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Dynamic Traffic Allocation Model Considering the Effects of Vehicle Emission Diffusion

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ABSTRACT

Vehicle exhausts diffuse into roadside crowd breathing zones, thereby jeopardising human health. This study applies dynamic traffic distribution theories to comprehensively consider the impact of vehicle emission diffusion. The results provide a theoretical basis for improving the diffusion of urban traffic pollution to benefit the surrounding environment for roadside crowds. Firstly, a multi-vehicle cellular transport model that is suitable for analysing dynamic traffic distribution is constructed considering the distinct emission factors of various types of vehicles. Secondly, a multi-vehicle emission model is established to consider a range of driving conditions. Then, the concept of roadside crowd exposure risk is introduced, and we describe a method for calculating the total amounts of pollutants emitted by vehicles and inhaled by roadside crowds. The impact of vehicle emission diffusion is comprehensively discussed in terms of vehicle emissions and roadside crowd exposure risk. A generalised impedance function considering the influence of vehicle exhaust emission diffusion is also established based on the weighted average of actual vehicle travel time, multi-model emissions and roadside crowd exposure risk. Finally, this generalised impedance function is integrated into the dynamic optimal user allocation model, and a dynamic traffic allocation model considering the influence of vehicle emission control is developed.

KEYWORDS

vehicle emission; emission diffusion effect; generalised impedance; dynamic traffic allocation.

1. INTRODUCTION

In contrast to other prominent pollution sources, vehicle exhaust pollution increases the pollution of the entire atmospheric environment even after the diffusion of pollutants, and as a result it directly affects the health of roadside people (e.g. causing chest tightness and sore throat). Research has demonstrated that the closer the main traffic line to children's housing, the higher the probability that they will develop respiratory diseases [1]. Unlike residents, roadside pedestrians or non-motorised road users are not protected by any shielding and are therefore completely exposed to the emitted pollutants, leading to greater health risks. With recent efforts aimed at environmentally sustainable development, it has become crucial to reduce vehicle pollutant emissions and their impact on the health of roadside people.

Two methods are commonly used to control the impact of vehicle exhaust emissions on urban road networks. The first approach involves establishing emission standards and controlling the vehicles themselves. For example, limiting the vehicle exhaust pollutant emission threshold promotes the development and implementation of clean vehicle exhaust technology. This strategy can reduce the emissions of some vehicles, although it requires long research periods and high costs. The second approach is to strengthen traffic management (e.g. via traffic guidance or demand management) to promote a reasonable distribution of traffic flow within the region, optimise travel modes and reduce traffic flow conflicts. In general, controlling road sections with high automobile exhaust pollutant emissions can reduce vehicle emissions by directly affecting the number of people using the roads. This strategy can be developed rapidly and is therefore the most practical.

Dynamic traffic flow allocation models can quickly and accurately simulate the traffic flow characteristics of a traffic system while reflecting changes in traffic flow. The present study applied a dynamic traffic flow distribution model to conduct mathematical modelling of urban road network traffic flow. We consider the influence of road segment vehicle emission diffusion by reasonably distributing the time-varying traffic flow across various routes according to specific rules. This enables coordinated road network travel modes, improves urban road congestion, reduces the time travellers spend on the roads and effectively controls the influence of vehicle pollutant emissions. The model developed herein provides a theoretical basis for urban traffic planning and comprehensive management.

2. LITERATURE REVIEW

Scientific traffic distribution management strategies are crucial in urban planning. In particular, dynamic traffic allocation methods represent an effective approach to solving traffic problems impacting intelligent transportation systems. Szeto et al. [2] studied a stochastic dynamic user optimal (DUO) model based on logit, which considered the randomness of node factors and travel time. Anavatti et al. [3] proposed a path-based dynamic traffic allocation model that accounted for the queuing delay between intersections and was facile to implement. Tajtehranifard et al. [4] developed a novel path marginal cost (PMC) approximation algorithm to establish and optimise a quasi-dynamic traffic allocation model for efficient systems based on path costs. Sfab et al. [5] developed a network dynamic traffic allocation model based on traffic, relative trip lengths and regional routes, and they demonstrated that it could sufficiently estimate traffic-affected trip lengths.

Traffic impedance is a complex factor that can be influenced by a single parameter or a combination of multiple parameters, including travel time, safety, road conditions and road environments over a certain path or section of the road network system. Wang and Xu [6] established an improved impedance function based on a long short-term memory (LSTM) neural network to accurately calculate road impedance. To allow for control over vehicle pollutant emissions on the road network according to traffic distribution, Liu et al. [7] established a road resistance network table for identifying nodes in the road network. They relied on an Internet of Vehicles platform to update in real time and then obtained more accurate results based on road resistance, which enabled optimal fuel consumption path planning. Zhang et al. [8] introduced an impedance function considering the total CO_2 control and CO concentration control, which they used to establish a traffic distribution model with low carbon emissions constraints.

Dynamic traffic allocation must account for vehicle emissions, as well as roadside crowd density, to minimise the detrimental impacts of vehicle emissions diffusion. Experts have begun to study generalised impedance functions and traffic distribution theories that consider vehicle emissions. However, such theories typically focus on reducing the total emissions, whereas relatively few studies have investigated the impacts of vehicle emissions on roadside-related activities or discussed dynamic traffic distribution in this context. Therefore, the present work focuses on generalised traffic impedance while considering time costs and effects of vehicle emission diffusion. These factors are analysed and used to develop a dynamic traffic allocation model. Finally, an adaptive ant colony system algorithm is constructed to solve the problem and generate a reasonable flow distribution result considering the objective constraints.

3. GENERALISED ROAD RESISTANCE MODEL

3.1 Emission estimations under different driving conditions

The cell transmission model (CTM) discretises time and road space. The road space is divided into small lattices (cells) of the same nature, such that the length of each cell is equal to the discretised space. A time step is determined based on the vehicle's free-flow velocity in segment space. In the multi-vehicle cellular transmission model, the traffic status in different cells can be obtained at different time intervals through calculations, and the vehicles driving conditions in a given cell can be identified by comparing the vehicle density in that cell with the adjacent downstream cells. *Figure 1* illustrates how to assess the driving conditions of a vehicle in a cell.

Assuming the current cell is i and the downstream cell is $i-1$, the corresponding vehicle densities are denoted as k_i and k_{i-1}. Vehicle density can be determined from the flow-density relationship. To accurately describe non-signal control cells, a flow-density ladder is used (*Figure 1*), where k_c is the critical density and k_{jam} is the blocking density. According to the relationships among k_i, k_{i-1}, k_c and k_{jam}, *Figure 1* is divided into

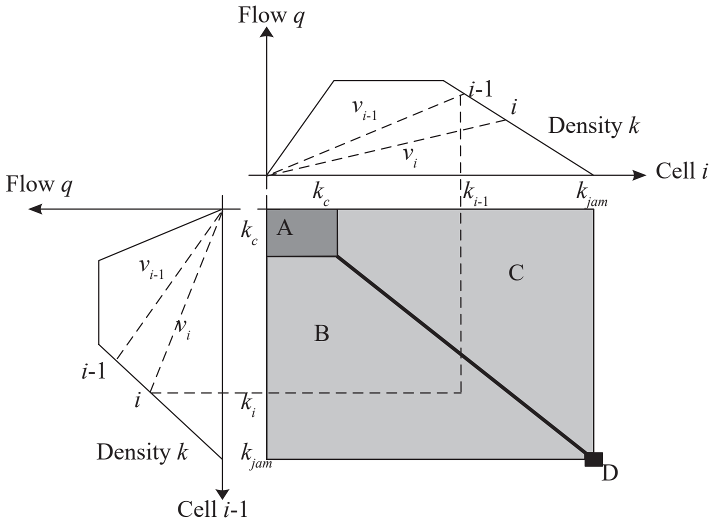


Figure 1 – Driving mode of cell i

four regions: A, B, C and D. Region C represents the acceleration mode, which satisfies $k_i > k_{i-1} > k_c$. Region B represents the deceleration mode, which satisfies $k_i < k_{i-1}$ and $k_c < k_{i-1}$. The two parts of area A and the line segment dividing areas B and C represent the uniform speed mode; area A satisfies $k_{i-1} \leq k_c$ and $k_i \leq k_c$, and the line segment dividing areas B and C satisfies $k_i = k_{i-1} < k_{jam}$. Region D represents the idle mode, which satisfies $k_i = k_{i-1} = k_{jam}$, where the speed of all vehicles is zero.

Table 1 – Pollutant emission rates of different vehicle types [9]

Vehicle model	Driving conditions	NO_x [mg/s]	HC [mg/s]	CO [mg/s]	CO_2 [mg/s]
Light vehicle	Accelerate	7.65	1.26	46.77	1979.09
	Slow down	0.86	0.48	16.73	634.59
	Idle speed	0.21	0.22	3.59	549.77
	Uniform speed	3.67	0.77	24.62	1203.83
Heavy vehicle	Accelerate	253.32	3.85	31.11	3507.87
	Slow down	281.74	2.76	10.29	1087.81
	Idle speed	236.68	1.99	6.76	758.03
	Uniform speed	133.3	2.19	11.29	1989.70

Thus, vehicle driving conditions can be classified as uniform speed, deceleration, acceleration or idle speed. The emission values corresponding to these driving conditions have been described previously by Zhou [9]. Based on values from the literature (*Table 1*), the unit vehicle exhaust emission in cell *i* can be calculated using *Equation 1*:

$$ER_i(t) = \sum_n x_i(t) EF_i^n(t) \tag{1}$$

where $ER_i(t)$ represents the exhaust emissions of the vehicle passing through cell i starting at time t; $x_i(t)$ is the time that the departure vehicle passes through cell i at time t; $EF_i^n(t)$ is the average emission rate (g/veh·s) of the nth pollutant of the vehicle in cell i under different driving conditions, i.e. converted to a standard car under different driving conditions (e.g. acceleration, deceleration) to obtain the average emission rate of the nth pollutant at idle speed and uniform speed.

Then, the emissions per unit vehicle entering a given road section a at time t are determined using *Equation 2*:

$$E_a(t) = \sum_{i=1}^{L} ER_i(t) \tag{2}$$

where L is the number of cells of road segment a.

3.2 Risk assessment of roadside population exposure

Concept of exposure to pollutants

In terms of pollutants emitted by vehicles, exposure mainly refers to the contact between the respiratory system and the environment, e.g. through the mouth and nose. The concept of "dose" is introduced when contamination enters the human body through the respiratory system [10]. The dose refers to the amount of pollutants absorbed by or deposited in the human body over a period of time, and this is equal to the exposure (i.e. the concentration of pollutants emitted by vehicles) multiplied by the population inhalation rate. *Figure 2* shows the process by which a vehicle emits pollutants that affect the human body. This process contains four steps: motor vehicle pollutant emissions, pollutant migration and diffusion, roadside population exposure to pollutants (exposure) and roadside population inhalation of pollutants (dose).

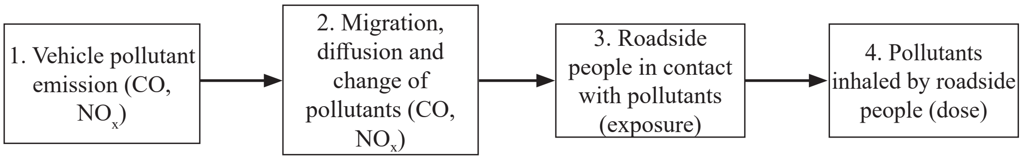


Figure 2 – The process by which exhaust pollutants from motor vehicle emissions reach the human body

Motor vehicle pollutant emissions

Treating motor vehicle emissions as line source pollution, the emission intensity of such road-derived line source pollutants is generally equal to the amount of pollutants emitted per unit time on a fixed length of road. This parameter can be impacted by various emission properties and driving speed, among other factors. The relevant expression is shown in *Equation 3*:

$$G_{an}(t) = \frac{\sum_{m} E_{amn}(t) q_a(t)}{3600} = \frac{\sum_{m} E_{amn}(t) n_{am}(t) S_{am}(t)}{3600 L_a} \tag{3}$$

where $E_{amn}(t)$ represents the emission factor of an m-type vehicle of the nth pollutant on road section a (g/veh·km), see *Table 2*; $n_{an}(t)$ is the number of m-type vehicles passing through section a; $S_{am}(t)$ is the speed of m-type vehicles passing through road segment a.

Table 2 – Relationships between vehicle emission factors and average speed (v)

Vehicle model	Types of pollutants	Motor vehicle emission factor (g/veh·km) [11]
Gasoline-powered sedan (light vehicle)	CO	167.154 - 5.2911v + 0.0662v2 - 0.0003v3
	NO_x	2.0164 - 0.0142v + 0.0001v2 - 5.3×10^{-7}v3
Heavy-duty diesel vehicles (heavy-duty vehicles)	CO	64.5194 - 2.2960v + 0.0319v2 - 0.0001v3
	NO_x	77.3436 - 1.6314v + 0.0179v2 - 3×10^{-5}v3

Pollutant diffusion model

The concentration of pollutants at each roadside point (e.g. at the bottom of a canyon-shaped road section) can be calculated using the canyon-type street pollutant dispersion model (OSPM). The semi-empirical OSPM model was developed in Denmark and serves as a street canyon pollution diffusion model [12]. This approach is primarily suitable for urban roads with dense buildings on both sides, where "street canyons" have been formed. Because of the buildings on both sides of the road section, the influence of street airflow must also be considered when analysing how vehicle emissions are spread and diffused. Therefore, the pollutant concentration of the wth type of pollutant emitted by vehicles and diffused to the roadside involves two aspects: the direct contribution (transported by the wind at the bottom of the canyon) and the circulating contribution (transported by the canyon eddy current). The concentration of the nth pollutant caused by vehicle emissions at any receiving point of road section a can be calculated using *Equation 4*:

$$C_{an}(t) = C_{Dan}(t) + C_{Ran}(t) \tag{4}$$

where $C_{an}(t)$ represents the concentration of pollutants diffused to the roadside; $C_{Dan}(t)$ represents the direct contribution concentration of the nth type of pollutant emitted by vehicles at the receiving point of road section

a; $C_{Ran}(t)$ is the circulating contribution concentration of the nth pollutant at the receiving point of road section a.

Finally, $C_{Dan}(t)$ is the concentration generated directly from diffusion to the receiving point, which can be computed using *Equations 5–12*:

$$C_{Dan}(t)=\sqrt{2/\pi}\frac{G_{an}(t)}{L_a\sigma_w}\left\{\ln\left(\frac{h_0+\sigma_w dl/\mu_b}{h_0}+R\left(1+\frac{\sigma_w f_1}{\mu_b h_0}\right)+\frac{\sigma_w}{\sigma_{wt}}\left[1-\exp\left(-\sigma_{wt}f_2/\left(H\mu_b\right)\right)\right]\right)\right\} \tag{5}$$

$$dl=\min\left[L/\sin\theta,L_r\right] \tag{6}$$

$$L_r=2H\gamma \tag{7}$$

$$f_1=\min\left[\max(L/\sin\theta,L_r\right] \tag{8}$$

$$f_2=\max\left(L/\sin\theta,x_1\right)-x_1 \tag{9}$$

$$x_1=\mu_b\left(H-h_0\right)/\delta_w \tag{10}$$

$$\delta_w=\sqrt{\left(0.1\mu_b\right)^2+0.1^2} \tag{11}$$

$$R=\max\left[0,\cos\left(2\gamma\theta\right)\right] \tag{12}$$

where θ is the angle between the wind direction and the street (°); H is the height of the building (m); L_r is the length of the bottom of the circulation area (m); h_0 is the initial mixing height of vehicle emission pollutants (m); γ is the low wind speed correction factor, which is used to reduce the scope of the circulation area under low wind speed conditions; x is the distance from the pollutant receiving point to the source of the emission line (m).

The concentration of the circulating contribution can be calculated using a simplified box model, i.e. $C_{Ran}(t)$ is calculated using *Equations 13–18*:

$$C_{Ran}(t)=\frac{\left(G_{an}(t)/L_a\right)dl\sin\theta}{\sigma_{wt}d_3+u_d d_4} \tag{13}$$

$$u_d=\sqrt{u_b^2+0.1^2} \tag{14}$$

$$\delta_{wt}=\sqrt{\left(0.1\mu_t\right)^2+0.1^2} \tag{15}$$

$$d_3=\min\left[L/\sin\theta,0.5L_r\right] \tag{16}$$

$$d_4=\max\left[0,\left(dl/0.5L_r-1\right)L_s\right] \tag{17}$$

$$L_s=\sqrt{\left(0.5L_r\right)^2+H^2} \tag{18}$$

where μ_t is the maximum wind speed (m/s); u_d is the convection velocity at the side of the circulation zone (m/s); L_a is the side length of the trapezoidal circulation area (m).

The vertical diffusion of pollutants in canyon-type streets can also be computed, although the spread of vehicular pollutants along buildings in the vertical direction in canyon-type streets is very complex. Liu et al. [13] selected typical canyon-type streets and installed pollutant receivers at various heights to detect the vertical distribution of the CO concentration to study the relationship between concentration and height (i.e. vertical distance). The pollutant concentrations measured at different heights are shown in *Table 3*.

When the height H in the vertical direction is lower than 13 m, the CO concentration changes significantly as H increases. When the height exceeds 13 m, the CO concentration does not change appreciably with height. The exponential fitting function can be expressed as shown in *Equation 19*:

$$C_H=\left\{\begin{matrix} C_{1.5}e^{-0.09752H+0.104532}, H\le 13m \\ 0.312C_{1.5}, H\ge 13m \end{matrix}\right\} \tag{19}$$

where C_H represents the CO concentration at height H in the vertical direction (μg/m^3); $C_{1.5}$ (μg/m^3) is the concentration of CO at a height of 1.5 m.

Incorporating the time factor gives *Equation 20*:

$$C_H = \begin{Bmatrix} C_{1.5}(t)e^{-0.09752H+0.104532}, H \leq 13m \\ 0.312C_{1.5}(t), H \geq 13m \end{Bmatrix} \tag{20}$$

The correlation coefficient can then be obtained by the correlation test using *Equation 21*:

$$r = \frac{I_{XY}}{\sqrt{I_{XX} I_{XY}}} = 0.92 \tag{21}$$

The correlation coefficient equation reveals that the mass concentration of pollutants is correlated with the height of the measurement point, and therefore the experimental results can be approximated by *Equation 20*.

Table 3 – CO concentrations and relational expressions at different heights

Height [m]	CO mass concentration [μg/m^3]	CO concentration at a given height / CO concentration at 1.5 m (i.e., $C/C_{1.5}$)	ln($C/C_{1.5}$) [13]
1.5	277	1.00	0.00
5.0	186	0.67	-0.17
8.5	126	0.45	-0.34
11.5	101	0.36	-0.44
13.0	92	0.33	-0.48
30.0	85	0.31	-0.51
60.0	80	0.29	-0.54

Risk assessment of roadside population exposure

Environmental concentrations can only be used to reflect the concentration of pollutants; however, they cannot indicate the number of people exposed to the pollutants, the frequency of exposure or various other factors. The exposure dose refers to the total quantity of pollutants entering the human body, taking into account factors such as pollutant concentration, exposure time and the number of people exposed; thus, it is more suitable for exposure risk assessments. The exposure dose is also related to the age distribution of the population (i.e. proportions of elderly, young, middle-aged), population respiration rate and time period. The present study focuses on urban road networks, and therefore the OSPM model was selected as the diffusion model. For convenience, two assumptions were made: (i) the respiration rates of different populations remain unchanged, and the pollutants exposure time periods [0,k] were the same; (ii) the roadside population in each period is evenly distributed at the spatial level.

However, there are clear differences in the respiration rates of people of different ages; thus, the population was classified according to their respiration rates. The inhalation dose $D_{a,q}(t)$ of pollutants emitted by vehicles during the period [0,k] was obtained for a given group of people q using *Equation 22*:

$$D_{a,q}(t) = BR_q(x)\int_0^k dx \int_{h_1}^{h_2} P_q(r,x)\gamma C_a(r,x)dr \tag{22}$$

where h_1, h_2 represent the lower and upper limits, respectively, of the height of the crowd (m); $P_q(r,x)$ is the number of people q in the receiving space r during the x period; $BR_q(x)$ is the average respiration rate of population q (m^3/day); $C(r,x)$ is the concentration of pollutants from vehicles in the receiving space r during the x period (μg/m^3); γ is the penetration parameter (i.e. the difference between indoor and outdoor pollutant concentrations), which is generally between 0.1–0.7 [14].

The exposure risk of all people on the roadside is obtained by summing the inhaled doses of different populations $D_a(t)$ according to *Equation 23:*

$$D_a(t) = \sum_1^q Da,q(t) = \sum_1^q BR_q(x)\int_0^k dx \int_{h_1}^{h_2} p_q(r,x)\gamma C_a(r,x)dr \tag{23}$$

3.3 Generalised impedance model

The travel time, total vehicle emission pollution (mainly NO_x, HC, CO and CO_2) and vehicle emissions comprise the total exposure risk (i.e. dose) of roadside people. The corresponding multi-factor weighted generalised impedance model is thus established, as shown in *Equations 24 and 25*

$$F_a(t) = \lambda_1 \xi_a^{rs}(t) + \lambda_2 E_a(t) + \lambda_3 D_a(t) \tag{24}$$

$$\xi_a^{rs}(t) = \frac{\alpha_1 \cdot (t+1-t) + \alpha_2 \cdot (t+2-t) + \ldots + \alpha_m \cdot (t+m-t)}{\alpha_1 + \alpha_2 + \ldots + \alpha_m} = \frac{\alpha_1 + 2\alpha_2 + \ldots + m\alpha_m}{f_\alpha^{rs}(t)} \tag{25}$$

where $E_a(t)$ represents the total pollutant emissions (NO_x, HC, CO and CO_2) on the road section where the vehicle is passing through (μg/m³), see *Equation 2*; $D_a(t)$ is the total amount of pollutants emitted by vehicles and inhaled by roadside people, i.e. risk of exposure of roadside people (μg/m³), see *Equation 23*; λ_1 is the vehicle travel time (weighted); λ_2 is the vehicle pollutant emissions (weighted); λ_3 is the risk of roadside population exposure due to vehicle emissions (weighted).

4. DYNAMIC USER OPTIMAL TRAFFIC ALLOCATION MODEL

Typically, travel time is the dominant factor in a traveller's choice of route. To control the impact of vehicle emissions, travel route selection criteria must consider the risks of travel emissions and roadside crowd exposure. Therefore, the user's travel time + travel emissions + roadside crowd exposure risks were calculated, and transport network analysis was performed with risk as the dominant factor.

The DUO model based on generalised impedance refers to all OD (origin-destination) pairs in the road network, and users with the same travel purpose tend to choose travel paths through non-cooperative travel. Therefore, the generalised travel impedance of different travellers is equal and minimised. The DUO discrete model based on the definition of optimal traffic allocation for dynamic users and considering the influence of vehicle emission diffusion under fixed demand is expressed in *Equations 26–29*:

$$\min_{u,v,x} \eta = \sum_{t=1}^{T} \sum_{\alpha \in A} F_a\left[u_a(t), t\right] = \sum_{t=1}^{T} \sum_{a \in A} \int_0^{v_a(t)} F_a\left[x_a(t), w\right] dw \tag{26}$$

such that,

$$x_a^s(t+1) = x_a^s(t) + u_a^s(t) - v_a^s(t), \forall a, s, t \tag{27}$$

$$a \sum_{a \in A_l} v_a^s(t) + g_l^s(t) = \sum_{a \in B_l} u_a^s(t), \forall l \neq s; s, t \tag{28}$$

$$x_a^s(t) = \sum_{i=t}^{t+\tau_a(t)} v_a^s(i), \forall a, s, t \tag{29}$$

$$x_a^s(t) \geq 0, u_a^s(t) \geq 0, v_a^s(t) \geq 0, \forall a, s, t$$

$$x_a^s(0) = 0, v_a^s(0) = 0, \forall a, s$$

5. EXAMPLE ANALYSIS

5.1 Basic conditions

We selected the classical Nguyen and Dupius (N-D) road network [15] as a construction example to discuss the impact of pollutant emission control in the dynamic traffic distribution model considering vehicle emission diffusion. The N-D road network topology is shown in *Figure 3*. The road network has a total of four OD pairs, namely (1, 2), (1, 3), (4, 2) and (4, 3), including 13 nodes and 25 paths, comprising 5 signal control nodes and 8 non-signal control nodes. The number of research periods was set to 5, where each period is 1 min. In the first five periods, each OD pair has a certain travel demand. The travel demand mainly involves heavy-duty vehicles and small cars (light vehicles), with a ratio of 1:4.

The main road forms in the calculation example include Zhenxing East 1st Road (primarily roadside commercial buildings) and Shawan Road (primarily roadside residential buildings). Both road sections are located in the central area of Chengdu, and the surrounding building density and crowd density are high, so the road can be regarded as a canyon-shaped street. The one-way lanes of the road are all three lanes wide (width = 20 m),

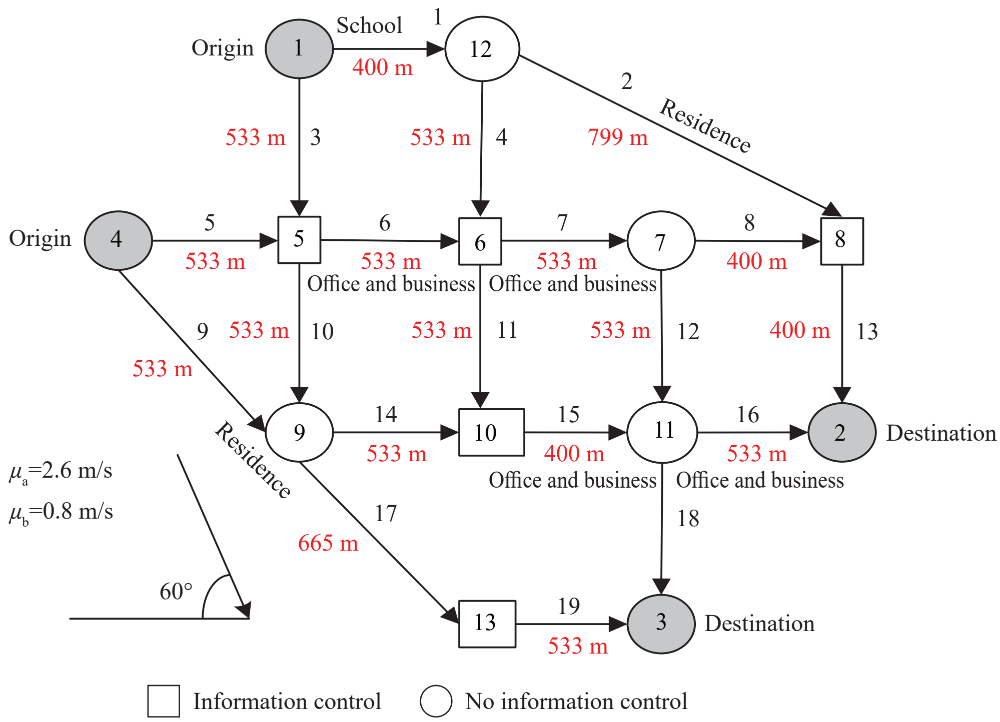


Figure 3 – N-D road network topology

the free-flow speed of the road section is 48 km/h, the single-lane traffic capacity is 1500 pcu/h, and the congestion density is 125 veh/km. There are sidewalks and non-motorised vehicle lanes on the roads as well. The average height of buildings on each side of the road section is 10 stories (where each floor height is 3 m). For this example, the road sections are divided into three categories: office and commercial areas (where population density in roadside buildings decreases during rush hour, and pedestrian traffic increases); residential areas (where population density in roadside buildings increases during rush hour, and pedestrian traffic increases significantly); and mixed office and residential areas (where roadside population density did not change significantly). The emission of vehicles departing within the same time period had a fixed effect on the roadside population. The specific roadside populations density in each area are presented in *Table 4*. The normal breathing rate ranges from 15 to 35 m^3/day. The population is divided into elderly, middle-aged and young people, with proportions of 10%, 60% and 30%, respectively. The corresponding breathing rates are 20, 25 and 30 m^3/day.

The wind speed was deduced according to the method described by Liu and Wang [16] with appropriate adjustments. The average wind speed is μ_a=2.6 m/s, the wind speed at the bottom of the street is μ_b=0.8 m/s, and the wind direction is 60° from horizontal (θ=30°). Additional basic parameters corresponding to atmospheric diffusion theory include: α=0.1, γ=1, h_0=2 m, w_0=0.1 m/s. Therefore, $L\gamma$=60, R=0.5, σ_w=0.13, σ_{wt}=0.25, d_2=0 m, d_3=30 m and d_4=14 m.

Table 4 – Population distribution parameters around an N-D road network section

Road properties	Road section	Population density in roadside buildings [person/layer/km]					Roadside pedestrian density [person/km]				
		Period 1	Period 2	Period 3	Period 4	Period 5	Period 1	Period 2	Period 3	Period 4	Period 5
Office and commercial areas	4,6,7,8,14,15,16	25	15	10	5	10	200	150	130	110	100
Residential area	2,9,10,17,19,13	5	15	22	30	37	100	200	300	400	500
Office and residential mixed area	3,5,11,12,18	10	10	10	10	10	200	200	200	200	200
School section	1	40	30	20	15	10	100	200	350	500	700

Note: Each period is 1 min

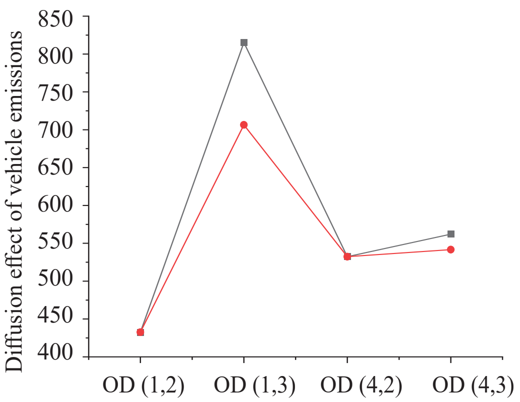
The cell division time step is typically in the range of 5–12 s. Considering the N-D road network path length assignments, the cell division time step in this work is 10s, and the effective length of each cell is approximately 133 m. The carrying capacity is set at 16 vehicles. The signal control parameters of the cell division map are shown in *Table 5*.

Table 5 – Signal control positions and timing

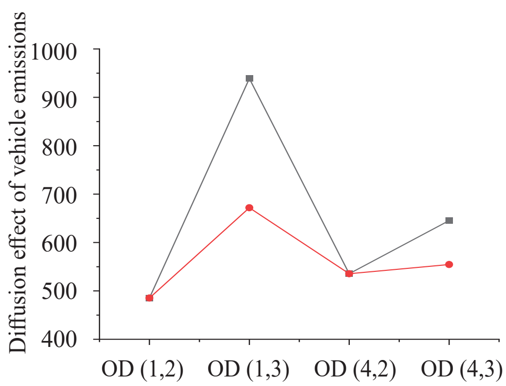
Signal setting section	Signal cell location	Period (10 s)	Green time (10 s)	First green light (time period)
1→5	50	5	2	0
7→8	26	3	1.5	0
9→10	41	6	3	0
9→13	22	6	3	0
12→6	54	7	4	0
1→5	50	5	2	0

5.2 Example results and analysis

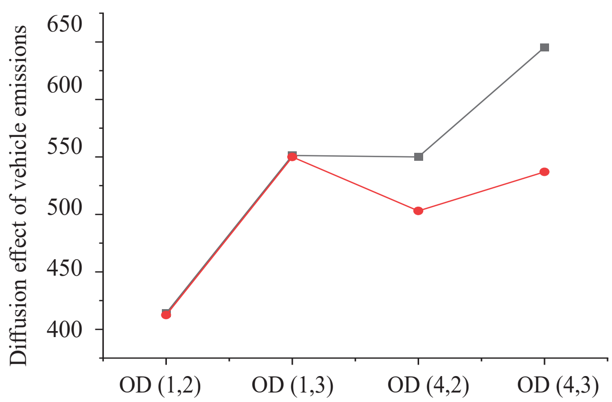
The total emission of four motor vehicle-derived pollutants in the entire country reaches 15.93 million tons, and CO accounts for as much as 48.32%. Therefore, in this example, CO inhalation is used to calculate the exposure risk to roadside people. The traffic environment, atmospheric environment, local policies and the purpose of traffic guidance management were considered to construct a generalised impedance model, i.e. the travel time, pollutant emissions and roadside crowd exposure risk weights are equivalent.



a) Pollutant discharge in time period 3



b) Pollutant discharge in time period 4



c) Pollutant discharge in time period 5

Traffic assignment based on time impedance — Traffic assignment based on generalised impedance

Figure 4 – Comparisons of vehicle emission diffusion under various dynamic traffic allocation conditions

The relationship between the impact of vehicle emission diffusion with dynamic traffic allocation and the amount of pollutant emissions caused by dynamic traffic allocation (travel time + amount of pollutants inhaled by roadside people) was also analysed, as shown in *Figures 4a–4c*. The impact of vehicle emission diffusion with dynamic traffic allocation based on generalised impedance is significantly lower than that of dynamic traffic allocation with temporal impedance only. Considering the influence of vehicle emission diffusion in terms of traditional time impedance and constructing a corresponding dynamic traffic distribution model has significant practical applicability for controlling vehicle emissions and reducing the impact of emissions on the health of roadside pedestrians and residents.

6. CONCLUSIONS

A dynamic traffic allocation model is proposed here based on the impact of vehicle emission diffusion. The model, which can be applied to potentially reduce the impact of vehicle emission diffusion, takes into account the travel efficiency of the road network system by analysing the negative impact of vehicle emissions on the atmospheric environment and roadside crowds. Owing to the complexity of dynamic traffic allocation efforts that consider the influence of vehicle emission diffusion, several assumptions are made in the model (e.g. the independent diffusion of each road section and the stability of crowd breathing factors), which will inevitably affect the final accuracy of the results. Subsequently, traffic simulation software can be used to simulate the road pollutant emissions, or the map can be used to analyse the road conditions to obtain vehicle pollutant emissions data. Real survey data can then be combined with the dynamic traffic allocation model to allocate vehicles, thereby further reducing the gap between the allocation results and reality.

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考虑车辆排放扩散影响的动态交通分配模型

摘要
汽车尾气扩散到路旁人群呼吸带，危害人体健康。本研究运用动态交通分配理论，综合考虑车辆排放扩散的影响。研究结果为改善城市交通污染扩散对大气环境和路旁人群影响提供了理论依据。首先，考虑不同类型车辆排放因子的差异，构建适用于动态交通分配的多车型元胞传输模型；其次，建立考虑行驶工况的多车型排放模型。再引入路边人群暴露风险概念，给出路旁人群吸入车辆排放污染物总量的计算方法。从车辆排放量和路旁人群暴露风险两个方面综合讨论车辆排放扩散的影响。基于车辆实际行驶时间、多车型排放量和路边人群暴露风险加权平均建立考虑车辆尾气排放扩散影响的广义阻抗函数。最后，将该广义阻抗函数集成到动态最优用户分配模型中，建立了考虑车辆排放控制影响的动态交通分配模型。

关键词
车辆排放；排放扩散影响；广义阻抗；动态交通分配