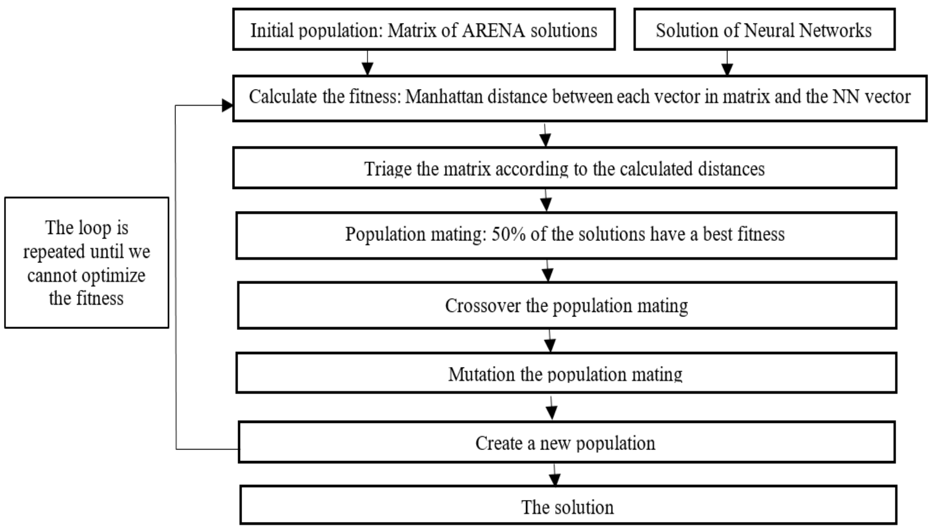

Figure 5. Hybrid genetic algorithm architecture

b. Algorithm description

This algorithm used the decimal representation for genes, one point crossover, and uniform mutation. Steps of the GA: The first step is to define the inputs. The evaluation vector of NN and the initial population based on the proposed solutions of ARENA Software (matrix), each chromosome (solution or individual) in the population will definitely have 9 genes, one gene for each resource. But the difficulty is to find how many solutions per the initial population? There is no fixed value for that and we can select the value that fits well with the number of victims. After preparing the initial population, the next steps consists to calculate the fitness function, which allows selecting first the best individuals within the current population as parents for mating. After, is to apply the GA variants (crossover and mutation) to produce the new individuals of the next generation, creating then the new population by appending both parents and new individuals, and repeating such steps for a number of iterations/generations. The algorithm will stop when the fitness could not be optimized.

5.3.3. Hybrid HA

a. Algorithm architecture

The hybrid heuristic algorithm architecture can see in Figure 6.

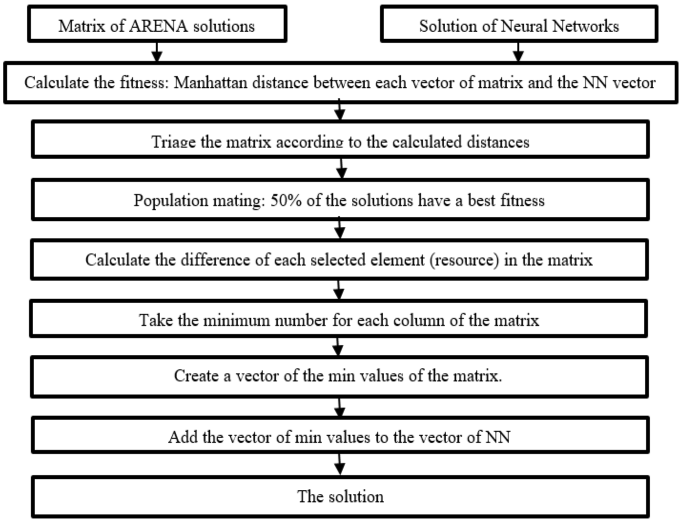

Figure 6. Hybrid heuristic algorithm architecture

b. Algorithm description

The basic idea is to hybrid the same inputs used in GA by a new HA using the Manhattan distance. This algorithm is proposed in order to generate another solution better than the solution provided by GA. Steps of the HA: The first step is to define the matrix of solutions based on the simulation under ARENA Software, each vector (solution) in the matrix will definitely have 09 resources. Based on the fitness function, we select 50% of the best solutions from the matrix, next is to calculate the difference between each resource (element of the vector) in the matrix and its similar element in the evaluation vector, creating then a new vector that contains the minimal values of each column, after creating the new solution which the sum of the evaluation vector and the vector of the minimal values. The idea is to propose a new solution that has more resources that near to the experience feedback solution.

5.3.4. Analysis and discussion

In order to validate our propositions, we implemented the two hybrid algorithms which use the same inputs and display the desired results, then we have set up an application called Emergency Support Decision Tool. The results are shown in Figure 7.

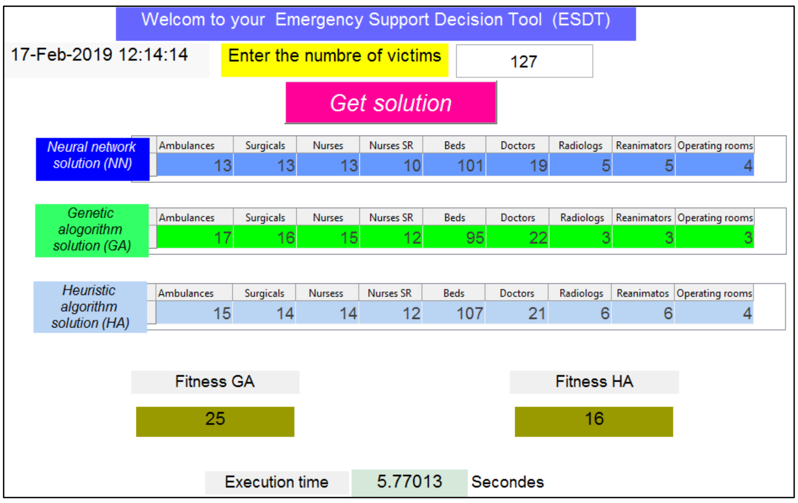

Figure 7. Results of three hybrid algorithm

5.4. Analysis and discussion of a result

After many simulations with different number of victims, the applied algorithm's results shown in the Figure 7 considering 127 victims (3 red, 28 orange, 44 yellow, 34 green and 18 blue). These results are based on 12 hours of work per team with the following repartition in Table 4.

Table 4. Resources by stage

Operating room	Observation room	Putting into packaging	Triage
Surgical+ Reanimator + Nurses SR	Doctor + Reanimator + Nurses	Doctor + Reanimator+ Radiolog	Doctor + Nurses

The performance indicators calculated are, the error (R^2 = 0.98) and the execution time (T= 06 seconds with a microcomputer with the following characteristics: I5 of a 2.6G processor and 6G of RAM). The idea of these algorithms consisted in finding the optimal number of resources that approaches theory and feedback. The goal is to provide a solution that is first feasible according to available resources. Second, it is in accordance with theoretical needs, in order to save the large number of lives.

The solutions proposed by simulation improved with the hybrid GA that provided a new one. Although, this GA suggested number of resources less than the feedback of experiences. In consequence, we proposed a new hybrid HA that provided a solution that approaching first between the theory and feedback of experiences, next, it suggested number of resources more than the solution based on experience feedback. By comparing the results of the two proposed algorithms, we concluded that the hybrid HA not only had an effectiveness performance fitness, but also illustrated the idea that the number of resources should more or equal than feedback of experiences. The result of the HA is more feasible than the results found by [6, 14] considering the available resources in the Hospital Center.

6. CONCLUSION

Our research aim is to save handers of lives and eliminate thousands of disabilities in disaster situations according the available resources in the hospital center. In fact, we proposed an improvement of Moroccan disaster management plan (EHP) through three methods: (a) Reorganize the management process of victims by proposing 5 levels of triage to avoid prioritizing less urgent case; (b) Estimate the hospital humans and material resources according to the number of victims and the available resources using a Hybrid Heuristic algorithm; (c) Make a decision support tool for the hospital managers that helps them to make an efficient decision.

As we can see in the railway accident, they were 7 deaths and 127 injuries. If we used our solution, we could save more lives and eliminate teens of disabilities. By using this hybrid algorithm, we can save handers of lives and injuries in unsuspected disasters. In perspective, we will adopt this approach for a HC network to treat the rest of victims in the case of a crisis situation (lack of capacity for one HC), especially for more urgent cases that require immediate surgical procedures of operating rooms in a single HC is limited. In the other hand, we will adopt a prognostic approach by using big data and machine learning to get a system that predicts the number of victims expected especially for road accidents

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