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Research on Excessive Emission Identification Method of Heavy-Duty Vehicle Based on Remote Supervision

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Abstract. The low efficiency of NOx excessive emission identification of heavy-duty vehicle is an urgent problem in the transportation field. In this paper, the excessive emission identification method of heavy-duty vehicle based on remote supervision is studied. Based on the characteristic law between vehicle emission and operating condition, the screening basis of vehicle emission calculation basic data is clarified. The two most critical parameters which affect the emission are obtained. Meanwhile, the suggestions of vehicle field detection are put forward. It is of great significance to improve the accuracy of online remote identification of heavy-duty vehicles with excessive emission and the success rate of on-site detection based on violation clues of online identification.

1 Introduction

The issue of excessive nitrogen oxides (NOx) emissions from heavy-duty vehicles has become increasingly severe [1]. These pose significant threats to atmospheric quality and human health [2,3]. Therefore, obtaining evidence of non-compliance from excessive-emission heavy-duty vehicles and conducting on-site inspections and enforcement actions have become critical measures in controlling NOx emissions [4]. With the advancement of remote supervision technology for heavy-duty vehicles [5], the online and remote identification of excessive-emission vehicles and the provision of violation evidence have markedly enhanced the enforcement efficiency of regulatory authorities, playing a crucial role in addressing the issue of NOx emissions [6,7].

However, the existing methods for online and remote identification of excessive-emission heavy-duty vehicles primarily rely on monitoring techniques specified in local standards [8], which involve randomly acquiring remote monitoring data within a 2000-meter window to calculate the NOx emissions and compare them against regulatory limits. Feedback from on-site monitoring results reveals two significant limitations of these methods.

Firstly, the online and remote identification process does not adequately account for the impact of operational conditions, such as vehicle speed and torque, on heavy-duty vehicle emissions. This oversight often results in the frequent capture of vehicles that temporarily exceed emission limits under harsh operating conditions, while they may operate within compliance for extended periods. Consequently, this leads to misclassification of excessive-emission vehicles as compliant vehicles, thereby diminishing the accuracy of online identification.

Secondly, the on-site detection of vehicles flagged based on online identification is typically conducted over a randomly selected 2000-meter distance, where the lack of clear operational standards can lead to significant discrepancies. Frequently, vehicles that have long operated under normal conditions may be tested under milder conditions, resulting in reduced emissions during the assessment. This not only undermines the detection success rate based on online identification evidence but also misallocates enforcement resources.

In response to these challenges, this paper presents a study on the identification methods for excessive NOx emissions from heavy-duty vehicles based on remote supervision. By analyzing the relationship between vehicle emissions and operational conditions, we establish criteria for the selection of the 2000-meter window. Additionally, we propose recommendations for the operational conditions during on-site inspections, with the aim of improving the accuracy of online identification of excessive-emission heavy-duty vehicles and enhancing the success rate of on-site inspections based on online identification evidence.

2 Materials & methods

2.1 Data description

By remote supervision platform for heavy-duty vehicles, the remote monitoring data from 20 representative heavy-duty vehicles can be collected. All vehicles complied with the China VIb emission regulations. The dataset includes parameters such as time, vehicle speed, acceleration, torque, engine speed, fuel consumption, and NOx

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emission rate. The data was sampled at a frequency of 1 Hz, with each vehicle's data spanning a period of one month. The total mileage of all vehicles exceeded 10,000 kilometers.

To ensure data quality, invalid data points were removed during the preprocessing stage. Additionally, a moving average window method was employed to segment the data into 30-second intervals. Within each segment, the average values of all parameters were calculated as the final parameters for that segment. Here, invalid data refers specifically to anomalies that exceed reasonable ranges for the parameters. Table 1 presents the acceptable ranges for the required parameters.

Table 1. Parameters' reasonable range.

Parameter	***Reasonable range***
Vehicle speed	[0, 120] km/h
Torque	[0%, 100%]
NOx emission rate	[0, 3000] ppm/s

2.2 Identification method

In order to solve the problem that the existing standard method can not identify the heavy vehicles accurately, a method based on remote supervision is proposed. Figure 1 shows the flow chart of the method.

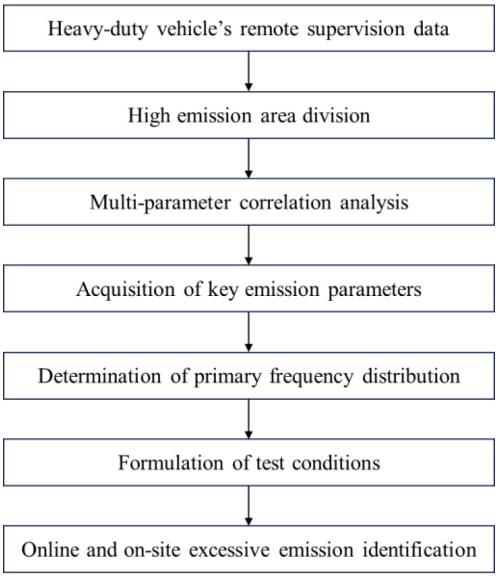


Figure 1. Method flow chart.

2.2.1 Acquisition of key emission parameters

Among all segments of the remote monitoring data, the 80th percentile of the NOx emission rate was identified as the threshold value T_{NOx}. Segments with NOx emission rates exceeding T_{NOx} were classified into the high emission area, as illustrated in Figure 2. In Figure 2, the deep blue scatter points represent the NOx emission rates for each segment. Due to the substantial number of scatter points, the results appear as a continuous deep blue line. The calculated 80th percentile of the NOx emission rate is 1229.5 ppm. Within the high emission area, correlation analysis methods [9,10] were employed to compute the correlation coefficients between vehicle speed, acceleration, torque, engine speed, fuel consumption, and the NOx emission rate. The results are presented in Table 2. The two parameters with the largest absolute correlation coefficients were identified as key emission parameters, specifically torque and fuel consumption.

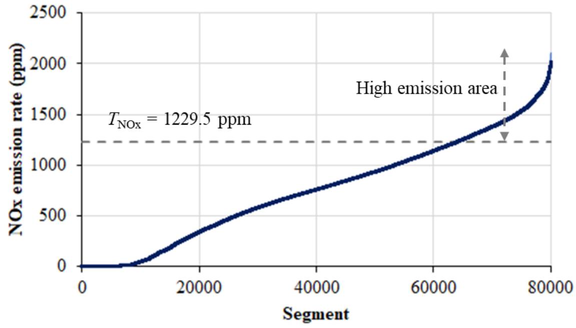


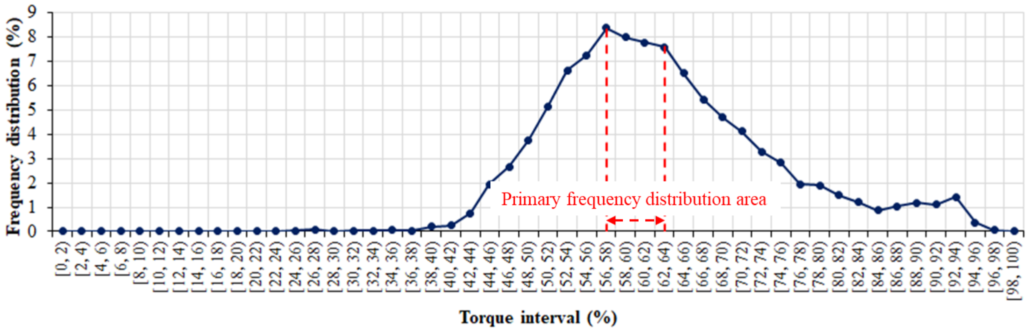
Figure 2. High emission area division.

Table 2. Correlation coefficient between parameters and NOx emission rate.

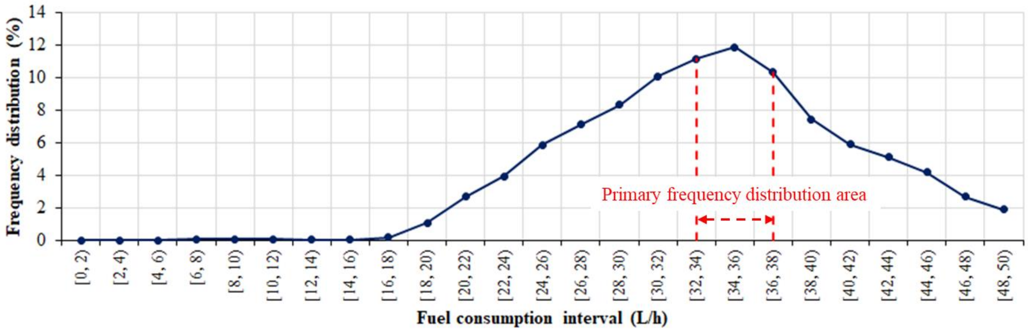
Parameter	***Absolute value of correlation coefficient***
Vehicle speed	0.23
Acceleration	0.11
Torque	0.75
Rotational speed	0.12
Fuel consumption	0.56

Figure 3 illustrates the frequency distribution of torque and fuel consumption within the high emission area. The deep blue scatter points and lines represent the frequency distribution across each interval. The area enclosed by the red dashed line indicates the primary frequency distribution area for either torque or fuel consumption. This primary frequency distribution area is defined as the area with the highest frequency distribution, where the cumulative frequency reaches approximately 30%. As shown in Figure 3(a), the torque within the high emission area predominantly falls within the region exceeding 44%. Notably, the interval [56%, 64%) represents the area of highest torque frequency distribution, exceeding 30%. Furthermore, there is virtually no torque frequency distribution below 44% in the high emission area, suggesting that higher torque is associated with increased vehicle emissions.

Figure 3(b) demonstrates that the fuel consumption in the high-emission interval is primarily concentrated in the region above 18 L/h. The interval [32, 38) L/h marks the area of highest frequency distribution for fuel consumption, again exceeding 30%. Similar to torque, there is almost no frequency distribution of fuel consumption below 18 L/h in the high emission area, further indicating that higher fuel consumption correlates with elevated vehicle emissions.



(a) Torque's frequency distribution



(b) Fuel consumption's frequency distribution

Figure 3. Schematic for urea consumption segment acquisition.

2.2.2 Online and on-site excessive emission identification

According to local standards [8], the method for on-site testing of heavy-duty vehicle emissions involves randomly driving the vehicle for a distance of 2000 meters, measuring the NOx emissions, and comparing them with the regulatory limits to determine whether the vehicle exceeds emission standards. This method, however, does not account for the influence of key emission parameters on heavy-duty vehicle emissions and is subject to randomness, as well as instability in the on-site emissions measurement process. To address this, a method for identifying high-emission heavy-duty vehicles both online and on-site is proposed. Specifically, based on the frequency distribution of key emission parameters (torque and fuel consumption), the emission detection operating conditions for the heavy-duty vehicle are determined. These conditions are defined as follows: during the 2000-meter test distance, the time proportion in which the torque and fuel consumption of the vehicle fall within the intervals of [56%, 64%] and [32, 38] L/h, respectively, must be no less than 30%. The determination of these intervals is based on the primary frequency distribution areas of torque and fuel consumption.

Using the heavy-duty vehicle emission detection conditions, a high-probability identification method for excessive-emission vehicles is implemented online. Subsequently, on-site testing is conducted for the high-probability excessive-emission vehicles. The detailed steps are as follows:

First, remote monitoring data from the heavy-duty vehicles are obtained and segmented into several 2000-meter distance intervals. Based on the emission detection operating conditions, valid segments that meet the requirements are filtered. Then, the excessive emission probability Pe of the heavy-duty vehicle is calculated using Equation (1). Vehicles with Pe greater than 80% are identified as high-probability excessive-emission vehicles. Finally, the high-probability excessive-emission vehicles are subject to on-site testing based on the emission detection operating conditions. This completes the closed-loop process, supporting enforcement actions by relevant authorities.

$$Pe = \frac{N_{\text{excessive}}}{N_{\text{all}}} \times 100\% \tag{1}$$

where $N_{\text{excessive}}$ represents the number of valid segments with an average NOx emission rate exceeding 550 ppm/s, and N_{all} represents the total number of valid segments of the vehicle.

3 Results and Discussion

Based on the excessive emission identification method for heavy-duty vehicles proposed in this study, a discussion of the results is presented. A heavy-duty vehicle, known to exceed the NOx emission limits, was selected as the test vehicle. Remote monitoring data from the test vehicle over the course of one week were obtained. In accordance with the mileage requirements, 31 valid segments were extracted from the remote monitoring data of the test vehicle through segmenting and data processing. Using a moving window averaging method, the average NOx emission rate for each valid segment was calculated and compared to the regulatory limit (550 ppm/s). The excessive emission probability Pe of the test vehicle was calculated to be 93.55%.

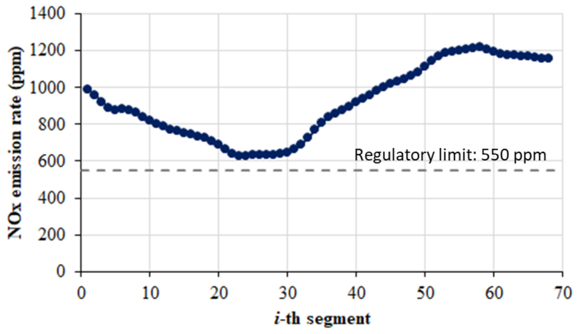


Figure 4. Determination process for excessive emissions of a valid segment.

Figure 4 illustrates the determination process for whether a specific valid segment exceeds emission limits. As shown in Figure 4, the blue solid line represents the results obtained using the moving window averaging method for this valid segment. When compared to the regulatory limit (550 ppm/s), the NOx emissions for this segment consistently exceed the threshold. Therefore, this segment is classified as excessive emission.

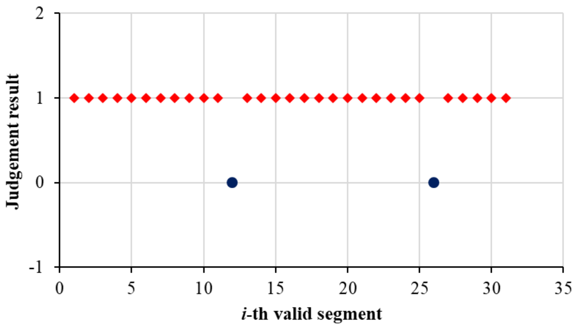


Figure 5. Determination results of 31 valid segments.

Figure 5 presents the determination results for the 31 valid segments. The red diamond marked "1" indicates segments where emissions are above the limits, while the dark blue circle marked "0" signifies segments with normal emissions. Utilizing Equation (1), the excessive emission probability *Pe* for the test vehicle was calculated to be 93.55%. Since *Pe* exceeds 80%, the test heavy-duty vehicle is classified as a high-probability excessive-emission vehicle. The processing results of the remote monitoring data provide accurate violation clues for enforcement agencies during on-site inspections.

4 Conclusions

This study investigates a remote monitoring-based method for identifying excessive emissions from heavy-duty vehicles, utilizing remote monitoring data. The method enables the accurate online identification of high-probability excessive-emission heavy-duty vehicles, while also providing precise operational conditions for on-site emission testing. The main findings are as follows:

(1) High emission area of heavy-duty vehicles are obtained. The correlation between vehicle speed, acceleration, torque, speed, fuel consumption and NOx emission rate was also studied. The two most critical parameters influencing heavy-duty vehicle emissions—termed key emission parameters—were determined to be torque and fuel consumption.

(2) An identification method for excessive emissions from heavy-duty vehicles was proposed for both online and on-site applications. It is stipulated that during the 2000-meter travel distance of the tested heavy-duty vehicle, the time proportions in which torque and fuel consumption fall within the ranges of [56%, 64%] and [32, 38] L/h, respectively, should not be less than 30%.

(3) A known excessive NOx emitter heavy-duty vehicle was selected as the test vehicle. Applying the proposed method, the excessive emission probability for the test vehicle was calculated to be 93.55%, thereby validating the accuracy of the online identification approach.

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