Optimal Solution Design for Initial Post-earthquake Casualty Dispatch Considering Road Disruption Scenarios: Based on Network Optimization Model

Linze Guo
School of Management, Shandong University, Jinan, China
13969526186@163.com

Abstract. The optimization of casualty dispatch is a key problem faced in the initial post-earthquake relief process. In view of the urgency and uncertainty of casualty rescue in the early post-earthquake period, this paper investigates the decision optimization problem of casualty dispatching in the early post-earthquake period. Based on the fact that current research on emergency disaster relief in the early post-earthquake period rarely considers the bi-objective optimization problem of transport time and system cost, this paper quantifies the risk of road disruption based on the earthquake risk level and designs a location-routing optimization model with the goal of minimizing the cost of the casualty dispatch system and minimizing the casualty transport time, which provides a solution for casualty dispatch in the initial post-earthquake period. Finally, the example of Sichuan Ya'an Lushan earthquake is used to search for the least costly and most efficient emergency rescue solution. Under this solution, even if the road network in some of the affected sites is severely damaged, timely treatment of casualties and optimal transportation system cost can still be ensured. Moreover, it can adjust measures to local conditions, and decision-makers can make a trend between shortening casualty dispatching time and reducing total system cost based on casualty injuries and road network conditions in the affected sites. Based on the casualty situation and the road network condition in the affected area, we make a trade-off between shortening the casualty dispatch time and reducing the total cost of the system to achieve the optimal casualty dispatch benefit.

Keywords: Post-earthquake Rescue; Casualty Dispatch; Bi-objective Optimization; LRP Model.

1. Introduction

Frequent seismic disasters greatly threaten human lives and property safety. For example, the Chilean earthquake that occurred on May 21, 1960 not only killed over 20,000 people, but also triggered secondary disasters such as volcanic eruptions and tsunamis; the 2005 Kashmir earthquake killed 73,000 people. Therefore, emergency medical services in the early post-earthquake period have become a widely discussed issue in academia and industry. Numerous scholars have conducted rich research on the improvement of rescue response speed, control of rescue costs, and improvement of rescue effectiveness in the post-earthquake period.

Existing studies describe the optimal design problem of post-earthquake emergency relief as the Location Allocation Problem (LAP), the Vehicle Routing Problem (VRP), and the Location Routing Problem (LRP). Tzeng et al. [1] studied a multi-objective LAP model for the construction of earthquake relief transit facilities from the perspective of the post-earthquake emergency relief supplies deployment problem. Yahyaei and Bozorgi-Amiri [2] studied the integrated siting of emergency relief shelter facilities and emergency supplies warehouses in the early post-earthquake period. Boonmee et al. [3] synthesized a humanitarian-based emergency relief logistics network optimization design problem. Mete et al. [4] studied the LRP problem of emergency relief material distribution and established an optimization model based on stochastic programming. Sheu et al. [5] established a dynamic LRP model for emergency material distribution and studied the problems of emergency relief, disaster area classification, and dynamic emergency demand prediction under sudden large-scale geological disasters.

The above studies on the LPR problem for post-emergency relief were based on the premise that the road network in the disaster area is intact and the transport time is not affected by the disaster, ignoring the damage to the transportation roads between the medical centers and the affected sites caused by the earthquake disaster. Some of the current literature has studied the planning of emergency relief networks under the risk of road disruption. Snyder et al. [6] first introduced the risk of disruption, proposed and studied the Reliable Facility Location Problem (RFLP), and divided it into two categories, namely, the Reliability Uncapacitated Fixed-charge Location Problem (RUFLP) and Reliability P-median Problem (RPMP). CHENG et al. [7] used a two-stage robust optimization model as a framework to study the fixed-charge problem with fuzzy demand under facility disruption scenarios. The robust siting problem was solved using a column constraint generation algorithm. Aydin et al. [8] studied the reliability p-hub overlay siting problem based on the premise of capacity constraints. Fu et al. [9] constructed an intraregional RFLP model to study the optimal design of emergency storage facilities.

In addition, most of the current research on the LRP problem of post-earthquake emergency relief is based on the objectives of meeting emergency material demand expectations, minimizing material transportation costs or transport time, and only a few studies have focused on the problem of casualty dispatch or classification for the treatment. NA and BANERJEE [10] performed on-site diagnosis of casualties to achieve injury classification, allocated rescue resources suitable for their injuries on the basis of classification, and established a MILP model with the objective of minimizing the costs. LIU et al. [11] developed a multi-objective optimization model for medical center selection and medical service allocation based on the factors of casualty classification, injury deterioration, diversification of rescue methods and fairness of medical resource allocation to maximize the number of survivors and minimize the total cost. SHIN and LEE [12] studied the allocation of emergency medical resources in major sudden casualty events by combining factors such as medical resource allocation and injury priority.

In summary, most of the current post-earthquake EMS optimization problems focus on the LRP problems with the main objectives of EMS material deployment and emergency facility location, and less on the location-routing problem with the minimization of casualty dispatch time, which is lacking in the integration of the two influencing factors of casualty transport time and system cost. In the meanwhile, only a small number of papers have integrated several scenarios of road disruption risk in the emergency process, where the mainstream research problem still aims at maximizing the demand point coverage expectation, and focuses only on several typical disruption scenarios in studying the road disruption risk problem, ignoring the fact that the damage intensity of earthquakes in different regions is different due to the influence of various topographic and geological factors. Therefore, it is crucial to assess the effects of seismic risks with varying degrees of damage on the state of the road system.

Since topographic and geological factors play a key role in the triggering of earthquakes [13], and among them seismic intensity and affected area are the fundamental factors triggering a large number of geological disaster risks [14], this paper classifies different affected sites into several disaster risk grades based on seismic intensity and affected area. In earthquake scenarios with different disaster risk levels, there are different ways to transport the wounded, and accordingly, the transport time and transportation cost spent are different. In this paper, the road condition is taken as the main factor affecting the time and cost of casualty transportation after the earthquake, and the optimization model of casualty dispatching under different earthquake situations is established with the objectives of minimizing the time of casualty transportation and minimizing the system cost of the rescue process. Also, the location-routing optimization model is designed to suggest the location for official post-earthquake casualty dispatch and medical service facilities using the Ya'an earthquake in Sichuan as an example.

2. Model Study

2.1 Problem Description and Model Hypotheses

In the early post-earthquake period, the number of casualties can surge and medical resources may be in short supply. Therefore, it is of great importance to quickly build an effective emergency casualty dispatch network for post-earthquake relief. The core of the emergency casualty dispatch network is to determine the location of emergency medical centers, to ensure that emergency medical centers can meet the demand for casualty treatment at the corresponding affected sites, and to realize nearby treatment and timely dispatch under the premise of optimizing transportation costs. This requires the selection of the optimal routing and the best service medical center at the affected sites for casualty transportation to ensure the shortest casualty transport time and minimize the total system cost to the greatest extent.

At the same time, since it is difficult to predict and characterize the damage to the road network caused by the earthquake, this paper selects two indicators, i.e., the percentage of the affected area and the disaster intensity, to quantify the disaster risk level of the affected sites based on the literature of previous studies. Among them, the affected area indicates the proportion of the total area occupied by the earthquake disaster, and the disaster intensity indicates the intensity level of the earthquake disaster suffered by the current affected site. The ultimate purpose of portraying the risk of road disruption by disaster risk level is to reasonably select the transportation means to ensure the timeliness and cost optimization of casualty dispatch.

Therefore, the following hypotheses are constructed based on the above analysis:

Each ambulance can only transport one casualty at a time, and each helicopter can transport two casualties at a time.

The locations of the affected sites and medical centers are clearly known, and there is an upper limit to the number of casualties that can be accommodated at each medical center.

Each affected site is served by 1 medical center, and each medical center can serve multiple affected sites.

The disaster risk level for the affected area is divided into two categories -- high and low.

Under different disaster risk levels, the degree of road damage and facility failure varies from one another, and ambulances cannot travel on the roads in high-risk areas.

The cost of using a rescue helicopter for casualty dispatch is much higher than the cost of using an ambulance for transport.

2.2 Variable Settings

The set, parameters and decision variables are set according to the previous analysis and problem description as shown in the following table.

As the earthquake may cause the road network to be broken, the roads in the affected areas cannot pass ambulances normally, and rescue helicopters need to be activated for casualty dispatching, at which time the risk of road disruption needs to be reasonably quantified. Here, the disaster risk level is used to portray and assess the degree of damage in the affected area, and the disaster risk level is quantified by using 2 indicators, namely the percentage of affected area and the disaster intensity level, as shown in the following equation:

$$H_i = 0.5 f_i + \frac{0.5 l_i}{10}$$

For the disaster risk level of the affected site calculated by the above formula, if $0 \le H_i < 0.5$, it means “low” risk level; if $0.5 \le H_i < 1$, it means “high” risk level.

Table 1. Model variable settings

Symbols	Meaning
Set	

I={1, 2,⋯,i}	Set of affected sites
J={1, 2,⋯, j}	Set of medical centers
Parameters	
p_i	Number of casualties at the i-th affected site
H_i	Value of disaster risk level of the i-th affected point
f_i	Proportion of the area of the i-th affected site with earthquake disaster to the total area
l_i	Intensity level of the earthquake disaster at the i-th affected site
t_{ij}^a	Transport time for an ambulance to transport a casualty from the i-th affected site to the j-th medical center
t_{ij}^h	Transport time of the rescue helicopter to transport the wounded from the i-th affected site to the j-th medical center
d_{ij}^a	Transport distance of ambulance transporting casualties from the i-th affected site to the j-th medical center
d_{ij}^h	Transport distance of the rescue helicopter to transport the wounded from the i-th affected site to the j-th medical center
V_a	Ambulance travel speed
V_h	Rescue helicopter travel speed
c_{fix}	Activating costs for medical treatment at selected medical centers
c_a	Ambulance transportation cost per unit distance
c_h	Cost per unit distance transported for rescue helicopters
Q_j^w	Maximum number of casualties that can be accommodated in the j-th medical center
c_{ij}	Total transportation cost of transporting the casualty from the i-th affected site to the j-th medical center
a_i	Auxiliary variable of the ceiling method
Decision Variables	
x_j	A value of 1 means that the j-th medical center is activated, and a value of 0 means that it is not activated.
y_{ij}	A value of 1 means that the i-th affected site is served by the j-th medical center, and a value of 0 means that it is not served.
Z_i	A value of 1 means that the ambulance is activated for casualty transport at the i-th affected point, and a value of 0 means that it is not activated.
G_i	A value of 1 means that the rescue helicopter is activated for casualty transport at the i-th affected site, and a value of 0 means that it is not activated.

2.3 Model Construction

Based on the need for timely dispatch of casualties and cost control in the emergency relief process in the early post-earthquake period, a routing-location optimization model for casualty dispatch is constructed as follows:

$$\min \quad z = \sum_{j \in J} c_{fix} x_j + \sum_{i \in I} \sum_{j \in J} c_{ij} y_{ij} \tag{1}$$

$$\min \quad w = 2\sum_{i \in I} \sum_{j \in J} (t_{ij}^a Z_i + t_{ij}^h G_i) y_{ij} \tag{2}$$

s.t.

$$c_{ij} = [2c_a d_{ij}^a Z_i p_i + 2c_h d_{ij}^h G_i (\frac{p_i}{2} + a_i)] y_{ij} \tag{3}$$

$$\frac{p_i}{2}+a_i \in Z, \forall i \in I \tag{4}$$

$$Q_j^w x_j \geq \sum_{i \in I} p_i y_{ij}, \forall j \in J \tag{5}$$

$$t_{ij} = \begin{cases} \frac{d_{ij}^a}{V_m}, 0 \leq H_i < 0.5 \\ \frac{d_{ij}^h}{V_n}, 0.5 \leq H_i < 1 \end{cases}, \forall i \in I, j \in J \tag{6}$$

$$\sum_{j \in J} y_{ij} = 1, \forall i \in I \tag{7}$$

$$x_j \geq y_{ij}, \forall j \in J \tag{8}$$

$$Z_i = \begin{cases} 1, 0 \leq H_i < 0.5 \\ 0, 0.5 \leq H_i < 1 \end{cases}, \forall i \in I \tag{9}$$

$$G_i = \begin{cases} 1, 0.5 \leq H_i < 1 \\ 0, 0 \leq H_i < 0.5 \end{cases}, \forall i \in I \tag{10}$$

$$H_i = 0.5 f_i + \frac{0.5 l_i}{10} \tag{11}$$

$$c_h \gg c_a \tag{12}$$

$$a_i \geq 0, \forall i \in I \tag{13}$$

$$x_j = \{0,1\}, \forall j \in J \tag{14}$$

$$y_{ij} = \{0,1\}, \forall i \in I, j \in J \tag{15}$$

Objective function (1) indicates that the sum of the total cost of casualty dispatch and medical center construction is minimized; objective function (2) indicates that the casualty transport time is minimized, i.e., all transport times for both phases of transport are minimized.

Equation (3) indicates the total transportation cost of transporting the casualties from the i-th affected site to the j-th medical center, i.e., including the cost of transporting the two distances; equation (4) indicates the integer constraint on the number of helicopters required to transport the casualties at the i-th affected site, and it is known that one helicopter can transport two casualties, so the number of helicopters required is the number of casualties at the i-th affected site divided by two and rounded up; equation (5) indicates that the number of people that can be accommodated at the j-th medical center is greater than the total number of casualties at all the affected sites it serves; equation (6) gives the expression of casualty transport time, which varies according to the different risk levels and requires different means of transportation; equation (7) indicates that each affected site is served by one and only one medical center; equation (8) indicates that only the activated medical center can provide services to the affected site; equation (9) indicates the use of ambulances as a means of transportation at the low risk level; equation (10) indicates that the rescue helicopter is used as the transportation for high risk level; equation (11) gives the basis for the disaster risk level of the affected site; equation (12) indicates that the transportation cost of the rescue helicopter is much larger than that of the ambulance; equation (13) indicates the auxiliary variable constraint of the ceiling method; equations (14) and (15) are 0-1 integer variable constraint.

3. Example Analysis

3.1 Example Description

This paper follows the data from the study of Chen Gang et al. [15] for the arithmetic analysis. The Ya'an earthquake in Sichuan was a 7.0 magnitude earthquake that occurred in Lushan County, Ya'an City, Sichuan Province (30.3 N, 103.0 E) at 8:02 p.m. Beijing time on April 20, 2013, with a depth of 13 km, causing an affected population of 1.52 million and an affected area of 12,500 km².

The above earthquake disaster caused a large number of casualties. Thus, it is necessary to construct an emergency dispatch network for casualties in time to ensure timely treatment of casualties and optimal system cost. Taking townships as the affected sites, Lushan County has 5 towns and 4 townships under its jurisdiction, with a total of 9 affected sites, and the number of casualties in each affected site is shown in Table 2.

Table 2. Number of wounded persons at each affected site

		Number of the wounded/ person			
Number (I)	Affected spots	Number of serious causalities	Number of moderate casualties	Number of minor injuries	Total (pi)
1	Luyang Town	59	143	292	494
2	Feixianguan Town	21	48	124	193
3	Siyan Township	23	71	142	236
4	Qingren Township	29	116	177	322
5	Shuang Shi Town	20	59	147	226
6	Longmen Township	70	153	416	639
7	Baosheng Township	12	46	100	158
8	Taiping Town	16	71	122	209
9	Okawa Town	5	23	40	68

According to the selection requirements of medical centers, it is necessary to ensure that the terrain in the area near the medical centers is flat, the road traffic is smooth, and the area covered is not less than 800m2. Therefore, according to the above requirements, there are a total of seven medical centers in the area near the Ya'an earthquake. There is an upper limit to its medical resources, i.e., an upper limit to the number of casualties it can accommodate, as shown in Table 3 below.

Table 3. Maximum medical resources for each medical center

Number (J)	Name of medical center	Available medical resources
1	Lushan Middle School	800
2	Fei Xian Central School	400
3	Siyan Health Center	400
4	Qingren Central School	800
5	Shuang Shih Middle School	600
6	Zhonglin Central School	600
7	Dachuan Health Center	200

The distances between each affected site and the alternative medical centers are shown in Table 4 below.

Given that the ambulance travels at 40km/h and the helicopter travels at 120km/h, it can be seen from the information that the transportation cost of the ambulance is 10 RMB within 3km and 2 RMB per km over 3km; the transportation cost of the rescue helicopter is 20,000 RMB per 0.5 hour, and less than 0.5 hour is calculated as 0.5 hour.

According to the disaster risk grade classification criteria set by the previous analysis, and the data obtained from the query data on the percentage of affected area and earthquake intensity level of each affected site, the disaster risk grade of each affected site was derived as shown in Table 5 below.

Table 4. Distance between each affected site and alternative medical centers (unit: km)

Affected sites	Medical centers						
	1	2	3	4	5	6	7
1	3	16	7	6	17	42	86
2	17	3	14	22	35	57	102
3	6	12	2	13	46	46	92
4	6	19	12	2	13	42	86
5	18	33	25	13	2	46	92
6	17	30	23	17	22	26	70
7	27	41	34	27	32	14	59
8	35	49	42	36	45	5	50
9	82	95	88	81	86	43	3

Table 5. Data related to the disaster risk level of each affected site

Number (I)	Affected site	Seismic intensity rating	Affected area (km2)	Percentage of affected area (%)	Hi	Disaster risk level
1	Luyang Town	9	354	2.832	5.92	high
2	Feixianguan Town	6	52.12	0.417	3.21	low
3	Siyan Township	6	23.62	0.189	3.09	low
4	Qingren Township	6	51.48	0.412	3.21	low
5	Shuang Shi Town	9	78.02	0.624	4.81	low
6	Longmen Township	7	92.22	0.738	3.87	low
7	Baosheng Township	8	116.42	0.931	4.47	low
8	Taiping Town	9	192.35	1.539	5.27	high
9	Dachuan Town	7	519.57	4.157	5.58	high

3.2 Model Solution

The MATLAB R2022a solution model was used to first solve for the objective function (1) in Section 2.3, resulting in an optimal system cost of $31,284,660. The activation status of medical centers is shown in Table 6 below

Table 6. Activation status of medical centers at minimum system cost

Number (J)	Medical centers	Activation status
1	Lushan Middle School	Activated
2	Fei Xian Central School	Not activated
3	Siyan Health Center	Not activated
4	Qingren Central School	Enable
5	Shuang Shih Middle School	Enable
6	Zhonglin Central School	Enable
7	Dachuan Health Center	Not activated

The specific services of the activated medical centers are shown in Table 7 below.

Next, the objective function (2) of Section 2.3 is solved optimally for the shortest casualty dispatch time of 2.18 hours, and the medical center activation is shown in Table 8 below.

Table 7. Service status of medical centers at the lowest system cost

Affected sites	Medical centers						
	1	2	3	4	5	6	7
1	None	None	None	None	None	Servicing	None
2	Servicing	None	None	None	None	None	None
3	Servicing	None	None	None	None	None	None
4	Servicing	None	None	None	None	None	None
5	None	None	None	None	Servicing	None	None
6	None	None	None	Servicing	None	None	None
7	None	None	None	Servicing	None	None	None
8	None	None	None	None	Servicing	None	None
9	None	None	None	None	None	Servicing	None

Table 8. Medical center activation at the shortest transport time

Number (J)	Medical centers	Activation status
1	Lushan Middle School	Activated
2	Fei Xian Central School	Activated
3	Siyan Health Center	Activated
4	Qingren Central School	Activated
5	Shuang Shih Middle School	Activated
6	Zhonglin Central School	Activated
7	Dachuan Health Center	Activated

The details of the services provided by each activated medical center to each affected site are shown in Table 9 below.

Table 9. Service status of medical centers at the shortest transport time

Affected sites	Medical centers						
	1	2	3	4	5	6	7
1	Servicing	None	None	None	None	None	None
2	None	Servicing	None	None	None	None	None
3	None	None	Servicing	None	None	None	None
4	None	None	None	None	Servicing	None	None
5	None	None	None	None	Servicing	None	None
6	None	None	None	Servicing	None	None	None
7	None	None	None	None	None	Servicing	None
8	None	None	None	None	None	Servicing	None
9	None	None	None	None	None	None	Servicing

Finally, adding the shortest transport time (2.18h) as a constraint to the optimization of solving the objective function (1) cannot satisfy the objectives of minimizing the system cost and minimizing the casualty transport time at the same time, so the constraint of the casualty transport time is reasonably relaxed to ensure the optimal system cost and the timeliest casualty dispatch to the greatest extent.

Therefore, the optimal system cost of $31,657,670 can be derived when the constraint of casualty transport time is relaxed to 2.73h, and the timeliness requirement of casualty dispatch is satisfied, and each medical center is activated as shown in Table 10 below.

Table 10. Activation status of medical centers under multiple objectives

Number (J)	Medical centers	Activation status
1	Lushan Middle School	Activated
2	Fei Xian Central School	Activated
3	Siyan Health Center	Activated
4	Qingren Central School	Activated
5	Shuang Shih Middle School	Activated
6	Zhonglin Central School	Activated
7	Dachuan Health Center	Activated

The specific services of each medical center are shown in Table 11 below.

Table 11. Service status of medical centers under multiple objectives

Affected sites	Medical centers						
	1	2	3	4	5	6	7
1	Servicing	None	None	None	None	None	None
2	None	Servicing	None	None	None	None	None
3	None	None	Servicing	None	None	None	None
4	None	None	None	None	Servicing	None	None
5	None	None	None	None	Servicing	None	None
6	None	None	None	Servicing	None	None	None
7	None	None	None	None	None	Servicing	None
8	None	None	None	None	None	Servicing	None
9	None	None	None	None	None	None	Servicing

The cost of casualty transportation for each affected site can be derived based on the medical center activation and specific service recipients, as shown in Figures 1 and 2.

The cost of transportation to the affected sites using ambulances and rescue helicopters is shown in Figures 1 and 2 below.

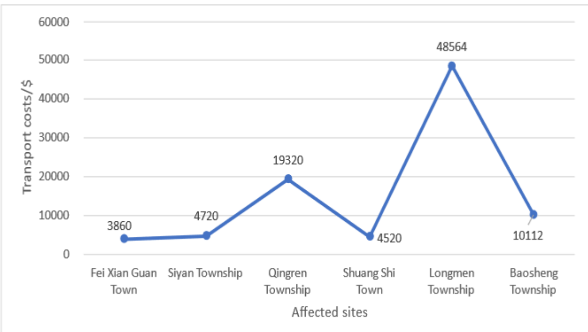

Figure 1. Cost of casualty transportation at the affected site by

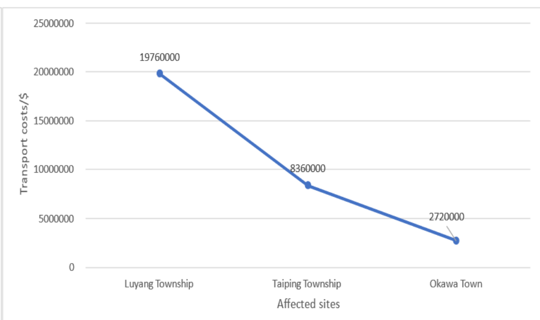

Figure 2. Cost of casualty transportation at the affected site by

3.3 Model Sensitivity Analysis

According to the previous analysis it is known that the optimal system cost is derived when setting the constraint of casualty transport time of 2.73 h. In order to study the changing relationship between transport time and system cost, the total system cost changes as shown in Table 12 and Figure 3 below, with 2.73 h as the starting point and 0.1 h as the step to gradually increase the casualty transport time constraint.

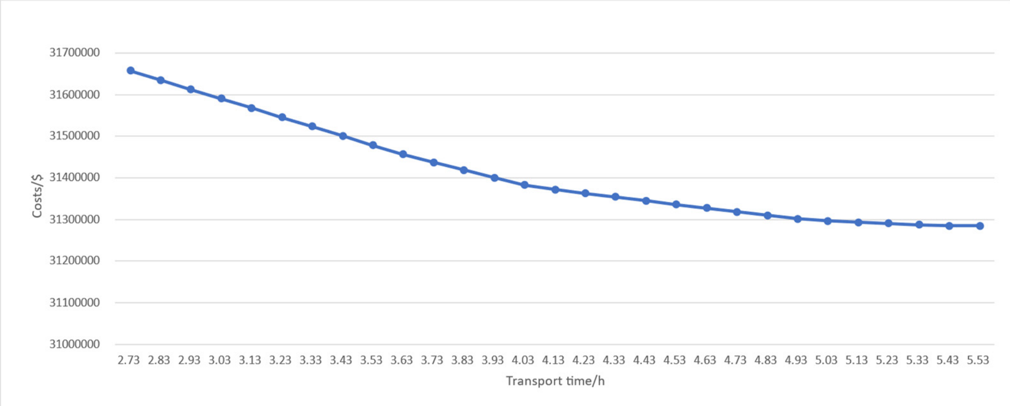

Figure 3. Line graph of system cost versus transport time

According to Figure 3, it can be observed that the system cost decreases gradually with the increase of transport time. Also, the decrease of system cost slows down gradually. In order to study the trend of system cost during the increase of casualty transport time from 5.43h to 5.53h, we increase the casualty transport time in steps of 0.01h and plot the trend of system cost during this increase as shown below.

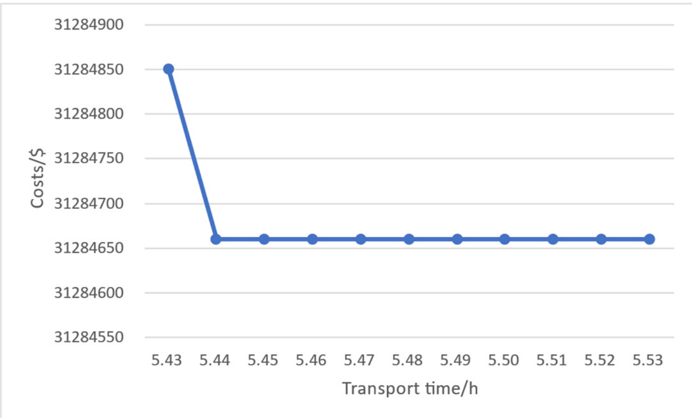

Figure 4. Trend of system cost with transport time

According to Figure 4, it can be visualized that the system cost reaches its minimum value when the casualty transport time increases to 5.44h and remains stable.

According to the sensitivity analysis, the system cost decreases gradually with the increase of the casualty transport time, and the rate of decline slows gradually. The system cost reaches the minimum value when the transport time is 5.44h, and no longer changes with the increase of transport time, so the optimal transport time should be controlled near 5.44h.

To gain insight into the decreasing trend of system cost, a line graph of the decrease in system cost for each transport time growth interval is plotted as shown in 5 below.

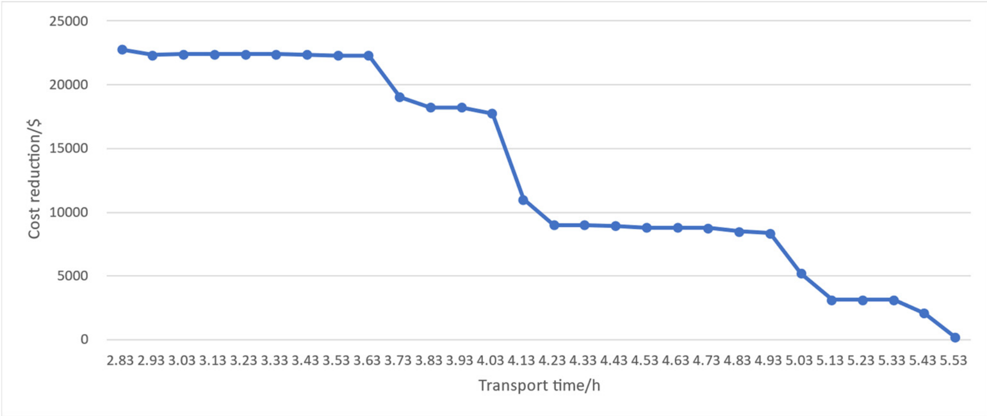

Figure 5. Line graph of system cost reduction rate

Figure 5 above shows the trend of the decrease in system cost during the gradual increase in transport time from 2.73h in steps of 0.1h, i.e., the amount of decrease in system cost due to each 0.1-hour increase in casualty transport time. According to Figure 5, it can be concluded that the decrease in system cost is large and remains stable until the casualty transport time decreases to 3.63h.

Thus, a reasonable casualty dispatching plan can be formulated according to the change of system cost reduction with transport time. In the case of serious casualty injury requiring emergency transportation, the optimization plan of shortening the casualty transport time is given priority. Also, since the maximum system cost reduction does not exceed 25,000 yuan, the cost reduction benefit brought by increasing the casualty transport time is not significant. Thus, it can be considered as appropriate to maximize the timely treatment of casualties. In the case of more moderate injuries, the upper limit of casualty transport time can be appropriately relaxed to reduce the system cost of casualty transportation. In conclusion, the model in this paper can be used to optimize the emergency casualty dispatch system by comprehensively analyzing the different injuries of the casualties and the different transportation conditions at the affected sites and selecting a reasonable upper limit of the casualty transport time, and comprehensively weighing the casualty dispatch time and the transportation system cost.

4. Conclusion

Casualty dispatch design is one of the main tasks in the emergency relief process in the early post-earthquake period. Based on the above requirements, this paper designs a location-routing optimization system for post-earthquake casualty dispatching with the main objective of minimizing casualty transport time and system cost, taking into account the road network condition factors affecting casualty dispatching and transportation cost, and quantifying the risk of road disruption near the affected area by the disaster risk level of the affected sites. In quantifying the risk level, the disaster risk level of the affected area and the disaster intensity level of the affected area are considered to carve the disaster risk level of the affected sites. Again, taking into account the degree of destruction of the road network will have a certain impact on the selection of transportation means, if the high-risk level is used to rescue helicopters for transport, low risk level is normal use of ambulances for casualty dispatch.

The LRP optimization model was thus designed in this paper and solved using MATLAB R2022a, resulting in a minimum system cost of RMB 31,284,660 and a minimum casualty transport time of 2.18 hours. In order to meet the timeliness of casualty transportation and optimize the cost of transportation system, the optimal system cost of RMB 31,657,670 is obtained by appropriately relaxing the casualty transport time to 2.73 hours, and the optimal medical center activation scheme and the casualty transportation scheme to the affected sites are derived. The trend of the system cost with the change of casualty transport time is studied again, and it is concluded that the system cost decreases gradually with the increase of casualty transport time, and its decrease shows a shrinking trend with the increase of time, and after the increase of casualty transport time to 5.44 hours, the system cost no longer changes with the increase of transport time, and the system cost reaches the minimum value at this time. Thus, when formulating a reasonable casualty dispatch plan, we can consider taking into account the different injuries of the casualties in different affected areas and the different transportation conditions of the road network, and comprehensively weigh whether to shorten the casualty dispatch time or reduce the cost of the transportation system, so as to optimize the casualty emergency dispatch system.

Therefore, the location-routing optimization system of casualty dispatching considering the risk of road disruption proposed in this paper can take the casualty transport time and the cost of the casualty transportation system into comprehensive consideration. Furthermore, based on the model solution results, we can analyze the specific problems of post-earthquake emergency relief, develop a scientific and reasonable casualty dispatching plan based on a comprehensive analysis of casualty injury conditions and road network conditions in the affected area, and ensure timely treatment of casualties and optimization of the cost of the casualty dispatching system.

In addition, the combination of road disruption and facility timing scenarios can be considered as a basis to study the facility planning problem under the risk of disruption in post-earthquake emergency relief. The relief and rescue problem in the post-earthquake recovery period can also be considered to study the casualty dispatching plan after the recovery of the damaged road network in the affected area, and factors such as casualty transfer and medical resource sharing can be incorporated into the analysis to study the location-routing dispatching of casualties in the post-earthquake recovery period.

References

[1] Tzeng G H, Cheng H J, Huang T D. Multi-objective optimal planning for designing relief delivery systems [J]. Transportation Research Part E: Logistics & Transportation Review, 2007, 43(6): 673-686.

[2] Yahyaei M, Bozorgi-Amiri A. Robust reliable humanitarian relief network design: an integration of shelter and supply facility location [J]. Annals of Operations Research, 2018.1-20.

[3] Boonmee C, Arimura M, Asada T. Facility location optimization model for emergency humanitarian logistics [J]. International Journal of Disaster Risk Reduction, 2017, 24(9): 485-498.

[4] Mete H O, Zabinsky Z B. Stochastic optimization of medical supply location and distribution in disaster management J]. International Journal of Production Economics,2010,126(1):76~84.

[5] Sheu J B, Dynamic relief demand management for emergency logistics operations under large-scale disasters [J]. Transportation Research Part E, 2010,46(1).1~17.

[6] Snyder L V, Daskin M S. Reliability models for facility location: the expected failure cost case [J]. Transportation Science, 2005, 39(3): 400-416.

[7] CHENG C, YOSSIRI A, LOUIS-MARTIN R. Robust facility location under demand uncertainty and facility disruptions [J]. Omega, 2019, 103: 1-24.

[8] Aydin N, Murat A. A swarm intelligence-based sample average approximation algori-thm for the capacitated reliable facility location problem [J]. International Journal of Production Economics, 2013, 145(1): 173-183.

[9] FU D, Chen Y Z, WAN X. The study on the reliable model for the regional emergency storage facility under the risk of natural disaster [J]. Operations Research and Management Science, 2015, 24(3): 14-19.

[10] NA H S, BANERJEE A. A disaster evacuation network model for transporting multiple priority evacuees [J]. IIE Transactions, 2015, 47(11): 1287-0299.

[11] LIU Y, CUI N, ZHANG J. Integrated temporary facility location and casualty allocation planning for post-disaster humanitarian medical service [J]. Transportation Research Part E: Logistics and Transportation Review, 2019, 128: 1-16.

[12] SHIN K, LEE T. Emergency medical service resource allocation in a mass casualty incident by integrating patient prioritization and hospital selection problems[J]. IISE Transactions, 2020, 52(10): 1141-1155.

[13] CHEN B, LI Z H, Huang W B, Liu Z J, Zhang C L, Du J T, Song B, Ding M T, Zhu W, Zhang S C, Wang J W, Peng J B. Spatial Distribution and Influencing Factors of Georisks Induced by the 2022 Mw6.6 Luding (Sichuan, China) Earthquake [J/OL]. Journal of Earth Sciences and Environment,1-15[2022-11-25]. DOI: 10.19814/j.jese.2022.10012.

[14] HUANG R Q. Mechanism and Geomechanical Modes of Landslide risks Triggered by Wenchuan 8.0 Earthquake [J]. Chinese Journal of Rock Mechanics and Engineering, 2009, 28(06):1239-1249.

[15] CHEN G, FU J Y. Emergency Medical Mobile Hospital Robust Location Problem in Post-disaster under Demand Uncertainty[J]. Chinese Journal of Management Science, 2021, 29(09): 213-223.DOI: 10. 16381 / j. cnki. issn1003-207x.2019.1103.