International Journal of Control and Automation
Vol.7, No.3 (2014), pp.359-370
http://dx.doi.org/10.14257/ijca.2014.7.3.34

The Construction of Emergency Logistics and Integrated Transport System Based on "Scenario-Response" Mode

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Abstract

By describing the meanings and characteristics of emergency logistics and integrated transport, as well as the relationship between the two, a multi-objective, multi-stage mathematical optimization model based on "scenario-response" mode is proposed in this article. When factors such as time, cost and accident rate are taken into account, the optimization of integrated transport at different stages of public emergencies can be solved and analyzed using the improved Dijstra algorithm. The results show that this algorithm avoids the limitations of traditional multi-objective optimization methods, and can effectively resolve the multi-objective and multi-stage integrated transport in the optimization of emergency logistics effectively.

Keywords: *scenario-response; emergency logistics; integrated transport; public emergencies*

1. Introduction

China has vast and complex geographical conditions, and the ecological environment is very fragile. In recent years, public emergencies have become more frequent and shown chain characteristics, the impact of which is getting more and more serious. Due to the comprehensive requirement of timeliness, security and economy, the emergency processing of public emergencies has become a complex system engineering. And the capacity and performance of emergency logistics transport will impact the effectiveness of the entire emergency rescue operation directly.

As early as 1990s, the United States has begun to invest a lot of capital in the construction and improvement of the warning defense system for public emergencies, in which the Metropolitan Medical Response System (MMRS) is an important part. Britain, France and Italy have established the warning defense system for public emergencies one after another. The emergency logistics system of China has been tested since the outbreak of SARS in 2003, the snowstorm in South China, the Wenchuan earthquake in 2008, and the Ya'an earthquake in 2013, reflecting that the emergency relief supplies reserves and emergency distribution system of China are not perfect. With the emergency treatment and experience summary of a series of public emergencies, emergency logistics has become the focus at home and abroad. The aspects of the emergency logistics: Kembali-Cook and his team [1], based on the issue of Somali refugees rescue, proposed the supply process of the relief supplies logistics management used firstly in 1984; Ardekani and others [2], who committed to the rescue and

ISSN: 2005-4297 IJCA

reconstruction efforts after the Mexico City earthquake, analyzed the situation of the road transport network and the status of the road transport network after the disaster, and pointed out the problems which are faced by the transport of relief supplies in the field of the management process; Fiedrich [3] researched the model of multiple locations affection distribution and transportation resources optimization after the earthquake, which sets the Minimum-time, resources, limited quantity and quality of the case, the minimum number of deaths as a target; Linet [4],who detailed description of the constraints of the transportation of emergency supplies, including the condition of the number of vehicles, materials supply etc, designed the mode of the emergency supplies of Transportation Planning, which is mainly to solve the problem of time-varying dynamic transport of commodity. The aspects of the comprehensive transportation: Suleyman Tufekciand Wallam A. Wallace [5], as the authority of emergency management experts, pointed out that the nature of the emergency management is a complex multi-objective optimization problem, which is mainly to solve the utilization of the compromise resource in the case of limited emergency resources; Haghani and Oh [6]research the material dispatching of emergency disaster relief, established the deterministic network flow model of the multi-varieties of materials, the multi-mode of transport and the Time-window based on the Time-space Network, and proposed two inspired-algorithm; Nierat [7] determined the market scope of road transport and rail transport and its influencing factors, which are as a prerequisite in order to minimize shipping costs; Ozdamar and his team [8] studied the problem of the deterministic dynamic transportation, which is based on the time-dependent in the natural disaster emergency logistics plan, established the integrated optimization model of the problem of the vehicle routing under the flow problem of the multi-cycle and multi-species and the problem of the multi-mode of transport, as well as pointed out a kind of iterative algorithm based on the relaxation of the Lagrange. The aspects of the mode on “Scenario-Response”: Sheu J. B. [9] researched the classification and demand of the unconventional emergency supplies in the paper, including the method of classification, the standards, and the demand for emergency supplies-level; Kalashnikov D. V., Ma Y., Mehrotra S., *et al.* [10], Han Q., Venkatasubramanian N. [11] and Raschid L., Knoblock C., Naumann F. [12], the well-known scholars, researched the unconventional emergency platform system, including the data integration, the organization and storage, and the method of data sharing under the unconventional emergency scene, as well as the design and construction of the emergency management platform under the national emergency platform system integration, *etc.*; Many of scholars like Mahmoud [13] introduced the scenario planning theory into all kinds of unconventional emergencies decision-making system, and proposed the strategies and methods of the scenario-based emergency decision-making. In recent years, there was an endless stream of domestic academic researching on emergency logistics, for instance, Yunpeng Liu [14] made a comparative analysis of the disaster emergency logistics center location, and took into account the method of the sited selection that not only considered a quantitative factors, but also considered qualitative factors; Wei Li [15], who based on emergency logistics system and risk theory, made a systematic analysis of emergency logistics connotation, the uncertainty of the emergency logistics, anti-risk ability of the emergency logistics, and built the model of the evaluation and the Logistics anti-risk ability index system under the uncertain environments; Xinxin Jia [16] summarized the objectives of the emergency management system, the specific content of the emergency management system, the scope of the emergency management system, and pointed out the model of the emergency supplies vehicle scheduling of the multi-demand, multi-point and multi-model transport.

The above make the corresponding analysis on the connotation of general emergency logistics from the viewpoint of generation purpose, pursuit of objectives, and operational modes. But the number of relevant literatures on emergency logistics and integrated transport based on "Scenario-response" mode is limited, and comprehensive analysis on the connotation has not been carried out. At present, China is devoid of researches on the integrated transport of emergency logistics at both the strategic level and the operational level. Therefore, the establishment of theoretical and application system of emergency logistics and integrated transport based on "scenario-response" mode can improve the scientific nature of the national emergency management system, and has important theoretical value and broad prospects for practical application.

2. Emergency Logistics Integrated Transport System

2.1. Connotation and characteristics of the emergency logistics integrated transport system

Emergency logistics is a special logistics activity to supply emergency safeguard to meet the demand for supplies, personnel and funds in all kinds of unexpected events, the purpose of which is to provide emergency supplies in major natural disasters, sudden public health incidents and public safety events, in pursuit of the maximization of the time benefits and the minimization of the losses caused by the disasters [17]. As a special case of the general logistics activities, emergency logistics exhibits the features of burst, uncertainty, weak economy and unconventional.

Integrated transport is, in the conditions of market economy, taking sustainable development as a precondition, to allocate resources comprehensively and arrange the transport structure rationally in accordance with the economic characteristics of highways, waterways, railways, aviation and pipelines, forming an integrated transport system of divide-and-cooperate, organic combination, rational layout and effective docking, to maximize the comparative advantages and combination efficiency of the various transport modes [18]. Compared to the single-mode and one-way traditional transportation, integrated transport system exhibits the features of relevance, effectiveness, simplicity, full process, versatility, interoperability etc.

2.2. The relationship between emergency logistics and integrated transport

(1) Emergency Logistics should take full advantage of integrated transport

When public emergencies occurs, in pursuit of the maximization of the time benefits and the minimization of the losses caused by the disasters, the traffic transport link must meet the following requirements: transit time, frequency, safety, reliability, convenience of the transport networks and modes, timeliness and accuracy of information etc.; these factors will affect the performance and quality of emergency logistics services, and must be considered carefully.

(2) Integrated transport is an integral part of emergency logistics

During the entire public emergencies, emergency logistics activity is composed of transportation, inventory management, material handling, warehouse location, packaging and distribution etc., in which the integrated transport is the core area of emergency logistics. Based on transportation technology and information technology, in pursuit of the maximization of the time benefits and the minimization of the losses caused by the disasters, the emergency logistics is completed by integrated transport system to protect people's life and property safety as much as possible.

3. “Scenario-Response” Mode

3.1. The conception of the “scenario-response” mode

"Scenario-response" mode is a decision-making method that, according to the “scenario” of the current public emergencies, the decision-making agent evaluates the "trend" for the future, the probability of the "trend" happening, and the impact range and harm degree of the "trend", thereby generating contingency plans [19]. The “scenario” of public emergencies is always changing; therefore, during emergency logistics integrated transportation decision-making, decision-making actors should focus on those key hazard points and decision points which are changed by the situation now and in the future, when facing the public emergencies. According to environmental constraints and objective management of different stages of the emergency logistics, effective "response" programs should be proposed for different “scenario”. Considering the emergency supplies scheduling and time-varying demand and supply information, effective multi-objective and multi-stage transportation scheduling with different transport modes should be constituted, to resolve the awkward reality problems, such as "what supplied is not what required", "an utterly inadequate supply" and "dry rut fish", *etc.*, and to establish integrated transport system based on the "scenario-response" mode.

3.2. The generation process of the emergency decision-making program under the "scenario-response" mode

During the emergency decision-making for public emergencies, the eternal contradiction between the urgency in time and the shortage in emergency resources proposes a higher demand for the generation of emergency decision-making plans. On the basis of the scenario situation analysis of public emergencies, combined with the features of "scenario-response" mode and special requirements of the public emergency decision-making system, the generation process of the emergency decision-making program generally includes the following three stages:

(1) Generation phase of the emergency decision-making "scenario". The emergency decision-making "scenario" of public emergencies is the real circumstance constantly

changing over time that the decision-making agent must deal with after the occurrence of the event. According to the extraction process of the scenario situation, the input scenario information can be divided into four levels: the awareness of the current scenario situation, the understanding of the current scenario situation, the deduction of the future scenario situation, the detection of the future scenario situation. Through information search and integration above the four scenario situations, the decision-making agent will make the emergency decision-making plans.

(2) The phase for the construction of problem space and the generation of the decision-making rules. Decision-making agent constitutes the problem space according to decision-making situation, and makes internal characterization analysis from the perspective of task structure in accordance with the characteristics of the problem space. As the core aspects of decision-making, the construction of problem space and the characterization of task structure are an extremely complex psychological information processing process. In the decision-making of public emergencies, the decision-making agent withstands the pressure of constraints such as limited resources, time and human resources in the environment of time-critical and uncertainty; therefore, the decision-making rules and decisions generated are built on the basis of ecological rationality and fast-and-frugal decision-making rules.

(3) The phase of the design and evaluation of the alternative emergency decision-making programs. The emergency decision-making program is the feasibility program proposed by the decision-making agent to resolve, alleviate and eliminate the problems caused by public emergencies effectively. For emergency decision-making tasks, decision-makers should make a number of alternative emergency decision-making programs according to the decision-making rules and heuristic rules generated; then assess the consequences of each alternative decision-making program to exclude the program with the worst consequences; finally, make emergency judgment and choose the relatively effective decision-making program from the alternative programs.

3.3. Evolution of the "scenario-response" mode

Facing the dynamic emergency response management of the public emergencies, when scenario evolution and "scenario-response" mode are considered, in pursuit of the maximization of the time benefits and the minimization of the losses caused by the disasters, the emergency supplies needed for all types of public emergencies should be organized, implemented and controlled through effective integrated transport plan. The whole process of the public emergencies can be divided into several key stages including initial scenario, middle scenario and end scenario according to the time sequence; the end scenario of the previous stage is often the initial scenario of the next stage. To sum up, the whole process of scenario evolution can be shown in Figure 1:

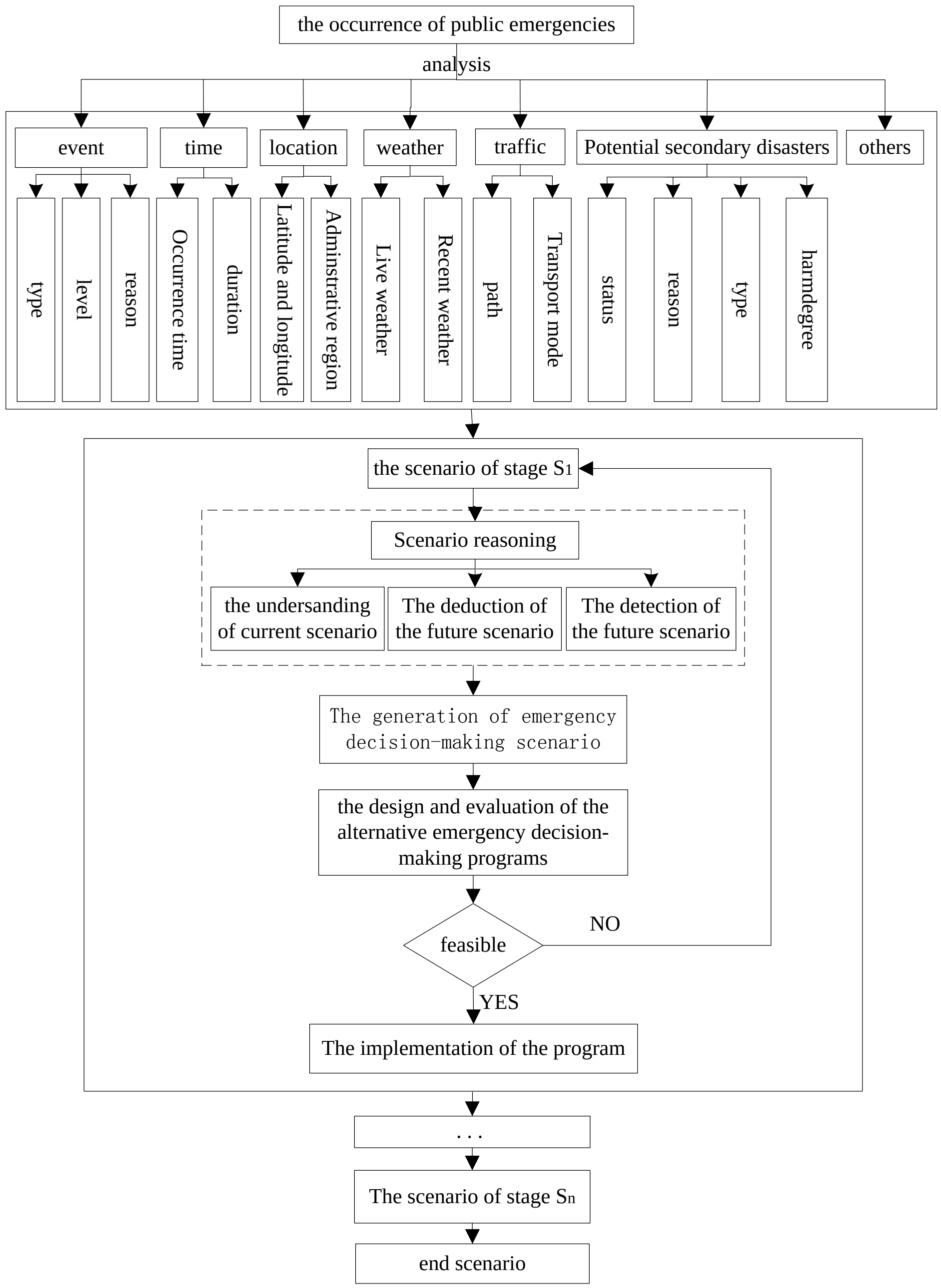

Figure 1. procedure chart of the scenario evolution

Here, assume all the possible scenarios are taken into account; the model will not be distorted due to this assumption, because all the scenarios that may emerge can be assumed into most situations in reality.

4. Modeling of Emergency Logistics Integrated Transport System based on the "scenario-response" Mode

4.1. Problem description

Suppose a shipment of goods should be ferried from the origin node O to the destination node D. There are m nodes in the system, and for node i, A_1, A_2, A_3 transport modes are available. Between two nodes, cost, time and accident rate are different for each transport mode; when switching from one mode to another, the cost, time and success probability should be considered; the accident rate of a certain transport mode should also be calculated. The optimum combination of the transport modes can be determined through measuring the above factors, to reduce the total cost, time and accident rate as much as possible. This model was first proposed by Reddy[20]. Based on this model, considering the factors of time and accident rate, this work is to quest the optimal mathematical model for the transport cost, time and accident rate.

4.2. Model construction

Hypothesis 1: only one transport mode is adopted between two nodes; hypothesis 2: the supplies can be transshipped only one time at each node; hypothesis 3:the transit capacity of each transport mode is adequacy during the transshipment at each node.

$$\min Zc = \sum_{i\in m}\sum_{l\in n_i} x_{i,i+1}^{l} c_{i,i+1}^{l} + \sum_{i\in m}\sum_{l\in n_i}\sum_{k\in n_i} y_i^{l,k} d_i^{l,k} \quad (1)$$

$$\min Zt = \sum_{i\in m}\sum_{l\in n_i} x_{i,i+1}^{l} t_{i,i+1}^{l} + \sum_{i\in m}\sum_{l\in n_i}\sum_{k\in n_i} y_i^{l,k} s_i^{l,k} \quad (2)$$

$$\min Zp = \sum_{i\in m}\sum_{l\in n_i} x_{i,i+1}^{l} \delta_{i,i+1}^{l} + \sum_{i\in m}\sum_{l\in n_i}\sum_{k\in n_i} y_i^{l,k} \gamma_i^{l,k} \quad (3)$$

$$s.t.\begin{cases} \sum_{i\in m} x_{i,i+1}^{l} = 1, i\in m, l\in n_i \\ \sum_{l\in n_i}\sum_{k\in n_i} y_i^{l,k} = 1, i\in m, l\in n_i, k\in n_i \\ x_{i-1,i}^{l} + x_{i,i+1}^{k} \ge 2y_i^{j,k}, i\in m, l\in n, \mathrm{k}\in n_i \\ x_{i-1,i}^{l} \in \{0,1\}, y_i^{l,k} \in \{0,1\}, i\in m, \mathrm{l}\in n_i, k\in n_i \\ 0\le \delta_{i,i+1}^{l} \le 1 \\ 0\le \gamma_i^{l,k} \le 1 \\ c_{i,i+1}^{l}, t_{i,i+1}^{l}, d_i^{l,k}, s_i^{l,k}, \mathrm{m}, \mathrm{n}_i \ge 0 \end{cases} \quad (4)$$

Where:

$$x_{i,i+1}^{l}=\begin{cases}1, \text{transport mode } l \text{ is adopted from node } i \text{ to node } i+1\\ 0, \text{transport mode } l \text{ is not adopted } i \text{ to node } i+1\end{cases};$$

$$y_{i}^{l,k}=\begin{cases}1, \text{transport mode } l \text{ is switched to mode k at node } i\\ 0, \text{no transshipment at node } i\end{cases};$$

$c_{i,i+1}^{l}$ − cost needed from node i to node $i+1$ when transport mode l is adopted;

$t_{i,i+1}^{l}$ − time needed from node i to node $i+1$ when transport mode l is adopted;

$s_{i}^{l,k}$ − time needed when transport mode l is switched to mode k at node i;

$\delta_{i,i+1}^{l}$ − accident when transported from node i to node $i+1$ with transport mode l;

$\gamma_{i}^{l,k}$ − accident rate when transport mode l is switched to mode k at node i; 。

Object function (1) is the sum of the minimum transport cost and transshipment cost; object function (2) is the sum of the minimum transport time and transshipment time; constraint (3) is the sum of the minimum transport accident rate and transshipment accident rate; constraint (4) says the supplies cannot be transported separately, that is only one transport mode is adopted between two nodes; the supplies can be transshipped only one time at each node; internal consistency, *i.e.*, if the transport mode is switched from mode l to mode k at node i, then the supplies are transported with mode l between node $i-1$ and node i, and with mode k between node i and node $i+1$; the corresponding decision variables take integer 0 or 1; the accident rate is a value greater than 0 and less than 1; the variables are nonnegative.

4.3. Model solution

The type of this model is both multi-object programming and mixed-integer programming, which can be resolved using branch-and-bound method, genetic algorithms etc. In this paper, the solution is implemented by the improved Dijstra[21] method using directed virtual transportation network. The specific steps are as follows:

(1) Translate the original problem into a directed virtual transportation network. The origin node O and the destination node D are non-expanded nodes; the rest $(m-2)$ nodes are expanded, namely node i is expanded into n_i nodes, as shown in Figure 2:

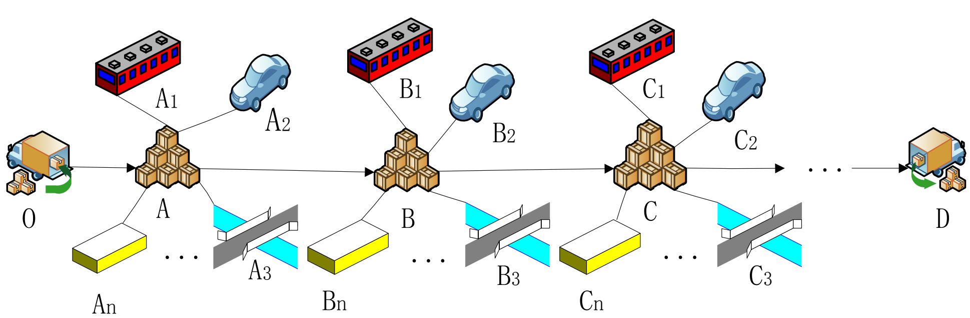

Figure 2. the virtual transportation network

(2) Line out the corresponding weights in the virtual transportation network: the weight of transverse connection is the transport cost, time and accident rate; the weight of longitudinal connection is the transshipment cost, time and accident rate.

(3) Obtain the shortest path set $R_q(\mathrm{q}=1,2,\cdots,\mathrm{Q})$ of the object $\mathrm{q}(\mathrm{q}=1,2,\cdots,\mathrm{Q})$ in the virtual transport network $G=(\mathrm{N},\mathrm{E})$ using the improved Dijstra algorithm;

(4) Determine the shortest path of each object function according to the shortest path set $R_q(\mathrm{q}=1,2,\cdots,\mathrm{Q})$.

(5) Select the transport mode based on the "scenario-response" mode.

4.4. Case study

Pipeline transport and water transport will be ignored in the following discussion due to they are particular in emergency logistics integrated transport. When relief supplies are transported from node O to node D via nodes A, B and C, the available transport modes and associated data between any two cities are shown in Table 1, 2 and 3:

Table 1. the transport cost, time and accident rate between two nodes

	O—A	A—B	B—C	C—D
railway	60/5/0.40	50/10/0.25	40/15/0.60	100/20/0.80
highway	20/6/0.50	50/10/0.18	80/15/0.12	74/18/0.60
air transport	70/2/0.35	30/4/0.70	150/10/0.25	50/5/0.10

Note: The first number is the transport cost, the second number is the transport time, and the third number is the accident rate.

Table 2. the transshipment cost, time and accident rate between two nodes

	railway	highway	air transport
railway	0/0/0.00	5/5/0.75	2/2/0.54
highway	5/5/0.75	0/0/0.00	1/1/0.25
air transport	2/2/0.54	1/1/0.25	0/0/0.00

Note: The first number is the transshipment cost, the second number is the transshipment time, and the third number is the accident rate

(1) The construction of virtual transport network

As shown in Figure 3, the origin node O and the destination node D are non-expanded nodes; the nodes of the second column (A_1, A_2, A_3) are expanded by A. The expanded node A_1 represents that railway transport is adopted from O to A; The expanded node A_2 represents that highway transport is adopted from O to A; The expanded node A_3 represents that air transport is adopted from O to A. The rules apply to the third and fourth columns, too. There are a total of 81 paths.

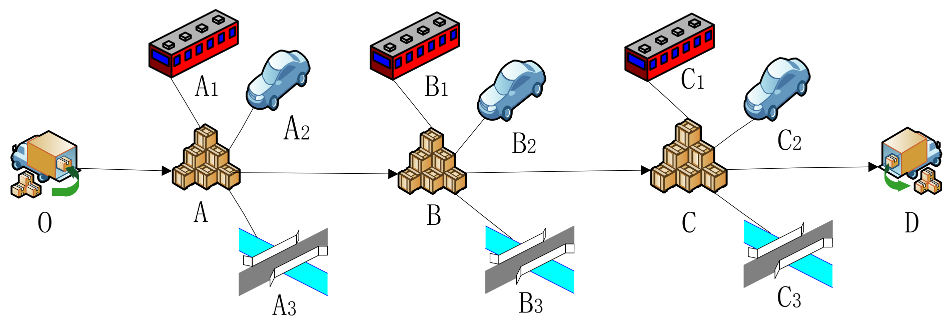

Figure 3. the virtual transport network

(2) Mark the weight of each link in the virtual transport network according to Table 1, 2, 3.

(3) Obtain the shortest path related to each object in the virtual transport network and the corresponding object value using the improved Dijstra algorithm, as shown in Table 3:

Table 3. the K-shortest path related to each object and the corresponding object value

	cost			time			accident rate	
number	K-shortest	value	number	K-shortest	value	number	K-shortest	value
59	0-A3-B3-B1-C1-C2-D	121	55	0-A3-B3-C3-D	21	30	0-A2-B2-C2-C3-D	1.15
51	0-A2-A3-B3-B1-C1-C3-D	145	19	0-A1-A3-B3-C3-D	26	79	0-A3-A2-B2-B3-C3-D	1.20
33	0-A2-B2-B1-C1-C3-D	167	46	0-A2-A3-B3-C3-D	26	75	0-A3-A2-B2-C2-C3-D	1.25
39	0-A2-A1-B1-C1-C3-D	167	43	0-A2-A1-B1-B3-C3-D	28	34	0-A2-B2-B3-C3-D	1.28
50	0=A2-A3-B3-B1-C1-C2-D	172	63	0-A3-B3-B2-C2-C3-D	28	28	0-A2-B2-C2-D	1.40
54	0-A2-A3-B3-B2-C2-C3-D	183	79	0-A3-A2-B2-B3-C3-D	29	55	0-A3-B3-C3-D	1.40
24	0-A1-A3-B3-B1-C1-C3-D	186	60	0-A3-B3-B1-C1-C3-D	30	73	0-A3-A2-B2-C2-D	1.50
49	0-A2-A3-B3-B1-C1-D	193	70	0-A3-A1-B1-B3-C3-D	31	63	0-A3-B3-B2-C2-C3-D	1.77
32	0-A2-B2-B1-C1-C2-D	194	7	0-A1-B1-B3-C3-D	32	12	0-A1-A2-B2-C2-C3-D	1.80
38	0-A2-A1-B1-C1-C2-D	194	34	0-A2-B2-B3-C3-D	32	46	0-A2-A3-B3-C3-D	1.80
60	0-A3-B3-B1-C1-C3-D	194	27	0-A1-A3-B3-B2-C2-C3-D	33	6	0-A1-B1-B2-C2-C3-D	1.87
30	0-A2-B2-C2-C3-D	201	54	0-A2-A3-B3-B2-C2-C3-D	33	3	0-A1-B1-C1-C3-D	1.89
3	0-A1-B1-C1-C3-D	202	75	0-A3-A2-B2-C2-C3-D	34	16	0-A1-A2-B2-B3-C3-D	1.93
52	0-A2-A3-B3-B2-C2-D	206	24	0-A1-A3-B3-B1-C1-C3-D	35	81	0-A3-A2-B2-B3-C3-C2-D	1.95
…	…	…	…	…	…	…	…	…
71	0-A3-A1-B1-B3-C3-C1-D	376	41	0-A2-A1-B1-B2-C2-C1-D	66	68	0-A3-A1-B1-B2-C2-C1-D	3.56

From Table 3 we can infer that the minimum object values of the shortest path of objects (1), (2) and (3) are 121, 21 and 1.15 respectively.

(4) Determine the shortest path

As shown in Table 3, the shortest cost path is M=121.The path R=O-A3-B3-B1-C1-C2-D means that air transport is adopted from node O to node A and from node A to node B, highway transport is adopted from node B to node C, and railway transport is adopted from node C to node D. The shortest time path is T=21, and the path R=O-A3-B3-C3-D means air transport is selected from node A to node D. The shortest accident rate path is P=1.15. The path R=O-A2-B2-C2-C3-D means that railway transport is adopted from node O to node A, highway transport is adopted from node A to node B and from node B to node C, and air transport is adopted from node C to node D.

(5) Transport mode selection based on "scenario-response"

At the early stage of public emergencies, what concerned is to transport the supplies to the destination as soon as possible, therefore, time is the priority, namely only the object function (2) is considered. In this case, the transport combination mode of "aviation-aviation-aviation-aviation" (the total cost is 300, the total time is 21, and the total accident rate is 1.40) is adopted.

At the late stage of public emergencies, effective and low-cost transport modes are taken into account, therefore, cost is the priority, namely only the object function (1) is considered. In this case, the transport combination mode of "aviation-aviation-highway-railway" (the total cost is 121, the total time is 46, and the total accident rate is 3.54) is adopted.

After the occurrence of public emergencies, traffic congestion or even disruption will occur in the vicinity of the incident site, therefore, safety is the priority, namely only the object function (3) is considered. In this case, the transport combination mode of "railway-railway-railway-aviation" (the total cost is 201, the total time is37, and the total accident rate is 1.15) is adopted.

5. Conclusions

In summary, emergency logistics exhibits the characteristics of suddenness or non-normal, the randomness and afterwards electivity of logistics demands, the imbalance of flow, the urgency of time constraints and social welfare etc. When public emergencies occurs, in pursuit of the maximization of the time benefits and the minimization of the losses caused by the disasters, the selection of transport mode based on "scenario-response" should be the optimized decision-making mode to protect people's life and property safety as much as possible. In the transport of emergency logistics, reasonable transport mode should be selected according to different requirements on goods transport under different scenarios of public emergencies. Aiming at the transportation problem in emergency logistics, an integrated transport model of multi-object and multi-stage based on the "scenario - response" mode is proposed in this work. The results of numerical example show that this model and algorithm can effectively resolve the multi-object and multi-stage transportation problem in emergency logistics systems under the "scenario - response" mode.

Acknowledgements

This work is supported by the Humanities Social Sciences Programming Project of the Ministry of Education of China No. 10YJA630126, 12YJC630200, 12YJC630100 and the State Social Science Fund Project No. 11CJY067 and the Natural Science Foundation of Gansu Province, China. No. 1107RJYA070, 1208RJZA164.

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