Multi-period dynamic model for emergency resource dispatching problem in uncertain traffic network

Xide Ren\textsuperscript{a*}, Jianming Zhu\textsuperscript{b}, Jun Huang\textsuperscript{b}

\textsuperscript{a}College of Mathematical Sciences, Graduate University of Chinese Academy of Sciences, Beijing, China
\textsuperscript{b}College of Engineering, Graduate University of Chinese Academy of Sciences, Beijing, China

Abstract

After large scale emergencies, rapid and effective emergency resource supply is a very important engineering to ensure the relief activities. Large scale disasters, such as earthquake, floods, often lead to traffic network uncertainty including connectivity uncertainty and travel time uncertainty. In this paper, in view of the connectivity uncertainty, a multi-period dynamic transportation model of variety emergency materials is presented based on CTM network, and a corresponding hybrid genetic algorithm is designed to solve the problem, the numerical example shows the effectiveness of the proposed algorithm.

Keywords: multi-period; dynamic; connectivity reliability; emergency resource dispatch;

1. Introduction

With the development of the society and the inspiration of emergency invents in recent years, such as the 1998 flood, ‘SARS’ in 2003, ‘Wenchuan’ earthquake in 2008 etc., research on emergency management is becoming more and more popular. Emergency resource dispatching decision is a very important engineering, only rapid and efficient material supply can ensure the relief activities. In many disasters, the connectivity of the network is uncertain, one road (edge) may be blocked caused by damages such as road surface broken, bridge collapse, on the other hand one road may be connected again after reparation. In most situations, the dispatch of relief materials should be considered in uncertain network, and an effective dispatch decision would be very beneficial.

Lots of research work about relief materials dispatching has been done by now. In respect to the variety of the materials, there are both single material dispatching problem\cite{1,2,3} and multi-variety materials dispatching problem\cite{4,5,6}. Some of the research aims at minimizing the transiting time in respect to the urgency of the demand\cite{2}, while others brought out two or more objection, such as cost, the number of save points and so on. Liu Beilin\cite{3} proposed a model to minimize both the time and the cost of relief materials dispatching. Meanwhile, dynamic dispatching models were proposed by researchers, such as ÖZDAMAR\cite{6} solved the dynamic dispatching problem with multi-supply nodes and multi-demand nodes. Considering demand uncertainty, Ben-Tal\cite{4} tried to dispatch the materials in the method of robust optimization, and Yuki Nakamura\cite{5} studied the dispatching problem with uncertain travel.
time by giving three different kind of shortest path. Liu Xing[7] presented a two stage integer programming method to solve the problem at war time when road maybe destroyed by enemies.

However, rarely seldom researchers considered the connectivity uncertainty. In this article, we proposed a multi-period dynamic dispatching method of variety materials with multi-supply nodes and multi-demand nodes considering the connectivity uncertainty. With the updating of the information, we can renew model input parameters and re-compute dispatching plan, so as to realize the whole rescue schedule in real time. The rest of this paper is organized as follow: the basic hypothesis and multi-period dispatch model is given in section2. In section 3 a hybrid heuristic method is proposed, followed by a 20 nodes example in section 4. Finally, section 5 concludes the paper.

2. Multi-period dynamic dispatch model

A cell transmission model based network was composed by adding dummy nodes, and in this network the travel time between any two adjacent nodes is one unit. Considering the uncertainty of the network after disasters, a multi-period dispatch model was described in this section.

2.1. Basic hypothesis and explanations of symbols

In order to describe the dispatch problem after large scale emergencies, there are some basic hypotheses. The planning of time scale is T periods, and both the demand and the supply are predictable; the dummy nodes added to compose CTM network has no supply or demand; the edges have connectivity uncertainty, and the connected probability is predictable using the information from GIS, GPS, and the connectivity is given by certain rules; the arriving materials amount in the next period can be got by GIS and GPS; the vehicles needn’t go back after finished transporting. The meaning of symbols that will be used is listed as bellow:

\[ n : \text{the number of nodes in the network;} \]
\[ V : \text{the number of materials kinds, the } V\text{th kind respect for vehicles;} \]
\[ RN, VN : \text{corresponding to the sets of real nodes and dummy nodes;} \]
\[ d_{int} : \text{the predicted demand amount at } i \text{ for materials } m \text{ at period } t; \]
\[ s_{int} : \text{the predicted supply amount at } i \text{ for materials } m \text{ at period } t; \]
\[ p_{ij} : \text{the probability of edge } (i,j) \text{ to be connected at period } t; \]
\[ a_{ij} : \text{the connectivity state of edge } (i,j) \text{ at period } t, 1 \text{ respect for connected and } 0 \text{ respect for blocked;} \]
\[ b_{jim} : \text{the arriving amount of material } m \text{ from } j \text{ to } i \text{ in the next period;} \]
\[ g_m : \text{volume of one unit material } m; \]
\[ \beta : \text{a coefficient of risk tolerance, the tolerance became weaker as } \beta \text{ became bigger;} \]
\[ K : \text{the traffic capacity of dummy nodes } M : \text{a large enough number;} \]
\[ x_{ijmt} : \text{the amount of material } m \text{ send from } i \text{ to } j \text{ at period } t; \]
\[ y_{int} = y_{int}^+ - y_{int}^- : \text{the absent\remaining amount of material } m \text{ at the end of period } t, y_{int}^+ \geq 0, y_{int}^- \geq 0, \]
\[ y_{int}^+ > 0 \text{ implies demand has been satisfied and the remaining amount is } y_{int}^- , \quad y_{int}^- > 0 \text{ implies the demand haven’t been satisfied and the absent amount is } y_{int}^+. \]

2.2. Multi-period dynamic dispatch model

This model was proposed considering the urgency and the connectivity reliability. So the objective function is composed by two different parts. The first part is the sum of all the nodes of absent and remaining amount of different materials during different time which applies the effect of the dispatching, and the second part is the risk of the dispatch decision described by the expected amount of delayed materials after some edges are blocked.
In the model, (1.2) and (1.4, 1.5) initialized the demand and supply amount at the period 1 corresponding to real and dummy nodes separately; (1.1) and (1.3) show the update method of the demand and supply amount, to be specific, the demand and supply amount of next period equals to the amount of the current plus the arrival amount, then minus the demand of the current period and the sum of the amount sent to other nodes; (1.6) means the cumulated vehicle amount can not exceed the traffic capacity of the dummy nodes, and (1.7) ensures the capacity constraint of trucks, (1.8) shows when material is sent from i to j only if the edge (i, j) is connected. It is constrained that the demand of the current node should be satisfied first by (1.9); and (1.10-1.12) are none negative constraints.

3. Hybrid genetic algorithm

The vehicle routing problem of multi-depot (MDVRP) is always NP-hard [10], the model in section 2 is multi-depot and there is a nonlinear constraint (1.9) which increase the difficulty dramatically. In this section, we propose a hybrid genetic algorithm (HGA) to solve the model, and the algorithm compounds greedy algorithm and genetic algorithm. The main operator of GA contains: coding, crossing, muting and choosing fitness function. We use the greedy algorithm to arrange the dispatch and calculate the fitness function. And the hybrid genetic algorithm is showed as following.

Supposed there are n nodes in the network and S supply nodes denoted as s(1), s(2), ..., s(S), the total number of plan periods is T, and including vehicles there are V kinds of materials altogether.

1) Coding: the dispatch routes from each supply node to the demand nodes is described by a section of code which consists of 1..n, started by s(i). That is to say, each code of a solution have S*n genes. So the solution is composed by S section of codes as bellow.

\[ s(1), 5, 4, 1, \ldots \ldots ; s(2), \ldots \ldots ; \ldots \ldots ; s(S) \ldots \ldots \]

section 1 started by s(1)

2) Crossing: we use Partheno genetic method to generate offspring in HGA. During the iterations, the gene cross is decomposed into S sections, two genes were selected randomly in each section and then the gene was exchanged separately to generate two different offspring. For example, there is a section whose length
is 15, and the genes selected are 6 and 11, then the cross can be illustrate as bellow.

\[
\begin{align*}
\text{codes of} & \quad \text{decendants} \\
1 & 2 3 4 5 6 7 8 9 10 11 12 13 14 15 \\
1 & 2 3 4 5 7 6 8 9 10 11 12 13 14 15 \\
1 & 2 3 4 5 6 7 8 9 10 12 11 13 14 15
\end{align*}
\]

In the same time, we brought out a cross method by three genes cross, the cross of one section with length 15 and the three genes is 6, 9, 11 is showed bellow as an example.

\[
\begin{align*}
\text{codes of} & \quad \text{decendants} \\
1 & 2 3 4 5 6 7 8 9 10 11 12 13 14 15 \\
1 & 2 3 4 5 9 7 8 11 10 6 12 13 14 15 \\
1 & 2 3 4 5 11 7 8 6 10 9 12 13 14 15
\end{align*}
\]

3) Muting: The process of muting is also decomposed into S sections, the muting is done independently of each section. Select two genes randomly in the section, and exchange the two selected genes. Which is as follow:

Before mutting : 1 5 4 6 8 9 7 2 1 3 1 4 1 5 2 1 0 3 1 1  
After mutting : 1 5 4 6 8 3 7 2 1 3 1 4 1 5 2 1 0 9 1 1

4) Calculating of the fitness function: Considering the coding method, a greedy algorithm is used to dispatch the materials and calculate the fitness function.

Starting from the first node in each section, if there is remaining amounts after satisfied its own demand, and the total demand of the following nodes is bigger than zero, and the edge is connected currently at the same time, compare the remains and the summed need of the following nodes to get the smaller one as the transmit amount, then transmit all materials with the obtained amount to the next node. Calculate the trucks needed by dividing the amount with the trucks capacity. If the number exceed the available trucks, then minus the transmitted amount as more as possible. For all the sections, calculate from the current period to period T. Then calculate the sum of the absent and remaining amount of all nodes and all materials in different periods. And calculate the value of object function by adding the risk measure.

In HGA, the parents is chosen by roulette wheel selection. The model is to minimize the object function, so we calculate the cumulative probability by 10000/f. In order to improve the effect of the algorithm, the best solution of each generation is passed to the next one without any change.

4. Numerical example

In this section, a numerical example with 20 nodes, 4 materials in the network, and there are 3 demand nodes (marked in red) and mainly three supply nodes (marked in blue). As showed in figure 1(a), the supply nodes are mainly 1,4, 17, and the demand nodes are 10,1,15. The predicted supply/demand in different period is shown in table 1. And the node 8 have a 200 units supply of material 2 in period 3, the other nodes have no supply. It is supposed that each period is half an hour, and T=6. We suppose that there are 20 same vehicles in each node at the very beginning, and the vehicle’s capacity is 10. The volume of material 1, 2, 3 is 0.5, 0.02, 0.02. There are 4 uncertain edges in the network, and the edge’s connectivity reliability is shown in table 2.

Run the HGA as described in section 3, the population is set as 100, the cross probability 0.8, the mut probability is 0.2, and the max generation is 2000. It costs about 1 minute to run the algorithm in Matlab with 2.0G RAM, on 2.93G Hz personal computer. We got the best objective function is 41409, and the iteration is showed in figure 1(b). The red line respects the best fitness function of the two genes cross at each generation while the dotted line in black shows the iterations of three genes cross. It is clear that the latter cross method is not as good as the former one. And the best solution is

\[
\begin{align*}
1 & 2 6 1 0 1 1 1 5 \ldots ; 4 \ 8 7 1 1 1 5 2 1 4 \ldots ; 1 7 1 3 1 4 1 5 1 1 1 0 2 \ldots \\
\end{align*}
\]

Because the length of each solution code is 60, and the total plan scale is T=6, we just have to think about the first six nodes. And it is easy to find that node 1 mainly supplies 10, 15, by the route 1→2→6→10→11., while node 4 supplies 11, 15 by the route 4→8→7→11→15, and node 17 supplies 15, 11, 10 by the route 17→13→14→15→11.. By the greedy method described in section 3 we can get the dispatch decision. Take material 1 as example, the dispatch is showed in table 3. Because all the demand for material 1 is satisfied, there is no follow in period T=6.
Table 1: Supply-demand in different periods

<table>
<thead>
<tr>
<th>Demand nodes</th>
<th>10</th>
<th>11</th>
<th>15</th>
<th>1</th>
<th>4</th>
<th>17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply</td>
<td>20</td>
<td>100</td>
<td>200</td>
<td>100</td>
<td>600</td>
<td>800</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>300</td>
<td>600</td>
<td>2000</td>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>300</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>T=6</td>
<td>200</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 2: Connected probability of uncertain edges

<table>
<thead>
<tr>
<th>Edges</th>
<th>(5,9)</th>
<th>(6,10)</th>
<th>(14,18)</th>
<th>(18,19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T=1</td>
<td>0.80</td>
<td>0.95</td>
<td>0.98</td>
<td>0.85</td>
</tr>
<tr>
<td>T=2</td>
<td>0.80</td>
<td>0.95</td>
<td>0.98</td>
<td>0.85</td>
</tr>
<tr>
<td>T=3</td>
<td>0.3</td>
<td>0.90</td>
<td>0.95</td>
<td>0.5</td>
</tr>
<tr>
<td>T=4</td>
<td>0</td>
<td>0.95</td>
<td>0.98</td>
<td>0.85</td>
</tr>
<tr>
<td>T=5</td>
<td>0</td>
<td>0.95</td>
<td>0.98</td>
<td>0.85</td>
</tr>
<tr>
<td>T=6</td>
<td>1</td>
<td>0.95</td>
<td>0.98</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Table 3: Dispatch Scheme for Material 1

<table>
<thead>
<tr>
<th>Period</th>
<th>T=1</th>
<th>T=2</th>
<th>T=3</th>
<th>T=4</th>
<th>T=5</th>
<th>T=6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edges</td>
<td>(1,2)</td>
<td>(2,6)</td>
<td>(1,2)</td>
<td>(2,6)</td>
<td>(6,10)</td>
<td>(6,10)</td>
</tr>
<tr>
<td>Amount</td>
<td>300</td>
<td>300</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Edges</td>
<td>(4,8)</td>
<td>(6,10)</td>
<td>(12,11)</td>
<td>(14,15)</td>
<td>(10,11)</td>
<td>(10,11)</td>
</tr>
<tr>
<td>Amount</td>
<td>30</td>
<td>300</td>
<td>30</td>
<td>30</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Edges</td>
<td>(17,13)</td>
<td>(8,12)</td>
<td>(14,15)</td>
<td>(10,11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount</td>
<td>100</td>
<td>30</td>
<td>100</td>
<td>215</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: (a) the traffic network (left); (b) the Mean-Min value of fitness function in the iterative process (right)
In order to show the effectiveness of HGA, we delete the nonlinear constraint (1.9), and supposed all the edges in the network is constant. Solve the linear integer programming in Lingo with Branch and Bound method, we get the lower bound of the problem is 35100. It is reasonable to conclude that HGA is effective, the best solution got by HGA is near to the optimal solution. And the HGA is a very fast algorithm compare with Branch and Bound method.

5. Conclusion

Emergency resource dispatch is a very important management engineering after emergencies. A multi-period multi-supply multi-demand dynamic relief materials dispatch model is proposed in this article, the dispatch decision and transport routes can be obtained by solving the program. What’s more, the decision can be renewed dynamically by updating the inputs of the model, and this ensures the arrival of emergency materials in time. However, the model is NP-hard, a hybrid genetic algorithm (HGA) is given to solve the problem. The 20 nodes numerical example showed the efficiency of the algorithm. The situation in which the travelling time of an edge is fluctuant is not discussed in the model. It should be very interesting to combine the edges’ connectivity and the travel time uncertainty in the dispatching problem. Future works may be done about the problem.

Acknowledgements

This work is supported in part by the National Natural Science Foundation of China under Grant No. 71001099, 90924008, 91024031, and the President Fund of Graduate University of Chinese Academy of Sciences.

References

3. LIU Beilin, Ma Ting, Research on the scheduling problem of emergency materials, Journal of Harbin university of commerce, 2007.3,(94)3-7