SCHEDULING AND OPTIMIZATION MODEL OF EMERGENCY RELIEF SUPPLIES IN THE CONSTRAINT-BASED MULTI-OBJECTIVE: SERVICE QUALITY PERSPECTIVE

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ABSTRACT

This paper studies the scheduling and optimization problems of emergency relief supplies. The minimum material response time and minimum transportation costs are the two major considerations in most studies. The factor of the affected population demand for relief supplies is considered in the scheduling model of emergency relief supplies from the service quality perspective. On the basis of the study, a multi-objective scheduling model of emergency relief supplies is proposed. The paper present two optimization strategies based on a step-by-step method and a two-dimensional Euclidean distance objective weighting algorithm is present in order to solve the multi-objective scheduling problem. To validate the proposed model, this paper conducts a case study on Wenchuan earthquake. The case study demonstrates that the scheduling model and the optimization strategy can provide effective methodological guidance for the scheduling of emergency relief supplies.

Keywords: emergency response, emergency relief supplies, resource scheduling, multi-objective, optimization strategy

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1 INTRODUCTION

Various types of disasters and incidents, such as the 2011 Japan tsunami, 2008 Sichuan earthquake, 2005 Hurricane Katrina, and 2003 SARS epidemic, cause huge loss of human lives and properties and highlight the need to improve our capabilities to prevent, protect against, respond to, mitigate, and recover from natural and manmade incidents. Effective rescue measures must be taken timely to minimize the losses by the unexpected events. A series of activities to respond to emergencies, including safe transfer of personnel in the disaster areas, timely rescue of casualties, health and epidemic prevention, disaster recovery and reconstruction activities of the affected areas, need to have the support of a large number of relief supplies. Quick response to the urgent relief needs right after natural disasters through efficient emergency logistics distribution is vital to the alleviation of disaster impact in the affected areas, which remains challenging in the field of logistics and related areas.

According to the needs of the affected areas to prepare and configure a variety of emergency resources, many experts have been studied. Tufekci and Wallace [8] thought that successful emergency management requires a better understanding of events with potentially disastrous consequences, a comprehensive, holistic view of managing such events, and the effective use of technology. Fiedrich et al. [3] proposed a dynamic optimization model that uses detailed descriptions of the operational areas and of the available resources to calculate the resource performance and efficiency for different tasks related to the response and an adequate solution method for the model was presented as well in order to find the best assignment of available resources to the operational areas. Barbarosoglu et al. [1] developed a mathematical model for helicopter mission planning during a disaster relief operation and proposed an interactive procedure is designed with the top level decision-maker to assess the preference of alternative non-dominated solutions in order to solve the multi-objective conflict. Sheu [6] presented a hybrid fuzzy clustering-optimization approach to the operation of emergency logistics co-distribution responding to the urgent relief demands in the crucial rescue period based on a proposed three-layer emergency logistics co-distribution conceptual framework involveing two recursive mechanisms: (1) disaster-affected area grouping, and (2) relief co-distribution. Ozdamar and Demir [5] proposed a hierarchical cluster and route procedure for coordinating vehicle routing in large-scale post-disaster distribution and evacuation activities in which a multi-level clustering algorithm that groups demand nodes into smaller clusters at each planning level is presented. Caunhye et al. [2] reviewed optimization models utilized in emergency logistics and thought that disaster operations can be performed before or after disaster occurrence and short-notice evacuation, facility location, and stock pre-positioning are drafted as the main pre-disaster operations, while relief distribution and casualty transportation are categorized as post-disaster operations. Hu [4] proposed an integer linear programming model to build the path selection for container supply chain in the context of emergency relief in order to schedule the multimodal transportation flow of the chain with time efficiency of higher reliability. Tzeng et al. [7] constructed a relief-distribution model using the multi-objective programming method for designing relief delivery systems in a real case and discussed three objectives: minimizing the total cost, minimizing the total travel time, and maximizing the minimal satisfaction during the planning period in order to enhance the distribution of relief materials effectively.

Although many studies on relief materials have been published, the specific challenges discussed above have not been thoroughly examined. The goal of this paper is to develop a scheduling and optimization model of emergency relief supplies that concentrates on these requirements. The main feature of the model proposed in the paper is that the emergency rescue work is considered to provide emergency rescue services to the affected people and the service quality methods is used to evaluate the quality of the relief work under multi-objective conditions. The factor of the affected population demand for relief supplies is considered in the scheduling model of emergency relief supplies from the service quality perspective. To validate the proposed model, this paper conducts a case study on Wenchuan earthquake. The case study demonstrates that the scheduling model and the optimization strategy can provide effective methodological guidance for the scheduling of emergency relief supplies.

The rest of this paper is organized as follows: Section 2 give the problem description of relief supplies scheduling. Section 3 presents the scheduling model and optimization strategy. A case study validating the scheduling model and optimization strategy is discussed in Section 4. Finally, conclusions are provided in Section 5.

2 PROBLEM DESCRIPTION

Assume after the occurrence of unexpected events, the emergency relief supplies supply points have been gathered in a certain demand for relief supplies to meet the emergency supplies demand points. At this time, the problem to be addressed is how the emergency relief supplies from multiple supply points are rationally deployed to multiple demand points. In other words, the problem is to determine reasonable relief supplies supply points and supply for each demand point. Assume $S_1, S_2, ..., S_m$ are m emergency relief supplies supply points, and $D_1, D_2, ..., D_n$ are n emergency relief supplies demand points. Emergency relief supplies from multiple supply points are deployed to multiple demand points, show as in Figure 1.

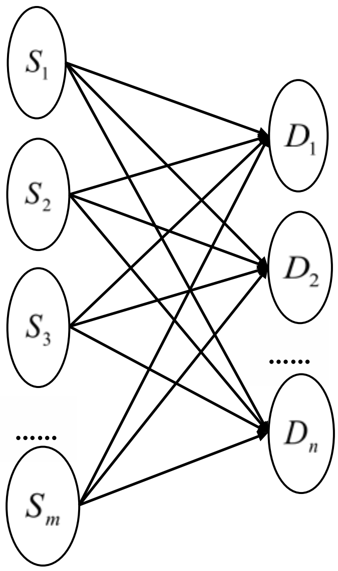

Figure 1: Relief supplies scheduled from supply points to demand points

3 SCHEDULING MODEL AND OPTIMIZATION STRATEGY

Assume, $s_i^{'} (i = 1,2,...,m)$ is the maximize supply of S_i supply point, s_i is the actual supply of the *i*th supply point. $s_i = 0$ means that the *i*th supply point does not participate in the emergency response relief supply activities. $d_j (j = 1,2,...,n)$ is the actual demand of the D_j demand point. x_{ij} is the relief supply from S_i to D_j. $x_{ij} = 0$ means that the relief supplies are not provided from *i*th supply point to *j*th demand point. The following planning model is the scheduling model:

$$\min \sum_{j=1}^{n} \sum_{i=1}^{m} c_{ij} x_{ij} \quad (1)$$

$$\min \sum_{j=1}^{n} \sum_{i=1}^{m} x_{ij} (t_{ij} - t_j) \quad (2)$$

$$\max \sum_{j=1}^{n} (\sum_{i=1}^{m} x_{ij} - d_j) y_j \quad (3)$$

$$s.t. \sum_{i=1}^{m} x_{ij} \geq d_j \quad (4)$$

$$\sum_{j=1}^{n} x_{ij} \leq s'_i \quad (5)$$

$$x_{ij} \geq 0 \quad (6)$$

where formula (1) is first objective function, and means minimum emergency cost. Formula (2) is second objective function, and means minimum delay time. Formula (3) is third objective function, and means that demand point receives maximize relief supplies. Formulas, (4), (5), and (6), represent constraints. Formula (4) means that the amount of supplies dispatched to each demand point is greater than or equal to its demand. Formula (5) means that the amount of relief supplies despatched from each supply point to all demand points is equal to the actual supply and the actual supply of a supply point cannot be greater than its supply capacity. Formula (6) means the quantity of relief supplies is a positive number. c_{ij} denotes the cost of relief supplies transported from the supply point i to demand point j. t_{ij} denotes the time of relief supplies transported from the supply point i to demand point j. t_j denotes the delay in the relief supplies needs of the demand point j to the limitation period. y_j is a weighting coefficient determined according to the affected degree of demand point j. The more serious the disaster is, the greater the value of y_j. The value indicates that the excess supplies in the demand region can make the affected people to get more comfort and also reflects the level of satisfaction of victims.

In order to improve the victims on the rescue work satisfaction, these three goals should be considered. This paper proposes an optimization strategy in order to improve the victims on relief work satisfaction. The optimization strategies are based on a step-by-step method and a two-dimensional Euclidean distance objective weighting algorithm in order to solve the multi-objective scheduling problem.

Step by step method is an iterative method. In the method, when every step forward, decision-makers can get the calculation and evaluate the results. If decision-makers satisfy the results, the iterations stop; otherwise, the results are calculated again until decision-makers to get satisfactory results. The steps are: (1) Seeking the optimal solution of the three single-objective linear programming problems respectively; (2) Drawing weight coefficient table and calculating weight coefficient; (3) Constructing a new single-objective linear programming and calculating the optimal solution of the planning; (4) If satisfied with the results obtained, stop the calculation; Otherwise, go back to step (3), to continue the calculation.

Based on the previous calculation results, a two-dimensional Euclidean distance objective weighting algorithm is proposed in order to solve the multi-objective scheduling problem. The steps of the two-dimensional Euclidean distance objective weighting algorithm are: (1) Solving each of the target component of the maximum and minimum; (2) Calculating the component membership degrees of each target; (3) Conversing the original multi-objective model to an equivalent single-target model; (4) Constructing a Lagrange function and to solve it.

Table 1: Available water resources

Supply point	**Available water resources (Ten thousand boxes)**
S1	58
S2	72
S3	20
Total	150

Table 2: Distance between three supply points to demand points (Kilometre)

Demand points	**S1**	**S2**	**S3**
Dujiangyan City	79	98	145
Pengzhou City	92	103	140
Qingchuan County	152	138	87
Beichuan County	185	97	91
Jiangyou City	77	50	114
Pingwu County	35	89	77
An County	71	28	50
Wenchuan County	100	98	156
Li County	100	75	63
Mao County	50	72	166
Zhongjiang County	101	114	45
Shifang City	89	71	173
Mianzhu City	98	84	54
Nanchong City	125	173	80
Chongzhou City	76	69	131
Suining City	81	81	119
Ziyang City	100	157	77

Demand points	S1	S2	S3
Yaan City	90	61	112
Meishan City	56	98	40

4 CASE STUDY

In this paper, the 2008 Wenchuan Earthquake is as a case. Through various sources, we collected the drinking water resources data about the 19 county-level city in the Sichuan region. Available water resources in three supply points are shown in Table 1. The distance between the three supply points to 19 in the affected areas is shown in Table 2. These affected areas are the demand points. Demand for water resources is shown in Table 3.

Table 3: Demand for water resources

Demand points	Demand (Ten thousand boxes)
Dujiangyan City	10.5
Pengzhou City	11.2
Qingchuan County	9.5
Beichuan County	10.9
Jiangyou City	4.7
Pingwu County	8.5
An County	9
Wenchuan County	12
Li County	5.5
Mao County	10.3
Zhongjiang County	3.4
Shifang City	12.8
Mianzhu City	11.3
Nanchong City	3.2
Chongzhou City	2.5
Suining City	5.9
Ziyang City	1.9
Yaan City	2.5

Demand points	Demand (Ten thousand boxes)
Meishan City	9
Total	144.6

We construct the water resources scheduling model according to the formula (1) - (7). Calculating the single objective function $\min f_1(x), \min f_2(x), -\min f_3(x)$, respectively and getting its optimal solution $x^{(1)}, x^{(2)}, x^{(3)}$ and its optimal target function value $f_1(x^{(1)}), f_2(x^{(2)}), f_3(x^{(3)})$. We can get the weight coefficient table shown in Table 4, where M_j, m_j is the maximum and minimum of $f_j(x)$.

Table 4: Weight coefficient table

	$f_1(x)$	$f_2(x)$	$-f_3(x)$
$x^{(1)}$	10431.00	180.80	-116.8
$x^{(2)}$	11034.00	129.30	-261.4
$x^{(3)}$	13966.00	373.61	-114.7
M_j	10431.00	129.30	-261.4
m_j	11034.00	373.61	-114.7

Based on step by step method, target function values are: $f_1(x) = 10279, f_2(x) = 178, f_3(x) = 114.7$. Based on the two-dimensional Euclidean distance objective weighting algorithm, target function values are: $f_1(x) = 10779, f_2(x) = 129.3, f_3(x) = 116.8$. The substance of these two methods is to conversion the multi-objective problems into single objective problem by computing the weight equivalently. By constructing the Lagrangian function and to solve it, we can get the effective solution of the original multi-objective function. In fact, the two methods, step by step method and the two-dimensional Euclidean distance objective weighting algorithm, are all weight methods. By giving different weights to different objective functions, the original multi-objective functions can be converted into a single objective function. However, how to choose the weight of the objective function is a optimization strategy. After the disaster, the different stages, victims have different needs and relief workers should have different relief strategies. Early in the emergency response, the victims usually pay more attention to the shortest possible time and more relief supplies. Then the two-dimensional Euclidean distance objective weighting algorithm is a better way. Late in the relief work, relief time and relief supplies demand are no longer the most important factors. The step-by-step method is a better way because the emergency cost usually should be considered some more.

5 CONCLUSION

The main contribution of this paper is to relief supplies scheduling model and optimization strategies to solve multi-objective optimization problem from a service quality perspective. Due to the limitations of scientific and technological means, we can not accurately predict the emergency incident. It is very necessary how to scientifically deal with emergency cases. Emergency resource scheduling is an important part of emergency response. This paper studies the scheduling and optimization problems of emergency relief supplies. The factor of the affected population demand for relief supplies is considered in the scheduling model of emergency relief supplies from the service quality perspective. On the basis of our study, a multi-objective scheduling model of emergency relief supplies is proposed. The model can be used to solve multi-objective resource scheduling problems in the emergency response process. The paper present two optimization strategies based on a step-by-step method and a two-dimensional Euclidean distance objective weighting algorithm is present in order to solve the multi-objective scheduling problem. Early in the relief, the more effective method is two-dimensional Euclidean distance objective weighting algorithm. The step-by-step optimization strategy is suit for the later stage of emergency response. To validate the proposed model, this paper conducts a case study on 512 Wenchuan Earthquake. The case study demonstrates that the scheduling model and the optimization strategy can provide effective methodological guidance for the scheduling of emergency relief supplies.

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