Hindawi
Mathematical Problems in Engineering
Volume 2018, Article ID 7896926, 34 pages
https://doi.org/10.1155/2018/7896926

Research Article

An Improved Shuffled Frog Leaping Algorithm and Its Application in Dynamic Emergency Vehicle Dispatching

Xiaohong Duan, Tianyong Niu, and Qi Huang

School of Economics and Management, North China University of Technology, Beijing 100144, China

Correspondence should be addressed to Xiaohong Duan; 12116350@bjtu.edu.cn

Received 22 November 2017; Revised 20 January 2018; Accepted 28 January 2018; Published 28 March 2018

Academic Editor: Guillermo Cabrera-Guerrero

The traditional method for solving the dynamic emergency vehicle dispatching problem can only get a local optimal strategy in each horizon. In order to obtain the dispatching strategy that can better respond to changes in road conditions during the whole dispatching process, the real-time and time-dependent link travel speeds are fused, and a time-dependent polygonal-shaped link travel speed function is set up to simulate the predictable changes in road conditions. Response times, accident severity, and accident time windows are taken as key factors to build an emergency vehicle dispatching model integrating dynamic emergency vehicle routing and selection. For the unpredictable changes in road conditions caused by accidents, the dispatching strategy is adjusted based on the real-time link travel speed. In order to solve the dynamic emergency vehicle dispatching model, an improved shuffled frog leaping algorithm (ISFLA) is proposed. The global search of the improved algorithm uses the probability model of estimation of distribution algorithm to avoid the partial optimal solution. Based on the Beijing expressway network, the efficacy of the model and the improved algorithm were tested from three aspects. The results have shown the following: (1) Compared with SFLA, the optimization performance of ISFLA is getting better and better with the increase of the number of decision variables. When the possible emergency vehicle selection strategies are 8^{15}, the objective function value of optimal selection strategies obtained by the base algorithm is 210.10% larger than that of ISFLA. (2) The prediction error of the travel speed affects the accuracy of the initial emergency vehicle dispatching. The prediction error of ±10 can basically meet the requirements of the initial dispatching. (3) The adjustment of emergency vehicle dispatching strategy can successfully bypassed road sections affected by accidents and shorten the response time.

1. Introduction

Urban Expressway can ease the traffic pressure on large cities and plays an important role in the urban traffic system. However, with the increasing amount of traffic, accidents often happen on expressways and cause great damage to people's life and property. Rapid emergency rescue can effectively reduce accident loss, and emergency vehicle dispatching is the key to emergency rescue.

Research of emergency vehicle dispatching started with assumptions of static travel time or distance, and the original dispatching problem mainly included two basic issues. In the problem with one accident, we only need to choose the nearest emergency vehicle to rescue the accident. The core is the shortest paths of emergency vehicles in the road network [1]. In the problem with multiple accidents, choosing the nearest emergency vehicle need not be an optimal decision [2]. We also need to select suitable emergency vehicles for different accidents to minimize their response times. It is a combinatorial optimization problem. Therefore, models for solving combinatorial optimization, such as Hungarian method, direct cost model, and opportunity cost model, were used to solve the emergency vehicle dispatching [3]. Aiming at the random resource requirements of potential incidents, Ozbay et al. used probabilistic constraint to improve the opportunity cost model [4]. Emergency vehicle dispatching with multiple accidents is a complex problem relating to various factors. In addition to response time, factors such as fairness, cost, and loss were considered to set up multi-objective dispatching models [5, 6]. In order to solve these

NP-hard problems, ant colony algorithm [7], particle swarm optimization [8], genetic algorithm [9], and other intelligent optimization algorithms had been widely applied.

Emergency vehicle dispatching problem considering the dynamic change of link weight (travel time, distance) started in the late 1990s. Taking the minimum response time as objective, Zografos et al. [10] integrated routing and dispatching module to set up an emergency response decision support system. Haghani et al. [11] built a simulation model of emergency vehicle dispatching. The model can assist decision makers to select suitable emergency vehicles and guide them to avoid congested areas. Dan et al. [12] divided dynamic dispatching problem into a series of static problems. Dispatching strategy was updated based on the time axis. A multiobjective model was established to solve these static problems. Yang et al. [13] set up an online dispatching and routing model for emergency vehicles. One day was divided into a number of intervals, and dispatching strategy was updated according to link travel time in each interval. Fu et al. [14] calculated the earliest response time using iteration method. A dynamic emergency resource dispatching system was designed. This research is essentially a static method for solving the dynamic problem. Dispatching strategies are continuously adjusted based on real-time traffic data at each decision-making instant. They suppose traffic data remain unchanged in the decision-making horizon. Emergency vehicles may be stopped up on the way to accidents because of changes in road conditions.

If link weight is thought to be a time-dependence function, this network is a kind of time-dependence network. Research on the time-dependence network still focuses on universal shortest path problem. On the assumption of discrete link weight based on travel time, Cooke and Halsey [15] proposed a model of the time-dependence network. Iteration method was used to solve the shortest path problem. Kaufman and Smith [16] proved that the time-dependence shortest path problem can be solved by polynomials only when the network satisfies the first-in-first-out (FIFO) property. Most of the research on the shortest path of time-dependence traffic network is based on FIFO property [17]. However, road network with discrete link travel time proposed by Cooke is not FIFO [16]. In order to solve this problem, Duan et al. [18] proposed a universal shuffled frog leaping algorithm for solving the shortest path of the non-FIFO and FIFO network. Ichoua et al. [19] replaced link travel time with link travel speed to build time-dependent function. Travel time calculated by travel speed function changes continuously and satisfies the FIFO property. Since link travel speed cannot be known ahead of the decision-making instant, Ichoua et al. divided a day into three horizons to distinguish between congestion and free flow. During each time horizon, link travel speed remains unchanged. If this travel speed function is used to solve emergency vehicle dispatching problem, the whole dispatching process may be at a certain time horizon with constant link travel speed. This travel speed function cannot satisfy the requirement of emergency vehicle dispatching. On the assumption that link travel speed decreases continuously with the entry instant, Yuan and Wang [20] proposed an emergency vehicle routing model taking the shortest travel time as objective. Zhou et al. [21] built a multiobjective optimization model to solve the multiperiod dynamic emergency resource scheduling problems. In order to solve the model, a multiobjective evolutionary algorithm was proposed. Zhou and Liu [22] designed a multiagent genetic algorithm to solve the multiperiod emergency resource scheduling problem considering the uncertainty of traffic. The experimental results show that the multiagent genetic algorithm precedes genetic algorithm for the problem.

According to the review of the literature, link travel speed function can reflect the dynamic changes of road conditions. However, it is difficult to model link travel speed function and solve the dynamic dispatching problem, and the dynamic problem is usually divided into a series of static problems. It only can get a local optimal strategy in each horizon. In order to get the overall optimal strategy, real-time data (reflecting the real-time road condition at decision-making instant) fuses with prediction data (reflecting the change of road condition in the whole dispatching process) to establish the link travel speed function. Meanwhile, considering the unpredictable changes in road conditions during the dispatching process, dispatching strategies are adjusted according to real-time travel speed. Multiple-incident and multiple-response (MIMR) emergency vehicle dispatching discussed in this paper is NP-hard problem with large scale variables. The metaheuristic algorithm has advantages in solving the NP-hard problem. Shuffled frog leaping algorithm (SFLA) is a relatively new heuristic algorithm. It was first proposed and applied in water distribution network designed by Eusuff et al. [23, 24]. This algorithm combines the advantages of particle swarm optimization (PSO) and shuffled complex evolution (SCE) algorithm, and it has been proved that the algorithm has good performance in convergence speed and solution precision [25, 26]. It was used to solve many real-word problems such as job shop scheduling and cloud computing resource allocation [27–29].

According to the above, in this paper, the polygonal time-dependent function based on real-time and prediction link travel speed is built to simulate real road conditions in expressway network. Integrating routing and selection of emergency vehicles, a dynamic dispatching model is built. The model takes time-dependent travel speed, response time, time window, and accident severity as key factors to get the optimal strategy. And the dispatching strategy is adjusted when the new accidents happen. An improved shuffled frog leaping algorithm (IFSLA) is put forward to solve the dynamic dispatching model. The algorithm uses the probabilistic model of the distribution estimation algorithm to generate new frog population. It can avoid a local optimum of shuffled frog leaping algorithm.

2. Problem Statement

Based on graph theory, the expressway network is abstracted as a time-dependent directed network model $(N, E, T(t) \times Q)$ as shown in Figure 1. $N = \{n_1, n_2, \ldots, n_M\}$ is the node set. It consists of hubs and interchanges on the expressway. M is the total number of nodes. The link arc between adjacent nodes n_i

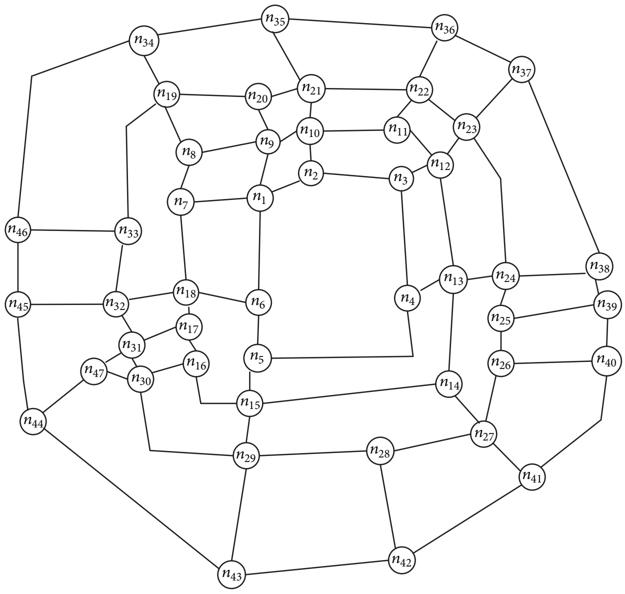

Figure 1: Expressway network model.

and n_j is road section $(n_i, n_j) \in E$. The expressway network is a directed network, so $(n_i, n_j) \neq (n_j, n_i)$. Emergency vehicles must run along the direction of the road section, and they can change the direction at the nodes. Q is the interested time horizon. $T_{ij}(t) \in T(t)$ is the link travel time function defined in time horizon Q. It represents a time for the emergency vehicle, leaving at an instant t, traveling from node n_i to n_j. $\forall t \in Q, t + T_{ij}(t)$ is always defined. For $t \notin Q, T_{ij}(t)$ is defined as infinity.

(1) Link Travel Time Function. Taking κ as the minimum time interval, Q is divided into discrete time intervals, that are $Q = \{[t_0, t_1], [t_1, t_2], \dots, [t_\phi, t_{\phi+1}], \dots, [t_{\Phi-1}, t_\Phi]\}$, $t_\phi = t_0 + \phi \cdot \kappa$, $\phi = 0, 1, \dots, \Phi - 1$. t_0 is the initial dispatching decision-making instant. $t_\Phi = t_0 + \Phi \cdot \kappa$ is the last instant, and make sure it is large enough for the emergency vehicle to arrive at the accident during the time period $[t_0, t_\Phi]$. $v_{ij}(t)$ is the link travel speed function. It represents the average speed of the road section $(n_i, n_j) \in E$ at $t \in [t_0, t_\Phi]$. Based on the link travel speed function of Ichoua et al. [19], it is assumed that travel speed in each time interval changes in the form of the polygonal line, and the polygonal-shaped travel speed function is shown in Figure 2. At the decision-making instant t_0, the real-time link travel speed $v_{ij}^1(t_0)$ is known. However, the real-time link travel speed $v_{ij}^1(t), t \in \{t_1, t_2, \dots, t_\phi, \dots, t_\Phi\}$, $t_\phi = t_0 + \phi \cdot \kappa, \phi = 1, 2, \dots, \Phi$, cannot be obtained. Therefore, they are approximated by the prediction travel speeds $v_{ij}^2(\phi)_{t_0}$.

The polygonal-shaped travel speed function shown in Figure 2 can be expressed as

$$v_{ij}(t)_{t_0} = \begin{cases} \dfrac{v_{ij}^2(1)_{t_0} - v_{ij}^1(t_0)}{\kappa} \cdot t + \dfrac{t_1 \cdot v_{ij}^1(t_0) - t_0 \cdot v_{ij}^2(1)_{t_0}}{\kappa} & t_0 \le t < t_1 \\ \dfrac{v_{ij}^2(\phi+1)_{t_0} - v_{ij}^2(\phi)_{t_0}}{\kappa} \cdot t + \dfrac{t_{\phi+1} \cdot v_{ij}^2(\phi)_{t_0} - t_\phi \cdot v_{ij}^2(\phi+1)_{t_0}}{\kappa} & t_\phi \le t < t_{\phi+1},\ \phi = 1, \dots, \Phi - 1. \end{cases} \tag{1}$$

$v_{ij}(t)_{t_0}$ is continuous on $[t_0, t_\Phi]$, and it must be integrable on the interval $[t_0, t_\Phi]$. If the emergency vehicle enters the road section (n_i, n_j) at the instant $y\ (y \ge t_0)$, its travel distance is a function of travel time $x\ (y \le x \le t_\Phi)$.

$$\begin{aligned} \int_y^x v_{ij}(t)_{t_0}\, dt &= \int_{t_0}^x v_{ij}(t)_{t_0}\, dt - \int_{t_0}^y v_{ij}(t)_{t_0}\, dt \\ &= \eta(x) - \vartheta(y), \end{aligned} \tag{2}$$

in which,

$$\begin{aligned} \eta(x) &= \int_{t_0}^x v_{ij}(t)_{t_0}\, dt = \int v_{ij}(x)_{t_0}\, dx + C_1, \\ \vartheta(y) &= \int_{t_0}^y v_{ij}(t)_{t_0}\, dt = \int v_{ij}(y)_{t_0}\, dy + C_2. \end{aligned} \tag{3}$$

Let formula (2) equal to the length Ls_{ij} of the road section (n_i, n_j); the time when the emergency vehicle leaves the road section is

$$x = g\left(Ls_{ij} + \vartheta(y)\right), \tag{4}$$

in which, g is the inverse function of η.

When the emergency vehicle enters the road section at instant t, the travel time function of the road section is

$$T_{ij}(t) = g\left(Ls_{ij} + \vartheta(t)\right) - t. \tag{5}$$

(2) Dynamic Emergency Vehicle Dispatching Process. $U(t)$ accidents are waiting for rescue at the instant t, and they compose set $AC(t)$. $Ac_u(t) \in AC(t)$ is the uth accident, $u = 1, 2, \dots, U(t)$. The road section where the accident $Ac_u(t)$ occurred is expressed as $(n_0^u, n_1^u) \in E$, and its location node is $Nc_u(t)$, its rescue time window is $[0, T_{\max}^u(t)]$, and the required number of emergency vehicles is $Na_u(t) > 0$. $As_u(t)$ represents the severity of the accident $Ac_u(t)$. $EV(t)$ is the emergency vehicle set, and $Ev_l(t) \in EV(t), l = 1, 2, \dots, L(t)$, stands for the lth emergency vehicle. $L(t)$ is the total number of emergency vehicles. The road section where the emergency vehicle $Ev_l(t)$ is locatïż£ed is expressed as $(n_0^l, n_1^l) \in E$, and its location node is $Nv_l(t)$. When the emergency vehicle $Ev_l(t) \in EV(t)$ starts traveling at an instant t, the shortest time path to the accident $Ac_u(t) \in AC(t)$ is $P_{lu}(t)$, and the shortest travel time is $\mathrm{T}_{lu}(t)$.

The basic purpose of emergency vehicle dispatching is to shorten the response time of accidents. The response time

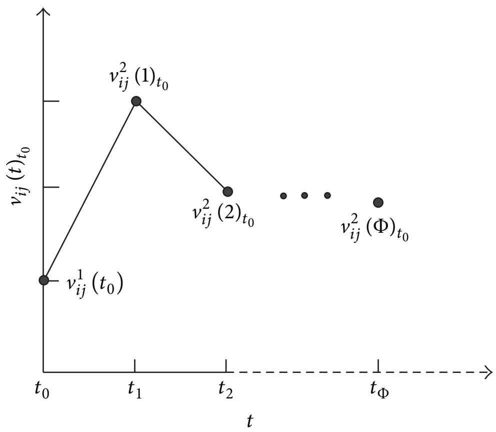

Figure 2: Polygonal-shaped travel speed function.

mainly depends on the travel time of the emergency vehicles. In the complex expressway network, emergency vehicles can reach accidents through multiple paths. Therefore, the shortest time path problem should be solved and the shortest travel time $\mathrm{T}_{lu}(t)$ from each emergency vehicle $Ev_l(t) \in EV(t)$ to each accident $Ac_u(t) \in AC(t)$ should be obtained firstly. Then, taking $\mathrm{T}_{lu}(t)$ as the key factor, the suitable emergency vehicles are selected to rescue the accidents, that is, to solve the problem of emergency vehicle selection.

According to the emergency vehicle selection strategy, emergency vehicles head for accidents along the shortest paths. In this process, if there are no new accidents in the road network, travel speed function of each road section does not change obviously, but once an accident happened, travel speeds of road sections in the accident area will be greatly affected. In order to avoid the rescue delay caused by sudden changes in road conditions, it is necessary to update link travel speed function according to the real-time speed, and the dispatching decision should be adjusted. We only need to update the travel time functions of road sections where the new accidents are located and their upstream road sections. If the rescue paths of the accident go through the new accidents, the rescue strategy for the affected accident needs to be recalculated, and the rescue strategies for the new accidents need to be calculated too.

The dynamic dispatching process consists of two stages: (1) At the decision instant $t = t_\varphi$, taking the polygonal-shaped travel speed function as the weight of the road section, the travel path from $Ev_l(t_\varphi)$ to $Ac_u(t_\varphi)$ is planned and the shortest travel time $\mathrm{T}_{lu}(t_\varphi)$ is obtained. (2) Taking the shortest travel time $\mathrm{T}_{lu}(t_\varphi)$ as input, emergency vehicles are selected to rescue the accidents. (3) At the instant $t = t_{\varphi+1}$, a new accident occurs in the road network. The dispatching strategy, including vehicle routing and selection, is dynamically adjusted according to the updated real-time link travel speed.

3. Dynamic Emergency Vehicle Dispatching Modeling

At the decision-making instant $t = t_\varphi$, the shortest travel time, the required number of emergency vehicles, the upper limit of rescue time window, and the accident severity are taken as the key factors. A dynamic dispatching model with vehicle routing is built. A list of all symbols is given in Symbols.

$$
\begin{aligned}
\min \quad & \left\{ \sum_u \sum_l As_u\left(t_\varphi\right) \times \mathrm{T}_{lu}\left(t_\varphi\right) \times x_{lu}\left(t_\varphi\right) + \sum_u M \times z_u\left(t_\varphi\right) \right\}, \\
& Ev_l \in EV\left(t_\varphi\right), \qquad (6) \\
& \forall Ac_u \in \begin{cases} AC\left(t_\varphi\right) & t_\varphi = t_0 \\ AC^1\left(t_\varphi\right) & t_\varphi \neq t_0 \end{cases} \\
\text{s.t.} \quad & \sum_l x_{lu}\left(t_\varphi\right) = Na_u\left(t_\varphi\right), \\
& Ev_l \in EV\left(t_\varphi\right), \qquad (7) \\
& \forall Ac_u \in \begin{cases} AC\left(t_\varphi\right) & t_\varphi = t_0 \\ AC^1\left(t_\varphi\right) & t_\varphi \neq t_0 \end{cases} \\
& t_{\max}^u\left(t_\varphi\right) - T_{\max}^u\left(t_\varphi\right) \leq M \times z_u\left(t_\varphi\right), \\
& t_{\max}^u\left(t_\varphi\right) = \max\left\{\mathrm{T}_{lu}\left(t_\varphi\right) \times x_{lu}\left(t_\varphi\right)\right\}, \\
& Ev_l \in EV\left(t_\varphi\right), \qquad (8) \\
& \forall Ac_u \in \begin{cases} AC\left(t_\varphi\right) & t_\varphi = t_0 \\ AC^1\left(t_\varphi\right) & t_\varphi \neq t_0 \end{cases}
\end{aligned}
$$

$$\begin{aligned}&\sum_u x_{lu}\left(t_\varphi\right)+\sum_l xx_l\left(t_\varphi\right)=1,\\&Ac_u\in AC\left(t_\varphi\right),\\&\forall Ev_l\in EV\left(t_\varphi\right)\end{aligned}\tag{9}$$

$$\begin{aligned}&\sum_l x_{lu}\left(t_\varphi\right)+\sum_l xx_l\left(t_\varphi\right)=L\left(t_\varphi\right),\\&Ev_l\in EV\left(t_\varphi\right),\\&\forall Ac_u\in AC\left(t_\varphi\right)\end{aligned}\tag{10}$$

$$\begin{aligned}&x_{lu}\left(t_\varphi\right)=0,1,\\&\forall Ev_l\in EV\left(t_\varphi\right),\\&\forall Ac_u\in\begin{cases}AC\left(t_\varphi\right) & t_\varphi=t_0\\AC^1\left(t_\varphi\right) & t_\varphi\neq t_0\end{cases}\end{aligned}\tag{11}$$

$$\begin{aligned}&z_u\left(t_\varphi\right)=0,1,\\&\forall Ac_u\in\begin{cases}AC\left(t_\varphi\right) & t_\varphi=t_0\\AC^1\left(t_\varphi\right) & t_\varphi\neq t_0\end{cases}\end{aligned}\tag{12}$$

$$\begin{aligned}&xx_l\left(t_\varphi\right)=0,1,\\&\forall Ev_l\left(t_\varphi\right)\in EV\left(t_\varphi\right)\end{aligned}\tag{13}$$

$$\begin{aligned}\mathrm{T}_{lu}\left(t_\varphi\right)=\min\quad&\sum_{n_i=Nv_l(t)}^{n_0^u}T_{i,i+1}\left(t_i\right)_{t_\varphi},\\&\forall Ev_l\left(t_\varphi\right)\in EV\left(t_\varphi\right),\\&\forall Ac_u\in\begin{cases}AC\left(t_\varphi\right) & t_\varphi=t_0\\AC^1\left(t_\varphi\right) & t_\varphi\neq t_0\end{cases}\end{aligned}\tag{14}$$

$$\text{s.t.}\quad t_i=\begin{cases}t_{i-1}+T_{i-1,i}\left(t_{i-1}\right)_{t_0} & n_i=n_1^l,\ldots,n_0^u\\t_0 & n_i=Nv_l\left(t\right)\end{cases}\tag{15}$$

$$\left(Nv_l\left(t\right),n_1^l\right),\left(n_1^l,n_2^l\right),\ldots,\left(n_i,n_{i+1}\right),\ldots,\left(n_{-1}^u,n_0^u\right),\left(n_0^u,Nc_u\left(t\right)\right)\in E\tag{16}$$

$$Nv_l\left(t\right),n_1^l,\ldots,n_i,\ldots,n_0^u,Nc_u\left(t\right)\in N\tag{17}$$

$$n_1^l\neq\cdots\neq n_i\neq\cdots\neq n_0^u\tag{18}$$

$$\begin{aligned}&\left(n_1^l,n_2^l\right),\ldots,\left(n_i,n_{i+1}\right),\ldots,\left(n_{-1}^u,n_0^u\right)\neq\left(n_0^{u'},n_1^{u'}\right),\\&Ac_u\neq Ac_{u'}.\end{aligned}\tag{19}$$

Formula (6) is the objective function of emergency vehicle dispatching. It consists of two parts, the total travel time for emergency vehicles Ev_l to arrive at accidents Ac_u and the punishment caused by the exceeding rescue time. In which, M is a huge constant. At the initial decision-making instant $t_\varphi = t_0$, every accident $Ac_u \in AC(t_0)$ needs to be rescued. At other decision-making instants, accident set $AC^1(t_\varphi)$ includes new accidents that happened at t_φ and the accidents whose rescue paths at $t_{\varphi-1}$ are affected by new accidents. Emergency vehicle set $EV(t_\varphi)$ contains all emergency vehicles.

Formulas (7) are the emergency vehicle requirements constraints. They make sure that the vehicle requirements of each accident can be satisfied.

Formulas (8) are time window constraints of accidents. They guarantee that the latest arrival time $t^u_{\max}(t_\varphi)$ of emergency vehicle does not exceed the upper limit of the time window $T^u_{\max}(t_\varphi)$.

Formulas (9) are constraints for the state of emergency vehicles. The emergency vehicle Ev_l can only be dispatched to an accident Ac_u or in an idle state.

Formula (10) is the constraint for the total number of emergency vehicles. It ensures that the total number of emergency vehicles dispatched to the accidents and in the idle state is L.

Formulas (11) are constraints for the state of variables $x_{lu}(t_\varphi)$. At the decision-making instant t_φ, if the emergency vehicle Ev_l, $l = 1, 2, \ldots, L$, is dispatched to the accident Ac_u, $u = 1, 2, \ldots, U$, then $x_{lu}(t_\varphi) = 1$; otherwise, $x_{lu}(t_\varphi) = 0$.

Formulas (12) are constraints for the state of variables $z_u(t_\varphi)$. At the decision-making instant t_φ, if the latest rescue time for accident Ac_u, $u = 1, 2, \ldots, U$, exceeds the upper limit of rescue time window, then $z_u(t_\varphi) = 1$; otherwise, $z_u(t_\varphi) = 0$.

Formulas (13) are constraints for the state of variables $xx_l(t_\varphi)$. At the decision-making instant t_φ, if the emergency vehicle Ev_l, $l = 1, 2, \ldots, L$, is in the idle state, then $xx_l(t_\varphi) = 1$; otherwise, $xx_l(t_\varphi) = 0$.

Formula (14) is the objective function of rescue path for the accident $Ac_u(t_\varphi)$. It minimizes the travel time of the emergency vehicle from node $Nv_l(t_\varphi)$ to the destination $Nc_u(t_\varphi)$, where road sections (n_i, n_{i+1}) and (n_{i+1}, n_{i+2}) are connected.

Formula (15) calculates the instant t_i when the emergency vehicle enters the road section (n_i, n_{i+1}), $n_i = Nv_l(t), \ldots, n^u_0$.

Formulas (16)–(18) are connectivity constraints of the path. They ensure that there are no loops in the path sequence.

Formulas (19) ensure that the emergency vehicles do not pass road sections with accidents.

4. Solution for the Emergency Vehicle Dispatching Model

The shuffled frog leaping algorithm (SFLA) is a kind of metaheuristic algorithm that imitates the frog population's behavior in obtaining food. The initial frog population is generated and divided into several memeplexes. Then the frogs search for the optimal solution within each memeplex for the defined number of times. Then frogs in different memeplex are shuffled so that the information can be exchanged globally. The group optimization and global information exchange alternate with each other until the convergence condition is satisfied. The mathematical model of SFLA is as follows.

(1) Initialization. H frogs are randomly generated to compose the initial population IP. The position of the hth frog is encoded as $X_h = [x_{h1}, x_{h2}, \ldots, x_{hd}, \ldots, x_{hD}]$, $h = 1, \ldots, H$, in which, D is the dimension of the optimization problem. Each X_h represents a feasible solution to the optimization problem. And each feasible solution corresponds to a performance function $f(X_h)$ associated with the optimization objective.

(2) Rank and Grouping. H frogs are ranked in descending order of performance function value. Position $Px = [px_1, px_2, \ldots, px_d, \ldots, px_D]$ of the optimal frog in the population is marked. The population IP is divided into a memeplexes, and there are c frogs in each memeplex according to

$$M_{o_1} = \left\{X_{o_1+a(o_2-1)} \in \text{IP} \mid 1 \le o_2 \le c\right\} \quad (1 \le o_1 \le a). \quad (20)$$

(3) Local Search. Within each memeplex, the local optimization process is repeated for the specified number of iterations It.

(3.1) Positions of the frogs in the memeplex, the best and the worst, are marked as $Pb = [pb_1, pb_2, \ldots, pb_d, \ldots, pb_D]$ and $Pw = [pw_1, pw_2, \ldots, pw_d, \ldots, pw_D]$, respectively. Pw is renewed along with Pb according to

$$Ds_d = \begin{cases} \min\left[\text{INT}\left(r \times (pb_d - pw_d)\right), D_d^{\max}\right] & pb_d - pw_d \ge 0 \\ \max\left[\text{INT}\left(r \times (pb_d - pw_d)\right), -D_d^{\max}\right] & pb_d - pw_d < 0, \end{cases} \quad d = 1, 2, \ldots, D, \quad (21)$$

$$pw'_d = pw_d + Ds_d, \quad d = 1, 2, \ldots, D \quad (22)$$

$$pw'_d = \begin{cases} Z_d^{\max} & pw'_d > Z_d^{\max} \\ pw'_d & Z_d^{\min} \le pw'_d \le Z_d^{\max} \\ Z_d^{\min} & pw'_d < Z_d^{\min}, \end{cases} \quad d = 1, 2, \ldots, D \quad (23)$$

in which, r is a random number, $r \in [0, 1]$. Ds_d is the adjustment of the dth decision variable, $d = 1, 2, \ldots, D$. $D_d^{\max}$ is the maximum adjustment of the dth decision variable. pw'_d is the renewed position of the dth decision variable. $Z_d^{\max}$ and $Z_d^{\min}$ are the upper and lower limits of the position of the dth decision variable.

(3.2) If the performance value of $Pw' = [pw'_1, pw'_2, \ldots, pw'_d, \ldots, pw'_D]$ is better than Pw, then $Pw = Pw'$; otherwise, Pb in formula (21) is replaced with Px, and the position updating is executed repeatedly.

(3.3) If the performance value of Pw is still better than Pw', then Pw is substituted by a random frog location.

(4) Mix and Global Search. After a local search, all memeplexes are shuffled to form a new population. Frogs are ranked and the best frog Px is marked. Then the next grouping and local search are performed until the specified number of global iterations IT is completed.

4.1. Solution for the Emergency Vehicle Dispatching Model Based on Improved Shuffled Frog Leaping Algorithm. In order to solve the dynamic emergency vehicle dispatching model, an improved shuffled frog leaping algorithm (ISFLA) is

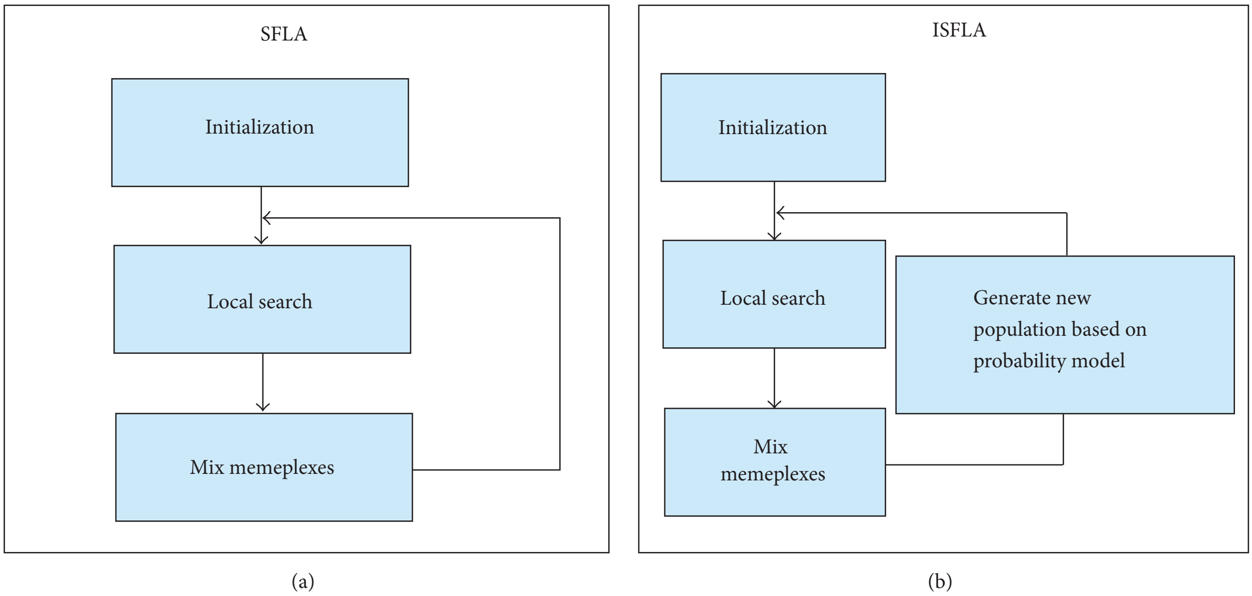

Figure 3: Principle of the ISFLA.

proposed. As shown in Figure 3, the improved algorithm is guided by the idea of a base SFLA. The local search uses the optimization strategy of SFLA, and the global search uses the probability model of estimation of distribution algorithms (EDA) to avoid the partial optimal solution.

4.1.1. Encoding and Decoding. Decision variables of the emergency vehicle dispatching are 0-1 numerical variables $x_{lu}(t_\varphi)$, which express whether the vehicle $Ev_l(t_\varphi)$ should be dispatched to the accident $Ac_u(t_\varphi)$. The working object of SFLA is integer vector, so it is necessary to convert $x_{lu}(t_\varphi)$ to integer variable $x_l(t_\varphi)$. $x_l(t_\varphi)$ represents the dispatching strategy of $Ev_l(t_\varphi)$, $l = 1, 2, \ldots, L$ at the decision-making instant t_φ. Each vehicle can go to one of the accidents $Ac_u(t_\varphi)$, $u = 1, 2, \ldots, U$ or in the idle state. The feasible set of $x_l(t_\varphi)$ is $x_l(t_\varphi) = \{0, 1, 2, \ldots, U\}$. The emergency vehicle is an idle vehicle while $x_l(t_\varphi) = 0$. In this case, the encoding of frog position can be expressed as a row vector matrix.

$$X\left(t_\varphi\right) = \left[x_1\left(t_\varphi\right), x_2\left(t_\varphi\right), \ldots, x_l\left(t_\varphi\right), \ldots, x_L\left(t_\varphi\right)\right]. \quad (24)$$

Similarly, $x_l(t_\varphi)$ should be decoded in the reverse way of encoding, and we can get the emergency vehicle dispatching strategy.

4.1.2. Performance Function. According to the objective function of the dynamic dispatching model of emergency vehicles, the performance function is defined as

$$\begin{aligned} f\left(X\left(t_\varphi\right)\right) = -&\left\{\sum_u\sum_l As_u \times \mathrm{T}_{lu}\left(t_\varphi\right) \times x_{lu}\left(t_\varphi\right)\right. \\ &\left.+ \sum_u M \times y_u\left(t_\varphi\right) + \sum_u M \times z_u\left(t_\varphi\right)\right\} \\ y_u\left(t_\varphi\right) &= \left|Na_u\left(t_\varphi\right) - \sum_u x_{lu}\left(t_\varphi\right)\right| \\ z_u\left(t_\varphi\right) &= \max\left\{0, t^u_{\max}\left(t_\varphi\right) - T^u_{\max}\left(t_\varphi\right)\right\}, \\ t^u_{\max}\left(t_\varphi\right) &= \max\left\{\mathrm{T}_{lu}\left(t_\varphi\right) \times x_{lu}\left(t_\varphi\right)\right\}. \end{aligned} \quad (25)$$

Using the quantification method in the literature [30], the accident severity As_u is divided into four levels, and the value is shown in Table 1.

4.1.3. Process of the Improved Shuffled Frog Leaping Algorithm. Process of the ISFLA is shown in Figure 4, and the specific process is as follows.

(1) Build Probability Model. The decision vector of emergency vehicle dispatching is $X(t_\varphi) = [x_1(t_\varphi), x_2(t_\varphi), \ldots, x_l(t_\varphi), \ldots, x_L(t_\varphi)]$, $x_l(t_\varphi) = \{0, 1, 2, \ldots, U\}$. $U \times L$ dimensional matrix $B_{U\times L}$ is used to describe the probability distribution of the frog population. $b_{u\times l} \in [0, 1]$ is the element of the matrix $B_{U\times L}$. It represents the probability that the lth decision variable $x_l(t_\varphi)$ is valued as u.

(2) Generate the Initial Population. The value of the element $b_{u\times l}$ is set as $1/U$. According to a uniform distribution, H frogs are generated randomly to form the initial population IP. Each frog's position $X_h = [x_{h,1}, x_{h,2}, \ldots, x_{h,L}]$ represents a feasible decision vector.

(3) Local Search. H frogs are ranked in descending order of performance function value $f(X_h)$. Location Px of the optimal frog in the population is marked. The population IP is divided into a memeplexes, and there are c frogs in each memeplex according to formula (20). Within each memeplex,

Table 1: Value of accident severity.

Accident level		Description of the accident: Death toll	The number of serious injuries (SI)	The number of slight injuries	Property loss (L)	Accident severity
Minor accident	Situation 1	-	-	1-2	-	40
	Situation 2	-	-	-	Motor vehicle accidents: <1,000 Nonmotor vehicle accidents: <200	
Ordinary accident	Situation 1	-	1-2	-	-	60
	Situation 2	-	-	⩾3	-	
	Situation 3	-	-	-	<30,000	
Major accident	Situation 1	1-2	-	-	-	80
	Situation 2	-	$3 \leqslant SI < 10$	-	-	
	Situation 3	-	-	-	$30{,}000 \leqslant L < 60{,}000$	
Extra serious accident	Situation 1	⩾3	-	-	-	100
	Situation 2	-	⩾11	-	-	
	Situation 3	1	⩾8	-	-	
	Situation 4	2	⩾5	-	-	
	Situation 5	-	-	-	⩾60,000	

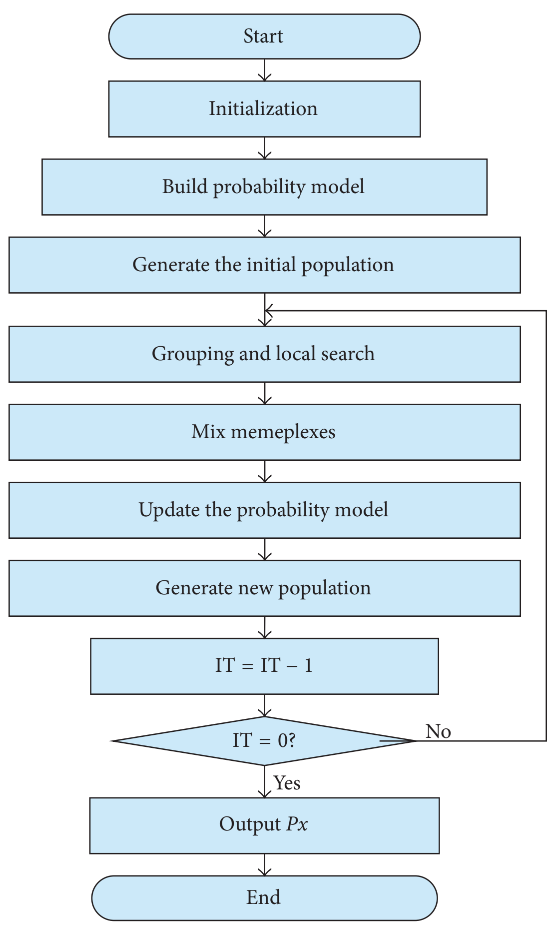

Figure 4: Process of the improved SFLA.

the local optimization process is repeated for the specified number of iterations It according to formula (21)–(23).

(4) Select the Superior Individual and Update the Probability Model. The performance function value $f(X_h)$ of each frog in the population is calculated. H frogs are reordered in descending order of performance function value. The first $H/2$ frogs are selected to calculate the distribution of decision variables, and then the probability matrix B' is obtained. The updated probability model is

$$B = \theta \cdot B' + (1 - \theta) \cdot B, \tag{26}$$

in which, θ is the forgetting factor.

(5) Generate New Population. According to the updated probability model $B_{U\times L}$, H frogs are generated to form a new population IP.

5. Illustrative Examples

Beijing expressway network shown as in Figure 1 was taken as an example to demonstrate the efficacy of the model and the improved algorithm. The interested time horizon Q was 9:30 to 10:30 on December 1, 2016. The minimum time interval κ was 5 minutes. Real link travel speeds at the instant $t \in \{9{:}30, 9{:}35, 9{:}40, \ldots, 10{:}30\}$ are given in Table 2. The upper limit of the time window $T^u_{\max}$ was 50 minutes. Firstly, based on real link travel speeds at the instant $t \in \{9{:}30, 9{:}35, 9{:}40, \ldots, 10{:}30\}$, five examples with different scale variable were used to test the performance of the emergency vehicle dispatching based on ISFLA. Secondly, based on prediction link travel speeds with different error ranges, two examples were used to test the performance of the dynamic emergency vehicle dispatching based on the polygonal-shaped travel speed function. Thirdly, we simulated a scene of a new accident to demonstrate the efficacy of adjustment mechanism of dispatching strategy.

5.1. Illustrative Examples of Emergency Vehicle Dispatching Based on the Improved Shuffled Frog Leaping Algorithm

(1) Calculating Link Travel Time Time-Dependent Function. Real link travel speeds $v^1_{ij}(t)$ at instant $t \in \{9{:}30, 9{:}35, 9{:}40, \ldots, 10{:}30\}$ were used to build the polygonal-shaped travel speed function. Then the travel time function $T_{ij}(t)$, $t \in [9{:}30, 10{:}30]$, of each road section was calculated according to formula (5). Figure 5 shows travel speed time-dependent functions of road sections (n_1, n_2), (n_2, n_1), (n_{18}, n_{32}), (n_{32}, n_{18}), and Figure 6 shows corresponding travel time time-dependent functions of these road sections.

(2) Parameters of Illustrative Examples of Emergency Vehicle Dispatching. We assume that there are 15 emergency vehicles at most in the expressway network. At 9:30, 7 accidents at most occurred simultaneously. Tables 3 and 4 list the parameters of the example.

(3) Calculating the Shortest Travel Time for Each Emergency Vehicle to Each Accident. We assume 5 emergency vehicle dispatching examples with different complexity. The first example has 8 emergency vehicles and 3 accidents. Then, the numbers of emergency vehicles and accidents gradually increase, and the other four examples are formed. Emergency vehicles and accidents in each example are shown in Table 5.

The dynamic shortest path algorithm of emergency vehicles in expressway network proposed in our previous research [18] was used to calculate the shortest travel time and path, and the results are shown in Tables 6 and 7.

The expressway network is a directed network. When the emergency vehicle Ev_l, $l = 1, 2, \ldots, L$, goes to the accident Ac_u, $u = 1, 2, \ldots, U$, it must run along the direction of the road section to arrive at the node n^l_1 and then choose the next road section. In which, n^l_1 is the end of the road section (n^l_0, n^l_1) where the emergency vehicle Ev_l is located. Road section from the emergency vehicle's location Nv_l to node n^l_1 is a necessary way for emergency vehicle Ev_l. In the same way, the emergency vehicle must arrive at the node n^u_0 and then run along the direction of the road section to reach the accident node Nc_u. In which, n^u_0 is the start of the road section (n^u_0, n^u_1) where the accident Ac_u is located. Road section from the node n^u_0 to the accident's location Nc_u is a necessary way for emergency vehicle Ev_l too. We only need to calculate the optimal path from the node n^l_1 to the node n^u_0, so the optimal path from the node n^l_1 to the node n^u_0 is given in Table 7.

(4) Calculating the Optimal Dispatching Strategy. ISFLA was used to find the optimal dispatching strategy of the five examples. The improved algorithm was compared with SFLA. After some testing, parameters of ISFLA were defined as in Table 8. After ten runs, the best solutions of the five examples obtained by using these two algorithms are summarized in Table 9. Figure 7 shows the evolutionary processes of the two algorithms of example I and example V.

(5) Result Analysis. The applicability of the model and the improved algorithm for solving the emergency vehicle dispatching problems with different complexity were verified by the five illustrative examples. Under the constraints of emergency vehicle requirements and time windows, the optimal dispatching strategy takes accident severity as key factor to optimize the total travel times of emergency vehicles. The results correspond to the decision rules of emergency vehicle dispatching.

In example I, there are 4^8 possible emergency vehicle selection strategies. Analyzing Table 9 shows that SFLA and ISFLA get the same optimal selection strategies. Their objective function values are 7987.

In example II, there are 5^{10} possible emergency vehicle selection strategies. Analyzing Table 9 shows that the objective function of optimal selection strategy obtained by using ISFLA is 8113. The SFLA is unwanted early convergence. Its objective function value of optimal selection strategies is 13.14% larger than that of ISFLA.

In example III, there are 6^{12} possible emergency vehicle selection strategies. Analyzing Table 9 shows that the objective function of optimal selection strategy obtained by using ISFLA is 10247. The SFLA is unwanted early convergence.

TABLE 2: The table gives travel speeds of (n_i, n_j) at 9:30, 9:35, 9:40, . . . , 10:30 on December 1, 2016. In which, (n_i, n_j) is the road section of Beijing expressway network. They are the basic data of illustrative examples in Section 5.

Road section	9:30	9:35	9:40	9:45	9:50	9:55	10:00	10:05	10:10	10:15	10:20	10:25	10:30
(n_1, n_2)	35.8215	20.3765	28.2279	31.8677	35.7043	38.8095	28.6015	17.5589	22.8039	20.5689	33.2365	23.6908	26.1908
(n_1, n_6)	22.5825	33.7016	14.5643	26.573	27.6807	19.0503	22.7254	23.13	22.2	21.6732	11.8164	23.3327	26.3327
(n_1, n_7)	19.7129	20.9999	15.7227	20.0905	17.6481	23.1212	26.4123	24.617	21.1975	17.4778	29.8401	32.2002	27.2002
(n_1, n_9)	15.355	15.528	11.5561	20.1183	19.7576	17.6415	22.0847	14.5041	14.1869	15.4142	16.9405	20.3074	22.5378
(n_2, n_1)	23.1756	27.1385	29.4663	30.5464	19.6817	24.3868	17.9294	18.4325	23.9658	31.6632	20.1517	25.8569	24.6569
(n_2, n_3)	26.4831	27.1754	21.7814	24.0784	17.1708	23.5244	17.2602	26.6113	35.9275	19.6655	23.9367	22.5875	17.5875
(n_2, n_{10})	16.693	13.9778	11.2268	18.5879	15.5855	17.1857	13.8282	10.7979	18.6863	17.7514	22.7961	21.2068	16.2068
(n_3, n_2)	25.0379	30.4431	22.1758	18.9887	28.441	25.1131	27.0197	33.0966	27.4579	26.9891	33.9385	21.9777	26.9777
(n_3, n_4)	21.4607	30.1089	16.8812	11.7818	11.621	26.9056	21.581	39.804	35.43943	28.224	21.4316	34.3545	29.3545
(n_3, n_{12})	23.7186	13.5768	22.6461	28.554	22.1646	13.8365	19.1874	18.0001	21.5321	21.6481	21.622	18.5449	23.5449
(n_4, n_3)	15.4424	20.2254	30.8515	25.626	23.4888	22.7928	25.596	25.40945	41.652	34.4304	25.5643	19.6756	22.6436
(n_4, n_5)	30.2678	19.3306	39.0199	32.8014	27.6075	30.1831	27.904	39.059	11.088	15.9983	27.7148	25.7315	28.6734
(n_4, n_{13})	20.139	21.9476	18.3451	21.4544	12.4372	24.3021	13.8022	9.6058	25.6725	18.4364	20.9946	16.9337	11.9337
(n_5, n_4)	9.3128	23.4184	15.3372	48.2641	31.6018	36.0318	16.5346	22.9536	28.1376	21.2511	22.8202	18.4113	23.4113
(n_5, n_6)	35.7092	42.1002	34.1108	37.9314	35.7767	28.5644	32.7456	25.1776	36.9073	22.659	23.2064	25.022	27.0654
(n_5, n_{15})	18.1438	22.07	25.7119	21.4686	15.3884	22.5308	15.1383	16.1952	17.7313	14.853	19.6452	16.5002	11.5002
(n_6, n_1)	15.6426	36.723	22.8957	30.8007	25.6438	32.4282	25.1974	49.986	33.9197	35.9149	21.4228	37.6876	32.6876
(n_6, n_5)	25.1075	31.5886	11.1249	26.73	24.013	15.8807	20.2512	24.1323	40.3112	36.2664	15.6697	26.0462	21.0462
(n_6, n_{18})	24.2849	18.1288	17.2682	25.7382	30.8254	14.5333	20.753	22.5785	13.04	27.2062	20.9267	32.5609	27.5609
(n_7, n_1)	33.1513	25.6162	28.3083	24.1654	28.8115	17.0718	25.6522	24.2943	26.9422	30.1469	29.6986	38.7776	33.7776
(n_7, n_8)	45.289	42.7567	39.8016	45.4383	43.9181	54.312	36.4771	36.7876	46.5368	53.676	29.1054	41.8043	36.8043
(n_7, n_{18})	24.2919	26.4158	27.8619	15.4707	24.595	9.864	24.684	7.38	22.212	32.076	21.8051	19.9445	23.3452
(n_8, n_7)	45.2188	42.6165	48.6611	48.0486	34.7927	42.0564	32.445	55.548	40.0004	29.4257	47.3986	39.5606	34.5606
(n_8, n_9)	24.8046	34.816	22.4496	28.5366	24.6233	16.668	12.8682	7.38	19.1072	28.6751	24.6707	18.2876	23.2876
(n_8, n_{19})	23.6014	17.8158	18.7145	22.1506	22.0417	18.6709	23.9033	29.3326	21.7442	21.9771	11.9924	19.1274	17.1434
(n_9, n_1)	25.5525	22.7526	26.5187	19.5367	34.5426	25.6112	30.2352	23.8654	25.1875	29.4503	28.7788	20.3987	15.3987
(n_9, n_8)	31.4897	36.8907	32.8745	42.5121	33.336	34.4962	42.436	38.276	31.005	29.628	26.215	31.2124	26.2124
(n_9, n_{10})	12.4945	15.9981	11.0279	18.8998	12.4372	25.544	14.796	22.2355	10.6805	15.7968	12.1055	28.9159	23.9159
(n_9, n_{20})	26.3711	18.6249	20.6505	13.2397	22.2702	19.9457	12.22	18.1987	15.747	18.5462	16.7472	17.0505	12.0505
(n_{10}, n_2)	23.482	19.0404	27.7911	20.6294	22.1208	27.5455	18.4591	16.173	30.329	29.8818	23.7257	29.2399	34.2399
(n_{10}, n_9)	19.6502	21.1314	19.5799	16.8456	17.5475	29.628	21.7406	12.8068	26.6456	22.2932	27.195	24.6179	22.3426
(n_{10}, n_{11})	11.6789	25.0173	23.1734	15.8519	10.4692	15.7769	17.2203	19.3803	17.6942	21.2171	20.9595	12.7466	17.7466
(n_{10}, n_{21})	16.6906	23.4181	21.1797	23.4837	21.5237	16.9955	16.4308	22.9818	15.644	24.9333	22.9535	20.4386	15.4386
(n_{11}, n_{10})	21.1883	19.3399	21.2697	30.4105	18.6214	20.5809	19.44	17.1289	23.0388	22.6296	31.6504	22.7549	27.7549
(n_{11}, n_{12})	29.7455	23.1488	36.2439	41.5484	32.6593	48.132	30.6737	32.5309	32.5309	26.2273	31.0559	33.5541	28.5541
(n_{11}, n_{22})	19.6753	16.1579	22.8854	19.7345	28.2388	23.4119	33.845	32.5529	25.8201	23.5862	30.7608	19.2675	23.2453
(n_{12}, n_3)	31.2132	24.0045	23.2547	21.9237	29.9919	39.1563	30.9103	24.9077	32.3465	24.4867	23.3021	31.8698	29.4568
(n_{12}, n_{11})	33.088	35.2858	30.6669	28.0342	25.4681	38.1852	29.059	32.6558	38.8695	32.2736	27.1765	33.8246	28.8246
(n_{12}, n_{13})	15.7673	18.1255	24.3937	18.8885	22.8062	14.7927	21.5846	19.7057	16.6918	25.0319	24.1279	23.1339	25.3462
(n_{12}, n_{23})	15.5967	22.1842	30.6917	11.3833	18.6417	10.7881	24.5125	25.0496	9.6873	27.7184	12.5765	19.1341	14.1341
(n_{13}, n_4)	22.9506	21.4434	25.3072	15.7694	23.0083	22.2823	20.4405	28.2635	21.3286	27.7032	29.8792	24.2156	29.2156
(n_{13}, n_{12})	21.9029	30.2519	25.8323	13.7023	33.4922	27.0706	25.3517	29.1525	26.6141	14.5851	11.252	22.3766	17.3766

Table 2: Continued.

Road section	9:30	9:35	9:40	9:45	9:50	9:55	10:00	10:05	10:10	10:15	10:20	10:25	10:30
(n_{13}, n_{14})	11.1064	25.6402	15.2103	19.3209	26.4223	30.3127	13.0589	32.0853	27.2811	25.506	21.4571	20.4382	15.4382
(n_{13}, n_{24})	15.4208	17.5974	24.8324	25.0641	21.4277	24.1301	23.3536	17.0912	21.1445	17.5043	14.5007	22.1737	27.1737
(n_{14}, n_{13})	23.6147	38.1495	28.9343	24.2838	40.8111	24.048	28.2018	45.36	25.2878	27.65	23.2166	21.039	26.039
(n_{14}, n_{15})	25.379	22.6816	16.5716	19.1937	21.2507	25.92	30.8738	16.8351	26.708	23.8517	20.5968	15.6582	20.6582
(n_{14}, n_{27})	21.3262	21.9084	24.3039	28.8116	24.2594	30.2419	11.8582	19.7537	23.18	17.8241	15.6202	25.0852	20.0852
(n_{15}, n_{5})	21.8971	11.6351	30.1314	25.5666	26.0133	29.028	19.9033	23.3528	32.7366	29.9893	20.5936	15.9837	21.2351
(n_{15}, n_{14})	22.5953	26.6376	28.3237	25.4259	21.0793	19.422	15.9731	25.92	26.6161	46.296	29.4048	34.293	36.3256
(n_{15}, n_{16})	24.8356	29.7005	35.0005	13.6867	36.468	22.2797	20.34	24.7755	11.088	33.676	30.3817	27.5295	32.5295
(n_{15}, n_{29})	23.5872	31.4391	20.8336	9.2175	28.447	26.4114	17.0868	21.1131	23.8973	21.9235	23.4818	19.4364	14.4364
(n_{16}, n_{15})	28.7868	28.331	27.7535	22.1266	29.8588	36.296	19.422	31.4111	25.0175	26.1084	44.1895	19.9332	25.3457
(n_{16}, n_{17})	23.5312	20.7604	22.3994	35.63	34.2775	19.7144	21.6727	27.5377	26.1173	20.34	25.3507	30.9571	35.9571
(n_{16}, n_{30})	26.7026	16.7753	19.1615	25.0103	22.2606	30.4504	30.7058	21.096	28.3757	30.9772	25.6049	32.1169	27.1169
(n_{17}, n_{16})	16.9842	34.7854	32.1204	28.8798	29.7914	26.69	25.211	36.1121	26.7128	39.1083	29.6514	27.4658	22.4658
(n_{17}, n_{18})	26.443	28.7525	32.2085	27.9107	33.5474	42.424	33.1352	44.132	29.628	21.285	38.88	22.4163	27.4163
(n_{17}, n_{31})	20.0635	18.4469	18.9766	12.6472	14.5116	16.4666	13.5609	18.6594	28.8261	14.5888	20.2372	11.8279	6.8279
(n_{18}, n_{6})	28.5716	27.6879	36.1665	27.9511	27.4823	33.0515	30.2954	22.6653	21.871	20.1762	43.026	34.8619	38.3462
(n_{18}, n_{7})	17.1967	25.6923	22.2066	30.8889	40.716	15.114	12.96	5.544	25.92	13.0093	18.7247	23.7387	28.7387
(n_{18}, n_{17})	32.0776	31.2593	49.3007	31.5098	56.466	46.3468	24.048	24.048	41.652	23.13	23.3579	31.7037	36.7037
(n_{18}, n_{32})	21.765	13.6177	24.1532	20.6376	22.2606	17.6057	20.226	26.3626	7.6245	10.8335	21.0773	15.7262	17.5275
(n_{19}, n_{8})	30.0455	34.0459	26.2879	28.8757	26.1564	33.9629	38.5092	29.0318	34.1819	29.4782	32.5105	37.9813	36.3864
(n_{19}, n_{20})	9.971	19.224	11.088	24.048	14.796	24.048	21.3077	28.6925	20.7057	10.2956	16.9843	15.5002	10.5002
(n_{19}, n_{33})	37.9415	31.3179	23.2697	28.7727	26.4532	38.88	27.6162	26.532	46.296	32.088	34.3308	27.6593	22.6593
(n_{19}, n_{34})	24.5436	17.0723	22.9667	30.4918	19.9406	17.1968	15.9998	23.2988	27.0237	31.7541	19.3243	19.9782	20.2351
(n_{20}, n_{9})	16.0336	21.0688	25.6279	30.6163	31.9925	22.4156	21.399	27.0876	25.4508	26.8263	26.8914	15.5985	20.5985
(n_{20}, n_{19})	26.5774	22.212	17.5736	27.2318	15.442	13.6652	26.5167	17.5446	24.1079	30.6512	24.6187	27.79	32.79
(n_{20}, n_{21})	31.4044	31.4625	47.808	37.008	40.1212	35.172	42.588	23.882	33.7562	36.6223	31.0834	29.3702	24.3702
(n_{21}, n_{10})	19.8354	23.3835	28.8326	33.7234	19.1974	36.8871	32.6304	25.8425	23.494	21.5067	29.1639	21.527	26.527
(n_{21}, n_{20})	28.3482	29.4714	19.5844	21.8987	25.765	28.5483	33.6437	26.5502	35.3078	31.3771	34.8706	29.6347	32.5326
(n_{21}, n_{22})	26.0216	27.5469	21.8179	32.4478	33.4188	21.0689	23.4394	28.1423	24.1956	32.7357	29.0167	20.4584	29.5815
(n_{21}, n_{35})	22.5705	28.1672	18.9582	31.5342	35.7092	23.1775	24.9478	28.0398	32.2195	28.1321	27.3823	22.1031	32.4264
(n_{22}, n_{11})	32.0161	33.8281	49.6334	31.4378	24.217	41.5755	35.0492	28.7604	45.0867	34.7548	33.471	28.1108	23.1108
(n_{22}, n_{21})	21.5587	24.7503	13.8207	28.1799	36.1223	28.797	22.4211	26.1431	19.8201	34.3893	29.7035	28.9367	33.9367
(n_{22}, n_{23})	12.8279	35.172	20.358	10.17	23.1605	21.7582	22.824	29.3252	17.6377	28.4508	16.513	25.1189	30.1189
(n_{22}, n_{36})	16.8102	19.7036	20.046	17.7061	18.0843	19.2021	21.7497	26.6898	22.7205	17.28	22.5881	17.5268	22.5268
(n_{23}, n_{12})	26.3685	19.6544	20.9984	19.641	25.8781	19.1095	17.6822	25.7649	20.8829	24.8079	21.2406	24.3477	29.3477
(n_{23}, n_{22})	16.8402	20.5886	16.65	29.8227	21.1968	19.2456	17.586	16.668	30.4934	20.9667	24.2786	25.0395	20.0395
(n_{23}, n_{24})	29.2047	24.7494	18.3338	26.4002	14.7043	28.692	24.4668	11.088	20.34	25.92	27.8506	24.2783	19.2783
(n_{23}, n_{37})	23.8144	22.3499	18.5552	20.8287	21.6968	11.4653	20.4559	26.4973	18.5754	24.9654	27.9486	28.4628	33.4628
(n_{24}, n_{13})	30.4946	25.7359	36.4783	38.7628	25.6916	15.4647	23.175	20.7594	21.1762	19.3615	25.3909	35.5331	30.5331
(n_{24}, n_{23})	36.1943	31.331	37.8856	28.1583	27.6649	37.044	39.9093	25.92	24.432	27.98	34.4391	29.0487	24.0487
(n_{24}, n_{25})	27.5556	25.9729	24.751	29.2513	28.6489	25.1988	20.5482	25.7422	30.9605	16.9408	24.8777	15.2558	20.2558
(n_{24}, n_{38})	26.3805	23.4738	24.2851	21.887	18.8264	21.3668	22.3002	12.6113	22.0732	26.5655	20.3389	30.4344	35.4344

TABLE 2: Continued.

Road section	9:30	9:35	9:40	9:45	9:50	9:55	10:00	10:05	10:10	10:15	10:20	10:25	10:30
(n_{25}, n_{24})	25.331	28.2618	26.6353	30.4132	31.0304	22.7455	27.2853	21.2781	20.3911	31.6241	27.0002	26.7254	21.7254
(n_{25}, n_{26})	16.8309	27.0856	23.9089	19.3628	24.066	34.794	20.89029	46.908	29.004	19.89	25.92	24.7748	29.7748
(n_{25}, n_{39})	19.7948	24.4553	22.3961	13.2497	13.9135	29.1571	18.4512	35.4701	9.6681	25.6926	23.0038	18.4626	13.4626
(n_{26}, n_{25})	27.6015	29.85	28.5529	18.1117	23.5015	44.424	33.3481	23.598	18.504	34.254	31.464	25.7385	20.7385
(n_{26}, n_{27})	14.2224	19.9524	16.5509	16.6665	31.572	24.3207	20.976	20.5671	7.38	12.96	21.9918	24.4198	19.4198
(n_{26}, n_{40})	33.5522	19.6369	25.2266	22.8186	25.8973	13.3329	34.1434	28.2749	37.0596	33.5	25.0689	19.3657	19.2819
(n_{27}, n_{14})	30.6965	22.8707	28.1807	28.9659	20.5081	25.7812	32.9863	25.5622	23.4569	27.2833	23.6245	27.2157	32.2157
(n_{27}, n_{26})	29.3327	37.7083	34.5393	35.3089	27.3833	33.152	55.548	36.1578	25.9193	31.8867	18.8907	25.4497	25.3257
(n_{27}, n_{28})	34.5428	33.1044	26.3141	38.216	36.9792	19.828	37.179	26.652	21.296	28.5949	40.3886	37.2857	42.2857
(n_{27}, n_{41})	22.6554	18.3384	20.6647	19.5223	20.0416	21.7215	15.3789	14.2179	21.1639	30.3106	17.1591	12.9237	14.3215
(n_{28}, n_{27})	24.7294	13.4349	23.6613	27.7224	22.9866	23.672	35.172	25.92	15.732	7.38	23.5587	20.7311	25.7311
(n_{28}, n_{29})	27.7343	45.2357	46.278	48.204	18.504	29.628	30.9123	31.895	42.7445	24.5717	19.9995	39.019	44.019
(n_{28}, n_{42})	32.757	35.1901	29.7974	36.8838	39.0422	31.2206	43.6835	27.4834	34.6492	28.0919	34.9322	29.0565	24.0565
(n_{29}, n_{15})	18.7413	22.9066	30.6725	31.2796	26.8011	27.437	29.1645	18.7048	23.0915	16.8493	23.7545	30.7464	32.7321
(n_{29}, n_{28})	16.5841	23.1357	17.9721	5.544	24.984	26.1818	31.1185	28.4255	21.7963	16.2167	34.7601	26.723	21.723
(n_{29}, n_{30})	35.7481	41.2172	50.004	58.632	23.6078	36.4782	55.548	46.296	34.4414	36.9133	41.7204	39.5694	44.5694
(n_{29}, n_{43})	24.4832	35.7813	28.6492	24.5854	50.2455	34.5999	38.4233	43.1548	25.8914	38.4789	39.0105	36.4984	31.4984
(n_{30}, n_{16})	32.8059	33.4404	29.0517	40.1148	33.0317	36.4324	28.7253	27.6238	32.5452	31.7361	38.9741	36.0303	41.0303
(n_{30}, n_{29})	33.3402	32.9426	26.4765	40.716	32.813	22.212	29.628	27.7627	32.9475	25.4733	23.6324	29.8145	24.8145
(n_{30}, n_{31})	18.0093	23.7247	25.822	28.7387	24.6348	33.8815	23.5953	27.6376	30.3237	27.4259	31.4048	28.6161	23.6161
(n_{30}, n_{47})	29.9271	28.0907	21.013	30.969	20.7049	37.5447	31.1589	29.5889	25.6384	14.9421	20.8261	30.192	35.192
(n_{31}, n_{17})	27.3122	23.0705	26.384	22.972	19.9255	23.7923	22.1811	20.1768	30.8551	23.1064	35.6519	20.5192	25.5192
(n_{31}, n_{30})	13.3395	29.7268	20.8545	17.9808	23.7303	17.8568	24.8957	22.1967	36.8889	31.6923	13.5156	28.2066	26.3212
(n_{31}, n_{32})	29.9233	27.5431	24.8307	20.7151	25.5793	26.5665	19.653	27.9609	23.8885	27.5288	29.6811	23.4767	28.4767
(n_{31}, n_{47})	18.2443	21.0437	26.6463	22.7714	18.1332	14.5623	21.7784	22.6731	20.7887	22.4282	17.4275	27.2954	22.2954
(n_{32}, n_{18})	34.6978	23.1543	29.0436	24.907	30.5601	28.0568	27.7801	42.7455	24.8498	27.7656	41.4151	22.2665	23.066
(n_{32}, n_{31})	20.0793	14.9731	33.293	20.9773	25.5168	27.8158	25.568	20.4764	23.6614	25.3756	33.3948	21.6959	21.3256
(n_{32}, n_{33})	22.4128	20.5054	20.34	35.796	14.796	45.548	29.3574	26.5325	26.7919	20.8342	33.6774	31.6365	26.6365
(n_{32}, n_{45})	20.3312	24.4924	24.2836	31.2118	30.8979	28.6509	25.9583	22.4449	28.0319	34.8349	30.5642	29.0862	24.0862
(n_{33}, n_{19})	34.5595	27.3606	36.8804	38.7388	41.0041	30.1619	38.1456	35.7044	34.9696	43.0544	21.1344	32.4679	27.4679
(n_{33}, n_{32})	28.0225	19.644	36.4511	20.716	38.88	20.34	13.672	25.7334	31.2822	23.6385	24.025	29.1403	34.1403
(n_{33}, n_{46})	16.0562	29.5635	23.2929	36.0355	39.4106	26.7698	36.1572	34.7219	20.5097	28.7999	30.5667	32.138	28.3215
(n_{34}, n_{19})	28.3858	34.4957	41.3754	26.8214	20.2584	29.8203	17.0806	23.3569	26.6312	33.9373	33.6228	24.8346	19.8346
(n_{34}, n_{35})	38.7342	42.1347	43.8738	47.8653	39.3315	48.2212	46.5461	55.2707	45.5078	46.0586	38.8005	37.3032	42.3032
(n_{34}, n_{46})	45.4	34.8313	33.05829	51.8472	28.38	42.5736	49.98857	43.7484	47.011	41.9231	58.2984	34.9144	32.4512
(n_{35}, n_{21})	28.2038	41.6719	31.5473	29.1606	45.1054	36.8593	36.2981	25.9666	34.6039	35.1209	25.4465	30.6452	25.6452
(n_{35}, n_{34})	38.3401	35.6249	48.5614	38.4442	40.0985	32.3709	22.9813	29.4015	27.6955	29.0522	36.886	29.1026	24.1026
(n_{35}, n_{36})	45.1644	46.6339	42.4113	35.9576	59.1703	28.4833	41.4302	35.7486	41.5471	48.225	46.9663	41.0249	46.0249
(n_{36}, n_{22})	22.611	27.6803	34.0971	27.4104	16.7638	26.5984	23.4473	22.5357	22.6849	18.7214	22.0752	19.2935	21.2924
(n_{36}, n_{35})	17.8407	29.7715	34.5095	28.9844	30.6518	27.3529	19.6213	29.6933	37.7258	43.1677	27.9886	19.6087	24.6087
(n_{36}, n_{37})	43.7953	54.4549	61.5546	31.3509	68.5008	36.09	35.0472	66.11143	49.50514	41.346	35.172	57.6846	45.4344
(n_{37}, n_{23})	19.3156	15.9166	19.7184	28.5772	26.2822	25.679	30.2439	26.0461	26.2169	33.6578	34.694	44.6195	49.6195

Table 2: Continued.

Road section	9:30	9:35	9:40	9:45	9:50	9:55	10:00	10:05	10:10	10:15	10:20	10:25	10:30
(n_{37}, n_{36})	23.8205	32.8456	23.8767	28.0697	27.765	25.64229	23.42025	25.82571	30.67714	23.35015	32.391	32.8346	37.8346
(n_{37}, n_{38})	34.1043	48.0765	36.7424	37.1687	44.4156	40.54	41.9454	47.7629	52.3747	42.4163	46.6214	42.0936	47.0936
(n_{38}, n_{24})	32.6611	14.441	24.6137	33.4089	30.3681	28.0291	30.6215	34.7804	28.9226	23.4482	26.919	26.7533	31.7533
(n_{38}, n_{37})	44.8318	51.211	52.254	60.2107	65.5371	60.4039	55.0154	64.5239	65.3911	59.9616	63.57	62.3024	67.3024
(n_{38}, n_{39})	37.1429	49.9001	44.5609	36.0501	40.989	47.9961	38.0558	53.7996	41.8743	51.4709	38.3611	48.5935	45.4235
(n_{39}, n_{25})	34.3629	28.4779	30.0763	29.3488	32.4467	35.5281	29.2485	33.7507	41.5317	36.5889	35.9516	26.1112	31.1112
(n_{39}, n_{38})	47.4719	62.2148	68.7616	56.3855	66.4986	64.3643	51.5869	63.1797	57.5995	65.7155	60.4977	44.8243	49.8243
(n_{39}, n_{40})	51.8907	47.8745	58.5121	49.4962	62.436	42.215	52.2124	45.918	53.8011	31.5118	53.7514	38.3837	42.3321
(n_{40}, n_{26})	35.4259	28.2369	38.1587	33.4012	23.1637	18.4515	31.297	39.8748	34.087	33.3255	37.1265	24.6396	19.6396
(n_{40}, n_{39})	48.7455	42.1488	55.2439	60.5484	52.6593	50.6737	52.5309	46.2273	52.0559	54.5541	56.3667	55.4897	50.4897
(n_{40}, n_{41})	40.428	41.73709	51.84	36.22629	44.79943	56.88655	51.228	40.9608	48.7695	43.925	45.6818	52.9536	52.9536
(n_{41}, n_{27})	21.5665	32.1018	33.315	38.2749	26.2941	36.7688	32.4286	27.3579	36.645	33.5939	30.5894	43.2638	38.2638
(n_{41}, n_{40})	49.7784	60.5336	44.939	57.9558	64.3915	59.1353	62.1333	60.4039	47.4822	54.6687	67.7975	57.6513	59.6323
(n_{41}, n_{42})	46.8069	54.2979	43.1809	42.617	57.6107	39.9223	43.9772	51.3589	46.1985	56.2395	53.273	47.3326	46.3216
(n_{42}, n_{28})	23.5687	22.0959	23.0359	27.8531	24.22	21.4339	22.3374	17.0648	19.8429	16.522	21.9041	18.4894	17.4394
(n_{42}, n_{41})	41.7558	50.9238	45.4815	42.6664	58.9132	52.9074	55.1869	59.0718	54.4421	57.4068	58.4637	62.3649	59.3321
(n_{42}, n_{43})	22.452	37.3327	45.7083	42.5393	44.3089	36.3833	42.152	27.8907	35.9193	35.4497	46.1578	41.8867	36.8867
(n_{43}, n_{29})	26.551	25.5558	22.89	17.6108	33.3904	42.0009	43.34	27.0469	29.724	27.2055	30.4557	24.4874	19.4874
(n_{43}, n_{42})	50.6882	50.4938	70.0271	61.6079	51.544	60.1915	52.1194	60.6471	56.3798	69.9701	57.2431	46.103	51.103
(n_{43}, n_{44})	51.9058	24.5301	43.5541	43.2413	65.1582	32.2113	45.666	53.676	42.588	29.616	47.6023	31.0086	36.0086
(n_{44}, n_{43})	41.0666	47.6639	50.3153	57.3912	49.8147	42.576	56.672	57.4133	55.8927	59.5123	69.7826	64.2306	69.2306
(n_{44}, n_{45})	28.6551	34.8394	33.4949	33.7306	45.8684	35.6184	47.1494	33.747	46.7805	34.822	40.4126	46.7659	41.7659
(n_{44}, n_{47})	19.9468	15.8323	23.3384	13.9004	14.2217	23.352	29.1193	16.6816	15.9695	21.4484	25.4341	24.8079	29.8079
(n_{45}, n_{32})	24.7969	26.8204	20.6999	26.4952	22.3768	23.7876	20.971	24.3051	47.4192	46.4452	32.8815	30.7235	25.7235
(n_{45}, n_{44})	37.7425	56.6497	42.6488	44.8774	54.1986	44.5991	55.2349	44.2395	56.1024	53.0347	46.2959	41.0744	40.0421
(n_{45}, n_{46})	33.3609	41.1878	35.4696	36.3263	38.1141	41.0098	49.226	44.7845	31.1314	26.2193	38.532	25.257	30.257
(n_{46}, n_{33})	30.9449	30.5055	17.3013	27.1126	24.4442	14.7958	19.0287	25.0807	31.9526	25.6242	28.5735	21.6121	26.6121
(n_{46}, n_{34})	35.3327	29.628	26.838	32.908	37.332	45.66	44.424	45.1164	37.9687	39.0396	37.2611	40.5312	35.5312
(n_{46}, n_{45})	44.8368	46.52	38.0651	45.1987	48.8088	44.7385	57.8387	39.1315	39.1035	31.001	52.2839	51.9367	46.9367
(n_{47}, n_{30})	11.9523	25.8677	29.0142	19.907	24.6575	26.7507	21.3123	24.9181	27.4727	19.3771	30.0109	31.5672	31.5672
(n_{47}, n_{31})	30.0607	30.0464	30.0704	24.1245	28.2755	12.4826	18.9899	33.2118	22.0356	27.9654	35.0488	20.6665	22.6325
(n_{47}, n_{44})	23.6209	18.1936	25.7786	21.5246	30.2617	13.5507	22.8474	29.7383	19.0304	18.2511	16.3982	20.3277	25.3277

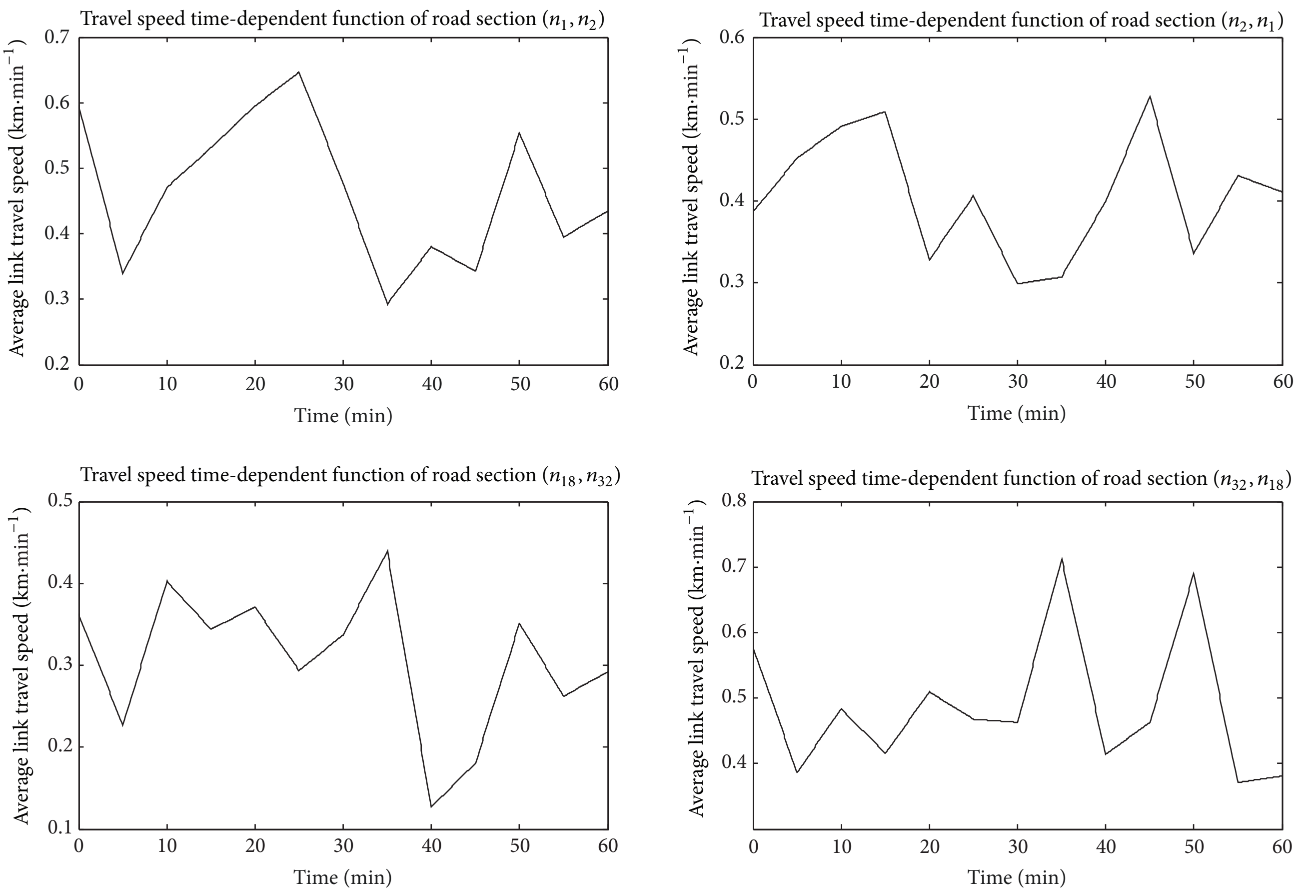

Figure 5: Link travel speed time-dependent functions.

Table 3: Accident parameters of the illustrative example.

Accident no.	Accident node	Road section of accident	Location of accident	Accident level	Accident severity	Accident demand
1	Nc_1/n_{48}	(n_{21}, n_{22})	$L_{21,48} = L_{48,22}$	Minor	40	1
2	Nc_2/n_{49}	(n_6, n_5)	$L_{6,49} = L_{49,5}$	Ordinary	60	2
3	Nc_3/n_{50}	(n_{27}, n_{14})	$L_{27,50} = L_{50,14}$	Major	80	2
4	Nc_4/n_{51}	(n_{16}, n_{15})	$L_{16,51} = L_{51,15}$	Minor	40	1
5	Nc_5/n_{52}	(n_9, n_{20})	$L_{9,52} = L_{52,20}$	Minor	40	2
6	Nc_6/n_{53}	(n_{38}, n_{39})	$L_{38,53} = L_{53,39}$	Ordinary	60	2
7	Nc_7/n_{54}	(n_{47}, n_{44})	$L_{47,54} = L_{54,44}$	Minor	40	1

Table 4: Emergency vehicle parameters of the illustrative example.

Vehicle no.	1	2	3	4	5
Vehicle node	Nv_1/n_{55}	Nv_2/n_{56}	Nv_3/n_{57}	Nv_4/n_{58}	Nv_5/n_{59}
Road section of vehicle	(n_2, n_3)	(n_9, n_8)	(n_{12}, n_{13})	(n_{18}, n_{17})	(n_{15}, n_{29})
Location of vehicle	$L_{2,55} = L_{55,3}$	$L_{9,56} = L_{56,8}$	$L_{12,57} = L_{57,13}$	$L_{18,58} = L_{58,17}$	$L_{15,59} = L_{59,29}$
Vehicle no.	6	7	8	9	10
Vehicle node	Nv_6/n_{60}	Nv_7/n_{61}	Nv_8/n_{62}	Nv_9/n_{63}	Nv_{10}/n_{64}
Road section of vehicle	(n_{39}, n_{25})	(n_{30}, n_{31})	(n_{33}, n_{32})	(n_{19}, n_{33})	(n_{24}, n_{13})
Location of vehicle	$L_{39,60} = L_{60,25}$	$L_{30,61} = L_{61,31}$	$L_{33,62} = L_{62,32}$	$L_{19,63} = L_{63,33}$	$L_{24,64} = L_{64,13}$
Vehicle no.	11	12	13	14	15
Vehicle node	Nv_{11}/n_{65}	Nv_{12}/n_{66}	Nv_{13}/n_{67}	Nv_{14}/n_{68}	Nv_{15}/n_{69}
Road section of vehicle	(n_{28}, n_{29})	(n_{12}, n_{23})	(n_{27}, n_{28})	(n_2, n_{10})	(n_{18}, n_{32})
Location of vehicle	$L_{28,65} = L_{65,29}$	$L_{12,66} = L_{66,23}$	$L_{27,67} = L_{67,28}$	$L_{2,68} = L_{68,10}$	$L_{18,69} = L_{69,32}$

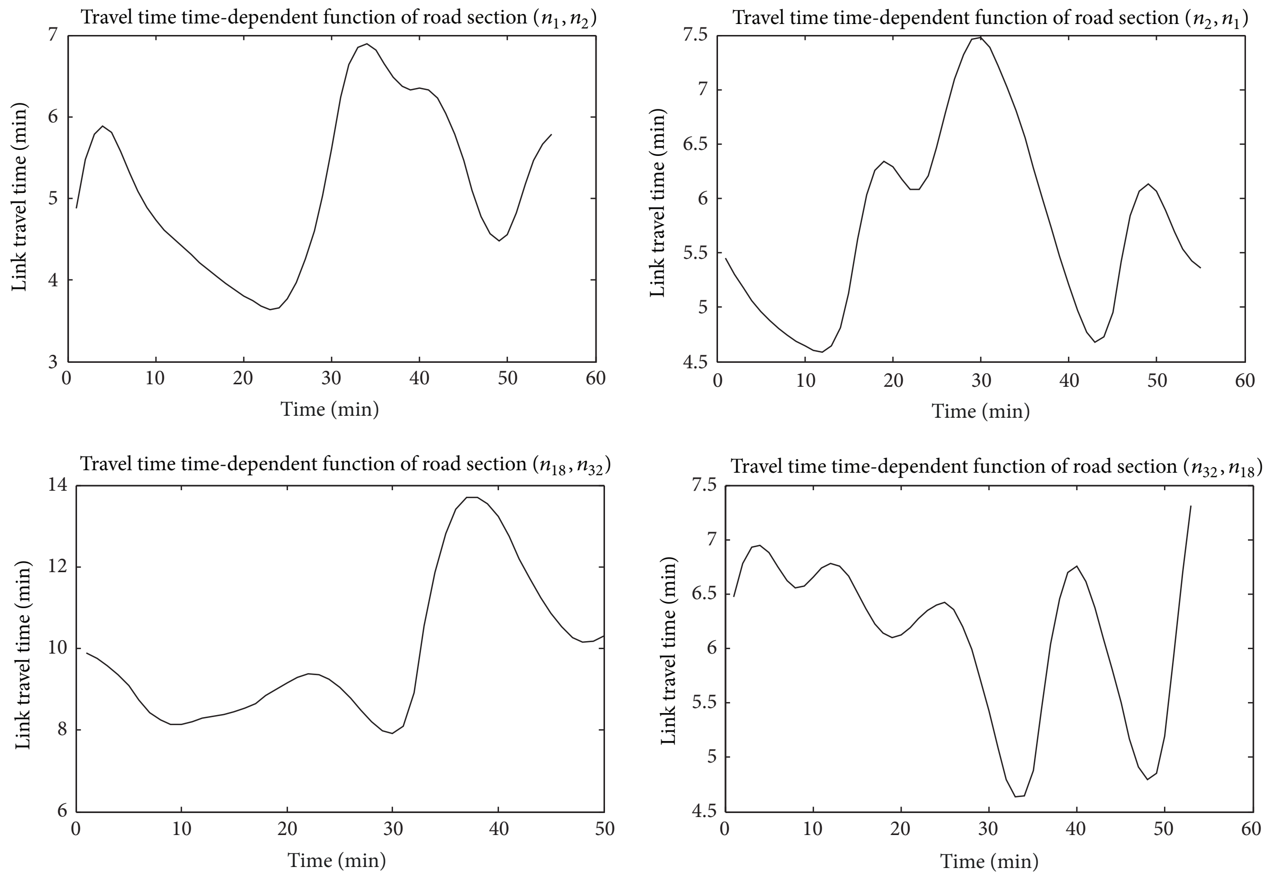

Figure 6: Link travel time time-dependent functions.

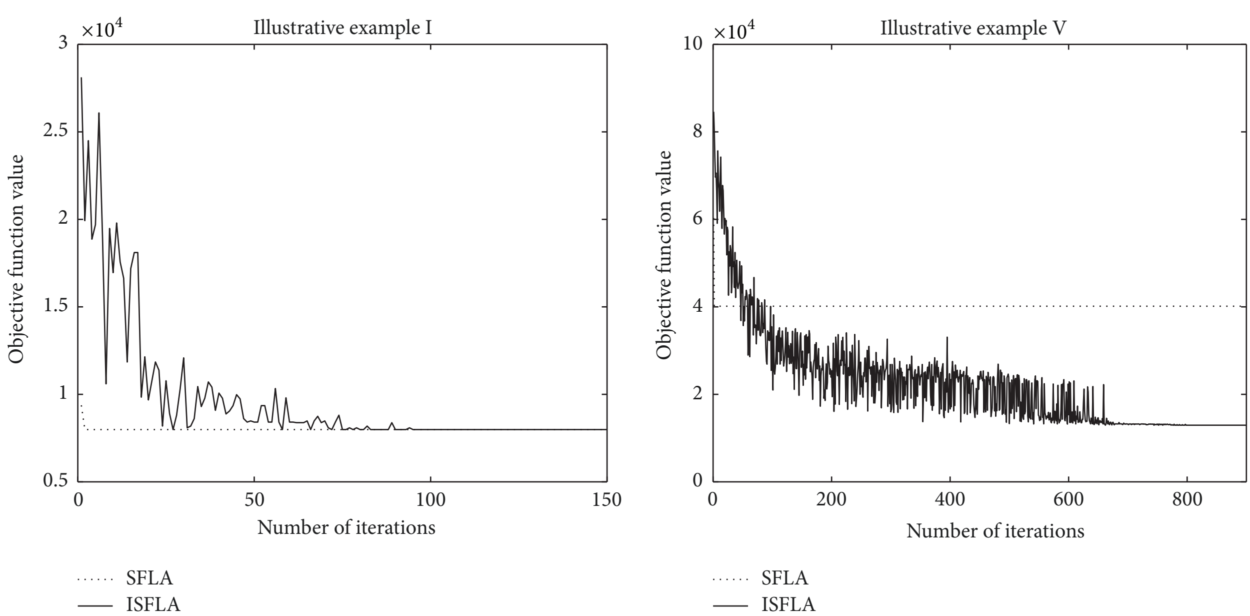

Figure 7: Evolutionary processes of the two algorithms for solving the illustrative examples.

Table 5: Emergency vehicles and accidents in each example.

Example no.	Vehicle no.	Accident no.
I	1, 2, 3, 4, 5, 6, 7, 8	1, 2, 3
II	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1, 2, 3, 4
III	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 2, 3, 4, 5
IV	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 4, 5, 6
V	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	1, 2, 3, 4, 5, 6, 7

Its objective function value of optimal selection strategies is 34.91% larger than that of ISFLA.

In example IV, there are 7^{14} possible emergency vehicle selection strategies. Analyzing Table 9 shows that the objective function of optimal selection strategy obtained by using ISFLA is 12061. The SFLA is unwanted early convergence. Its objective function value of optimal selection strategies is 50.04% larger than that of ISFLA.

In example V, there are 8^{15} possible emergency vehicle selection strategies. Analyzing Table 9 shows that the objective function of optimal selection strategy obtained by using ISFLA is 12947. The SFLA is unwanted early convergence. Its objective function value of optimal selection strategies is 210.10% larger than that of ISFLA.

Therefore, compared with SFLA, the optimization performance of ISFLA is getting better and better with the increase of the number of decision variables. ISFLA preceded SFLA in realizing the optimal resolution for the complicated emergency vehicle selection problem.

5.2. Illustrative Examples of Dynamic Emergency Vehicle Dispatching Based on the Prediction Link Travel Speed. Examples I and II in Section 5.1 were used to test the performance of dynamic emergency vehicle dispatching based on the prediction link travel speed. Polygonal-shaped travel speed functions $v_{ij}(t)$, $t \in [9{:}30, 10{:}30]$, $\forall(n_i, n_j) \in E$, were built using prediction travel speeds with different absolute error intervals (±3 km/h, ±5 km/h, and ±10 km/h). The present prediction methods can control the maximum absolute error of the prediction travel speed within ±10 km/h [31, 32], so the maximum prediction error was assumed as ±10 km/h. The prediction travel speed $v_{ij}^2(\phi)_{t_0}$ was randomly generated within the interval $[v_{ij}^1(t_\phi) - 10, v_{ij}^1(t_\phi) + 10]$, in which, $v_{ij}^1(t_\phi)$ is the real vehicle speed at the instant t_ϕ. In order to analyze the effect of the decrease of prediction error on the initial emergency vehicle dispatching strategy, the two prediction errors ±3 km/h and ±5 km/h were assumed. Then the travel time functions $T_{ij}(t)$, $t \in [9{:}30, 10{:}30]$, of each road section were calculated according to formula (5). The dynamic shortest path algorithm of emergency vehicles in expressway network proposed in our previous research [18] was used to calculate the shortest travel time and path, and the results are shown in Tables 10 and 11.

ISFLA was used to find the optimal dispatching strategy of the two examples under three prediction errors, and the best solutions are shown in Table 12.

In example I, the optimal emergency vehicle dispatching strategy (including vehicle routing and selection), which is based on the prediction link travel speed with prediction errors of ±3, ±5, is the same as the actual optimal strategy. However, when the prediction error is ±10, the rescue vehicle for the accident Ac_2 is different from the actual optimal strategy. The emergency vehicle Ev_7 instead of the vehicle Ev_8 is dispatched to the accident Ac_2. This led to a 23.4594 − 21.7823 = 1.6771 minutes extension of the rescue time for the accident Ac_2. The objective function value based on the prediction travel speed is 101 more than that based on the real travel speed. It can be seen that the prediction error of the travel speed affects the accuracy of the initial emergency vehicle dispatching, but when the absolute prediction error is within ±10, the effect is not obvious.

In example II, the optimal emergency vehicle dispatching strategy (including vehicle routing and selection), which is based on the prediction link travel speed with prediction errors of ±3, ±5, and ±10, is the same as the actual optimal strategy.

It is known from the two examples that the prediction error of ±10 can basically meet the requirements of the initial dispatching.

5.3. Illustrative Example of Dynamic Adjustment of Dispatching Strategy. Example I in Section 5.2 was used to test the performance of dynamic adjustment of dispatching strategy. Suppose that the prediction error of link travel speed was ±5. At 9:30, emergency vehicles were dispatched to accidents according to the optimal dispatching strategy obtained in Section 5.2. Emergency vehicle Ev_2 was dispatched to accident Ac_1. Emergency vehicle Ev_3 was dispatched to accident Ac_3. Emergency vehicle Ev_4 was dispatched to accident Ac_2. Emergency vehicle Ev_6 was dispatched to accident Ac_3. Emergency vehicle Ev_8 was dispatched to accident Ac_2. Emergency vehicles Ev_1, Ev_5, and Ev_7 were idle vehicles. The optimal dispatching strategy is shown in Figure 8.

At 9:35, a new accident Ac_4 happens on the road section $(9, 20)$. According to the real link travel speed, location of each emergency vehicle was calculated. They are shown in Figure 9.

Due to the influence of the accident Ac_4, road conditions of the accident section $(9, 20)$ and its upstream sections $(8, 9)$ and $(1, 9)$ changed. In order to consider the impact of accident Ac_4 on upstream sections, a weakening factor $\alpha_{ij}(t)$ to the travel speed of upstream section (n_i, n_j) was introduced. Therefore, the travel speed functions of sections $(8, 9)$ and $(1, 9)$ were $v'_{8,9}(t) = \alpha_{8,9}(t) \cdot v_{8,9}(t)$, $v'_{1,9}(t) = \alpha_{1,9}(t) \cdot v_{1,9}(t)$, respectively. Suppose that α_{ij} decreases linearly with time t. The initial value $\alpha_{ij}(t = t_\varphi) = 0.7$. When $t = t_\varphi + 30$ min, $\alpha_{ij}(t) = 0.53$.

The travel speed of each road section was recollected at 9:35, and the prediction travel speed function was calculated. We suppose that travel speed prediction error of road sections $(8, 9)$ and $(1, 9)$ was ±10 and that of other road sections was ±5. Then, travel paths of emergency vehicles were replanned, and the dispatching strategy was adjusted. The optimal dispatching strategy at 9:35 is shown in Figure 10. The dynamic emergency vehicle dispatching process is shown in Table 13.

Table 6: The shortest travel time of the illustrative examples based on the real link travel speed.

Vehicle no.	Example no.	Accident no.						
		1	2	3	4	5	6	7
1	I	31.2925	38.9665	54.9495	--	--	--	--
	II	31.2925	38.9665	54.9495	54.2331	--	--	--
	III	31.2925	38.9665	54.9495	54.2331	34.8666	--	--
	IV	31.2925	38.9665	54.9495	54.2331	34.8666	45.2505	--
	V	31.2925	38.9665	54.9495	54.2331	34.8666	45.2505	∞
2	I	22.1482	31.9124	∞	--	--	--	--
	II	22.1482	31.9124	∞	28.8721	--	--	--
	III	26.9763	31.9124	∞	28.8721	15.2541	--	--
	IV	26.9763	31.9124	∞	28.8721	15.2541	∞	--
	V	26.9763	31.9124	∞	28.8721	15.2541	∞	38.6391
3	I	48.3611	47.2027	33.8637	--	--	--	--
	II	48.3611	47.2027	33.8637	59.0018	--	--	--
	III	48.3611	47.2027	33.8637	59.0018	54.0921	--	--
	IV	48.3611	47.2027	33.8637	59.0018	54.0921	28.6649	--
	V	48.3611	47.2027	33.8637	59.0018	54.0921	28.6649	∞
4	I	41.0760	16.3454	53.4742	--	--	--	--
	II	41.0760	16.3454	∞	10.1881	--	--	--
	III	41.0760	16.3454	∞	10.1881	35.6330	--	--
	IV	41.0760	16.3454	∞	10.1881	35.6330	∞	--
	V	41.0760	16.3454	∞	10.1881	35.6330	∞	19.4956
5	I	49.9989	25.1126	38.7917	--	--	--	--
	II	49.9989	25.1126	38.7917	19.8843	--	--	--
	III	49.9989	25.1126	38.7917	19.8843	43.5353	--	--
	IV	49.9989	25.1126	38.7917	19.8843	43.5353	45.7355	--
	V	49.9989	25.1126	38.7917	19.8843	43.5353	45.7355	23.4806
6	I	44.4116	∞	26.3079	--	--	--	--
	II	44.4116	∞	26.3079	∞	--	--	--
	III	44.4116	∞	26.3079	∞	54.4887	--	--
	IV	44.4116	∞	26.3079	∞	54.4887	21.4419	--
	V	44.4116	∞	26.3079	∞	54.4887	21.4419	∞
7	I	43.6867	23.4594	56.5536	--	--	--	--
	II	43.6867	23.4594	56.5536	14.4705	--	--	--
	III	43.6867	23.4594	56.5536	14.4705	41.8074	--	--
	IV	43.6867	23.4594	56.5536	14.4705	41.8074	∞	--
	V	43.6867	23.4594	56.5536	14.4705	41.8074	∞	12.3566
8	I	42.6146	21.7823	∞	--	--	--	--
	II	42.6146	21.7823	∞	21.3312	--	--	--
	III	42.6146	21.7823	∞	21.3312	40.7481	--	--
	IV	42.6146	21.7823	∞	21.3312	40.7481	∞	--
	V	42.6146	21.7823	∞	21.3312	40.7481	∞	20.0396
9	II	37.8754	33.6324	∞	30.5210	--	--	--
	III	37.8754	33.6324	∞	30.5210	42.3188	--	--
	IV	37.8754	33.6324	∞	30.5210	42.3188	∞	--
	V	37.8754	33.6324	∞	30.5210	42.3188	∞	29.6284
10	II	42.3397	40.7709	28.2020	52.5731	--	--	--
	III	42.3397	40.7709	28.2020	52.5731	47.7124	--	--
	IV	42.3397	40.7709	28.2020	52.5731	47.7124	24.0304	--
	V	42.3397	40.7709	28.2020	52.5731	47.7124	24.0304	∞
11	III	∞	27.4119	40.8674	21.9920	45.8012	--	--
	IV	∞	27.4119	40.8674	21.9920	45.8012	48.8987	--
	V	∞	27.4119	40.8674	21.9920	45.8012	48.8987	25.3691

Table 6: Continued.

Vehicle no.	Example no.	Accident no.						
		1	2	3	4	5	6	7
12	III	25.3758	49.7617	48.7390	∞	33.5190	--	--
	IV	25.3758	49.7617	48.7390	∞	33.5190	32.6388	--
	V	25.3758	49.7617	48.7390	∞	33.5190	32.6388	∞
13	IV	∞	34.0944	21.9164	31.4456	54.1145	37.1084	--
	V	∞	34.0944	21.9164	31.4456	54.1145	37.1084	33.8540
14	IV	10.1994	32.9815	∞	48.1107	13.8316	54.7018	--
	V	10.1994	32.9815	∞	48.1107	13.8316	54.7018	∞
15	V	43.5208	22.7684	∞	22.3348	41.7501	∞	20.7021

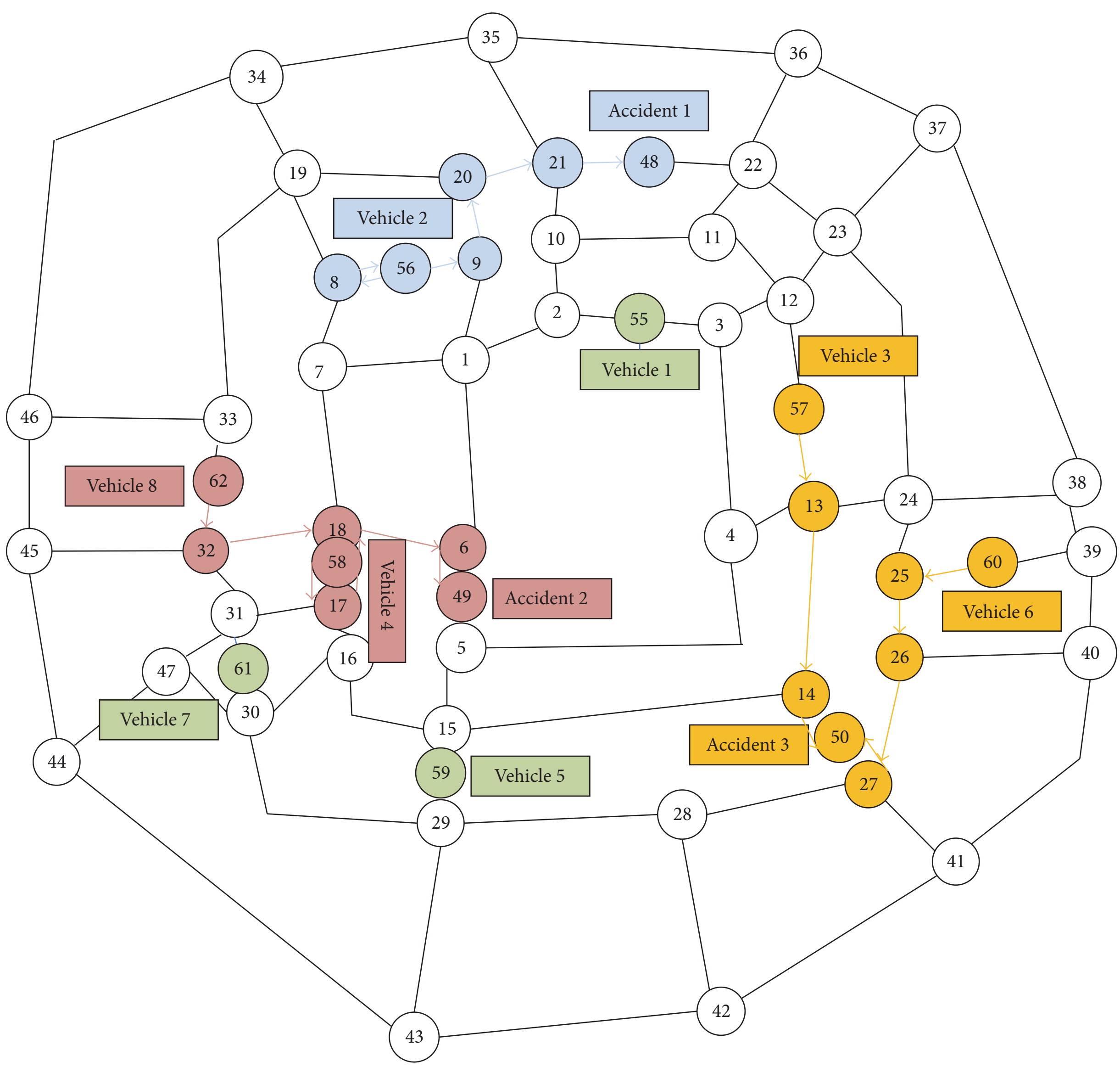

Figure 8: Optimal emergency vehicle dispatching strategy at 9:30.

Table 7: The shortest travel time path of the illustrative examples based on the real link travel speed.

Vehicle no.	Example no.	Accident no. 1	2	3	4	5	6	7
1	I	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	--			
	II	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	3, 2, 1, 6, 18, 17, 16			
	III	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	3, 2, 1, 6, 18, 17, 16	3, 2, 1, 9	--	--
	IV	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	3, 2, 1, 6, 18, 17, 16	3, 2, 1, 9	3, 12, 23, 37, 38	
	V	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	3, 2, 1, 6, 18, 17, 16	3, 2, 1, 9	3, 12, 23, 37, 38	BL
2	I	8, 9, 20, 21	8, 7, 18, 6	BL	--			
	II	8, 9, 20, 21	8, 7, 18, 6	BL	8, 7, 18, 17, 16			
	III	8, 9, 10, 21	8, 7, 18, 6	BL	8, 7, 18, 17, 16	8, 9	--	--
	IV	8, 9, 10, 21	8, 7, 18, 6	BL	8, 7, 18, 17, 16	8, 9	BL	
	V	8, 9, 10, 21	8, 7, 18, 6	BL	8, 7, 18, 17, 16	8, 9	BL	8, 7, 18, 17, 16, 30, 47
3	I	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	--			
	II	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16			
	III	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16	13, 12, 11, 10, 9	--	--
	IV	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16	13, 12, 11, 10, 9	13, 24, 38	--
	V	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16	13, 12, 11, 10, 9	13, 24, 38	BL
4	I	17, 18, 6, 1, 2, 10, 21	17, 18, 6	17, 16, 15, 14, 27	--			
	II	17, 18, 6, 1, 2, 10, 21	17, 18, 6	BL	17, 16			
	III	17, 18, 6, 1, 2, 10, 21	17, 18, 6	BL	17, 16	17, 18, 7, 8, 9	--	--
	IV	17, 18, 6, 1, 2, 10, 21	17, 18, 6	BL	17, 16	17, 18, 7, 8, 9	BL	--
	V	17, 18, 6, 1, 2, 10, 21	17, 18, 6	BL	17, 16	17, 18, 7, 8, 9	BL	17, 31, 47
5	I	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	--			
	II	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	29, 15, 16			
	III	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	29, 15, 16	29, 15, 5, 6, 1, 9	--	--
	IV	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	29, 15, 16	29, 15, 5, 6, 1, 9	29, 43, 42, 41, 40, 39, 38	--
	V	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	29, 15, 16	29, 15, 5, 6, 1, 9	29, 43, 42, 41, 40, 39, 38	29, 30, 47
6	I	25, 24, 23, 22, 21	BL	25, 26, 27	--			
	II	25, 24, 23, 22, 21	BL	25, 26, 27	BL			
	III	25, 24, 23, 22, 21	BL	25, 26, 27	BL	25, 24, 23, 12, 11, 10, 9	--	--
	IV	25, 24, 23, 22, 21	BL	25, 26, 27	BL	25, 24, 23, 12, 11, 10, 9	25, 24, 38	--
	V	25, 24, 23, 22, 21	BL	25, 26, 27	BL	25, 24, 23, 12, 11, 10, 9	25, 24, 38	BL

Table 7: Continued.

Vehicle no.	Example no.	Accident no. 1	2	3	4	5	6	7
7	I	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	--			
	II	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	31, 30, 16			
	III	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	31, 30, 16	31, 17, 18, 6, 1, 9	--	--
	IV	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	31, 30, 16	31, 17, 18, 6, 1, 9	BL	--
	V	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	31, 30, 16	31, 17, 18, 6, 1, 9	BL	31, 47
8	I	32, 33, 19, 20, 21	32, 18, 6	BL	--			
	II	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16			
	III	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16	32, 18, 6, 1, 9	--	--
	IV	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16	32, 18, 6, 1, 9	BL	--
	V	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16	32, 18, 6, 1, 9	BL	32, 31, 47
9	II	33, 19, 20, 21	33, 32, 18, 6	BL	33, 32, 18, 17, 16			
	III	33, 19, 20, 21	33, 32, 18, 6	BL	33, 32, 18, 17, 16	33, 19, 8, 9	--	--
	IV	33, 19, 20, 21	33, 32, 18, 6	BL	33, 32, 18, 17, 16	33, 19, 8, 9	BL	--
	V	33, 19, 20, 21	33, 32, 18, 6	BL	33, 32, 18, 17, 16	33, 19, 8, 9	BL	33, 32, 31, 47
10	II	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16			
	III	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16	13, 12, 11, 10, 9	--	--
	IV	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16	13, 12, 11, 10, 9	13, 24, 38	--
	V	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16	13, 12, 11, 10, 9	13, 24, 38	BL
11	III	BL	29, 15, 5, 6	29, 28, 27	29, 15, 16	29, 15, 5, 6, 1, 9	--	--
	IV	BL	29, 15, 5, 6	29, 28, 27	29, 15, 16	29, 15, 5, 6, 1, 9	29, 43, 42, 41, 40, 39, 38	--
	V	BL	29, 15, 5, 6	29, 28, 27	29, 15, 16	29, 15, 5, 6, 1, 9	29, 43, 42, 41, 40, 39, 38	29, 30, 47
12	III	23, 22, 21	23, 12, 3, 2, 1, 6	23, 24, 25, 26, 27	BL	23, 12, 11, 10, 9	--	--
	IV	23, 22, 21	23, 12, 3, 2, 1, 6	23, 24, 25, 26, 27	BL	23, 12, 11, 10, 9	23, 37, 38	--
	V	23, 22, 21	23, 12, 3, 2, 1, 6	23, 24, 25, 26, 27	BL	23, 12, 11, 10, 9	23, 37, 38	BL
13	IV	BL	28, 29, 15, 5, 6	28, 27	28, 29, 15, 16	28, 29, 15, 5, 6, 1, 9	28, 42, 41, 40, 39, 38	--
	V	BL	28, 29, 15, 5, 6	28, 27	28, 29, 15, 16	28, 29, 15, 5, 6, 1, 9	28, 42, 41, 40, 39, 38	28, 29, 30, 47
14	IV	10, 21	10, 2, 1, 6	BL	10, 9, 8, 7, 18, 17, 16	10, 9	10, 21, 35, 36, 37, 38	--
	V	10, 21	10, 2, 1, 6	BL	10, 9, 8, 7, 18, 17, 16	10, 9	10, 21, 35, 36, 37, 38	BL

Table 7: Continued.

Vehicle no.	Example no.	Accident no.						
		1	2	3	4	5	6	7
15	V	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16	32, 18, 6, 1, 9	BL	32, 31, 47

Note. BL means that the travel time of the optimal path exceeds the upper limit of the time window.

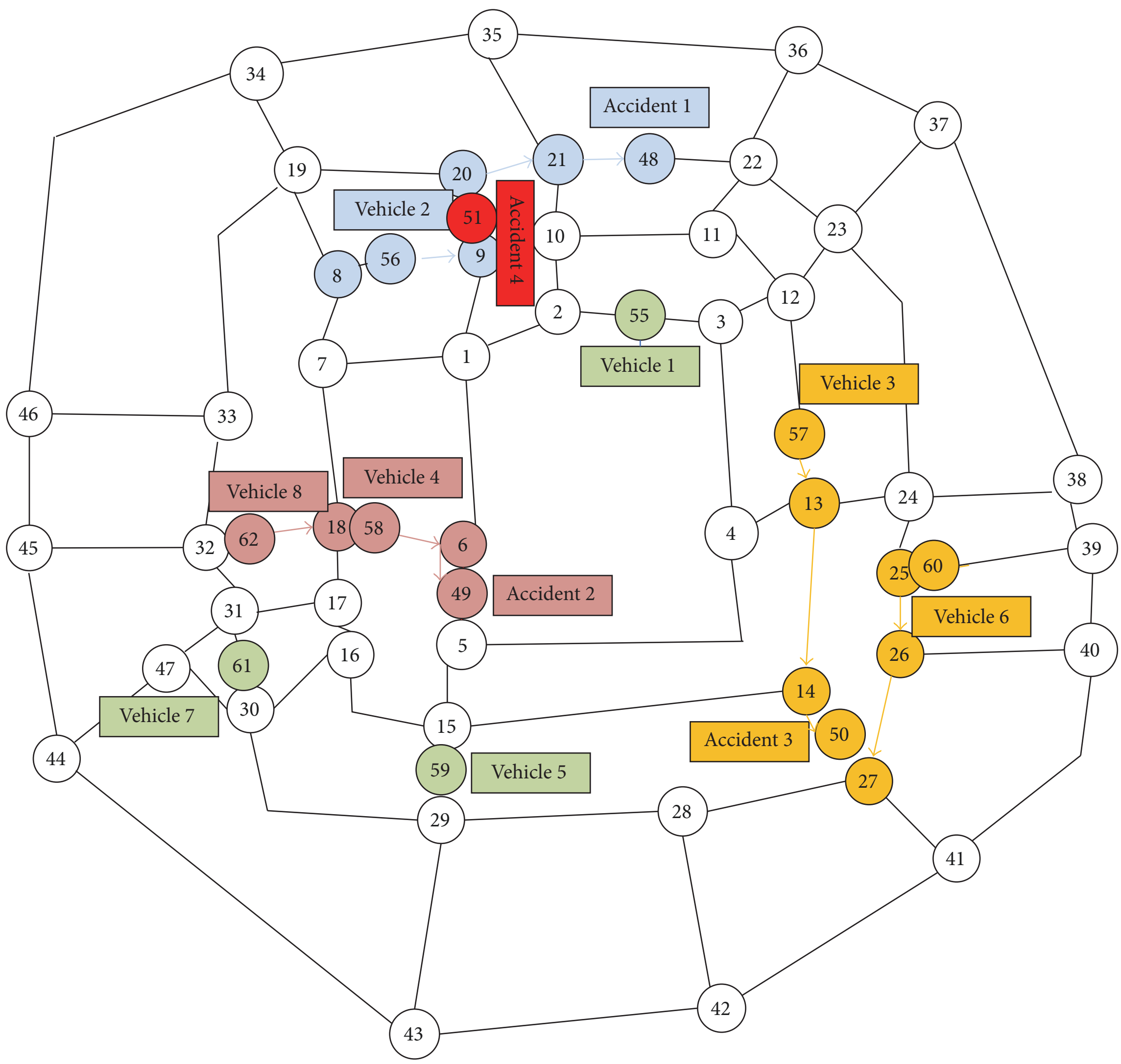

Figure 9: Locations of emergency vehicles and accidents at 9:35.

When the accident Ac_4 happened at 9:35, the dynamical adjustment mechanism timely responded to sudden changes in road conditions of the optimal path $(8, 9, 20, 21)$ of emergency vehicle Ev_2. After recalculating the dispatching strategy, the idle emergency vehicle Ev_1 replaced the emergency vehicle Ev_2 to rescue the accident Ac_1. The emergency vehicle successfully bypassed road sections $(9, 20)$ and $(8, 9)$ to ensure the time limit for emergency rescue. Meanwhile, the emergency vehicle Ev_2 with the shortest travel time was dispatched to the new accident Ac_4. Therefore, the adjustment of emergency vehicle dispatching strategy can effectively shorten the response time of accident.

6. Conclusions

The emergency vehicle dispatching in urban expressway network includes dynamic routing and emergency vehicles election. And the dispatching strategy needs to be adjusted according to the dynamic road conditions. Firstly, polygonal-shaped travel speed function based on real-time and

Table 8: Parameter selection of ISFLA.

Example no.	IP	a	c	IT	$D_d^{\max}$ $d=1,\ldots,D$	$Z_d^{\max}$ $d=1,\ldots,D$	$Z_d^{\min}$ $d=1,\ldots,D$	D	θ
I	150	15	10	150	3	4	1	8	0.05
II	150	15	10	350	4	5	1	10	0.05
III	300	20	15	600	5	6	1	12	0.05
IV	374	22	17	800	5	7	1	14	0.05
V	500	25	20	900	6	8	1	15	0.05

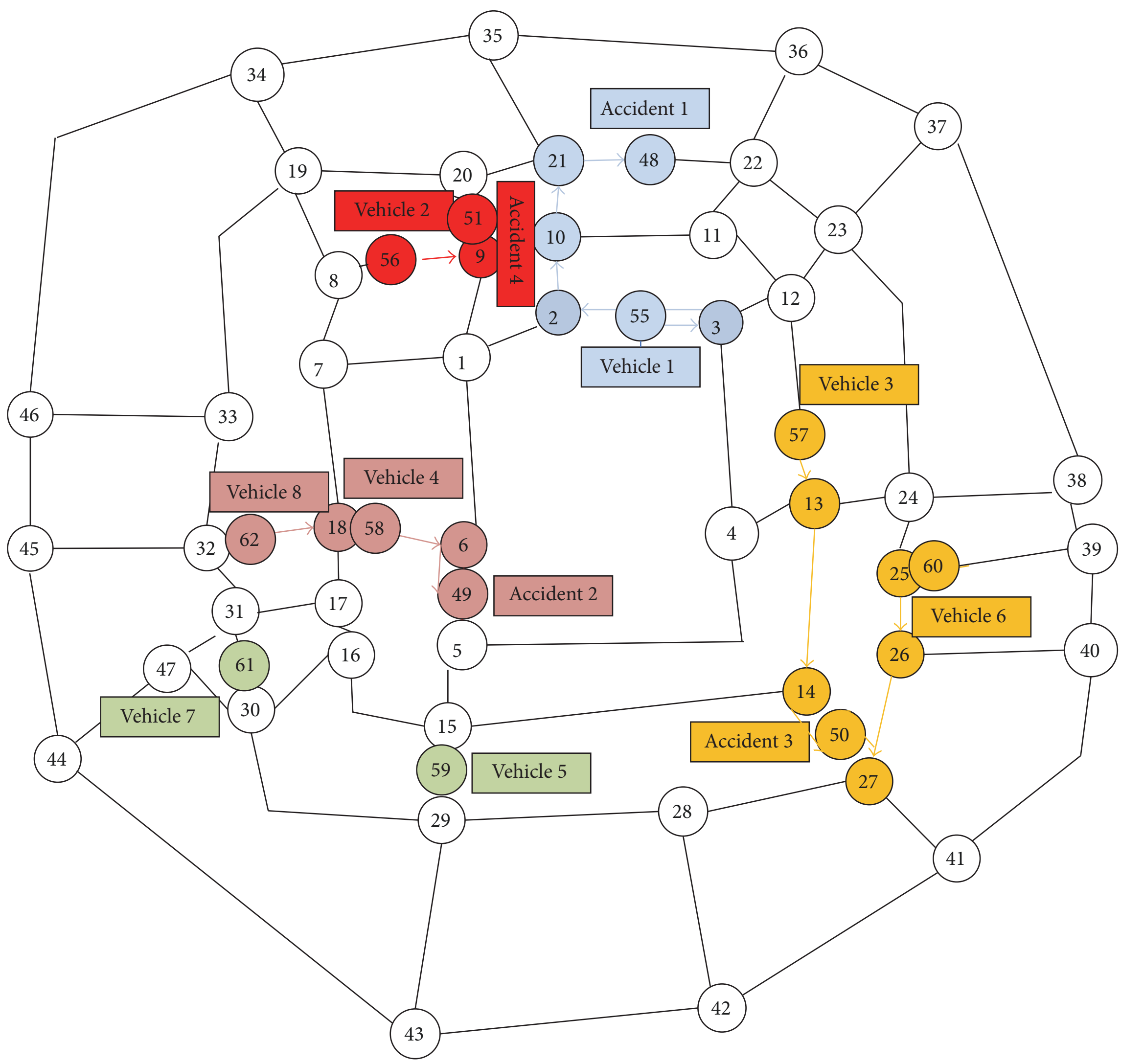

Figure 10: Optimal emergency vehicle dispatching strategy at 9:35.

prediction link travel speed is set up, and the dynamic emergency vehicle dispatching process is illustrated. Secondly, taking the accident severity as the key factor and the travel time as the objective function, a dynamic dispatching model considering the vehicle routing was established. The model consists of two stages: initial dispatching and dynamic adjustment. Thirdly, in order to avoid unwanted early convergence of SFLA in solving complex dispatching problems, the basic SFLA was combined with the probabilistic model of EDA, and the SFLA was improved. Finally, Beijing expressway network was taken as an example to test the efficacy of the model and the algorithm from three aspects. First, based on the real link travel speed, 5 emergency vehicle dispatching problems with different scale variable were modeled and solved by the improved shuffled frog leaping algorithm. Second, based on the prediction link travel speed and the

Table 9: Optimal emergency vehicle dispatching strategy of the illustrative examples based on the real link travel speed.

Example no.	Example parameters		Algorithm	The optimal solution	Optimal emergency vehicle dispatching strategy	Travel time (min)
I	Total number of vehicles	8			Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	22.1482
					Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.3454
	Total number of accidents	3	ISFLA	0,1,3,2,0,3,0,2	Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.7823
					Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	33.8637
	Accident severity	$As_1 = 40$			Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	26.3079
		$As_2 = 60$			Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	22.1482
		$As_3 = 80$			Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.3454
	Accident demand	$Na_1 = 1$	SFLA	0,1,3,2,0,3,0,2	Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.7823
		$Na_2 = 2$			Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	33.8637
		$Na_3 = 2$			Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	26.3079
II	Total number of vehicles	10			Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	22.1482
					Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.3454
	Total number of accidents	4	ISFLA	0,1,0,2,0,3,4,2,0,3	Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.7823
					Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	26.3079
	Accident severity	$As_1 = 40$			Ev_{10} to Ac_3: $Nv_{10} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	28.2020
		$As_2 = 60$			Ev_7 to Ac_4: $Nv_7 \rightarrow n_{31} \rightarrow n_{30} \rightarrow n_{16} \rightarrow Nc_4$	14.4705
		$As_3 = 80$			Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	22.1482
		$As_4 = 40$			Ev_5 to Ac_2: $Nv_5 \rightarrow n_{29} \rightarrow n_{15} \rightarrow n_5 \rightarrow n_6 \rightarrow Nc_2$	25.1126
	Accident demand	$Na_1 = 1$	SFLA	0,1,0,4,2,3,0,0,2,3	Ev_9 to Ac_2: $Nv_9 \rightarrow n_{33} \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	33.6324
		$Na_2 = 2$			Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	26.3079
		$Na_3 = 2$			Ev_{10} to Ac_3: $Nv_{10} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	28.2020
		$Na_4 = 1$			Ev_4 to Ac_4: $Nv_4 \rightarrow n_{17} \rightarrow n_{16} \rightarrow Nc_4$	10.1881

Table 9: Continued.

Example no.	Example parameters		Algorithm	The optimal solution	Optimal emergency vehicle dispatching strategy	Travel time (min)
					Ev_1 to Ac_5: $Nv_1 \rightarrow n_3 \rightarrow n_2 \rightarrow n_1 \rightarrow n_9 \rightarrow Nc_5$	34.8666
	Total number of vehicles	12			Ev_2 to Ac_5: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow Nc_5$	15.2541
					Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.3454
			ISFLA	5,5,0,2,0,3,4,2,0,3,0,1	Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	26.3079
	Total number of accidents	5			Ev_7 to Ac_4: $Nv_7 \rightarrow n_{31} \rightarrow n_{30} \rightarrow n_{16} \rightarrow Nc_4$	14.4705
					Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.7823
		$As_1 = 40$			Ev_{10} to Ac_3: $Nv_{10} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	28.2020
III		$As_2 = 60$			Ev_{12} to Ac_1: $Nv_{12} \rightarrow n_{23} \rightarrow n_{22} \rightarrow n_{21} \rightarrow Nc_1$	25.3758
	Accident severity	$As_3 = 80$			Ev_2 to Ac_2: $Nv_2 \rightarrow n_8 \rightarrow n_7 \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	31.9124
		$As_4 = 40$			Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	33.8637
		$As_5 = 40$			Ev_4 to Ac_5: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_7 \rightarrow n_8 \rightarrow n_9 \rightarrow Nc_5$	35.6330
		$Na_1 = 1$	SFLA	0,2,3,5,0,3,4,5,0,2,0,1	Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	26.3079
		$Na_2 = 2$			Ev_7 to Ac_4: $Nv_7 \rightarrow n_{31} \rightarrow n_{30} \rightarrow n_{16} \rightarrow Nc_4$	14.4705
	Accident demand	$Na_3 = 2$			Ev_8 to Ac_5: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow n_1 \rightarrow n_9 \rightarrow Nc_5$	40.7481
		$Na_4 = 1$			Ev_{10} to Ac_2: $Nv_{10} \rightarrow n_{13} \rightarrow n_4 \rightarrow n_5 \rightarrow n_6 \rightarrow Nc_2$	40.7709
		$Na_5 = 2$			Ev_{12} to Ac_1: $Nv_{12} \rightarrow n_{23} \rightarrow n_{22} \rightarrow n_{21} \rightarrow Nc_1$	25.3758
					Ev_2 to Ac_5: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow Nc_5$	15.2541
	Total number of vehicles	14			Ev_3 to Ac_6: $Nv_3 \rightarrow n_{13} \rightarrow n_{24} \rightarrow n_{38} \rightarrow Nc_6$	28.6649
					Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.3454
					Ev_6 to Ac_6: $Nv_6 \rightarrow n_{25} \rightarrow n_{24} \rightarrow n_{38} \rightarrow Nc_6$	21.4419
			ISFLA	0,5,6,2,0,6,4,2,0,3,0,1,3,5	Ev_7 to Ac_4: $Nv_7 \rightarrow n_{31} \rightarrow n_{30} \rightarrow n_{16} \rightarrow Nc_4$	14.4705
	Total number of accidents	6			Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.7823
					Ev_{10} to Ac_3: $Nv_{10} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	28.2020
					Ev_{12} to Ac_1: $Nv_{12} \rightarrow n_{23} \rightarrow n_{22} \rightarrow n_{21} \rightarrow Nc_1$	25.3758
		$As_1 = 40$			Ev_{13} to Ac_3: $Nv_{13} \rightarrow n_{28} \rightarrow n_{27} \rightarrow Nc_3$	21.9164
IV		$As_2 = 60$			Ev_{14} to Ac_5: $Nv_{14} \rightarrow n_{10} \rightarrow n_9 \rightarrow Nc_5$	13.8316
	Accident severity	$As_3 = 80$			Ev_1 to Ac_6: $Nv_1 \rightarrow n_3 \rightarrow n_{12} \rightarrow n_{23} \rightarrow n_{37} \rightarrow n_{38} \rightarrow Nc_6$	45.2505
		$As_4 = 40$			Ev_4 to Ac_5: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_7 \rightarrow n_8 \rightarrow n_9 \rightarrow Nc_5$	35.6330
		$As_5 = 40$			Ev_6 to Ac_6: $Nv_6 \rightarrow n_{25} \rightarrow n_{24} \rightarrow n_{38} \rightarrow Nc_6$	21.4419
		$As_6 = 60$			Ev_7 to Ac_2: $Nv_7 \rightarrow n_{31} \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	23.4594
		$Na_1 = 1$	SFLA	6,0,0,5,0,6,2,2,1,5,4,3,3,0	Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.7823
		$Na_2 = 2$			Ev_9 to Ac_1: $Nv_9 \rightarrow n_{33} \rightarrow n_{19} \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	37.8754
	Accident demand	$Na_3 = 2$			Ev_{10} to Ac_5: $Nv_{10} \rightarrow n_{13} \rightarrow n_{12} \rightarrow n_{11} \rightarrow n_{10} \rightarrow n_9 \rightarrow Nc_5$	47.7124
		$Na_4 = 1$			Ev_{11} to Ac_4: $Nv_{11} \rightarrow n_{29} \rightarrow n_{15} \rightarrow n_{16} \rightarrow Nc_4$	21.9920
		$Na_5 = 2$			Ev_{12} to Ac_3: $Nv_{12} \rightarrow n_{23} \rightarrow n_{24} \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	48.7390
		$Na_6 = 2$			Ev_{13} to Ac_3: $Nv_{13} \rightarrow n_{28} \rightarrow n_{27} \rightarrow Nc_3$	21.9164

Table 9: Continued.

Example no.	Example parameters		Algorithm	The optimal solution	Optimal emergency vehicle dispatching strategy	Travel time (min)
					Ev_2 to Ac_5: $Nv_2 \to n_8 \to n_9 \to Nc_5$	15.2541
					Ev_3 to Ac_3: $Nv_3 \to n_{13} \to n_{14} \to n_{27} \to Nc_3$	33.8637
	Total number of vehicles	15			Ev_4 to Ac_2: $Nv_4 \to n_{17} \to n_{18} \to n_6 \to Nc_2$	16.3454
					Ev_5 to Ac_4: $Nv_5 \to n_{29} \to n_{15} \to n_{16} \to Nc_4$	19.8843
					Ev_6 to Ac_6: $Nv_6 \to n_{25} \to n_{24} \to n_{38} \to Nc_6$	21.4419
			ISFLA	0,5,3,2,4,6,7,2,0,6,0,1,3,5,0	Ev_7 to Ac_7: $Nv_7 \to n_{31} \to n_{47} \to Nc_7$	12.3566
					Ev_8 to Ac_2: $Nv_8 \to n_{32} \to n_{18} \to n_6 \to Nc_2$	21.7823
	Total number of accidents	7			Ev_{10} to Ac_6: $Nv_{10} \to n_{13} \to n_{24} \to n_{38} \to Nc_6$	24.0304
					Ev_{12} to Ac_1: $Nv_{12} \to n_{23} \to n_{22} \to n_{21} \to Nc_1$	25.3758
					Ev_{13} to Ac_3: $Nv_{13} \to n_{28} \to n_{27} \to Nc_3$	21.9164
		$As_1 = 40$			Ev_{14} to Ac_5: $Nv_{14} \to n_{10} \to n_9 \to Nc_5$	13.8316
V		$As_2 = 60$			Ev_1 to Ac_1: $Nv_1 \to n_3 \to n_2 \to n_{10} \to n_{21} \to Nc_1$	31.2925
		$As_3 = 80$			Ev_2 to Ac_2: $Nv_2 \to n_8 \to n_7 \to n_{18} \to n_6 \to Nc_2$	31.9124
	Accident severity	$As_4 = 40$			Ev_4 to Ac_7: $Nv_4 \to n_{17} \to n_{31} \to n_{47} \to Nc_7$	19.4956
		$As_5 = 40$			Ev_5 to Ac_4: $Nv_5 \to n_{29} \to n_{15} \to n_{16} \to Nc_4$	19.8843
		$As_6 = 60$			Ev_6 to Ac_3: $Nv_6 \to n_{25} \to n_{26} \to n_{27} \to Nc_3$	26.3079
		$As_7 = 40$			Ev_7 to Ac_7: $Nv_7 \to n_{31} \to n_{47} \to Nc_7$	12.3566
		$Na_1 = 1$	SFLA	1,2,0,7,4,3,7,5,2,6,3,0,6,5,5	Ev_8 to Ac_5: $Nv_8 \to n_{32} \to n_{18} \to n_6 \to n_1 \to n_9 \to Nc_5$	40.7481
		$Na_2 = 2$			Ev_9 to Ac_2: $Nv_9 \to n_{33} \to n_{32} \to n_{18} \to n_6 \to Nc_2$	33.6324
		$Na_3 = 2$			Ev_{10} to Ac_6: $Nv_{10} \to n_{13} \to n_{24} \to n_{38} \to Nc_6$	24.0304
	Accident demand	$Na_4 = 1$			Ev_{11} to Ac_3: $Nv_{11} \to n_{29} \to n_{28} \to n_{27} \to Nc_3$	21.9920
		$Na_5 = 2$			Ev_{13} to Ac_6: $Nv_{13} \to n_{28} \to n_{42} \to n_{41} \to n_{40} \to n_{39} \to n_{38} \to Nc_6$	37.1084
		$Na_6 = 2$			Ev_{14} to Ac_5: $Nv_{14} \to n_{10} \to n_9 \to Nc_5$	13.8316
		$Na_7 = 1$			Ev_{15} to Ac_5: $Nv_{15} \to n_{32} \to n_{18} \to n_6 \to n_1 \to n_9 \to Nc_5$	41.7501

Example no.	The total number of feasible solutions	Algorithm	Objective function value	The average evolution time (s)	Success rate (%) in ten runs
I	4^8	ISFLA	7987	2.723	100
		SFLA	7987	2.809	30
II	5^{10}	ISFLA	8113	15.643	100
		SFLA	9179	5.324	0
III	6^{12}	ISFLA	10247	25.534	100
		SFLA	13824	25.163	0
IV	7^{14}	ISFLA	12061	97.333	100
		SFLA	18097	51.567	0
V	8^{15}	ISFLA	12947	144.199	100
		SFLA	40149	101.786	0

TABLE 10: The shortest travel time of the illustrative examples based on the prediction link travel speed.

Vehicle no.	Example no.	Prediction error (km/h)	Accident no. 1	2	3	4
1	I	0	31.2925	38.9665	54.9495	--
		±3	31.2737	38.5534	54.9460	--
		±5	32.1368	38.4649	55.5341	--
		±10	31.5763	42.7993	50.3388	--
	II	0	31.2925	38.9665	54.9495	54.2331
		±3	31.2737	38.5534	54.9460	53.9916
		±5	32.1368	38.4649	55.5341	53.4761
		±10	31.5763	42.7993	50.3388	∞
2	I	0	22.1482	31.9124	∞	--
		±3	20.8670	32.3468	∞	--
		±5	23.1840	31.3765	∞	--
		±10	18.3767	32.2828	∞	--
	II	0	22.1482	31.9124	∞	28.8721
		±3	20.8670	32.3468	∞	28.8694
		±5	23.1840	31.3765	∞	30.9670
		±10	18.3767	32.2828	∞	26.4442
3	I	0	48.3611	47.2027	33.8637	--
		±3	46.8840	47.3166	33.7495	--
		±5	46.8704	47.2581	33.8035	--
		±10	46.4381	52.2131	33.2153	--
	II	0	48.3611	47.2027	33.8637	59.0018
		±3	46.8840	47.3166	33.7495	59.8245
		±5	46.8704	47.2581	33.8035	∞
		±10	46.4381	52.2131	33.2153	58.7999
4	I	0	41.0760	16.3454	53.4742	--
		±3	41.2953	16.4075	54.8336	--
		±5	41.6761	16.6789	52.0917	--
		±10	40.3378	17.3145	53.4260	--
	II	0	41.0760	16.3454	∞	10.1881
		±3	41.2953	16.4075	∞	10.5117
		±5	41.6761	16.6789	∞	9.5027
		±10	40.3378	17.3145	∞	9.6885
5	I	0	49.9989	25.1126	38.7917	--
		±3	49.5269	25.4762	38.9094	--
		±5	50.8201	24.7458	38.8310	--
		±10	50.8567	28.2398	38.5163	--
	II	0	49.9989	25.1126	38.7917	19.8843
		±3	49.5269	25.4762	38.9094	19.9819
		±5	50.8201	24.7458	38.8310	18.5017
		±10	50.8567	28.2398	38.5163	22.5535
6	I	0	44.4116	∞	26.3079	--
		±3	43.5208	51.2845	25.8029	--
		±5	47.1051	51.4706	25.4729	--
		±10	50.1697	54.9481	31.6198	--
	II	0	44.4116	∞	26.3079	∞
		±3	43.5208	51.2845	25.8029	59.7672
		±5	47.1051	51.4706	25.4729	∞
		±10	50.1697	54.9481	31.6198	∞

Table 10: Continued.

Vehicle no.	Example no.	Prediction error (km/h)	Accident no.			
			1	2	3	4
7	I	0	43.6867	23.4594	56.5536	--
		±3	43.8486	23.8514	56.9816	--
		±5	42.8287	22.6855	53.4435	--
		±10	42.4865	24.9977	55.1983	--
	II	0	43.6867	23.4594	56.5536	14.4705
		±3	43.8486	23.8514	56.9816	14.7354
		±5	42.8287	22.6855	53.4435	13.9424
		±10	42.4865	24.9977	55.1983	13.5972
8	I	0	42.6146	21.7823	∞	--
		±3	42.7782	21.8997	∞	--
		±5	42.5819	21.8541	∞	--
		±10	40.9011	26.2546	∞	--
	II	0	42.6146	21.7823	∞	21.3312
		±3	42.7782	21.8997	∞	21.5001
		±5	42.5819	21.8541	∞	20.9878
		±10	40.9011	26.2546	∞	22.7096
9	II	0	37.8754	33.6324	∞	30.5210
		±3	37.3625	33.4413	∞	29.9943
		±5	39.1213	34.4820	∞	31.7022
		±10	37.5274	35.6110	∞	29.7247
10	II	0	42.3397	40.7709	28.2020	52.5731
		±3	40.9388	40.6356	28.5534	53.1496
		±5	42.4467	40.9227	28.6415	55.0761
		±10	41.3142	41.4190	26.8230	51.2051

real-time link travel speed, the dynamic emergency vehicle dispatching model and the improved SFLA were used to calculate the global optimal dispatching strategy. Third, a scene in which a new accident happened on the rescue path was simulated, and the dispatching strategy was adjusted. The results show the following: (1) The emergency vehicle dispatching model can obtain the optimal dispatching strategy under the constraints of accident demands and time windows. (2) For solving the complicated emergency vehicle selection problem, the improved SFLA has stronger search ability compared with the SFLA and can obtain more optimal dispatching strategy. (3) The optimal strategy obtained by the emergency vehicle dispatching model based on the prediction link travel speed takes into account the dynamic changes in the road conditions during the whole dispatching process. (4) The dynamic adjustment condition can timely respond to sudden changes in the road conditions and help emergency vehicles to avoid rescue delay.

Symbols

N: The expressway network node set
$n_i, i = 1, 2, \ldots, M$: The ith expressway network node
M: The total number of nodes in the expressway network
E: The road section set of the expressway network
$(n_i, n_j) \in E$: The road section form the node n_i to the node n_j
Q: The interested time horizon
$T_{ij}(t)$: The link travel time function defined in time horizon Q. It represents a time for the emergency vehicle, leaving at an instant t, from node n_i to n_j
$T(t)$: The link travel time function set
κ: The minimum time interval
t_0: The initial dispatching decision-making instant
$t_\phi, \phi = 0, 1, \ldots, \Phi$: The start time of the ϕth time interval
t_Φ: The last instant of the interested time horizon
$v_{ij}(t)$: The link travel speed function of the road section (n_i, n_j) at the instant t
$v_{ij}^1(t_0)$: The real-time link travel speed of the road section (n_i, n_j) at the instant t_0
$v_{ij}^2(\phi)_{t_0}$: The prediction travel speed at the instant t_ϕ calculated according to $v_{ij}^1(t_0)$

Table 11: The shortest travel time path of the illustrative examples based on the prediction link travel speed.

Vehicle no.	Example no.	Prediction error (km/h)	Accident no. 1	Accident no. 2	Accident no. 3	Accident no. 4
1	I	0	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	--
		±3	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	--
		±5	3, 12, 11, 22, 21	3, 2, 1, 6	3, 12, 13, 14, 27	--
		±10	3, 12, 11, 22, 21	3, 2, 1, 6	3, 12, 13, 14, 27	--
	II	0	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	3, 2, 1, 6, 18, 17, 16
		±3	3, 2, 10, 21	3, 2, 1, 6	3, 12, 13, 14, 27	3, 2, 1, 6, 18, 17, 16
		±5	3, 12, 11, 22, 21	3, 2, 1, 6	3, 12, 13, 14, 27	3, 2, 1, 6, 18, 17, 16
		±10	3, 12, 11, 22, 21	3, 2, 1, 6	3, 12, 13, 14, 27	BL
2	I	0	8, 9, 20, 21	8, 7, 18, 6	BL	--
		±3	8, 9, 20, 21	8, 7, 18, 6	BL	--
		±5	8, 9, 20, 21	8, 7, 1, 6	BL	--
		±10	8, 9, 20, 21	8, 7, 18, 6	BL	--
	II	0	8, 9, 20, 21	8, 7, 18, 6	BL	8, 7, 18, 17, 16
		±3	8, 9, 20, 21	8, 7, 18, 6	BL	8, 7, 18, 17, 16
		±5	8, 9, 20, 21	8, 7, 1, 6	BL	8, 7, 18, 17, 16
		±10	8, 9, 20, 21	8, 7, 18, 6	BL	8, 7, 18, 17, 16
3	I	0	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	--
		±3	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	--
		±5	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	--
		±10	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	--
	II	0	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16
		±3	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16
		±5	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	BL
		±10	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 14, 15, 16
4	I	0	17, 18, 6, 1, 2, 10, 21	17, 18, 6	17, 16, 15, 14, 27	--
		±3	17, 18, 6, 1, 2, 10, 21	17, 18, 6	17, 16, 15, 14, 27	--
		±5	17, 18, 7, 8, 19, 20, 21	17, 18, 6	17, 16, 15, 14, 27	--
		±10	17, 18, 6, 1, 2, 10, 21	17, 18, 6	17, 16, 15, 14, 27	--
	II	0	17, 18, 6, 1, 2, 10, 21	17, 18, 6	BL	17, 16
		±3	17, 18, 6, 1, 2, 10, 21	17, 18, 6	BL	17, 16
		±5	17, 18, 7, 8, 19, 20, 21	17, 18, 6	BL	17, 16
		±10	17, 18, 6, 1, 2, 10, 21	17, 18, 6	BL	17, 16
5	I	0	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	--
		±3	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	--
		±5	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	--
		±10	29, 15, 5, 6, 1, 9, 20, 21	29, 15, 5, 6	29, 28, 27	--
	II	0	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	29, 15, 16
		±3	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	29, 15, 16
		±5	29, 15, 5, 6, 1, 2, 10, 21	29, 15, 5, 6	29, 28, 27	29, 15, 16
		±10	29, 15, 5, 6, 1, 9, 20, 21	29, 15, 5, 6	29, 28, 27	29, 30, 16
6	I	0	25, 24, 23, 22, 21	BL	25, 26, 27	--
		±3	25, 24, 23, 22, 21	25, 24, 13, 4, 5, 6	25, 26, 27	--
		±5	25, 24, 23, 22, 21	25, 24, 13, 4, 5, 6	25, 26, 27	--
		±10	25, 24, 23, 22, 21	25, 24, 13, 4, 5, 6	25, 26, 27	--
	II	0	25, 24, 23, 22, 21	BL	25, 26, 27	BL
		±3	25, 24, 23, 22, 21	25, 24, 13, 4, 5, 6	25, 26, 27	25, 24, 13, 4, 5, 15, 16
		±5	25, 24, 23, 22, 21	25, 24, 13, 4, 5, 6	25, 26, 27	BL
		±10	25, 24, 23, 22, 21	25, 24, 13, 4, 5, 6	25, 26, 27	BL

Table 11: Continued.

Vehicle no.	Example no.	Prediction error (km/h)	Accident no. 1	2	3	4
7	I	0	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	--
		±3	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	--
		±5	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	--
		±10	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 43, 42, 41, 27	--
	II	0	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	31, 30, 16
		±3	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	31, 30, 16
		±5	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 28, 27	31, 30, 16
		±10	31, 32, 33, 19, 20, 21	31, 17, 18, 6	31, 30, 29, 43, 42, 41, 27	31, 30, 16
8	I	0	32, 33, 19, 20, 21	32, 18, 6	BL	--
		±3	32, 33, 19, 20, 21	32, 18, 6	BL	--
		±5	32, 33, 19, 20, 21	32, 18, 6	BL	--
		±10	32, 33, 19, 20, 21	32, 18, 6	BL	--
	II	0	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16
		±3	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16
		±5	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16
		±10	32, 33, 19, 20, 21	32, 18, 6	BL	32, 18, 17, 16
9	II	0	33, 19, 20, 21	33, 32, 18, 6	BL	33, 32, 18, 17, 16
		±3	33, 19, 20, 21	33, 32, 18, 6	BL	33, 32, 18, 17, 16
		±5	33, 19, 20, 21	33, 32, 18, 6	BL	33, 32, 31, 30, 16
		±10	33, 19, 20, 21	33, 32, 18, 6	BL	33, 32, 18, 17, 16
10	II	0	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16
		±3	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16
		±5	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 4, 5, 15, 16
		±10	13, 12, 11, 22, 21	13, 4, 5, 6	13, 14, 27	13, 14, 15, 16

Note. BL means that the travel time of the optimal path exceeds the upper limit of the time window.

$v_{ij}(t)_{t_0}$: The polygonal-shaped travel speed function at the instant t_0
Ls_{ij}: The length of the road section (n_i, n_j)
$U(t)$: The total number of accidents at the instant t
$AC(t)$: The accident set at the instant t
$Ac_u(t) \in AC(t)$, $u = 1, 2, \ldots, U(t)$: The uth accident at the instant t
$(n_0^u, n_1^u) \in E$: The road section where the accident $Ac_u(t)$ occurred at the instant t
$Nc_u(t)$: The location node of the accident $Ac_u(t)$
$T_{\max}^u(t)$: The upper limit of rescue time window of the accident $Ac_u(t)$
$Na_u(t)$: The required number of emergency vehicles for the accident $Ac_u(t)$
$As_u(t)$: The severity of the accident $Ac_u(t)$
$EV(t)$: The emergency vehicle set at the instant t
$Ev_l(t) \in EV(t)$, $l = 1, 2, \ldots, L(t)$: The lth emergency vehicle at the instant t
$L(t)$: The total number of emergency vehicles at the instant t
$(n_0^l, n_1^l) \in E$: The road section where the emergency vehicle $Ev_l(t)$ is located
$Nv_l(t)$: The location node of the emergency vehicle $Ev_l(t)$
$P_{lu}(t)$: When the emergency vehicle $Ev_l(t) \in EV(t)$ starts traveling at an instant t, the shortest time path to the accident $Ac_u(t) \in AC(t)$
$T_{lu}(t)$: The travel time of the shortest time path $P_{lu}(t)$ at the instant t
t_φ: The φth decision instant
$x_{lu}(t_\varphi)$: The decision variable; at the decision-making instant t_φ, if the emergency vehicle Ev_l, $l = 1, 2, \ldots, L$, is dispatched to the accident Ac_u, $u = 1, 2, \ldots, U$, then $x_{lu}(t_\varphi) = 1$; otherwise, $x_{lu}(t_\varphi) = 0$
$z_u(t_\varphi)$: The decision variable; at the decision-making instant t_φ, if the latest rescue time for accident Ac_u, $u = 1, 2, \ldots, U$ exceeds the upper limit of rescue time window, then $z_u(t_\varphi) = 1$; otherwise, $z_u(t_\varphi) = 0$
M: A huge constant
$AC^1(t_\varphi)$: The accident set includes new accidents that happened at t_φ and the accidents whose rescue paths at $t_{\varphi-1}$ are affected by new accidents

Table 12: Optimal emergency vehicle dispatching strategy of the illustrative examples based on the prediction link travel speed.

Example no.	Prediction error (km/h)	The optimal solution	Objective function value based on the prediction travel speed	Objective function value based on the real travel speed
I	0	0, 1, 3, 2, 0, 3, 0, 2	--	7987
	±3	0, 1, 3, 2, 0, 3, 0, 2	7897	7987
	±5	0, 1, 3, 2, 0, 3, 0, 2	7981	7987
	±10	0, 1, 3, 2, 0, 3, 2, 0	8461	8088
II	0	0, 1, 0, 2, 0, 3, 4, 2, 0, 3	8113	8113
	±3	0, 1, 0, 2, 0, 3, 4, 2, 0, 3	8071	8113
	±5	0, 1, 0, 2, 0, 3, 4, 2, 0, 3	8126	8113
	±10	0, 1, 0, 2, 0, 3, 4, 2, 0, 3	8569	8113
Example no.	Prediction error (km/h)	Optimal emergency vehicle dispatching strategy	Prediction travel time (min)	Real travel time (min)
I	0	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	--	22.1482
		Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	--	16.3454
		Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	--	21.7823
		Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	--	33.8637
		Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	--	26.3079
	±3	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	20.8670	22.1482
		Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.4075	16.3454
		Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.8997	21.7823
		Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	33.7495	33.8637
		Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	25.8029	26.3079
	±5	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	23.1840	22.1482
		Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.6789	16.3454
		Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.8541	21.7823
		Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	33.8035	33.8637
		Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	25.4729	26.3079
	±10	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	18.3767	22.1482
		Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	17.3145	16.3454
		Ev_7 to Ac_2: $Nv_7 \rightarrow n_{31} \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	24.9977	23.4594
		Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	33.2153	33.8637
		Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	31.6198	26.3079

TABLE 12: Continued.

II	0	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	--	22.1482
		Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	--	16.3454
		Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	--	21.7823
		Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	--	26.3079
		Ev_{10} to Ac_3: $Nv_{10} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	--	28.2020
		Ev_7 to Ac_4: $Nv_7 \rightarrow n_{31} \rightarrow n_{30} \rightarrow n_{16} \rightarrow Nc_4$	--	14.4705
	±3	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	20.8670	22.1482
		Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.4075	16.3454
		Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.8997	21.7823
		Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	25.8029	26.3079
		Ev_{10} to Ac_3: $Nv_{10} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	28.5534	28.2020
		Ev_7 to Ac_4: $Nv_7 \rightarrow n_{31} \rightarrow n_{30} \rightarrow n_{16} \rightarrow Nc_4$	14.7354	14.4705
	±5	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	23.1840	22.1482
		Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	16.6789	16.3454
		Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	21.8541	21.7823
		Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	25.4729	26.3079
		Ev_{10} to Ac_3: $Nv_{10} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	28.6415	28.2020
		Ev_7 to Ac_4: $Nv_7 \rightarrow n_{31} \rightarrow n_{30} \rightarrow n_{16} \rightarrow Nc_4$	13.9424	14.4705
	±10	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$	18.3767	22.1482
		Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	17.3145	16.3454
		Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$	26.2546	21.7823
		Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$	31.6198	26.3079
		Ev_{10} to Ac_3: $Nv_{10} \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$	26.8230	28.2020
		Ev_7 to Ac_4: $Nv_7 \rightarrow n_{31} \rightarrow n_{30} \rightarrow n_{16} \rightarrow Nc_4$	13.5972	14.4705

Table 13: Dynamic emergency vehicle dispatching process.

Decision making instant	Vehicle no.	Road section of vehicle	Location of vehicle	The optimal solution	Optimal emergency vehicle dispatching strategy
9:30	1	(n_2, n_3)	$L_{2,55} = L_{55,3}$	0,1,3,2,0,3,0,2	Ev_2 to Ac_1: $Nv_2 \rightarrow n_8 \rightarrow n_9 \rightarrow n_{20} \rightarrow n_{21} \rightarrow Nc_1$ Ev_4 to Ac_2: $Nv_4 \rightarrow n_{17} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$ Ev_8 to Ac_2: $Nv_8 \rightarrow n_{32} \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$ Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow n_{27} \rightarrow Nc_3$ Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$
	2	(n_9, n_8)	$L_{9,56} = L_{56,8}$		
	3	(n_{12}, n_{13})	$L_{12,57} = L_{57,13}$		
	4	(n_{18}, n_{17})	$L_{18,58} = L_{58,17}$		
	5	(n_{15}, n_{29})	$L_{15,59} = L_{59,29}$		
	6	(n_{39}, n_{25})	$L_{39,60} = L_{60,25}$		
	7	(n_{30}, n_{31})	$L_{30,61} = L_{61,31}$		
	8	(n_{33}, n_{32})	$L_{33,62} = L_{62,32}$		
9:35	1	(n_2, n_3)	$L_{2,55} = L_{55,3}$	1,4,3,2,0,3,0,2	Ev_1 to Ac_1: $Nv_1 \rightarrow n_3 \rightarrow n_2 \rightarrow n_{10} \rightarrow n_{21} \rightarrow Nc_1$ Ev_4 to Ac_2: $Nv_4 \rightarrow n_6 \rightarrow Nc_2$ Ev_8 to Ac_2: $Nv_8 \rightarrow n_{18} \rightarrow n_6 \rightarrow Nc_2$ Ev_3 to Ac_3: $Nv_3 \rightarrow n_{13} \rightarrow n_{14} \rightarrow Nc_3$ Ev_6 to Ac_3: $Nv_6 \rightarrow n_{25} \rightarrow n_{26} \rightarrow n_{27} \rightarrow Nc_3$ Ev_2 to Ac_4: $Nv_2 \rightarrow n_9 \rightarrow Nc_4$
	2	(n_8, n_9)	$L_{8,56} = 0.12 \times L_{8,9}$ $L_{56,9} = 0.88 \times L_{8,9}$		
	3	(n_{12}, n_{13})	$L_{12,57} = 0.77 \times L_{12,13}$ $L_{57,13} = 0.23 \times L_{12,13}$		
	4	(n_{18}, n_6)	$L_{18,58} = 0.10 \times L_{18,6}$ $L_{58,6} = 0.90 \times L_{18,6}$		
	5	(n_{15}, n_{29})	$L_{15,59} = L_{59,29}$		
	6	n_{25}	n_{25}		
	7	(n_{30}, n_{31})	$L_{30,61} = L_{61,31}$		
	8	(n_{32}, n_{18})	$L_{32,62} = 0.16 \times L_{32,18}$ $L_{62,18} = 0.84 \times L_{32,18}$		

$t^u_{\max}(t_\varphi)$: The latest rescue time of the accident $Ac_u(t_\varphi)$
$xx_l(t_\varphi)$: The decision variable; at the decision-making instant t_φ, if the emergency vehicle Ev_l, $l = 1, 2, \ldots, L$ is in the idle state, then $xx_l(t_\varphi) = 1$; otherwise, $xx_l(t_\varphi) = 0$
$T_{i,i+1}(t_i)_{t_\varphi}$: The link travel time function at the decision-making instant t_φ. It represents a time for the emergency vehicle, leaving at an instant t_i, from node n_i to n_{i+1}
H: The total number of frogs
IP: The frog population
$X_h = [x_{h1}, x_{h2}, \ldots, x_{hd}, \ldots, x_{hD}]$, $h = 1, \ldots, H$: The position of the hth frog
D: The dimension of the optimization problem
f: The performance function of the optimization problem
$Px = [px_1, px_2, \ldots, px_d, \ldots, px_D]$: The position of the optimal frog in the population IP
a: The total number of memeplexes
c: The total number of frogs in each memeplex
It: The total number of iterations within each memeplex
$Pb = [pb_1, pb_2, \ldots, pb_d, \ldots, pb_D]$: The position of the best frog in the memeplex
$Pw = [pw_1, pw_2, \ldots, pw_d, \ldots, pw_D]$: The position of the worst frog in the memeplex
$Ds_d, d = 1, 2, \ldots, D$: The adjustment of the dth decision variable
$r \in [0, 1]$: A random number
$D^{\max}_d$: The maximum adjustment of the dth decision variable
pw'_d: The renewed position of the dth decision variable
$Z^{\max}_d$: The upper limits of the position of the dth decision variable
$Z^{\min}_d$: The lower limits of the position of the dth decision variable
IT: The total number of global iterations
$x_l(t_\varphi)$: The coding of the decision variable $x_{lu}(t_\varphi)$; it represents the dispatching strategy of $Ev_l(t_\varphi)$, $l = 1, 2, \ldots, L$, at decision-making instant t_φ
$B_{U\times L}$: The probability distribution matrix of the frog population
$b_{u\times l} \in [0, 1]$: The element of the matrix $B_{U\times L}$; it represents the probability that the lth decision variable $x_l(t_\varphi)$ is valued as u
θ: The forgetting factor.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

This work is supported by Funding for Scientific Research Startup of North China University of Technology.

References

[1] T. Yamada, "A network flow approach to a city emergency evacuation planning," *International Journal of Systems Science*, vol. 27, no. 10, pp. 931–936, 1996.

[2] G. M. Carter, J. M. Chaiken, and E. Ignall, "Response areas for two emergency units," *Operations Research*, vol. 20, pp. 571–594, 1972.

[3] H. D. Sherali and S. Subramanian, "Opportunity cost-based models for traffic incident response problems," *Journal of Transportation Engineering*, vol. 125, no. 3, pp. 176–185, 1999.

[4] K. Ozbay, C. Iyigun, M. Baykal-Gursoy, and W. Xiao, "Probabilistic programming models for traffic incident management operations planning," *Annals of Operations Research*, pp. 1–18, 2012.

[5] X. Song, J. Wang, and C. Chang, "Nonlinear continuous consumption emergency material dispatching problem," *Systems Engineering*, vol. 32, no. 2, pp. 163–176, 2017.

[6] W. Tang, L. Zou, and Q. Guo, "Grey multi-objective programming for materials dispatching from multiple supply points to multiple demand points," *Open Journal of Safety Science and Technology*, vol. 12, no. 11, pp. 148–152, 2016.

[7] J. Liu and K. Xie, "Emergency materials transportation model in disasters based on dynamic programming and ant colony optimization," *Kybernetes*, vol. 46, no. 4, pp. 656–671, 2017.

[8] X.-H. Li and Q.-M. Tan, "Particle swarm optimization algorithm for emergency resources dispatch scheduling," *Recent Patents on Mechanical Engineering*, vol. 7, no. 3, pp. 237–240, 2014.

[9] J. Liu, L. Guo, and J. Jiang, "Emergency material allocation and scheduling for the application to chemical contingency spills under multiple scenarios," *Environmental Science Pollution Research*, vol. 24, no. 1, p. 13, 2017.

[10] K. G. Zografos, K. N. Androutsopoulos, and G. M. Vasilakis, "A real-time decision support system for roadway network incident response logistics," *Transportation Research Part C: Emerging Technologies*, vol. 10, no. 1, pp. 1–18, 2002.

[11] A. Haghani, Q. Tian, and H. Hu, "Simulation model for real-time emergency vehicle dispatching and routing," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 1882, pp. 176–183, 2004.

[12] B. Dan, W. Zhu, H. Li, Y. Sang, and Y. Liu, "Dynamic optimization model and algorithm design for emergency materials dispatch," *Mathematical Problems in Engineering*, vol. 2013, Article ID 841458, 2013.

[13] S. Yang, M. Hamedi, and A. Haghani, "Online dispatching and routing model for emergency vehicles with area coverage constraints," *Transportation Research Record*, no. 1923, pp. 1–8, 2005.

[14] B. Fu, D. G. Li, and M. K. Wang, "Review and prospect on research of cloud model," *Application Research of Computers*, vol. 28, no. 2, pp. 420–426, 2011.

[15] K. L. Cooke and E. Halsey, "The shortest route through a network with time-dependent internodal transit times," *Journal of Mathematical Analysis and Applications*, vol. 14, pp. 493–498, 1966.

[16] D. E. Kaufman and R. L. Smith, "Minimum travel time paths in dynamic networks with application to intelligent vehicle/highway systems," *IVHS Journal*, vol. 1, no. 1, pp. 1–19, 1993.

[17] M. Setak, M. Habibi, H. Karimi, and M. Abedzadeh, "A time-dependent vehicle routing problem in multigraph with FIFO property," *Journal of Manufacturing Systems*, vol. 35, pp. 37–45, 2015.

[18] X.-H. Duan, J.-D. Zhao, and S.-X. Song, "Dynamic shortest paths of emergency vehicles in expressway network based on shuffled frog leaping algorithm," *Journal of Transportation Systems Engineering and Information Technology*, vol. 16, no. 3, pp. 181–186, 2016.

[19] S. Ichoua, M. Gendreau, and J. Potvin, "Vehicle dispatching with time-dependent travel times," *European Journal of Operational Research*, vol. 144, no. 2, pp. 379–396, 2003.

[20] Y. Yuan and D. Wang, "Path selection model and algorithm for emergency logistics management," *Computers & Industrial Engineering*, vol. 56, no. 3, pp. 1081–1094, 2009.

[21] Y. Zhou, J. Liu, Y. Zhang, and X. Gan, "A multi-objective evolutionary algorithm for multi-period dynamic emergency resource scheduling problems," *Transportation Research Part E: Logistics and Transportation Review*, vol. 99, pp. 77–95, 2017.

[22] Y. Zhou and J. Liu, "A multi-agent genetic algorithm for multi-period emergency resource scheduling problems in uncertain traffic network," in *Proceedings of the 2017 IEEE Congress on Evolutionary Computation, CEC 2017*, pp. 43–50, Spain, June 2017.

[23] M. M. Eusuff and K. E. Lansey, "Optimization of water distribution network design using the shuffled frog leaping algorithm," *Journal of Water Resources Planning and Management*, vol. 129, no. 3, pp. 210–225, 2003.

[24] M. Eusuff, K. Lansey, and F. Pasha, "Shuffled frog-leaping algorithm: a memetic meta-heuristic for discrete optimization," *Engineering Optimization*, vol. 38, no. 2, pp. 129–154, 2006.

[25] H. Amirian and R. Sahraeian, "Solving a grey project selection scheduling using a simulated shuffled frog leaping algorithm," *Computers & Industrial Engineering*, vol. 107, pp. 141–149, 2017.

[26] D. Lei and X. Guo, "A shuffled frog-leaping algorithm for job shop scheduling with outsourcing options," *International Journal of Production Research*, vol. 54, no. 16, pp. 4793–4804, 2016.

[27] D. Lei, Y. Zheng, and X. Guo, "A shuffled frog-leaping algorithm for flexible job shop scheduling with the consideration of energy consumption," *International Journal of Production Research*, vol. 55, no. 11, pp. 3126–3140, 2016.

[28] D. Lei and X. Guo, "A shuffled frog-leaping algorithm for hybrid flow shop scheduling with two agents," *Expert Systems with Applications*, vol. 42, no. 23, pp. 9333–9339, 2015.

[29] B. Ning, Q. Gu, and Y. Wang, "Research based on effective resource allocation of improved SFLA in cloud computing," *International Journal of Grid and Distributed Computing*, vol. 9, no. 3, pp. 191–198, 2016.

[30] X. Duan, S. Song, and J. Zhao, "Emergency vehicle dispatching and redistribution in highway network based on bilevel programming," *Mathematical Problems in Engineering*, vol. 2015, Article ID 731492, pp. 1–12, 2015.

[31] T. Xu, *Study on Dynamic Prediction of Road Operating Speed Based on Floating Car Data*, Chongqing Jiaotong University, 2017.

[32] J. Weng, J. Rong, F. Ren et al., "Non-parametric regression model based short-term prediction for expressway travel speed," *Journal of Highway Transportation Research and Development*, vol. 24, no. 3, pp. 93–97, 2007.