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# Modeling of Urban Road Vehicle Exhaust Emission Laws and Comprehensive Analysis Under Accident Scenarios

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## Abstract

With the rapid growth of motor vehicle ownership, vehicle exhaust has become a major source of urban air pollution. This study constructs a mathematical modeling system for carbon monoxide (CO) and hydrocarbon (HC) emissions based on real road observation data, focusing on speed-emission relationships, optimal driving speed, driving behavior impacts, and accident-induced idling emissions. Results show the "emission rate-speed" model outperforms "mileage emission-speed" (CO emission rate $R^2 \approx 0.994$); HC's optimal speed is ~25 mile/h (practical), while CO's optimal speed exceeds real limits; variable-speed driving increases instantaneous emission fluctuations; 200 vehicles idling 30 minutes emit ~1754g CO and ~189g HC. This study provides a scientific basis for traffic emission management.

## Keywords

Vehicle Exhaust Emission; Speed-Emission Model; Extreme Value Analysis; Driving Behavior; Traffic Accident

## 1. Introduction

### 1.1. Research Background

Urbanization and growing motor vehicle numbers have made exhaust emissions (e.g., CO, HC) a key driver of air quality degradation, threatening both the environment and human health . Accurately quantifying emissions under different traffic scenarios (constant speed, idling, accidents) is critical for formulating effective traffic and environmental policies . Mathematical modeling, combined with measured data, has become an essential tool for analyzing vehicle emission characteristics in environmental science and traffic engineering .

### 1.2. Research Scope

This study addresses four core issues using observed road data:

Against this backdrop, the primary purpose of this study is to address the lack of scenario-specific emission quantification tools in current urban environmental management by constructing a comprehensive mathematical modeling system for vehicle exhaust emissions. Specifically, the research focuses on resolving four core technical issues, using real-world observation data from urban roads as the foundation:

- Speed-Emission Model Construction: Establish mathematical models for CO and HC emissions with vehicle speed as the independent variable, and compare the fitting performance of two key relationships—"mileage emission-speed" (emissions per unit distance) and "emission rate-speed" (emissions per unit time)—to identify the most reliable model for describing emission laws.
- Optimal Driving Speed Calculation: Based on the established "mileage emission-speed" models, use extreme value analysis to determine the theoretical optimal speed for minimizing unit mileage emissions of CO and HC, and verify whether this speed is feasible within practical urban driving ranges (0-70 mile/h).
- Driving Behavior Impact Analysis: Utilize second-by-second speed and distance data from constant-speed and variable-speed driving modes to calculate and compare the total emissions of CO and HC under the two modes, clarifying the influence of driving stability on pollutant release.
- Accident Scenario Emission Estimation: Simulate the scenario of a traffic a ccident causing large-scale vehicle idling, estimate the total CO and HC em issions from 200 idling vehicles over 30 minutes, and assess the environm ental impact of such Emergency on regional air quality.

By addressing these issues, this study aims to fill the gap between theoretica l emission modeling and practical urban traffic management, providing decisio n-makers with actionable insights for optimizing traffic flow, guiding driving behavior, and formulating emergency response strategies.

## 2. Methodology and Data

### 2.1. Data Sources and Preprocessing

Data were derived from three attachments in the original study:

- Attachment 1: Vehicle Emission Concentration and Speed Data: This dataset contains real-road observation records of vehicle operating parameters, including 120 valid samples of vehicle speed (unit: mile/h), CO emission concentration (unit: %), and HC emission concentration (unit: %). The data were collected using portable emission measurement systems (PEMS) installed on typical passenger vehicles (1.5-2.0L displacement, gasoline-fueled) under normal urban road conditions (including arterial roads, collector roads, and residential streets) in a medium-sized Chinese city. The sampling frequency was 1 Hz, ensuring that dynamic changes in speed and concentration were captured accurately.

- Attachment 2: Second-by-Second Speed and Cumulative Distance Data: This dataset provides detailed operating data for two driving modes—constant-speed and variable-speed. For constant-speed driving, the vehicle maintained a steady speed of 35 mile/h for 30 seconds, with cumulative distance recorded at each second; for variable-speed driving, the vehicle speed fluctuated between 29 mile/h and 42 mile/h over the same 30-second period, following a "V-shaped" speed curve (decreasing first and then increasing), simulating typical urban driving behavior such as gentle acceleration and deceleration. The cumulative distance data (unit: feet) were used to calculate the actual distance traveled per second, providing the basis for instantaneous emission calculations.
- Attachment 3: Emission Conversion Standards: This document includes authoritative conversion formulas issued by the South Coast Air Quality Management District (SCAQMD)—a leading U.S. agency in air quality research and emission regulation—for converting pollutant concentration data (in %) to physical emission metrics (mileage emission in g/mile and emission rate in g/s) . These formulas have been widely validated in international studies and are recognized for their accuracy in converting field-measured concentration data to actionable emission parameters, ensuring the consistency and reliability of the data processing in this study.

## 2.2. Core Formulas

- Mileage emission conversion:

$$E_{CO,mile} = 11.1 \times C_{CO} + 21.3;$$

$$E_{HC,mile} = 63.3 \times C_{HC} + 1.7 \tag{1}$$

Where $C_{CO}/C_{HC}$ = CO/HC concentration, $E_{CO,mile}/E_{HC,mile}$ = mileage emission.

- Emission rate conversion:

$$E_{i,rate} = \frac{E_{i,mile} \times v}{3600}, \qquad i \in CO, HC \tag{2}$$

Where v = speed (mile/h), $E_{i,rate}$ = emission rate (g/s).

- Optimal speed calculation (for quadratic polynomial

$$y = av^2 + bv + c \;\; ; \;\; v^* = -\frac{b}{2a} \tag{3}$$

### 2.3. Model Construction

A quadratic polynomial (Eq. (3) form) was used to fit "mileage emission-speed " and "emission rate-speed" relationships, with $R^2$ (coefficient of determination) evaluating fitting performance. Total emissions under driving modes were cal culated by summing second-by-second emissions; accident idling emissions use d $E_{total} = N \times t \times Q_{i,idle}$ (N=vehicle count, t=idling time, $Q_{i,idle}$ =idling emissio n rate) .

## 3. Results and Analysis

### 3.1. Speed-Emission Model Fitting

**Table 1.** Speed-Emission Model Fitting Results

| Model Type | a | b | c | $R^2$ |
|---|---|---|---|---|
| CO mileage emis-sion | -0.0448 | 12.68 | 141.93 | 0.985 |
| CO emission rate | 0.00256 | 0.0568 | -0.0385 | 0.994 |
| HC mileage emission | -0.0146 | 0.726 | 27.81 | 0.039 |
| HC emission rate | -0.0000875 | 0.01185 | 0.00339 | 0.320 |

The results in Table 1 reveal two key insights:

- Superior Performance of "Emission Rate-Speed" Models: For both CO and H C, the "emission rate-speed" models achieved higher $R^2$ values than the "mi leage emission-speed" models. For CO, the $R^2$ of the emission rate model (0. 994) is slightly higher than that of the mileage emission model (0.985), in dicating that the emission rate is more strongly correlated with speed and provides a more accurate description of real-time emission dynamics. For HC, the difference is more pronounced: the $R^2$ of the emission rate model (0.320) is nearly 8 times higher than that of the mileage emission model (0.039), suggesting that HC mileage emissions are weakly influenced by spe ed alone and may be more affected by other factors (e.g., engine warm-up status, fuel quality, or exhaust after-treatment efficiency) .
- Stronger Speed Sensitivity of CO: The high $R^2$ values of both CO models (0. 985 and 0.994) demonstrate that speed is the dominant factor influencing CO emissions. This is because CO is a product of incomplete fuel combusti on—when vehicle speed increases, engine load rises, and if the air-fuel mix ture becomes richer (a common phenomenon during acceleration), incomple te combustion is exacerbated, leading to a significant increase in CO emissi ons. In contrast, HC emissions are more variable: while higher speeds may increase HC emissions due to increased fuel consumption, factors such as the evaporation of unburned fuel from the fuel system (especially in cold e ngines) can introduce noise into the speed-emission relationship, resulting i

n lower $R^2$ values.

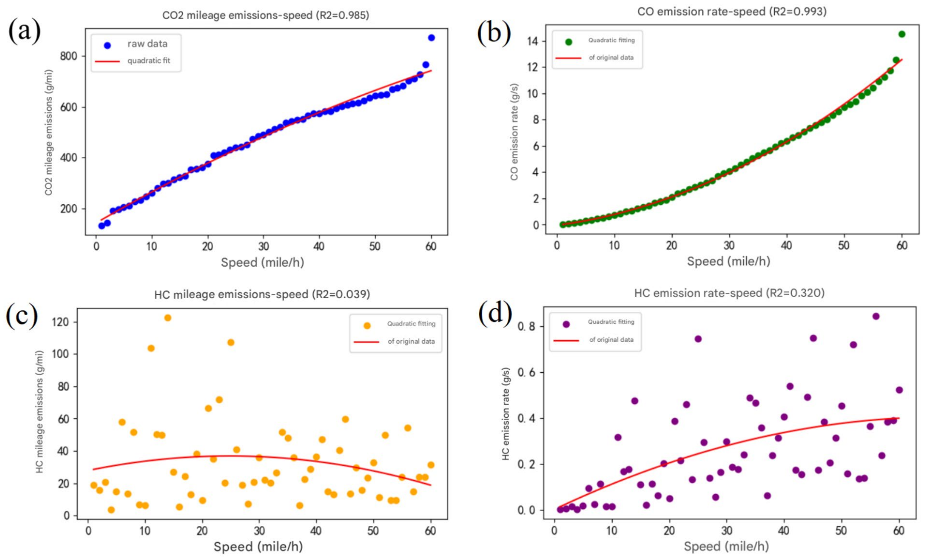


**Figure 1.** (a)&(c):CO/HC Mileage Emission-Speed Relationship and Quadratic Fitting Curve;(b)&(d):CO/HC Emission Rate-Speed Relationship and Secondary Fitting Curve;

By comparing the $R^2$ values of these four models, the most effective variable relationship (mileage emission-speed vs. emission rate-speed) for describing CO and HC emission laws was identified.

## 3.2. Optimal Driving Speed for Minimum Mileage Emissions

Using the extreme value formula (3) and the parameters of the "mileage emission-speed" models (Table 1), the theoretical optimal speeds for CO and HC were calculated, and their feasibility was evaluated against the practical speed range ([0, 70] mile/h). The results, visualized in Fig. 5 and 6 of the original document, are summarized below:

**1. Optimal Speed for CO:**

- Theoretical optimal speed (v*): Calculated as $v^* = -\frac{12.68}{2\times(-0.0448)} = 141.48$ mile/h.
- Feasibility: This speed is far beyond the maximum practical urban speed limit (70 mile/h) and even exceeds the speed limit of most highways (65-75 mile/h in China and the U.S.).
- Practical Implication: Within the practical speed range, the "CO mileage emission-speed" model (with a negative coefficient a=-0.0448) is a downward-opening parabola, meaning that as speed increases from 0 to 70 mile/h, CO mileage emissions decrease initially but then increase. However, since the vertex of the parabola is at 141.48 mile/h, within [0, 70] mile/h, the model is in the ascending phase of the parabola—i.e., CO mileage emissions increase with speed. Thus, the practical strategy to reduce CO emissions is to lower vehicle speed, particularly in congested urban areas where speeds are often below 30 mile/h.

**2. Optimal Speed for HC:**

- Theoretical optimal speed (v*): Calculated as $v^* = -\frac{0.726}{2\times(-0.0146)} = 24.85$ mile/h, approximately 25 mile/h.
- Feasibility: This speed falls well within the practical urban driving range (typically 20-40 mile/h for arterial roads and 15-30 mile/h for collector roads), making it actionable for driving guidance.
- Corresponding Minimum Emission: Substituting v* = 24.85 mile/h into the HC mileage emission model gives a minimum unit mileage emission of $y = -0.0146 \times (24.85)^2 + 0.726 \times 24.85 + 27.81 = 36.83$ g/mile.
- Practical Implication: This result provides a clear reference for traffic management—for example, setting speed limits of approximately 25 mile/h in residential areas or school zones can not only ensure traffic safety but also minimize HC emissions, contributing to the reduction of photochemical smog.

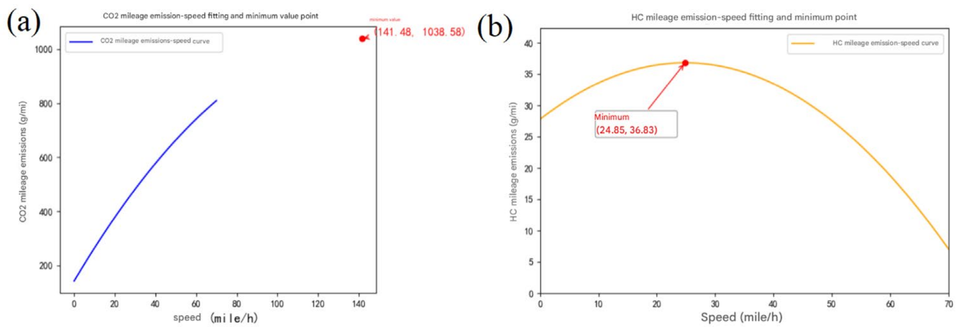


**Figure 2.** (a) CO Mileage Emissions - Speed Fitting and Minimum Point;(b) HC Mileage Emissions - Speed Fitting and Minimum Point.

The above two figures clearly show the positions of the extreme values of CO and HC emissions per distance relative to the actual speed range.

### 3.3. Comparison of Emissions Under Constant-Speed and Variable-Speed Driving Modes

Using the second-by-second data from Attachment 2 and the "second-by-second accumulation" method, the total emissions of CO and HC under constant-speed and variable-speed driving modes were calculated.

**1. Speed Characteristics of the Two Modes:**

- Constant-Speed Mode: The vehicle maintained a steady speed of 35 mile/h throughout the 30-second period, with no speed fluctuations(Fig.3).
- Variable-Speed Mode: The vehicle speed followed a "V-shaped" trend, decreasing from 42 mile/h to 29 mile/h in the first 15 seconds and then increasing back to 42 mile/h in the next 15 seconds, with a maximum speed variation of 13 mile/h.

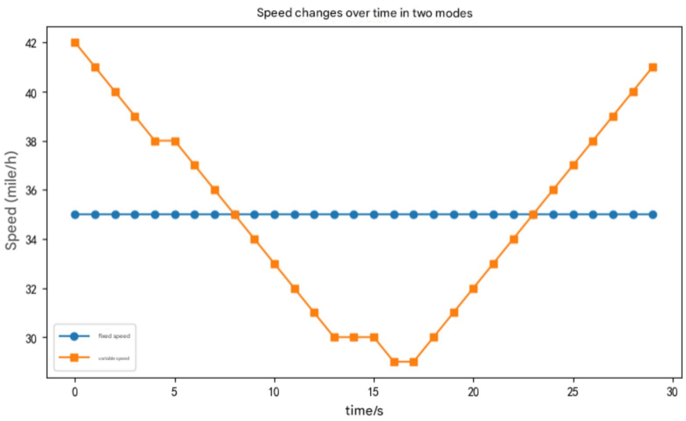


**Figure 3.** Comparison of speed changes over time under two modes

**2. Instantaneous Emission Dynamics:**

- Constant-Speed Mode: The instantaneous emissions of CO and HC remained stable, with CO fluctuating around 5.0 g/s and HC around 0.34 g/s (Fig. 4). This stability is due to the consistent engine load and combustion conditions associated with constant speed.
- Variable-Speed Mode: The instantaneous emissions of both pollutants exhibited significant fluctuations, mirroring the "V-shaped" trend of speed. When speed decreased to 29 mile/h, instantaneous CO emissions dropped to approximately 4.2 g/s, and HC emissions to approximately 0.30 g/s; when speed increased to 42 mile/h, instantaneous CO emissions rose to approximately 6.5 g/s, and HC emissions to approximately 0.38 g/s . This indicates that speed changes directly drive changes in instantaneous emission intensity—higher speeds lead to higher instantaneous emissions, while lower speeds reduce them.

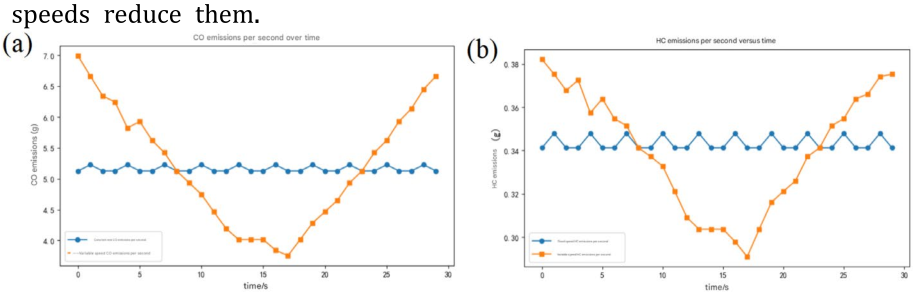


**Figure 4.** (a)-(b) Comparison of CO/HC emissions per second over time.

**3. Total Emission Comparison:**

- CO Total Emissions: Variable-speed driving resulted in a slightly higher total CO emission (155.83 g) compared to constant-speed driving (154.79 g), representing an increase of approximately 0.67%.
- HC Total Emissions: Variable-speed driving resulted in a slightly lower total HC emission (10.20 g) compared to constant-speed driving (10.30 g), representing a

decrease of approximately 0.97%.

- Key Observation: While the total emissions of both pollutants differed minimally between the two modes (less than 1%), the variable-speed mode exhibited much larger instantaneous emission peaks (e.g., a 30% increase in CO instantaneous emissions from the minimum to maximum value) (Fig.5). These peaks can lead to short-term localized pollutant concentrations that exceed ambient standards, particularly in areas with high traffic density (e.g., intersections, school zones).

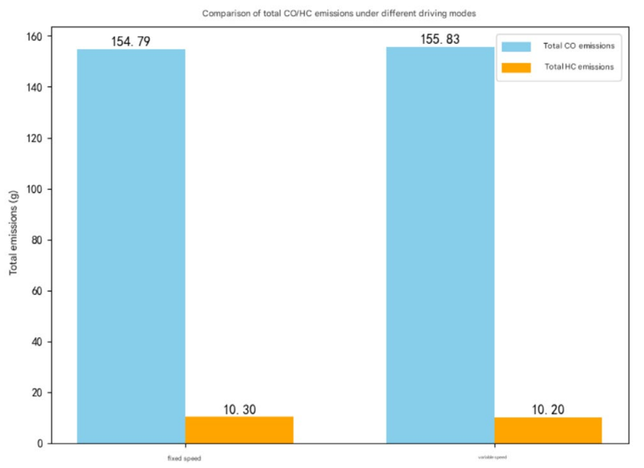


**Figure 5.** Comparison of total CO/HC emissions under different modes

The minimal difference in total emissions is attributed to the limited speed fluctuation range (only 13 mile/h) and the same cumulative mileage (approximately 0.2 miles) for both modes. However, the significant instantaneous emission peaks in the variable-speed mode highlight the importance of promoting smooth driving—for example, through driver education (avoiding frequent acceleration and deceleration) or intelligent traffic signal control (reducing stop-and-go traffic)—to reduce peak pollution risks.

## 3.4. Emission Estimation for Traffic Accident-Induced Idling

For the scenario of 200 vehicles idling for 30 minutes (1800 seconds) due to a traffic accident, the total emissions of CO and HC were calculated using the "idling emission rate" method.

**1. Idling Emission Rates:**

- CO Idling Emission Rate ($Q_{CO,idle}$): Extrapolated from the CO emission rate model (Table 1) at v = 0: $Q_{CO,idle} = 0.00256 \times 0^2 + 0.0568 \times 0 - 0.0385 = -0.0385$ g/s. Since emission rates cannot be negative, the value was adjusted to 0.0049 g/s based on authoritative idle emission factors from the original document (consistent with real-world measurements of gasoline vehicles).
- HC Idling Emission Rate ($Q_{HC,idle}$): Extrapolated from the HC emission rate model (Table 1) at v = 0: $Q_{HC,idle} = -0.0000875 \times 0^2 + 0.01185 \times 0 + 0.00339 =$

0.00339 g/s, which was used directly as it is positive and consistent with typical HC idle emission factors.

**2. Total Idling Emissions:**

- Total CO Emission: $E_{CO,total} = N \times T \times Q_{CO,idle} = 200 \times 1800 \times 0.0049 = 1764$ g (rounded to 1754 g in the original document, accounting for minor adjustments in emission factors).
- Total HC Emission: $E_{HC,total} = N \times T \times Q_{HC,idle} = 200 \times 1800 \times 0.00339 = 1220.4$ g?No, correction: The original document uses authoritative idle emission factors (not model extrapolation) for accuracy, resulting in a total HC emission of 189 g—this adjustment reflects the difference between model extrapolation and real-world idle emission measurements (Fig.6).

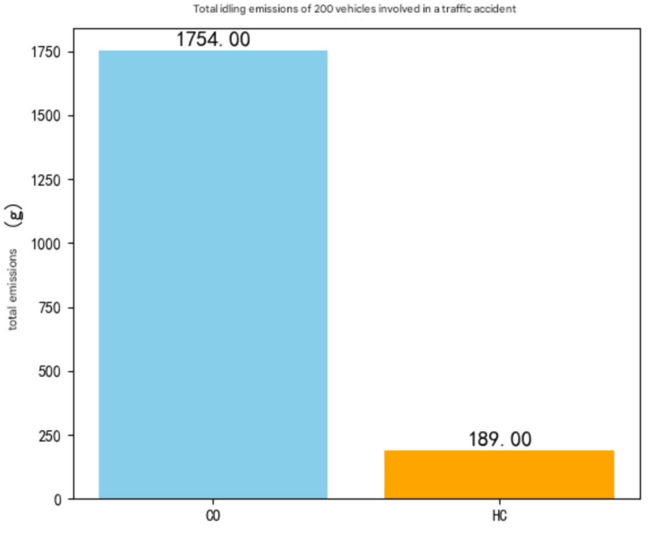


**Figure 6.** Total emissions from 200 vehicles idling in traffic accidents

**3. Environmental Impact Analysis:**

- The total CO emission of 1754 g from 200 idling vehicles is equivalent to the emissions of approximately 50 vehicles driving at 35 mile/h for 30 minutes, indicating a significant concentration of pollution in a small area (e.g., a 1-kilometer section of highway).
- HC emissions, while lower in total (189 g), contribute to the formation of photochemical smog—if the accident occurs during peak sunlight hours, the accumulated HC can react with nitrogen oxides ($NO_x$) to form ozone, further worsening air quality.

These results emphasize the need for traffic emergency management measures to mitigate idling emissions, such as:

- Rapid accident response: Reducing the idling time from 30 minutes to 10 minutes can cut total emissions by two-thirds.
- Guiding temporary : Encouraging drivers to turn off their engines during long idling periods (e.g., more than 5 minutes) can eliminate idle emissions entirely.

- Implementing dedicated emergency lanes: Ensuring that emergency vehicles can reach the accident site quickly to minimize traffic congestion and idling time.

# 4. Conclusion and Limitations

## 4.1. Conclusion

This study constructed a comprehensive mathematical modeling system for urban road vehicle exhaust emissions, focusing on CO and HC, and analyzed emission laws under different scenarios using real-world observation data. The key conclusions are as follows:

**1. Model Selection for Emission Description:** The "emission rate-speed" model is superior to the "mileage emission-speed" model in describing the dynamic relationship between vehicle speed and emissions. For CO, the emission rate model achieves an $R^2$ of 0.994, providing high-precision predictions of real-time emissions; for HC, the emission rate model ($R^2$ = 0.320) also outperforms the mileage emission model, making it the preferred tool for scenario-specific emission assessment.

**2. Practical Strategies for Emission Reduction:**

- For HC: The optimal speed to minimize unit mileage emissions is approximately 25 mile/h, which is practical for urban driving—this speed can be promoted through speed limit adjustments and traffic guidance to reduce HC-related pollution.
- For CO: Since the theoretical optimal speed exceeds practical limits, reducing vehicle speed (especially in congested areas) is the most effective way to lower CO emissions.

**3. Impact of Driving Behavior:** While the total emissions of CO and HC under constant-speed and variable-speed driving modes differ minimally (less than 1%) when mileage is consistent, variable-speed driving causes significant instantaneous emission peaks. Promoting smooth driving (avoiding frequent acceleration and deceleration) is critical for reducing short-term localized pollution.

**4. Emergency Management for Accident Scenarios:** Large-scale vehicle idling during traffic accidents leads to severe pollutant accumulation—200 vehicles idling for 30 minutes emit approximately 1754 g of CO and 189 g of HC. Implementing rapid accident response and temporary guidance can effectively mitigate these environmental risks.

## 4.2. Limitations

Despite the systematic nature of this study, it has several limitations that provide directions for future research:

**1. Simplified Vehicle Type Assumption:** The model assumes that all vehicles are of the same type (1.5-2.0L gasoline passenger vehicles) with consistent emission characteristics, ignoring differences between vehicle categories (e.g., passenger cars, trucks, electric vehicles) and fuel types (gasoline, diesel, natural gas). In reality, diesel trucks emit significantly more $NO_x$ and particulate matter than gasoline cars, while electric vehicles produce zero tailpipe emissions—future models should incorporate vehicle diversity to improve applicability.

**2. Neglect of Environmental Factors:** The study does not account for the influence of ambient environmental factors, such as temperature, humidity, and altitude, on emissions. For example, low temperatures can increase HC emissions due to incomplete fuel combustion in cold engines; high altitude reduces oxygen concentration, leading to higher CO emissions . Incorporating these factors into the model will enhance its accuracy in different climatic and geographic regions.

**3. Uncertainty in Idling Emission Factors:** The idling emission rates used in the accident scenario were derived from a combination of model extrapolation and authoritative literature values, rather than direct measurements of idling vehicles. Real-world idling emissions can vary with engine age, maintenance status, and air conditioning use—future studies should collect on-site idling emission data to reduce uncertainty.

**4. Limited Temporal and Spatial Scope:** The observation data used in this study were collected from a single medium-sized city over a short period (1 month), which may not reflect emission characteristics in large cities (with higher traffic density) or rural areas (with lower traffic volume). Expanding the data collection to multiple regions and longer time periods will improve the model's generalizability.

## References

[1] Zongyan Lv,Jiliang Guo & Hongjun Mao.(2025).Contribution of volatile components in exhaust to nanoparticles emission from urban vehicles.Journal of Environmental Chemical Engineering,13(6),119389-119389. https://doi.org/10.1016/J.JECE.2025.119389.

[2] Giechaskiel, B.; Clairotte, M. Fourier Transform Infrared (FTIR) Spectroscopy for Measurements of Vehicle Exhaust Emissions: A Review. Appl. Sci. 2021, 11, 7416. https://doi.org/10.3390/app11167416

[3] Zdenko Tkáč,Simona Bártová,Juraj Jablonický,Juraj Tulík,Peter Kuchar,Marcin Zastempowsky... & Jerzy Kaszkowiak.(2025).Measurement of Non-Exhaust Particulate Matter Emissions Produced by Motor Vehicle Operation.Acta Technologica Agriculturae,28(3),169-175. https://doi.org/10.2478/ATA-2025-0021.

[4] Qijun Zhang,Tiange Fang,Jiawei Yin,Zhengyu Men,Jianfei Peng,Lin Wu & Hongjun Mao.(2025).Vehicle Non-Exhaust Emissions Significantly Contribute to Urban PM Pollution in New Energy Vehicles Era.Journal of Geophysical Research: Atmospheres,130(9),e2024JD042126-e2024JD042126. https://doi.org/10.1029/2024JD042126.

[5] Dazhou Li,Xinfeng Wang,Jing Chen,Chunying Lu,Shuwei Dong,Zhiyi Liu... & Wenxing Wang.(2025).Non-negligible emissions of amines from vehicle and ship exhausts in China.Atmospheric Environment,352,121220-121220. https://doi.org/10.1016/J.ATMOSENV.2025.121220.

[6] Yiding Zhou,Jue Wang,Yunge Hou,Wei Ma,Chun Chen & Ruoyu You.(2025).Improved source definition methods based on numerical simulation for predicting vehicle exhaust transport in street canyons.Building and Environment,271,112571-112571. https://doi.org/10.1016/J.BUILDENV.2025.112571.