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# Patients Dispatch in Emergency Rescue with Traffic Congestion Considered

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**Abstract:** For the problem of assign the patients injured in the incident events to the medical institutions during the emergency rescue in a city, a decision model which considers the traffic congestions in the city and the treatment effect of different medical institutions on different injuries is constructed with a multi-objective to minimum the total rescue time and maximum the treatment utility. Firstly, Markov theory is used to estimate the travel time from the place where the event occurred to different hospitals under different traffic congestions. Secondly, the therapeutic effect of different medical institutions on different injured patients is determined. Thirdly, according to the characteristics of the model, an effective solution method is given. Finally, an example is given to illustrate the feasibility and effectiveness of the model.

**Keywords:** Emergent events, Emergency rescue, Traffic congestion, Choice of medical institutions, Optimization model

## 1. Introduction

In recent years, natural disasters, infectious diseases, terrorist attacks and many other unexpected disasters and accidents occurred frequently and thus result in many heavy casualties which put tremendous threats on people's lives and property. The main goal is to save more people in time after the occurrence. It is necessary to point out that the traffic congestion especially under densely populated areas such as cities has a great influence on the time of transit patients to the medical institutions for the reason that the ambulance is usually caught into the traffic jam and drivers slowly which may delay the treatment of the injured and even worse results. In addition, there is a limit for resource used for emergency rescue so that we should sent not too many injured people to a single hospital and with the capacity to cure different level of injury considered. Thus, the best scheme should obtain the fastest response speed and the greatest utility which is a practical problem and what is considered in this paper [1,2].

At present, it is rarely to see the dispatch problems which considers the traffic congestion environment in the city, but there are many relate problems that are resolved such as emergency rescue [3-7] and dispatch problems [8-10] under other backgrounds. For example, in terms of emergency rescue, Nogueira [3] analysis the emergency rescue in Belo Horizonte in Brazil through the optimization and simulation modeling technology, which put forward strategy on improve the efficiency of response by the allocation of rescue vehicles and base stations equipped with ambulances. Ingolfsson [4] takes the random of response time into account so as to determine the best position of rescue vehicles to achieve high efficiency of response; Afshin [5] builds a model to decide the minimum quantity of rescue vehicles and allocate them reasonably while set the upper limit to the response time and the coverage so as to obtain the minimum response time totally; Fiedrich [6] configures the resources to different search and rescue mission for the massive earthquake and other unexpected events to reduce casualties; LIU Tian-hu [7] focuses on the modeling of the resources location of medical rescue and the traditional Lagrangean relaxation algorithm is improved by using subgradient optimization algorithm. In terms of dispatch and assignment problem Seyda and Irem [8] established a mixed integer programming model to formulate the scheme of medical staff and resources while considered the working time and work intensity; Falasca and Zobel [9] formulate a multi-objective model aiming at the optimal assignment of the volunteer with the willingness and ability considered; YUAN Yuan [10] considers the degree of time satisfaction and the degree and workers' qualification for different rescue task so that an assignment model is constructed and the solution method are proposed.

The problem is that those related research deal with ordinary general emergency rescue with weakness in handle the special situations in urban traffic environment. In view of this, a comprehensive dispatch model with transit time and medical utility considered is proposed while the uncertainty of traffic congestion and limitation of medical resources nearby is studied. In the model, transit time is estimate based on Markov chain and then the treatment effect is defined on different level of injuries, the optimal assignment is obtained between the injured and medical institutions on the object of minimum the total transit time and maximum the total treatment effect. Finally, an example is given to illustrate the feasibility and validity of the proposed model.

## 2. Problem description

When an accident occurred, there may be many injuries with a level of injury from slightly to heavily hurt and there may be some hospitals with higher to lower quality of medical resources nearby. How to dispatch the injuries to hospitals efficiency is a practical problem which can be seen as Fig.1.

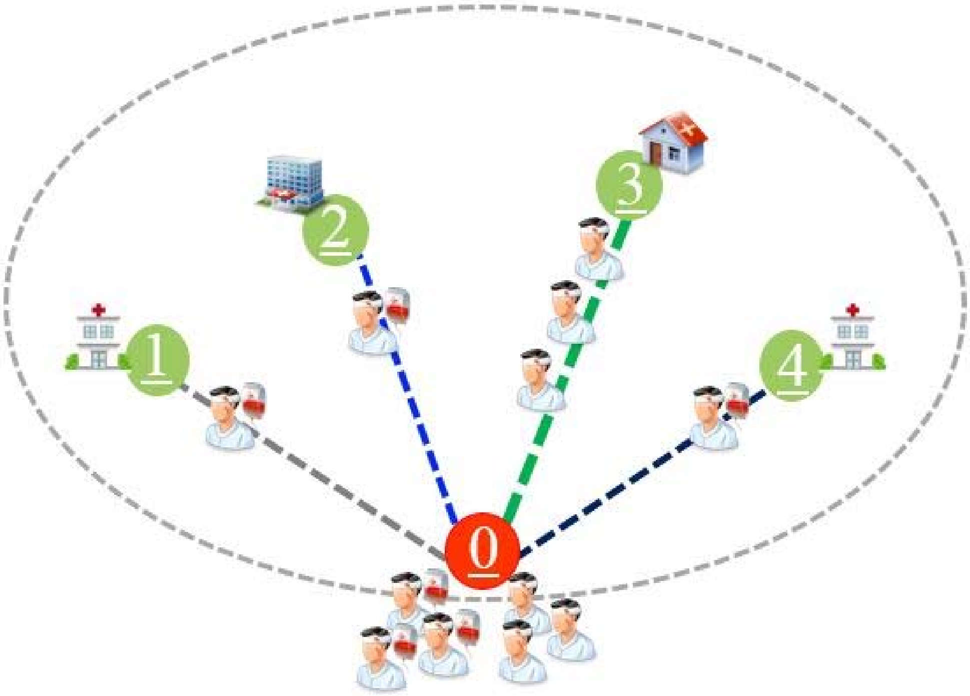


Fig. 1 The dispatch problem description

The following symbols are used to describe the set and the variables used in this model.

$V=\{V_1,V_2,\cdots,V_j,\cdots,V_m\}$: The set of hospitals, and $V_j$ defines the $j$ th hospital, while $j=1,2,\cdots,m$.

$C=\{1,2,\cdots,w\}$: The classification of different level of injuries, and in this paper is defined as heavily, medium, slightly, so that $c=1,2,3$ and the quantity of injuries of each level is defined as $n_c$.

$\tilde{Q}_j^c$: The quantity of the injuries with level $c$ can be accepted by the $j$ th hospital, while $c=1,2,3$, $j=1,2,\cdots,m$.

$U_c^r$: The set of treatment effect of different hospitals on different level injuries, and $r=\{1,2,3,4,5,6\}$ means ranking the best to the last hospitals in this paper.

$T_j$ : The estimated transit time from incident point to hospitals.

$X_j^c$: The quantity of patients of kind $c$ which assigned to the $j$th hospital, while $c=1,2,3$, $j=1,2,\cdots,m$.

This paper is aiming at obtaining the best scheme of the injuries to the hospitals matches best using a multiple object of minimum the total rescue time and maximum the treatment utility. While the following factors are considered: Firstly, the traffic situation in the cities varies which has effect on the transit time of injuries; Secondly, the treatment effect on different levels of injury if a patient is assigned to different hospitals. To make it simpler and applicable, we assume that the city's traffic congestion is consistent with usual times during the rescue process and there are enough vehicles for the transport. Besides, since the therapeutic effect can not be quantified, this paper assumes that the treatment effect on different levels of injuries can be given directly by some experts' assessment.

## 3. Estimation of transit time of the injuries

For the reason that the traffic congestion mainly functions on the transit time which is one of the most important indexes to study the effect rescue, it is relate to the success of emergency rescue directly. Therefore, the transit time of rescue vehicles is the main factor studied in this paper. The methods can be used to estimate travel time are as follows: historical trend method [11], artificial neural network method [12], Kalman filtering method [13], statistical method [14], quadratic function method and comprehensive estimation method [15] and many so on and here we use the Markov Chain theory to estimate the transit time.

At present, some large and medium-sized cities have been able to monitoring the urban traffic congestion and broadcast the traffic congestion index information so as to guide your drive. These real-time traffic congestion index information provides a great deal of traffic information that can be used to estimate the travel time of the rescue vehicle. And the traffic route is composed of a large number of unit sections, the unit road section is a very typical spatio-temporal process object with the state transfer properties. The state probability of the next section of the traffic link is only related to the state of the previous link, which is consistent with the basic theory of the Markov chain. Therefore, we use the Markov chain theory to estimate the travel time [16-18]. The specific calculation process is as follows:

(1) Calibrate the status of each section

We can calibrate the status of each section to 5 categories according to the traffic congestion index reported every day and mark as $S=\{1,2,3,4,5\}$, and can be seen in Table 1.

Table 1 The category of the traffic congestion and corresponding description

| status | traffic index | status desc. | traffic desc. | travel time desc. |
|---|---|---|---|---|
| 1 | [0,2] | Smooth | Almost no road is in congestion | You can travel according to road speed standards |
| 2 | (2,4] | Basic smooth | There may be some congestion | 0.2 to 0.5 times of the time than status 1 |
| 3 | (4,6] | Mild congestion | Part of the loop, trunk road in congestion | 0.5 to 0.8 times of the time than status 1 |
| 4 | (6,8] | Moderate congestion | most of loop, trunk road in congestion | 0.8 to 1.1 times of the time than status 1 |
| 5 | (8,10] | Serious congestion | Most of the city's road are in congestion | more than 1.1 times of the time than status 1 |

(2) Determine the transition probability between each states

When the ambulance vehicles drive into another section of the road, the status of the section is randomly changes so that we can use the probabilities statistics from usual data as the change probabilities of each states which marked as $P^{(1)}$ and showed as:

$$P^{(1)} = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{45} \\ p_{51} & p_{52} & p_{53} & p_{54} & p_{55} \end{bmatrix}$$

And $p_{ss'}$ means the change probabilities from status $s(s \in S)$ in a front section and it changed to status $s'(s' \in S)$ in the latter section. While the road consist with many section so that the n times change probabilities can be compute with the C-K formula as the follow:

$$P^{(n)} = \left(P^{(1)}\right)^n \quad (1)$$

(3) Estimation of the travel time from the incident point to hospitals

We can use formula (2) to estimate the time of a route from a incident point to a hospital, according to the structure of road network:

$$\overline{T} = \sum_{k \in K} \sum_{s \in S} \pi_s \alpha_s T_{(k)}(f) \quad (2)$$

Where $\overline{T}$ is the total time of the route; $K$ is the set of all the sections, $k(k \in K)$ is the $k$th section; $\pi_s$ is the limit probability in status $S$; $T_{(k)}(f)$ is the time of section $k$ in status 1 and can be compute as $T_{(k)}(f)=L_k/\overline{v}_0$ where the length of the section $L_k$ divided by the upper speed $\overline{v_0}$ ; $\alpha_s$ is the ratio of time consuming.

## 4. The dispatch model

(1) Analysis of the capacity of injuries can be cured in each hospital

The occurrence of the unexpected events usually causes many casualties and with great randomness, but there is a limitation of resources which is used for emergency medical so that there is a capacity of injuries which can be cured in just one hospital. It is inevitable that some of the injuries cannot be cured immediately if too many of the injuries are sent to a hospital which is exceed the capacity. It means that the quantity it can be accepted by one hospital is with a limitation in the availability time and be different with each hospital. In this paper, we assume that the number of injured patients can be treated in a hospital is ambiguous and we use triangular fuzzy numbers to define this quantity marked by $\tilde{Q}_j^c = \left(q_{1j}^c, q_{2j}^c, q_{3j}^c\right)$ which means the quantity of category $c\left(c=1,2,3\right)$ that can be accepted by the $j$th hospital, where $q_{1j}^c, q_{2j}^c, q_{3j}^c$ means the pessimistic, the most possible, the optimistic quantity of category $c\left(c=1,2,3\right)$ can be accepted.

(2) The construction of the optimization model

During the process of transport the injuries to hospitals, it is obvious that time is important for the cure of the wounded while the treatment utility is significant. From the analysis above we can gain the optimal model is as follows:

$$min\ z_1 = \sum_{j=1}^{m}\sum_{c=1}^{w} X_j^c T_j^0 \tag{3}$$

$$max\ z_2 = \sum_{j=1}^{m}\sum_{c=1}^{w} U_c^r X_j^c \tag{4}$$

$$\sum_{j=1}^{m} X_j^c = n_c \tag{5}$$

$$X_j^c \le \tilde{Q}_j^c \tag{6}$$

$$T_j = min\left\{\overline{T}_j\right\} \tag{7}$$

$$U_c^r \geq U_0^r (c=1,2) \tag{8}$$

$$X_j^c \geq 0 \tag{9}$$

Where $X_j^c$ represents the quantity of injuries of category $c$ which is transport to the $j$ th hospital, $\overline{T_j}$ represents the minimum time from the incident point to the $j$ th hospital. Formula (3) is to make sure the total transportation time of all the injuries in the medical network is minimum; formula (4) is to make sure the total treatment utility of all the injuries in the medical network is maximum; Formula (5) is to make sure that every wounded patient should be dispatch to one hospital; Formula (6) is to make sure that the accepted quantity of injuries should not exceed the capacity of each hospital; Formula (7) defines the computing method of the minimum transportation time; formula (8) is to make sure that the for every category of injuries the treatment utility meet with the minimum utility value so that for those seriously hurt patients should be transport to hospitals with great resource; formula (9) is non negative and integer constraints of the decision variables.

(3) Solution of the model

For this multi-objective optimization model, the two objective function can be transformed into just one as follows after take the characteristics of the problem and convenience of solving.

$$min\ z = \frac{\sum_{j=1}^{m}\sum_{c=1}^{w} X_j^c T_j^0}{\sum_{j=1}^{m}\sum_{c=1}^{w} U_c^r X_j^c} \tag{10}$$

And for the fuzzy estimation of capacity for each hospital corresponding of different category of injuries is calculated by average weighting method, $w_1, w_2, w_3$ represents the probability of the pessimistic estimation, the most likely estimate and the optimistic estimation weight respectively and $w_1 = w_2 = 1/6, w_3 = 2/3$ with experience. The specific process of solving the problem is: first of all, the transport time is calculated according to the incident point and the traffic conditions and so that the route is determined; Then, the treatment utility matches the injuries and the hospotals is accessed given by experienced exports; Finally, we can use Lingo or Matlab application to work out the scheme with the above parameters.

## 5. A case study

It is assumed that an accident occurred in the center of Xi'an city, shaanxi province which caused many casualties and the city road structure network is showed in Fig.2 and the star marks the incident place, the numbers with a circle is where a hospital lies, the line represents the road with number signs the distances with the unit is kilometers on it.

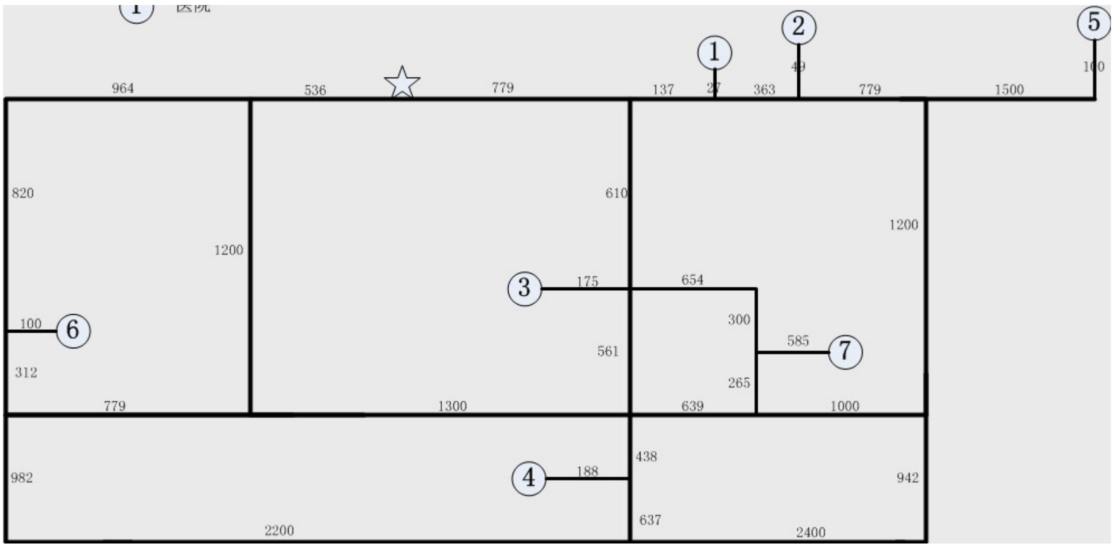


Fig. 2 The structure network of the road

We assume that there are 51 persons are injured and 9 injured seriously, 15 injured moderately, 27 injured slightly respectively. There are 7 hospitals nearby which are ranking A to F with the quality of its resource and the quantity of injuries can accepted with each category of injury is given below.

Table 2 The quantity of each category of injury accepted by each hospital

| Hospitals (ranking) | injured seriously | | | injured moderately | | | injured slightly | | |
|---|---|---|---|---|---|---|---|---|---|
| | pessimistic | most likely | optimistic | pessimistic | most likely | optimistic | pessimistic | most likely | optimistic |
| 1(D) | 1 | 2 | 3 | 4 | 6 | 8 | 8 | 10 | 12 |
| 2(F) | 1 | 2 | 3 | 4 | 6 | 6 | 8 | 9 | 10 |
| 3(A) | 2 | 4 | 6 | 6 | 8 | 10 | 10 | 13 | 16 |
| 4(B) | 2 | 3 | 5 | 4 | 5 | 6 | 10 | 12 | 14 |
| 5(C) | 2 | 3 | 4 | 6 | 7 | 8 | 10 | 12 | 14 |
| 6(E) | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 |
| 7(D) | 1 | 2 | 3 | 4 | 6 | 8 | 8 | 10 | 12 |

At the same time, according to the actual situation combined with expert advice, the treatment utility value (Note that the utility is 1 corresponding to the hospital that can be treated just the corresponding injury, and if the injury is more seriously, the better the therapeutic effect with the higher hospital quality; The lighter the injury is, the smaller the therapeutic effect gap is with different hospitals from A to F.) which matches the hospitals and the level of injuries is given below.

Table 3 The therapeutic effect of different degree of hospitals and injuries

| Utility Value | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| injured seriously | 1.8 | 1.5 | 1.3 | 1.0 | 0.9 | 0.0 |
| injured seriously | 1.5 | 1.4 | 1.3 | 1.2 | 1.0 | 0.8 |
| injured seriously | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Before calculate the travel time from the incident point to the hospitals we can determine the one-time transition probability from statistics of the traffic date and set it as follows.

$$p^{(1)} = \begin{bmatrix} \frac{2}{5} & \frac{2}{5} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} \\ \frac{1}{7} & \frac{3}{7} & \frac{1}{7} & \frac{1}{7} & \frac{1}{7} \\ \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} \\ \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{2}{5} & \frac{2}{5} \\ \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{2}{5} & \frac{2}{5} \end{bmatrix}$$

And the initial probability is $\alpha_s = [1.00,\ 1.35,\ 1.65,\ 1.95,\ 2.10]$. Besides, we set the speed is $30 {km}/{h}$ on the main road and $20 {km}/{h}$ on other road in traffic congestion status 1.

Then, we can estimate the minimum travel time from the incident place to hospitals which is showed in Table 4.

Table 4 The estimation of travel time

| hospital | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| estimated time(minute) | 3.04 | 4.32 | 5.04 | 8.45 | 12.21 | 7.95 | 9.14 |

Finally, the scheme is obtained from the optimal model using Lingo10 software, and the result is as follows:

Table 5 The scheme plan

| hospital | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| injured seriously | 2 | 0 | 5 | 2 | 0 | 0 | 0 |
| injured seriously | 7 | 0 | 8 | 0 | 0 | 0 | 0 |
| injured seriously | 11 | 9 | 7 | 0 | 0 | 0 | 0 |

From the results in Table 5, we can see that most of the injuries are sent to hospitals 1, 2, 3 for the travel time is much shorter than the others and also make full use of the resources. There are no patients sent to hospitals 5, 6, 7 for the travel time is much longer. Besides, the majority of the seriously injuries are sent to hospitals 1, 3, 4 with the better treatment utility and short travel time. Thus, it is indicate that this model can really simulate the real scene and work out an effective scheme for the rescue operation quickly.

## 6. Conclusion

In this paper, an optimal model of casualty assignment is established, considering the characteristics of urban traffic environment and emergency rescue, a concrete solution method is given simultaneously. In the model, the characteristics of urban traffic congestion, the degree of injury situation, the different abilities of different nodes in the medical network and the different utility of medical treatment are researched legitimately. It can provide theoretical guidance and reference for emergency medical rescue practice and guiding emergency effectively. For further study, it is necessary to develop more efficient and faster calculation method according to the specific characteristics of the model.

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