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Hybrid constrained flexible city resource scheduling scheme based on particle swarm optimization

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Abstract. Suppose that the types and number of supplies provided by the rescue cities to the affected city have been confirmed in the paper, and how to choose the best mode of transportation and to arrange transport the supplies to disaster area reasonably so as to produce the greatest benefits for relief supplies and to reduce the transportation cost as far as possible at the same time. First, mathematical model of question has been established aiming at the difference between benefits and cost, and then according to the thought in transport of priority to arranging high-level supplies, an algorithm for multi-transportation modes scheduling plan shall be designed in accordance with the greedy principle of using transportation cost as small as possible to produce benefits as high as possible, and its final scheduling plan shall be confirmed. Finally, the effectiveness and feasibility of the algorithm shall be verified by example solution.

Key words. Relief supplies of cities, Scheduling of resources, Transportation problem, Multiple constraints and optimal algorithm.

1. Introduction

Natural disasters and accidents occur frequently in recent years; these emergencies have caused large losses to us, which also highlights that the level of emergency management needs to be improved at present. Although many disasters cannot avoid, if the emergency can be treated timely, the losses can be fallen into the lowest level as far as possible. A key point in the field of emergency management is that rescue operation shall be carried out with the relief supplies to the scene as soon as possible so as to minimize losses in case of the emergency. At present, emergency resources can be scheduled well based on the domestic and foreign research on establishment of models and algorithms, the consideration shall be based on aiming

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at the minimum rescue time or minimum cost and determining that which retrieval depots shall be arranged to provide the specified number of resources. But faced with another scheduling problem of emergency resource in the real life, once the address of emergency service points and the number of supplies provided by the service points to disaster area have been confirmed, considering that harm caused by emergency will be less with the faster speed of emergency logistics, the benefits produced by emergency supplies will decline as time dragged on. Therefore, how to choose the best mode of transportation so as to send relief supplies to disaster area quickly and timely is an important part of relief work. The container multimodal transport of emergency supplies between two places has been considered by Hu Zhihua in the Literature [20] and mode of container transportation shall be confirmed by establishing model of integer linear programming so as to minimize transportation costs and transportation times. But the Literature is limited to shipping all emergency supplies by containers uniformly, and focuses on the choice of mode of transportation during the transportation, for example, air transportation shall be chosen in which section and land transportation shall be chosen in which section, etc. However, the limitation of carrier capability of emergency service points in real life has been considered in the paper, it is impossible to send all emergency supplies to emergency service points at first time, so different emergency grades shall need to be given in accordance with different kinds of emergency supplies and personnel, respectively, and different modes of transportation (such as air transportation, land transportation and sea transportation, etc.) shall be adopted to arrange a certain amount of emergency supplies by batch transportation in a reasonable way so as to maximize the benefits produced by emergency supplies as far as possible.

2. Establishment of model

If disaster occurs in some region, emergency supplies need to be mobilized to the region from all over the country, government often needs macro-control to assign tasks and determine which supplies shall be provided for each city and how much amount need to be sent to disaster area according to the specific circumstances of each rescue city. But each rescue city needs to finish disaster relief missions timely and effectively and arrange transportation supplies to disaster area in a reasonable way so that relief supplies can produce the maximum benefits and hope that the transportation cost can be as less as possible at the same time.

Suppose that City A can transport n kinds of supplies to Disaster Area B by m kinds of modes of transportation, relevant symbols are defined as follows:

a_i represents the amount of the kind i of supplies provided by City A for Disaster Area B $(i = 1, 2, ..., n)$;

b_j represents the maximum capacity of unit tool for the kind j of mode of transportation $(j = 1, 2, ..., m)$;

d_j represents unit expense for the kind j of mode of transportation $(j = 1, 2, ..., m)$, we suppose here that transportation expenses are only related to mode of transportation and the number of means of transport, which means it is irrelevant to loading capacity of unit means of transport;

k_j is an integer, and represents the number of tools owned by the kind j of mode of transportation $(j = 1, 2, ..., m)$;

c_{ij} represents unit benefits produced by the kind i of supplies when being sent to disaster area by j kind of mode of transportation $(i = 1, 2, ..., n; j = 1, 2, ..., m)$;

x_j represents the number of the kind $j$of means of transport chosen in case of actual transportation, which is an integer variable $(j = 1, 2, ..., m,\ x_j = 0, 1, ..., k_j)$;

y_{ij} represents the number of the kind i of supplies by the kind j of mode of transportation $(i = 1, 2, ..., n; j = 1, 2, ..., m)$, considering that supplies are often measured by integer in bags and other forms, we define the variable as integer variable.

The benefits produced by emergency supplies usually declines as time dragged on, especially emergency goods, such as medicine and food, etc, therefore, c_{ij} is generally a decreasing function about time, and transport time usually depends on means of transport, to simplify the model, we could assume that c_{ij} is only related to supplies and mode of transportation, which means that once the mode of transportation has been confirmed for some kinds of supplies, c_{ij} will be a given constant. According to the practical situation, usually, the mean of transport such as airplane takes little time relatively, but the cost is high relatively; though the cost of mode of ocean shipping is cheap, it will take a long time, which will seriously affect disaster relief benefits of some emergency supplies, therefore, we can believe ideally that benefits produced by the same kind of mode of transportation with high transportation expenses of supplies (with less transport time relatively) is not lower than that with low transportation expenses (with longer transport time relatively). We assume that $c_{i1} \geq c_{i2} \geq ... \geq c_{im}$ $(i = 1, 2, ..., n)$ can be met for any kinds of supplies$i$.

Because the effect is not the same in the process of emergency rescue, emergency supplies often have different priority levels; we may divide it into l types of supplies according to their significance, if the kind i of emergency supplies is classified as the type of $r(r = 1, 2, ..., l)$, $\delta_{ir} = 1$ will be defined, or $\delta_{ir} = 0$. Suppose that priority level of the r type of supplies is higher than that of the type$r + 1$. We can consider choosing reasonable mode of transportation based on different types of supplies. Suppose that x_j^r represents the number of the kind j of means of transport to transport the r type of supplies, we can get the following models.

$$(P)\text{Max} \quad \{\sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}y_{ij} - \sum_{j=1}^{m} d_j x_j\}\,. \tag{1}$$

$$\text{s.t.} \sum_{j=1}^{m} y_{ij} = a_i, \quad i = 1, 2, ..., n\,. \tag{2}$$

$$\sum_{i=1}^{n} y_{ij} \leq b_j x_j\,, \quad j = 1, 2, ...m\,. \tag{3}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} y_{ij}\delta_{ir} \le \sum_{j=1}^{m} x_j^r b_j, r = 1, 2, ..., l\,, \tag{4}$$

$$x_j^{r+1} x_{j+1}^r = 0,$$

$$j = 1, 2, ..., m - 1, r = 1, 2, ..., l - 1\,, \tag{5}$$

$$\sum_{r=1}^{l} x_j^r = x_j\,, j = 1, 2, ..., m \tag{6}$$

$0 \le x_j^r \le k_j$is integer, $0 \le x_j^r \le k_j$ is an integer ,

$$j = 1, 2, ..., m, r = 1, 2, ..., l \tag{7}$$

$0 \le x_j \le k_j$ is integer,

$$j = 1, 2, ..., m \tag{8}$$

$0 \le x_j \le k_j$ is an integer, $j = 1, 2, ..., m$

$y_{ij} \ge 0$is integer,

$$i = 1, 2, ..., n; j = 1, 2, ..., m \tag{9}$$

$y_{ij} \ge 0$ is an integer, $i = 1, 2, ..., n; j = 1, 2, ..., m$

Of which, objective function (1) represents the maximum disaster relief benefits can be produced by the minimum transportation expense; constraint (2) refers that each kind of emergency supplies must be sent to disaster area by all kinds of mode of transportation; constraint (3) represents capacity limitation of each kind of mean of transport; constraint (4) means transportation capacity limitation of the r type of supplies; constraint (5) means that the formula $x_j^{r+1} \ne 0 \Rightarrow x_{j+1}^r = 0$ or $x_{j+1}^r \ne 0 \Rightarrow x_j^{r+1} = 0$ is set up, to ensure the high-priority supplies can be transported at priority; constraint (6) refers to gross balance of means of transport; constraint (7) – (9) sets limitations on decision variable. The problem is about how to determine value of variablex_j, y_{ij}so as to maximize benefits.

3. Algorithm

Emergency supplies involve many kinds of supplies and need to be classified in order to cooperate with emergency system operation to realize effective management. Zhang Xufeng[21] divides emergency supplies into four types: life relief supplies, engineering support supplies, engineering construction supplies and post-disaster reconstruction supplies, according to priority level of supplies purchasing in the case of emergency.

The first type is life relief supplies, life relief is the first step forever in the process of emergency implementation, and these emergency supplies shall be arrived on the emergency spot at the first time. The second type is engineering support supplies,

supplies included in the part is the logistical support of carrying out emergency, which is the necessary process for carrying out work in next step, and the priority of engineering support supplies ranks second in the emergency supplies. The third type is engineering construction supplies, of which part is the focus on emergency work and the key to emergency implementation, and which ranks third according to the priority of logistic purchasing of emergency system. The fourth type is post-disaster reconstruction supplies, which is aftermath process of emergency, including all supplies for returning to normal production in damage area and life required.

Of course, different kinds of disaster and disaster situation can be classified in different way, emergency supplies to be transported will be classified into l types in the paper, and then the amount of each type of supplies is$A_r = \sum_{i=1}^{n} a_i\delta_{ir}, \quad r = 1, 2, ..., l$, so the amount of emergency supplies is$\sum_{i=1}^{n} a_i = \sum_{r=1}^{l} A_r$. Suppose that the priority of the $r$type of supplies is higher than that of the type$r + 1$.

We usually consider arranging high level of emergency supplies priority, especially as life relief supplies, which will be often transported to disaster area by the fastest mode of transportation, regardless of cost, which means that the type of relief supplies shall be transported by the mode of transportation with maximum (namely, c_{i1}) benefits c_{ij} produced by supplies. We consider firstly that the first type of supplies shall be transported in saturation by the fastest mode of transportation according to the principle of maximizing the benefits, and if the first means of transport has been remained, which can be considered to transport the second type of supplies; if the first means of transport cannot finish transporting the first type of supplies, then the second mode of transportation shall continue to be considered, and the actual number of tools participated in transportation for all kinds of means of transport shall be confirmed, and so forth.

Because the number of tools participated in transportation is an integer, we can confirm the actual number of tools participated in transportation by taking top integer. The number of means of transport required by the first kind of mode of transportation to transport the first type of supplies is $\lceil \frac{A_1}{b_1} \rceil$, and the surplus number of tools for the kind j of mode of transportation after transporting the first type of supplies can be denoted as k_j^1, $(j = 1, 2, ..., m)$.

If$\lceil \frac{A_1}{b_1} \rceil \leq k_1$, which represents that the first type of supplies can be transported only by such kind of mode of transportation, then the surplus number of means of transport is$k_1^1 = k_1 - \lceil \frac{A_1}{b_1} \rceil, k_2^1 = k_2, k_3^1 = k_3, ..., k_m^1 = k_m$; what is more, if$\lceil \frac{A_1}{b_1} \rceil \neq \frac{A_1}{b_1}$, it means that the tool used for transporting finally cannot reach saturation transportation in the$\lceil \frac{A_1}{b_1} \rceil$means of transport, of which surplus space is$b_1^1 = \lceil \frac{A_1}{b_1} \rceil \times b_1 - A_1$, otherwise, it is zero.

If$\lceil \frac{A_1}{b_1} \rceil > k_1$, which represents that the first type of supplies cannot be finished only by such mode of transportation, the second fast mode of transportation needs to be considered, namely, transporting by the mode of transportation with the second largest (namely, c_{i2}) benefits, and then taking $k_1^1 = 0$, the number of means of transport required by such mode of transportation for surplus supplies is $\lceil \frac{A_1 - k_1 b_1}{b_2} \rceil$. We can confirm the number of means of transport adopted by such type of supplies, and so forth.

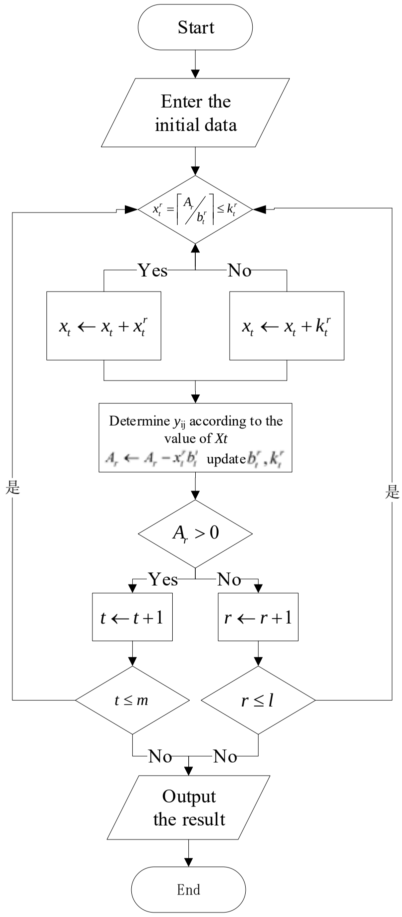

Fig. 1. Algorithm flow chart for scheduling plan of multi-transportation mode

For other emergency supplies, not only do we hope that relief supplies can produce maximum benefits, but also hope that the transportation cost can be as less as possible. According to priority level of emergency supplies, for the kind $i$of supplies in the type r of supplies, we calculate the specific value between benefits produced by each kind of mode of transportation in unit tool and transportation cost, namely, $b_j \frac{c_{ij}}{d_j} \delta_{ir}$, and rank from large to small, the supplies with high specific value between benefits and transportation cost shall be arranged at priority.

In order to design algorithm, we can suppose that the benefits produced by life relief supplies are big enough, and their benefits are far greater than that of produced by other supplies. So whichever types of relief supplies, we can design algorithm uniformly by the order of $b_j \frac{c_{ij}}{d_j} \delta_{ir}$from large to small.

According to such thought, scheduling problem which different priority level of emergency supplies shall be transported by multi-transportation mode can be solved by designing the following algorithm based on the flow of Fig. 1. Of which, k_t^r, b_t^r represents the number of tools and surplus capacity remained after arranging the kind t means of transport to transport the type r of supplies, respectively.

Algorithm of scheduling plan of multi-transportation mode

Step 0: Input initial data $r = 1$, $k_j^r = k_j$, $b_j^r = b_j$,
$(j = 1, 2, ..., m), X = \emptyset, Y = \emptyset, K^r = \underset{j}{\cup}\{k_j^r\}, B^r = \underset{j}{\cup}\{b_j^r\}(j = 1, 2, ..., m)$, $X = \emptyset$, $Y = \emptyset$, $K^r = \underset{j}{\cup}\{k_j^r\}$, $B^r = \underset{j}{\cup}\{b_j^r\}$.

Step 1: Set $t = 1$, $x_t = 0$.

Step 2: If $A_r = \sum\limits_{i=1}^{n} a_i\delta_{ir} > 0$, then calculate $x_t^r = \left\lceil \frac{A_r}{b_t^r} \right\rceil$, if not, turn into Step 8.

Step 3: If $k_j^r = \begin{cases} 0, & if \quad j < t \\ k_r^r - x_t^r, & if \quad j = t \\ k_j^r, & if \quad t < j < m \end{cases}$, update $K^r = \underset{j}{\cup}\{k_j^r\}$, calculate $x_t := x_t + x_t^r$, $X := X \cup \{x_t\}$, if not, turn into Step 5.

Step 4: Suppose that s is the first for the kind t of means of transport without being loaded in saturation, the actual surplus capacity of the kind t of means of transport is $b_{t_k}^r = \begin{cases} 0 & k < s \\ x_t^r \times b_t^r - A_r & k = s \\ b_{t_k}^r & s < k < k_t \end{cases}$, (of which, k_t is the number of the kind t of means of transport), update $B^r = \{b_j^r\}$, $A_r = 0$, $y_{ij} = \begin{cases} a_i\delta_{ir} & j = t \\ 0 & j \neq t \end{cases}$, $Y := Y \cup \{y_{it}\}$, and turn into Step 8.

Step 5: take $x_t^r = k_t^r$, calculate $x_t := x_t + x_t^r$,
$X := X \cup \{x_t\}$; calculate $\gamma_{it} = b_t \frac{c_{it}\delta_{ir}}{d_t}$, and rank from large to small, and denote as $\gamma_{i_1t} \geq \gamma_{i_2t} \geq ... \geq \gamma_{i_nt}$.

Step 6: the value of q_1 shall be confirmed by $\sum\limits_{q=1}^{q_1} a_{i_q}\delta_{i_qr} \leq x_t^r b_t^r < \sum\limits_{q=1}^{q_1+1} a_{i_q}\delta_{i_qr}$,

set $y_{i_qt} = \begin{cases} a_{i_q}\delta_{i_qr}, & q < q_1 \\ x_t^r b_t^r - \sum\limits_{q=1}^{q_1} a_{i_q}\delta_{i_qr}, & q = q_1 \\ 0, & q > q_1 \end{cases}$, when $j \neq t$, take $y_{i_qj} = 0$, $Y := Y \cup \{y_{i_qt}\}$.

$$A_r = A_r - x_t^r * b_t^r, k_j^r = \begin{cases} 0, & if \quad j \leq t \\ k_j^r, & if \quad t < j \leq m \end{cases}, t = t + 1\,.$$

Step 7: If $t \leq m$, turn into Step 2, if not, execute Step 9.

Step 8: Set $r := r + 1$, if $r \leq l$, turn into Step 2, if not, turn into Step 9.

Step 9: Output set X, K^r, B^r, Y.

The actual number of tools participated in transportation according to the above algorithm and the quantity of the i kinds of supplies by the j kinds of mode of transportation can be calculated to get transportation plan.

Theorem: scheduling plan determined by the above algorithm of scheduling plan of multi-transportation mode is feasible plan of problem (P).

Proof: feasibility of proof scheme can only verify that all constraint conditions are set up.

When $\left\lceil \frac{A_r}{b_t^r} \right\rceil \le k_t^r$, it means that the transportation mission of the type r of supplies can be finished by the kind t of tools, and suppose the kind i of supplies belong to the type$r$, $y_{ij} = \begin{cases} a_i\delta_{ir} & j = t \\ 0 & j \ne t \end{cases}$ can be known by the Step 4 of algorithm, and then $\sum\limits_{j=1}^{m} y_{ij} = a_i\delta_{ir} = a_i$. When $\left\lceil \frac{A_r}{b_t^r} \right\rceil > k_t^r$, constraint (2) $\sum\limits_{j=1}^{m} y_{ij} = a_i$is also set up in a similar way by Step 7.

can be got by Step 2, and $\sum\limits_{i=1}^{n} y_{ij} = \sum\limits_{i=1}^{n} a_i\delta_{ir} = A_r \le x_t^r b_t^r = x_t b_t^r$can be got from the calculation formula of$y_{ij}$by Step 4 and Step 6 and$x_t := x_t + x_t^r$.

$$\sum_{i=1}^{n} y_{ij} = \sum_{i=1}^{n} a_i\delta_{ir} = A_r \le x_t^r b_t^r = x_t b_t^r$$

So constraint (3) is also set up.

At the same time, constraint (4) which is also set up can be known directly by the derivation process of constraint (2) $\sum\limits_{j=1}^{m} y_{ij} = a_i$and constraint (3), namely, $\sum\limits_{i=1}^{n} \sum\limits_{j=1}^{m} y_{ij}\delta_{ir} = \sum\limits_{i=1}^{n} a_i\delta_{ir} = A_r \le x_t^r b_t^r$.

Because$x_t^r = \left\lceil \frac{A_r}{b_t^r} \right\rceil$, when $\left\lceil \frac{A_r}{b_t^r} \right\rceil \le k_t^r$, it means that the$t$kind of means of transport can finish to transport the type r of supplies, and it is likely to participate in the transportation of the type $r+1$ of supplies, so$x_t^{r+1} \ge 0$, on the other hand, when$j > t$, obviously, $x_j^r = 0$, so$x_t^{r+1} x_{t+1}^r = 0$is set up.

When $\left\lceil \frac{A_r}{b_t^r} \right\rceil > k_t^r$, $x_t^r = k_t^r$, it means that the kind t of means of transport cannot finish to transport the type r of supplies, so$x_{t+1}^r \ne 0$, but algorithm is cycled by$r$from small to large, only when$A_r = 0$, the transportation of the type $r+1$ of supplies can be considered, so$x_t^{r+1} = 0$, which also means $x_t^{r+1} x_{t+1}^r = 0$.

So constraint (5) is also set up.

It can be known from the formula$x_t := x_t + x_t^r$ that constraint (6) is obviously set up.

It can be known by definition of the algorithm variable and calculation formula that constraint (7)-(9) obviously set up.

Therefore scheduling plan determined by the algorithm of scheduling plan of multi-transportation mode is feasible plan of problem (P).

We need to confirm emergency resource scheduling by different priority levels according to actual requirements, and we shall confirm the number of means of transport and specific transportation plan in transportation of the same type of supplies in accordance with the greedy principle of using transportation cost as low as possible to produce benefits as high as possible. It shall be reached to saturation transportation state after confirming the number of one kind of mode of transportation, and this problem is equal to knapsack problem. If it is not required to be integer solution, and then it is obvious to get optimum solution, but integer solution is required in the paper, if only optimum non-integer solution can be adjusted fine, the excellent scheduling plan can be got. In addition, we need to note that the difference between this problem and general linear integer transportation problem is to determine which kind of mode of transportation being taken and the number of tools required by this mode of transportation, namely, determinex_j, transportation shall be arranged priority by different priority level of emergency supplies at the same time rather than confirm transportation plan directly by the maximum benefits. Therefore plan cannot be confirmed directly by general table dispatching method in the algorithm process.

4. Application example

Suppose that disaster occurs in certain region, one city needs to transport six kinds of supplies to disaster area based on government's macro-control, its quantity demanded is$A = \{a_1, a_2, a_3, a_4, a_5, a_6\}$={25, 40, 35, 35, 55, 60}. We can divide them by the Literature [21], of which, a_1 , a_3 belong to the first type of life relief supplies, a_2 , a_4 belong to the second type of engineering support supplies, a_6 belongs to the third type of engineering construction supplies, a_5 belongs to the fourth type of post-disaster reconstruction supplies. There are five kinds of modes of transportation, the number of each kind of mean of transport$K = \{k_1, k_2, k_3, k_4, k_5\}$={3, 5, 6, 10, 8}. The maximum capacity of unit tool for each kind of mode of transportation$B = \{b_1, b_2, b_3, b_4, b_5\}$={15, 20, 10, 5, 15}. And the unit expense of each kind of mode of transportation $D = \{d_1, d_2, d_3, d_4, d_5\}$={100, 50, 25, 20, 10}. Matrix of benefit produced when supplies shall be transported to disaster area by different modes of transportation$c = \begin{pmatrix} 100 & 40 & 8 & 5 & 1 \\ 9 & 8 & 6 & 3 & 2 \\ 120 & 50 & 9 & 4 & 2 \\ 9 & 7 & 5 & 4 & 1 \\ 7 & 6 & 5 & 4 & 3 \\ 8 & 5 & 4 & 3 & 2 \end{pmatrix}$. A scheduling plan is required to be given, so that relief supplies can produce maximum benefits and we also hope the transportation cost can be as less as possible at the same time.

According to different classification of supplies, we can get the following result by calculating.

$$A_1 = 25 + 36 = 60, \mathrm{K}^1 = \left\{k_1^1, k_2^1, k_3^1, k_4^1, k_5^1\right\} = \{0, 4, 6, 10, 8\};$$

$$A_2 = 40 + 35 = 75, \mathrm{K}^2 = \left\{k_1^2, k_2^2, k_3^2, k_4^2, k_5^2\right\} = \{0, 0, 6, 10, 8\};$$

$$A_3 = 60, \mathrm{K}^3 = \left\{k_1^3, k_2^3, k_3^3, k_4^3, k_5^3\right\} = \{0, 0, 1, 10, 8\};$$

$$A_4 = 55, \mathrm{K}^4 = \left\{k_1^4, k_2^4, k_3^4, k_4^4, k_5^4\right\} = \{0, 0, 1, 10, 4\}$$

So the number of means of transportation can be chosen in case of actual transportation:

$$X = \{x_1, x_2, x_3, x_4, x_5\} = \{3, 5, 5, 0, 4\}$$

The number of the$i$kind of supplies confirmed by the$j$kind of mode of transportation at the same time is:

$$Y = \begin{pmatrix} 10 & 15 & 0 & 0 & 0 \\ 0 & 40 & 0 & 0 & 0 \\ 35 & 0 & 0 & 0 & 0 \\ 0 & 35 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 55 \\ 0 & 10 & 50 & 0 & 0 \end{pmatrix}.$$

Object function value is Z=5965.

5. Conclusion

China is a country with frequent natural disasters, and plenty of social wealth has been spent on the logistics for natural disasters in every year, of which some are necessary, but others can be saved. Under the circumstances, suppose that the number and types of current emergency supplies have been known in the paper, and the type of mode of transportation, the number and the capacity of means of transport have been known at the same time, aimed at which relief supplies can produce maximum benefits and hope the transportation can be as less as possible at the same time, and how to arrange supplies transportation in a reasonable way, mathematical model has been built, and algorithm of emergency supplies dispatching suitable for solving multi-transportation mode has been designed, and the solution has been verified by example solution with favorable computational efficiency. The further work is how to combine operational research and management effectively to come up with a model which conforms to actual background and provide effective algorithm.

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