A Bi-Objective Model for Hospital Evacuation and Reliable Pharmaceutical Supply Chain for Critical Patients

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***Abstract*—With increasing natural and human-made disasters, governments need to have a comprehensive and precise plan for emergency evacuation is felt more than ever. Hospitals are places that, due to the presence of vulnerable people and some dangerous chemical materials, need a perfect and accurate plan for emergency evacuation. In this paper, we presented a bi-objective multi-period, multi-product model for hospital evacuation and pharmaceutical supply chain for critical patients. An epsilon constraint method and Finally, the performance of solution procedures is compared, and the results are analysed.**

Keywords: *Hospital evacuation, Uncertainty, Humanitarian logistics.*

I. INTRODUCTION

Evacuation is an operation that usually occurs at the time of disasters. Floods, earthquakes, storms, or unexpected events such as fires, bomb threats, partial destruction of buildings, etc. all can lead to evacuation operations. Offices, shopping centers, schools and universities, hospitals, or even all residents of a city may need evacuation under some circumstances.

The Building or population evacuation are cases where much research has been done about them. Shahparvari and Abbasi [1,2] using the Australian case study, and they presented two articles about emergency evacuation. Vehicle routing and scheduling for bushfire emergency is the main topic of their paper. Ghasemi, Khalili, Hafezalkotob, and Raissi [3] proposed a stochastic multi-objective mixed-integer mathematical programming for logistic distribution and evacuation planning during an earthquake. They considered both pre and post-disaster management phases. Some other researches that we assessed when we were on reviewing the evacuation article are as follow: [4], [5], [6], [7]. On the contrary, hospital evacuation has received much less attention from researchers.

Hospital evacuation has been investigated in two categories: 1. Behavioral and Social, 2. Modeling and Operation [8]. In the behavioral and social category, researchers evaluated some of the components and measures needed to evacuate the hospital and focused on the decision-making process for hospitals. In recent years, most of the studies have been conducted in the first category, and less attention has been paid to mathematical modelling.

In some situation due to the poor conditions that, can happen in emergency circumstances, hospital evacuation process may execute inefficiently; lack of capacity in receiving hospitals, poor road conditions due to the risk of their disruption, the lengthy transmission time of patients that may lead to the death of critical patients; These are some of the Cases that can lead to incomplete and inefficient evacuation. Based on the mentioned points, it seems we should look for methods and assumptions that covering the research gap mentioned. For example, the establishment of temporary facilities for hospitalization of patients can reduce the evacuation time; Although, an appropriate supply chain must be designed to provide the medicines and materials needed for the centers built and also, some methods can be used to increase the reliability or sustainability of the supply chain. In this paper, we designed an emergency network that covering hospital evacuation operations and delivering medication to patients in critical condition. Critical patients are cared in temporary centers that, must be selected between candidate locations [12-17, 26-28].

The remainder of this paper is organized as follow: In the next section, we review the related work that involved in evacuation problem, especially hospital evacuation. The Problem description and model formulation are presented in section 3. The fourth section includes numerical examples and sensitivity analysis, and conclusions and suggestions for future research are given in the final section.

II. LITERATURE REVIEW

In this section, we review studies about hospital evacuation. As mentioned, mathematical and quantitative modeling has less used in this area, and most research is qualitative. In the quantitative modeling category, some papers have Operational research models, and some of them have a simulation approach that is optimizing the evacuation process.

Golmohammadi and Shimshak [9], declared simulation is a time consuming process that includes such functions as model development, testing and validation, data gathering, and data interpretation. They developed a quantitative prediction model. Their prediction model is applied to a hospital building in order to estimate evacuation times and then, evacuation time results from the model for 19 different hospital evacuation scenarios were compared with the results of a previously designed simulation model. The advantage of the model presented by them was that both the computation time was short, and there was no need for long and costly validation of the simulation models. Bish, Agca, and Glick [10] appraised the risk of evacuation operation from two perspectives, 1. threat risk, which is the risk, patients are exposed to while waiting to be transported, and 2. the transportation risk, which is the risk incurred during travel. The combination of these two constitutes the total risk, and the main goal was to minimize total risk. They also considered vehicle transportation problem, but more comprehensive than previous research. According to their model, vehicle types had different capabilities and included Advanced Life Support (ALS) ambulances, Basic Life Support (BLS) ambulances, and buses. Furthermore, they categorized the patients into three groups: critical, pediatric, and infectious, and each type of the patient had their characteristics, and they had to be assigned according to their characteristics, and each had to be settled in a specific location. Nasrollahi and Razmi [11] designed a four-stage multi-period pharmaceutical supply chain to maximize the expected demand coverage at hospitals while minimizing the total costs. They proposed a reliability index for pharmaceutical substances to consider substances priority and improve the service level of hospitals for patients.

Based on our knowledge, there has been a little research in hospital evacuation that considered cost and people, simultaneously. If both aspects of cost and public satisfaction are taken into account, we can say that we have performed well in terms of management, because while satisfying people, we reduced our costs. Another gap that can be mentioned is the construction of temporary centers for patients to speed up evacuation operations.

We tried to fill these gaps. The main contributions of our paper that makes it different from other papers in hospital evacuation modeling are as follow:

- ❖ Providing a bi-objective model with cost, and humanitarian considerations, that covering both, our benefit and the benefit of the patients.
- ❖ Considering two types of destinations for evacuees, receiving hospitals and temporary care centers (TCC) which that, each of them has its own characteristics.
- ❖ Designing a pharmaceutical supply chain for transporting medicines to temporary care centers whit transshipment between them.
- ❖ The parameter of demand is considered probabilistic, which makes the situation more similar to the real world.
- ❖ Increasing reliability of supply chain by considering the risk of facility disruption.

III. PROBLEM STATEMENT

a. Problem description

In this paper, we designed a network for disaster response phase that, contained two subnets; First, the evacuation operation from evacuating hospitals and transfer the patients to receiving hospitals and temporary care centers and second, the pharmaceutical supply chain for patients transferred to centers. To better understand the network, see Fig 1. Evacuating hospitals, receiving hospitals, temporary care centers and government suppliers are four main components of the network and the flow of people and medicines is between them.

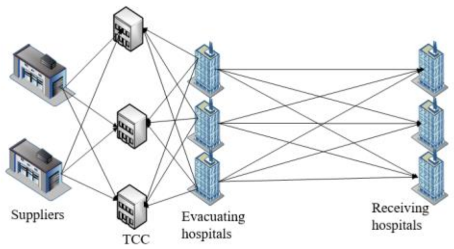

Fig 1. Supply chain configuration

Considering that some patients may be in critical conditions and require special medical care, we located several temporary care centers among from the candidate locations were much closer than receiving hospitals. In this study, patients are categorized into critical type and noncritical type. Critical patients are transferred to temporary care centers so that they can receive medical care sooner and noncritical patients are transferred to the receiving hospitals. Two types of transportation vehicles are considered (vans and ambulances); Ambulances are specified to critical patients and, noncritical patients are transported by vans.

Building the temporary centers can speed up evacuation but in times of disaster, they may disrupt and, lose their usage. For covering the risk of disruption and increasing the reliability of supply chain, we seek to minimize the risk of disruption in our model. To make it easier and more comprehensive to calculate the risk of facility disruption, TCC are considered in parallel system that, is embodied in Fig 2.

The main assumptions considering in formulating the proposed model are as follows:

- The receiving hospitals and government suppliers are known but TCC must be chosen from candidate points.
- The receiving hospitals and TCC have limited capacity and, its specified.
- Each ambulance has the capacity for one patient on each trip, so that they can take the necessary care of the patient.
- The vans have limited capacity.
- Critical patients use ambulances and noncritical patients use vans.
- It is possible to transshipment pharmaceutical items between TCC, to prevent shortage.

- There are three types of pharmaceutical items are considered in the supply chain.

The transhipment between TCC is prohibited in first period.

Fig 2. TCC parallel configuration

b. Mathematical modelling

A bi-objective multi periods mixed integer linear programming is presented in this section. The following notations are defined to formulate the problem:

Sets:	
i	Index of evacuating hospitals
j	Index of receiving hospitals
k	Index of candidate locations for TCC
p	Index of patients
t	Index of time periods
m	Index of pharmaceutical items
s	Index of suppliers
Parameters:	
tc_{ij}	The cost of each vans trip between evacuating hospital i to receiving hospital j.
tc_{ik}	The cost of each ambulances trip between evacuating hospital i to TCC k.
tc_{sk}	Unit transportation cost between supplier s to TCC k.
$tsc_{kk'}$	Unit transshipment cost from TCC k to TCC k.
crh_j	Capacity of receiving hospital j for noncritical patients.
ct_k	Capacity of TCC k for critical patients.
CV	Capacity of each van.
LP	The upper limit number for not evacuated patients
TNP_{pi}	Total number of patient type p in evacuating hospital i.
$\widetilde{D_{mkt}}$	Demand of pharmaceutical item m in TCC k at time period t.
FC	Fixed cost of establishing a TCC.
CS_{sm}	Capacity of supplier s to supply pharmaceutical item m.
re_k	The reliability of TCC k.
Decision variables:	
y_k	1, if TCC k is opened; 0, otherwise.
x_{ijt}	Number of noncritical patients transported from evacuating hospital i to receiving hospital j at period t.
y_{ikt}	Number of critical patients transported from evacuating hospital i to TCC k at period t.
NV_{ijt}	Number of vans used to transferred noncritical patients from evacuating hospital i to receiving hospital j at period t.
NA_{ikt}	Number of ambulances used to transferred critical patients from evacuating hospital i to TCC k at period t.
NPN_p	Number of patients type p not evacuated.
B_{mkt}	the shortage of relief items
I_{mkt}	Inventory level of pharmaceutical item m at TCC k at the end of period t.
Q_{skmt}	Quantity of pharmaceutical item m transported from supplier s to TCC k at period t.
$W_{mkk't}$	Quantity of pharmaceutical item m transshipped from TCC k to TCC k'.

The proposed model is as fallow:

$$MinZ_1 = \sum_k FC \cdot y_k + \sum_s \sum_k \sum_m \sum_t tc_{sk} \cdot Q_{skmt} + \sum_k \sum_{k'} \sum_m \sum_t tsc_{kk'} \cdot W_{kk'mt} + \sum_i \sum_j \sum_t tc_{ij} \cdot NV_{ijt} + \sum_i \sum_k \sum_t tc_{ik} \cdot NA_{ikt} \qquad (1)$$

$$MinZ_2 = \sum_p NPN_p + \prod_k (1 - y_k \cdot re_k) + \sum_m \sum_k \sum_t B_{mkt} \qquad (2)$$

$$\sum_i TNP_{pi} - \sum_i \sum_j \sum_t x_{ijt} = NPN_p \qquad p = 1 \qquad (3)$$

$$\sum_i TNP_{pi} - \sum_i \sum_k \sum_t y_{ikt} = NPN_p \qquad p = 2 \qquad (4)$$

$$x_{ijt} \leq NV_{ijt} \cdot CV \qquad \forall i, j, t \qquad (5)$$

$$y_{ikt} \leq NA_{ikt} \cdot y_k \qquad \forall i, k, t \qquad (6)$$

$$\sum_i \sum_t x_{ijt} \leq crh_j \qquad \forall j \qquad (7)$$

$$\sum_i \sum_t y_{ikt} \leq ct_k \cdot y_k \qquad \forall k \qquad (8)$$

$$\sum_k \sum_t Q_{skmt} \leq cs_{sm} \qquad \forall s, m \qquad (9)$$

$$Q_{skmt} \leq M \cdot y_k \qquad \forall s, k, m, t \qquad (10)$$

$$W_{kk'mt} \leq M \cdot y_k \qquad \forall k, k', m, t \qquad (11)$$

$$I_{mkt} = \sum_s Q_{skmt} \qquad t = 1, \forall m, k \qquad (12)$$

$$I_{mkt} = \sum_s Q_{skmt} + \sum_{k'} W_{k'kmt} - \sum_{k'} W_{kk'mt} \qquad t \geq 2, \forall m, k \qquad (13)$$

$$I_{mkt} - B_{mkt} = \widetilde{D_{mkt}} \qquad \forall m, k, t \qquad (14)$$

$$NPN_p \leq Lp \qquad \forall p \qquad (15)$$

$$x_{ijt} \ , \quad y_{ikt} \geq 0 \qquad (16)$$

$$NV_{ijt} \ , NA_{ikt} \ , NPN_{pt} \geq 0 \qquad (17)$$

$$I_{mkt} \ , Q_{skmt} \ , W_{k'kmt} \ \geq 0 \qquad (18)$$

The first objective function (1) minimizes the total cost and contains fixed stablishing cost of TCC, pharmaceutical items transportation cost from suppliers to TCC, pharmaceutical items transhipment cost from one TCC to another's and patients transformation cost from evacuating hospitals to receiving hospitals and TCC. Second objective (2) function is about overcome to risk of disruption and enhancing Patients satisfaction. It contains three phrase; sum of the number of not evacuated patients, probability of failure in TCC and, the shortage of relief items.

Constraints (3) and (4) calculate the number of not evacuated patients. Constraint (5) ensures that, the number of noncritical patients evacuated during one period must not be exceeded from sum of the vans capacity had trip at that period. Similarly, constraint (6) also expresses the same concept for critical patients are transferred by ambulanced provided that the TCC is opened at point k. Constraint (7) ensures that the number of noncritical patients evacuated during the periods, must not be exceeded from receiving hospital's capacity and constraint (8) ensures the same phrase for critical patients and TCC's capacity provided that the TCC is opened at point k. Constraint (9) ensures the quantity of pharmaceutical item m that transported to TCC during periods must not be exceeded from capacity of suppliers. Constraints (10) and (11) indicate that items transportation to TCC and transhipment between TCCs are allowed Provided that the TCC is open at point k. The balance of inventory levels of pharmaceutical items and covering the demand are indicated in constraints (12) - (14).

constraint (15) enforces that, the number of not evacuated patient must not be exceeded from the limited number. Constraints (16) - (18) determine the domain for variables.

C. Converting the model to deterministic mode

In this study, we considered the demand for medicines probabilistic to bring the circumstances closer to the real world. This parameter has a normal distribution $\sim N(\mu_d, \sigma_d^2)$ and, for convert stochastic model to deterministic model, we must convert constraints (14) to deterministic mode as follows.

$$I_{mkt} - B_{mkt} = \widetilde{D_{mkt}} \rightarrow \begin{cases} I_{mkt} - B_{mkt} \leq \widetilde{D_{mkt}} \\ I_{mkt} - B_{mkt} \geq \widetilde{D_{mkt}} \end{cases}$$

$$\sum_{j=1}^{n} a_{ij} x_j \leq \tilde{b}_i \qquad i = 1,2,\dots,m \ ; \ x_j \geq 0 \qquad (19)$$

$$P\left\{\sum_{j=1}^{n} a_{ij} x_j \leq \tilde{b}_i\right\} \geq (1-\alpha_i) \qquad (20)$$

We can do this using equations 19 and 20. assuming that $\alpha = 0.9$:

$$P\{I_{mkt} - B_{mkt} \leq \widetilde{D_{mkt}}\} \geq 0.1 \Rightarrow P\left\{\frac{I_{mkt} - B_{mkt} - \mu_d}{\sigma_d} \leq \frac{\widetilde{D_{mkt}} - \mu_d}{\sigma_d}\right\} \geq 0.1$$

$$P\left\{Z \leq \frac{I_{mkt} - B_{mkt} - \mu_d}{\sigma_d}\right\} \leq 0.9 \Rightarrow \emptyset\left\{\frac{I_{mkt} - B_{mkt} - \mu_d}{\sigma_d}\right\} \leq \emptyset(1.285)$$

Because $\emptyset$ is an ascending function, the following equation is established:

$$\frac{I_{mkt} - B_{mkt} - \mu_d}{\sigma_d} \leq 1.285 \Rightarrow I_{mkt} - B_{mkt} \leq 1.285(\sigma_d) + \mu_d$$

The same operation is performed on the other side of this constraint:

$$P\{I_{mkt} - B_{mkt} \geq \widetilde{D_{mkt}}\} \geq 0.9 \Rightarrow P\left\{\frac{I_{mkt} - B_{mkt} - \mu_d}{\sigma_d} \geq \frac{\widetilde{D_{mkt}} - \mu_d}{\sigma_d}\right\} \geq 0.9$$

$$\Rightarrow P\left\{Z \leq \frac{I_{mkt} - B_{mkt} - \mu_d}{\sigma_d}\right\} \geq 0.9 \Rightarrow \emptyset\left\{\frac{I_{mkt} - B_{mkt} - \mu_d}{\sigma_d}\right\} \geq \emptyset(1.285)$$

$$\Rightarrow \frac{I_{mkt} - B_{mkt} - \mu_d}{\sigma_d} \geq 1.285 \Rightarrow I_{mkt} - B_{mkt} \geq 1.285(\sigma_d) + \mu_d$$

IV. NUMERICAL EXAMPLE

In this section, we solved the small and medium instance of problem by using an ε-constraint method [12, 18-25] whit GAMS 24.1.2 software and BARON solver on an intel core i7 PC whit 16 GB of RAM and 4 GHz CPU.

The value of some of the important parameters are listed in table 3. And the generated problem dimensions are presented in table2 which, are categorized into small, medium and large scale of problem.

TABLE1. GENERATED PROBLEM

Problem size	Test problem	I	J	K	m	s
Small	1	2	2	2	2	2
	2	3	2	3	2	2
	3	3	3	3	2	3
	4	3	3	3	3	3
Medium	5	4	3	4	2	3
	6	5	4	5	3	4
	7	6	5	6	4	5
	8	7	6	6	5	5
Large	9	10	8	9	5	6
	10	11	9	11	6	6
	11	12	10	12	7	8
	12	12	11	12	8	8

TABLE2. TEST PROBLEM

Parameters	Value
ct_k	20
$\widetilde{D_{mkt}}$	~N(2*5,1)
crh_j	(30,25)
FC	25
CV	5
TNP_{pi}	(25,26,24,11,16,13)
CS_{sm}	(50,55,30,60)
re_k	0.7
Lp	20

V. RESULT AND DISCUSION

a. Experimental result

In this section, we showed the result of methods that, applied to solving the problem. For example, Problem instance No.2 is selected. The optimal pareto-solution of objective functions are presented in table 4.

Table 4: Pareto solutions of objective functions

Pareto solution	z_1	z_2
1	608	3700.03
2	617	3600.03
3	626	3500.03
4	644	3300.03
5	662	3100.03
6	671	3000.03
7	689	2800.03
8	707	2600.03
9	716	2500.03
10	734	2300.03
11	767	2100.03
12	794	1800.03

As you can see, the objective functions are inversely related. Given that the two objective functions are contradictory in nature and, as one increases, the other one decreases, the solutions obtained from the Epsilon method can be shown in the Pareto diagram. to better understand, Pareto chart is also shown in Fig 5.

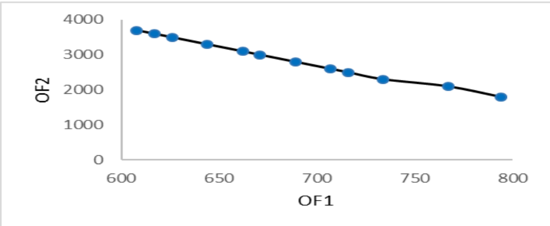

Fig 5: Pareto chart of objective functions

b. *Sensitivity analysis*

To evaluate the proposed model and, make better management decisions, the impact of changing several important parameters on objective functions is investigated.

Depending on the severity of the crisis or the circumstances, some parameters may change and, increase their uncertainty. In proposed model, we considered demand of pharmaceutical items for temporary care centres is an uncertain parameter which, has normal distribution. According to Fig 6, by increasing the variance of parameter D, the total cost increases too. On the other hand, the second objective function remains constant. This results reveal that, as the uncertainty in stochastic parameters like D increases in disaster, total cost also increases.

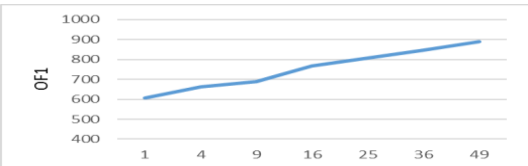

Fig 6: Impact of parameter D in objective function 1

In Fig 7, the effect of changing the capacity of the centres for patients on both objective functions is shown. It is obvious that, decreasing the capacity of patients, significantly increases both of the objective functions. Of course, increasing capacity from one special range onwards has no effect on improving the objective functions and, and it will only increase the additional cost.

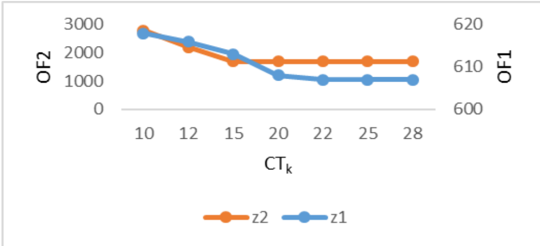

Fig 7: Impact of parameter CT_K in both objective functions

Parameter CV is the next parameter that, we evaluated it. Fig 8 reveals impact of CV on both objective functions. It has no effect on second objective function but has inverse relation whit firs objective function.

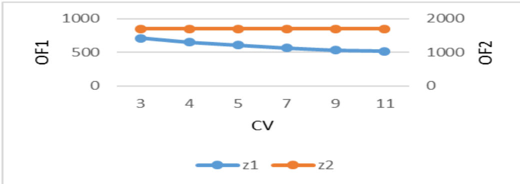

Fig 8: Impact of parameter CV in firs objective function

In Fig 9, a comparison has been made between the run time of the various dimensions considered for the problem. It is clear that as the complexity of the issue increases, the run time will increase.

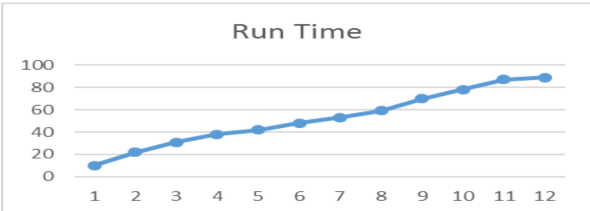

Fig 9: A comparison between Run Time

VI. CONCLUSION

In this paper, we presented a bi-objective model for hospital evacuation problem in order to minimize the total cost and dissatisfaction of patients. Patients are categorized into critical and noncritical types. To accelerate evacuation operations and increase patient safety, several temporary care centres are built, and a pharmaceutical supply chain is provided for hospitalized patients in temporary centres. The probability of disruption of centres as a result of disaster has been considered to increase the supply chain's reliability. An ε-constraint method were applied to solving the proposed model, then the results were analysed and Managerial advice was provided. The proposed model can help to manager to improved their plan for hospital evacuation operations in emergency times.

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