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Exhaust Pollutants Characteristic of In-Use Vehicles under Acceleration Simulation Mode and Emission Standard Revision for Hei Longjiang Province, China

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Abstract: The large sample data classification statistics of exhaust pollutants test data from 57,997 in-use vehicles were conducted under acceleration simulation mode conditions, two-speed idle conditions and free acceleration conditions. Aiming at the test data obtained from acceleration simulation mode, the implementation date of different stages national standards for vehicle emissions was regarded as the service life interval classification rules. Emission limits provided by the Ministry of Environmental Protection of the People's Republic of China are referred to analyze the unqualified rate, the changing trends and group deterioration trends systematically. The determining principles and requirements on exhaust pollutants limits when formulating a new local standard in China are described. Standard revision process through determining the revision object of exhaust pollutants limits and predicting unqualified rate based on the pre-revised limits and post-revised limits is proposed. The research can not only extract valuable information from large data for accurately determining the characteristics of high-emission vehicles, but help environmental management department to formulate relevant vehicles exhaust pollutants limits standard and management decisions.

Keywords: in-use vehicles; exhaust pollutants; emission standard revision; acceleration simulation mode; environmental governance

1. Introduction

In the past five years, the number of vehicles in China increases rapidly with an average annual growth rate of 16%, vehicle emissions has become one of the main sources of the urban air pollution [1,2]. Relevant research shows that vehicle exhaust emissions have accounted for about 85% of the air pollution sources [3,4]. In order to keep in-use vehicles in the best estate during their service life, and effectively control the deterioration of the fuel economy and emission in time, many researchers at home and abroad have carried out intensive studies and systematic practice on in-use automotive exhaust pollution control policies, emission status testing techniques, maintenance methods, and quality control [5–11]. Rhys-Tyler et al. [12] used remote sensing technology to detect instantaneous exhaust emissions of light vehicles. The results show that nitrogen and oxygen (NO_x) emissions can be reduced by 30% under Euro V emission standards. With the development of GIS technology, more and more high spatial resolution vehicle emission inventory for provinces and cities in China were established, and the share rate among them was also systematically studied [13–16]. Based on scenario analysis, Guo et al. [17] predicted that the emission reductions of carbon monoxide (CO), NO_x and hydrocarbon (HC) will reach 46.4%, 42.1% and 8.6%, respectively, in 2020 in Beijing.

Ji et al. [18] pointed out that since the implementation of the China I emission standard, the emission of new cars per vehicle has been reduced by 57–96%. Huo et al. [19–21] point that NO_x emission concentration plays a leading role in the emission test results under simple operating conditions. Giechaskiel et al. [22] have studied the feasibility of the current Euro VI emission standard based on the portable emission detection system and proposed an improved emission detection program. Liu et al. [23] showed that, during the implementation of the Foshan City restriction policy, the annual emissions of pollutants (CO, NO_x, VOC, PM) in the unit sections decreased by 48.1%, 39.2%, 43.6% and 49.2%, respectively. Li et al. [24] put forward a new vehicle management improvement program, which can reduce the NO_x emissions of 7460 tons in Hangzhou during the "12th Five-Year Plan" period with a reduction rate of 16.84%.

However, the above does not carry out relevant research on management decisions for data information on in-use vehicle detection results, which will become the inevitable trend of exhaust pollutions control as the accumulation of in-use vehicles exhaust pollutants detection data and the upgrades of management level [25–29], according to the relevant regulations provided by *HJ/T 240-2005* of *Principles and Methods for Determining the Emission Limits of Exhaust Emissions for Simple Ignition Engines under Simple Operating Condition* released by the Ministry of Environmental Protection of the People's Republic of China (MEPOPRC) [30]. Exhaust pollutants group state and trends were analyzed through large sample detection data of exhaust pollutants of in-use vehicles. The results can not only extract valuable information from large data for accurately determining the characteristics of high emission vehicles, but help environmental management department to formulate relevant vehicles exhaust pollutants limits' standards and management decisions.

In addition, the environmental protection requirements of NO_x compounds emission reduction proposed by the China's "12th Five-Year Plan" are considered [31–34], and combining with the actual situation of motor vehicle exhaust pollutions detection and control in Hei Longjiang Province, according to the requirements about formulating local emission standard proposed by *GB 18285-2005* of *Limits and Measurement Methods for Exhaust Pollutants from Vehicles Equipped Ignition Engine under Two-Speed Idle Conditions and Simple Driving Mode Conditions* released by MEPOPRC [35]. The revised method of the original execution standard *DB 23/1061-2006* of *Limits for Exhaust Pollutants from In-Use Vehicles Equipped Ignition Engine under Steady-State Loaded Mode Conditions* in Hei Longjiang province is put forward [36]. Fortunately, the standard revision process proposed has been adopted by Department of Environmental Protection of Hei Longjiang Province, and as one of standard drafting units, our team has helped policymakers of local environmental department to revise the *DB 23/1061-2006*. The new and stringent emission standard of *DB 23/1061-2013* is currently under implementation in Hei Longjiang province.

This paper is organized as follows, Section 2 introduces detection data source and presents the classification rule based on service life interval and explains the median values of Class I and Class II emission limits recommended by *HJ/T 240-2005*. The determining principles and requirements on exhaust pollutants limit (EPL) when formulating a new local standard in China are also described. In Section 3, we conduct the comparative analysis of unqualified rate (UR) of exhaust pollutants under the same test conditions and different test conditions, respectively. The average and variation of detection results along with the service life are discussed in this section. Finally, in this section, we present the standard revision process through determining the revision object of EPL and predicting UR based on the pre-revised limits and post-revised limits. Finally, conclusions and future work are summarized in Section 4.

2. Materials and Methods

2.1. Data Acquisition

On the basis of extensive investigation on the current situation of vehicle exhaust pollutants detection in Heilongjiang Province, 96,453 test data of exhaust pollutants for in-used vehicles were derived from the different vehicle environmental protection testing station in the province. Various types of vehicles were covered with service life over 12 years and different emission levels. The test methods classification and proportion of samples as shown in Figure 1. The number of vehicles tested by acceleration simulation mode (ASM) is 57,997, which meets the requirement that the sample should be more than 100 under different test methods regulated by *HJ/T 240-2005* when determining the new EPL.

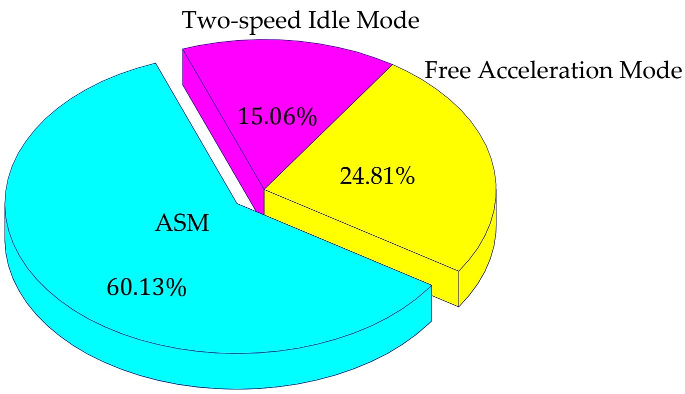

Figure 1. Proportion of test data samples.

2.2. ASM Test Conditions

Vehicles are accelerated to the specified speed and maintained within a certain range on a chassis dynamometer, and the engine's output power is multiplied by the specified ration as the dynamometer setting power under specified vehicle speed and acceleration, performing the detection of exhaust pollutants. The test sequence shall consist of either a single ASM mode or both ASM modes.

(1). ASM5025 test conditions

The vehicle is preheated to normal operating temperature and then accelerated to 25 km/h on the dynamometer, the dynamometer power is set as 50 percent of engine output power when the vehicle speed is 25 km/h and the acceleration is 1.475 m/s^2, and the speed is maintained within 25 $\pm$ 1.5 km/h during testing. ASM5025 belongs to the first test procedure of ASM.

(2). ASM2540 test conditions

When the ASM5025 has been performed, the vehicle is further accelerated to 40 km/h on the dynamometer, the dynamometer power is newly set as 25 percent of engine output power when the vehicle speed is 25 km/h and the acceleration is 1.475 m/s^2, and the speed is maintained within 40 $\pm$ 1.5 km/h during testing. ASM5025 belongs to the second test procedure of ASM.

2.3. Classification Method Based on Service Life Interval

Correlation analysis of exhaust pollutions' detection data of in-use vehicles includes classification statistics and group state statistics of test data, and group situation analysis under ASM conditions [14,23,37]. Among them, group situation analysis of detection data under ASM conditions uses the limits classification, service life, baseline quality, mileages and use properties as the classification rule to analyze the detection data by group characteristics. Our research only focuses on the service life as the classification rule to analyze the relevant test data. To facilitate the average service life of statistical test data, referring to the four stages of the national motor vehicle emission standards in China (China I, II, III and IV), the service life data are calculated according to the registration date of new vehicles, and all test samples are divided into 5 categories according to the service life. The classification rules are shown in Table 1, in which the GB is the Chinese phonetic abbreviation of Guojia Biaozhun.

Table 1. Classification rule of service life interval for in-use vehicles.

Interval Class	Classification Conditions of Service Life Interval	Service Life	National Standard	Analog Standard
1st	Registration date before 15 April 2001	>12	—	—
2nd	Registration date between 16 April 2001and 30 June 2004	9–12	GB 18352.1-2001 China I	Euro I
3rd	Registration date between 1 July 2004 and 30 June 2007	6–8	GB 18352.2-2001 China II	Euro II
4th	Registration date between 1 July 2007 and 30 June 2011	1.5–5	GB 18352.3-2005 China III, IV	Euro III
5th	Registration date between 1 July 2011 and 31 December 2012	<1.5		Euro IV

As from 16 April 2001 and 1 July 2004, China began to implement the first national vehicle emission standard limits (*GB 18352.1-2001*, China I standard for short), which is equivalent to the Euro I standard, and the second national vehicle emission standard limits (*GB 18352.2-2001*, China II standard for short), which is equivalent to the Euro II standard [17,38]. Therefore, the registration date between 16 April 2001 and 30 June 2004 by the vehicles are divided into second intervals, and other classification rules of the rest intervals are the same as the above.

2.4. Determining Principles and Requirements of Emission Standard

2.4.1. Determining Principles

According to the requirements of *HJ/T 240-2005*, the following principles should be considered when determining the emission limits.

(1). Follow the principle of new vehicles meeting new standards and old vehicles meeting old standards—according to the level of emission standards achieved during a new vehicle type approval, at the same time, considering the normal deterioration for the emission control system under the regular service and maintenance conditions, then determining the EPL for in-use vehicles.

(2). EPL determined should be able to detect high-emission vehicles effectively, and the recommended regulation proportion of the high-emission vehicles at 10–25% [34].

(3). Local realistic conditions ought to be taken into consideration when determining EPL, in addition, following the strategy of implementation of strict vehicle emission standards in continual phases after initial ease.

2.4.2. Basic Requirements

(1). Investigating the distribution of local in-use vehicles according to the different grades of national motor vehicle emission standards for newly produced vehicles, and then conducting emission tests for vehicles with different emission levels. In principle, for each type of emission level, the number of tested vehicles shall be no less than 100; meanwhile, the proportion of vehicles with different emission levels should be considered.

(2). Determine the local EPL after the statistical analysis of the detection results according to local regulation proportion of high-emission vehicles.

3. Results and Discussion

The maximum limits and minimum limits for three major exhaust pollutants, HC, CO and NO_x, are specified in *HJ/T 240-2005* released by MEPOPRC, where the NO_x emission limit is calculated at Nitric Oxide (NO). For the first type of light vehicles produced before 1 July 2000 and the second type of light vehicles produced before 1 October 2001, the recommended steady-state emission limits is called Class I emission limits, and for the first type of light vehicles produced from 1 July 2000 and the second types of light vehicles produced from 1 October 2001, the recommended steady-state emission limits is called Class II emission limits. The median values of Class I and Class II emission limits recommended by *HJ/T 240-2005* are shown in Table 2, and the median values is equal to half the sum of maximum limits and minimum limits provided by *HJ/T 240-2005* according to reference mass (RM) of vehicles.

Table 2. Median values of Class I and Class II emissions recommended by *HJ/T 240-2005*.

RM (kg)	Class I						Class II					
	ASM5025			ASM2540			ASM5025			ASM2540		
	HC ($\times10^{-6}$)	CO (%)	NO ($\times10^{-6}$)	HC ($\times10^{-6}$)	CO (%)	NO ($\times10^{-6}$)	HC ($\times10^{-6}$)	CO (%)	NO ($\times10^{-6}$)	HC ($\times10^{-6}$)	CO (%)	NO ($\times10^{-6}$)
RM ≤ 1020	175	1.75	3400	170	2.15	3150	175	0.95	1400	170	1.05	1275
1020 < RM ≤ 1250	145	1.45	2750	140	1.80	2700	145	0.80	1150	140	0.85	1025
1250 < RM ≤ 1470	130	1.30	2450	125	1.65	2275	130	0.75	1000	125	0.80	925
1470 < RM ≤ 1700	120	1.20	2175	115	1.45	2025	120	0.65	900	115	0.75	825
1700 < RM ≤ 1930	100	1.00	1800	100	1.20	1675	100	0.60	750	100	0.60	675
1930 < RM ≤ 2150	90	0.90	1650	90	1.15	1500	90	0.50	675	90	0.55	625
2150 < RM ≤ 2500	85	0.85	1400	80	1.00	1300	85	0.45	575	80	0.50	525

Note: ASM5025: ASM5025 test conditions; ASM2540: ASM2540 test conditions.

3.1. Overall UR

Under the test conditions of ASM5025 and ASM2540, according to the emission limits determined in Table 2, the unqualified amount (UA) and UR of HC, CO and NO are shown in Table 3.

Table 3. Unqualified rate (UR) based on service life interval class under ASM conditions.

Interval Class	ASM5025							ASM2540						
	Test Samples	HC		CO		NO		Test Samples	HC		CO		NO	
		UA	*UR* (%)	UA	*UR* (%)	UA	*UR* (%)		UA	*UR* (%)	UA	*UR* (%)	UA	*UR* (%)
1st	4738	650	13.72	440	10.04	553	11.68	3305	365	11.03	296	8.96	323	9.77
2nd	7675	787	10.25	685	8.93	602	7.84	6214	604	9.72	455	7.32	431	6.93
3rd	13,847	838	6.05	875	6.32	996	7.19	12,731	747	5.87	771	6.06	825	6.48
4th	28,964	1509	5.21	1602	5.53	1871	6.46	28,347	1429	5.04	1335	4.71	1437	5.07
5th	391	15	3.84	9	2.30	11	2.81	369	8	2.15	8	2.04	8	2.16
Total	55,615	3799	6.83	3611	6.49	4033	7.25	50,966	3153	6.19	2865	5.62	3024	5.93

Under the ASM5025 test conditions, the UA is 4649, which is the difference of test samples between ASM5025 and ASM5025, and corresponding UR is 8.36%. Under the condition of ASM2540 test conditions, the UR is at least 6.19% (the highest UR of HC, CO and NO). Therefore, the overall UR is at least 14.55% and the maximum is 26.1% under the ASM test conditions.

3.2. Comparative Analysis of UR

3.2.1. Under Different Test Conditions

According to the statistical results in Table 3, the UR of HC, CO and NO is shown in Figure 2 under different test conditions.

Figure 2 shows the UR of exhaust pollutants of the in-use vehicles increases with the service life, for example, the UR of vehicles in the 1st interval class is far higher than that of the 5th interval class. The UR under ASM5025 conditions is larger than that of ASM2540 in each service life interval, which is equivalent to the exhaust pollution level when the vehicle is operating at a medium load of 50% and a low speed of 25 km/h is greater than at a small load of 25% and a high speed of 40 km/h. Compared with other two exhaust pollutions, the UR of NO is larger under ASM5025 conditions and HC is larger under ASM2540 conditions. The result is consistent with the large amount of NO_x produced under a heavy load and HC produced under a high engine speed.

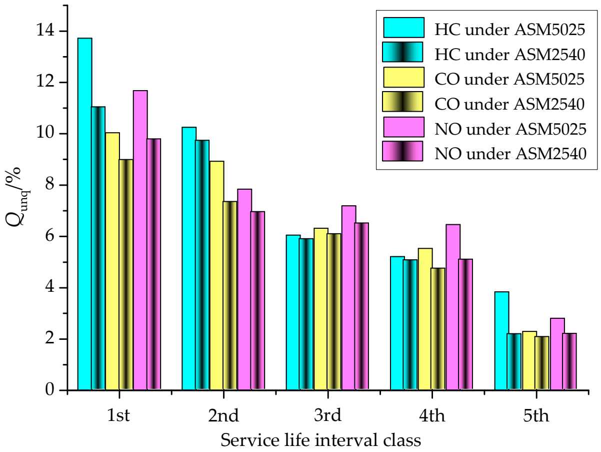

Figure 2. Unqualified rate comparison.

3.2.2. Under Same Test Conditions

Based on the UR of 5th interval class, statistics on the increase multiples of UR in different service life intervals are shown in Table 4, and the comparison results are demonstrated in Figure 3.

Table 4. Increase multiples comparison of unqualified rate in different service life intervals.

Interval Class		1st	2nd	3rd	4th	5th
ASM5025	HC	3.57	2.67	1.58	1.36	1.00 (3.84%)
	CO	4.37	3.88	2.75	2.40	1.00 (2.30%)
	NO	4.17	2.79	2.56	2.30	1.00 (2.81%)
ASM2540	HC	5.22	4.52	2.73	2.34	1.00 (2.15%)
	CO	4.39	3.59	2.97	2.16	1.00 (2.04%)
	NO	4.52	3.20	3.00	2.35	1.00 (2.16%)

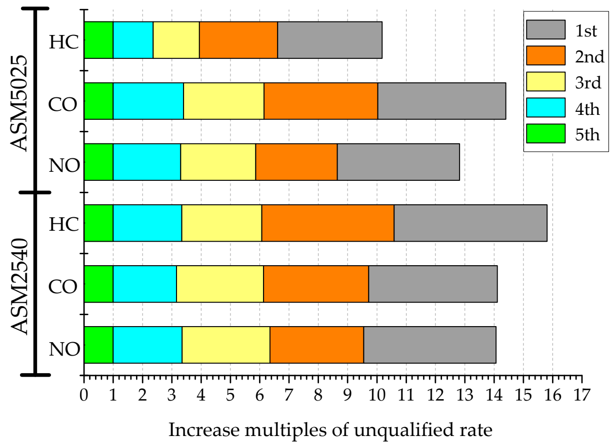

Figure 3. Increase multiples comparison of unqualified rate.

According to the statistical results, under the ASM5025 test conditions, the UR of vehicles caused by HC emission exceeding limit plays a small part in overall UR, and it is less than that of CO and NO with the increase of service life. On the contrary, the UR of vehicle detection caused by HC emission exceeding standard increases more greatly with the increase of service life compared with the UR of CO and NO under the ASM2540 test conditions. Generally, increase of service life promotes the deterioration of vehicle emission control system, which directly leads to the increase of exhaust pollution intensity. As a result, the UR of vehicle exhaust pollutions increases with service life.

In addition, the UR increment caused by HC and NO exceeding limit under ASM2540 test conditions is higher than ASM5025. In the two test conditions, the UR increment caused by CO exceeding limit is similar; however, in the 2nd interval class and 4th interval class, the UR increment caused by CO exceeding limits under ASM2540 test conditions is lower than that of ASM5025.

3.3. Average and Variation

Under the conditions of ASM5025 and ASM2540, the average of HC, CO and NO detection results is shown in Table 5.

Table 5. Average of detection results.

Interval Class	ASM5025			ASM2540		
	HC ($\times 10^{-6}$)	CO (%)	NO ($\times 10^{-6}$)	HC ($\times 10^{-6}$)	CO (%)	NO ($\times 10^{-6}$)
1st	132	0. 97	1542	121	0.81	1394
2nd	116	0.79	1312	103	0.67	1186
3rd	102	0.66	1008	95	0.54	968
4th	94	0.58	887	83	0.47	793
5th	86	0.45	648	71	0.39	571

Therefore, under different test conditions, according to the classification of service life interval, the variation tendencies of the average of detection results of exhaust pollutants HC, CO and NO are shown in Figure 4.

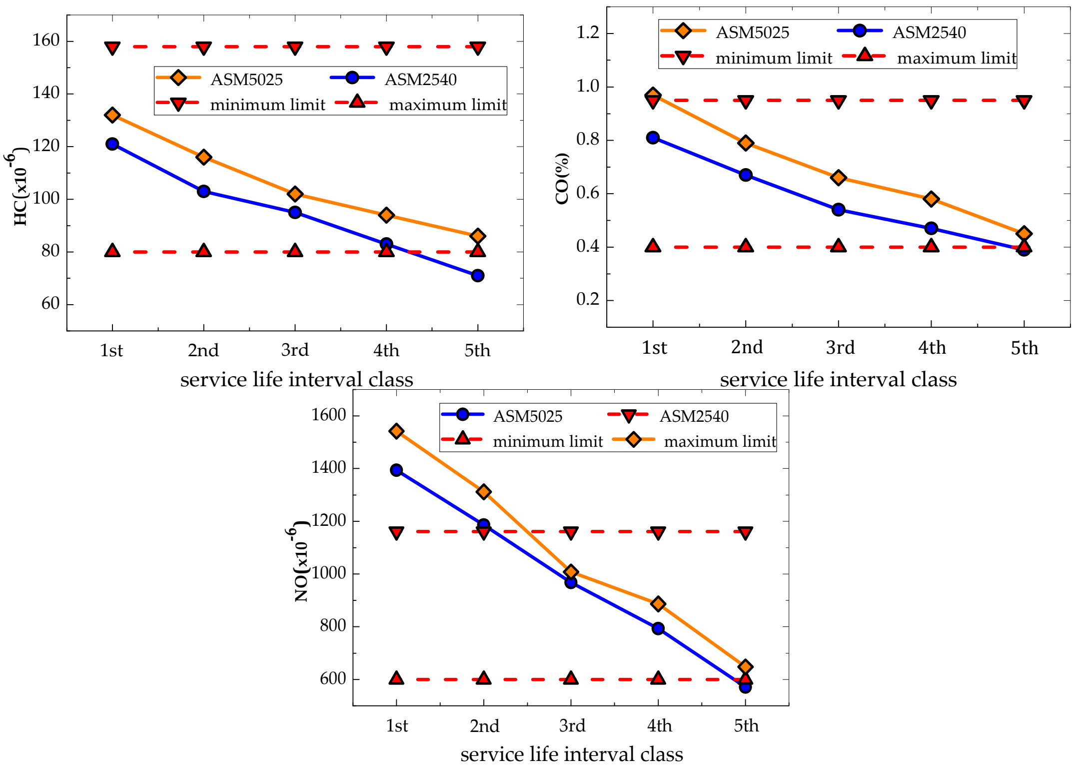

Figure 4. Variation tendencies of average of detection results.

The minimum limit and maximum limit of HC, CO and NO shown in Figure 4 are, respectively, averaged under the two test conditions of ASM5025 and ASM2540; meanwhile, the minimum and maximum limits recommended by *HJ/T 240-2005* are taken into consideration. As shown in Table 6, the average value of limits is determined through taking an average of all emission limits of vehicles in which RM is less than 2500, i.e., the average value of Class I and Class II. In fact, the minimum limit line (▼) and maximum limit line (▲) showed in Figure 4 are plotted by the average limit of Class II.

Table 6. Average values of the limits of vehicle emission pollutants.

Average Value of Limit (RM ≤ 2500 kg)	Minimum Limit (▼)						Maximum Limit (▲)					
	ASM5025			ASM2540			ASM5025			ASM2540		
	HC ($\times10^{-6}$)	CO (%)	NO ($\times10^{-6}$)	HC ($\times10^{-6}$)	CO (%)	NO ($\times10^{-6}$)	HC ($\times10^{-6}$)	CO (%)	NO ($\times10^{-6}$)	HC ($\times10^{-6}$)	CO (%)	NO ($\times10^{-6}$)
Class I	159	1.48	2735	157	1.96	2557	83	0.9	1729	77	1.0	1593
Class II	159	0.9	1214	157	1.0	1107	83	0.4	629	77	0.4	570
Average Limit	HC ($\times10^{-6}$)		CO (%)		NO ($\times10^{-6}$)		HC ($\times10^{-6}$)		CO (%)		NO ($\times10^{-6}$)	
Class I	158		1.72		2646		80		0.95		1665	
Class II	158		0.95		1160.5		80		0.4		600	

From the variation tendencies in Figure 4, the average of detection results of HC and CO is generally between the minimum limit line and the maximum limit line in the whole service life. However, the average of test results of NO is higher than the minimum limit line for vehicles with a service life of more than nine years; that is to say, the UR of NO increases significantly.

3.4. Emission Standard Revision

Aimed at the test data collected from in-use vehicles, the UR statistics of exhaust pollutants was conducted under the ASM test procedure based on the emission limits provided by *DB 23/1061-2006*, which is the local emission standard of Hei Longjiang Province in China [36]. The analysis result is shown in Table 7.

Table 7. Unqualified rate under ASM test conditions based on *DB 23/1061-2006*.

Testing Method	Vehicles Amount	Ratio (%)	Individual Unqualified Rate (%)						Total Unqualified Rate (%)
			ASM5025			ASM2540			
			HC	CO	NO	HC	CO	NO	
ASM	57,997	57.00	3.83	2.04	3.28	1.02	0.36	1.70	8.55
				6.41			2.14		

As shown in Table 7, the total UR of exhaust pollutants of in-use vehicle under ASM test procedure is 8.55%, which is lower than the recommended regulation proportion of 10–25% provided in *HJ/T 240-2005* for the high-emission vehicles [30]; therefore, it is necessary to tightened emission limits of *DB 23/1061-2006*.

According to the statistical analysis in Sections 2 and 3, the overall deterioration rate of CO and HC was both lower than NO, and the average emission value is also lower than the minimum limit recommended by *HJ/T 240-2005*. Moreover, the degradation rate of NO is higher, and the average emission value with service life over 8–10 years is higher than the minimum recommended by *HJ/T 240-2005*. Therefore, the standard revision object is emission limits of NO by tightening relatively for exhaust pollutants of in-use vehicles in Hei Longjiang province. In addition, considering the environmental protection requirements of nitrogen and oxygen compounds emission reduction proposed by the National "12th Five-Year Plan", the emission limits of CO and HC are not revised.

3.4.1. Pre-Revised Limits Comparison of NO

The pre-revised limits, original limits provided by *DB 23/1061-2006* and the maximum limits recommended by *HJ/T 240-2005* of NO for Class I and Class II vehicles are shown in Tables 8 and 9. The value in the NO column is pre-revised limits/original standard limits/the maximum limits recommended by *HJ/T 240-2005*, and the limits of CO and HC are the same as the original standard *DB 23/1061-2006*, respectively.

Table 8. Pre-revised Class I emission limits in a new standard.

RM (kg)	ASM5025			ASM2540		
	HC (10^{-6})	CO (%)	NO (10^{-6})	HC (10^{-6})	CO (%)	NO (10^{-6})
RM ≤ 1020	180	1.5	2800/3200/2600	170	1.6	2500/3000/2400
1020 < RM ≤ 1250	170	1.3	2300/2800/2100	160	1.4	2100/2600/2000
1250 < RM ≤ 1470	150	1.1	2100/2400/1900	150	1.2	2000/2300/1750
1470 < RM ≤ 1700	130	1.0	1800/2100/1700	130	1.1	1600/2000/1550
1700 < RM ≤ 1930	120	0.9	1600/1800/1400	120	1.0	1500/1600/1300
1930 < RM ≤ 2150	110	0.8	1400/1600/1300	110	0.9	1300/1400/1150
2150 < RM ≤ 2500	100	0.7	1200/1300/1100	100	0.8	1100/1200/1000
	Average Limit		1886/2171/1726	Average Limit		1729/2014/1600

Table 9. Pre-revised Class II emission limits in a new standard.

RM (kg)	ASM5025			ASM2540		
	HC (10^{-6})	CO (%)	NO (10^{-6})	HC (10^{-6})	CO (%)	NO (10^{-6})
RM ≤ 1020	150	0.9	1000/1300/950	140	1.0	900/1200/850
1020 < RM ≤ 1250	130	0.8	900/1100/800	120	0.9	800/1000/700
1250 < RM ≤ 1470	120	0.7	800/1000/700	110	0.8	700/900/650
1470 < RM ≤ 1700	110	0.6	700/900/600	100	0.7	650/800/550
1700 < RM ≤ 1930	100	0.5	600/700/500	90	0.6	550/650/450
1930 < RM ≤ 2150	90	0.4	500/600/450	80	0.5	450/550/450
2150 < RM ≤ 2500	90	0.4	450/500/400	80	0.5	400/450/350
	Average Limit		707/871/629	Average Limit		636/793/571

From the Tables 8 and 9, the pre-revised average limit of 16.50%, which is lower than the average limit provided by the original standard; however, it is higher than the average limit recommended by *HJ/T 240-2005* by 11.09%.

3.4.2. UR Prediction Based on the Pre-Revised Limits

(1). The prediction and analysis processes for total UA of in-use vehicles after pre-revising the emission limits are demonstrated in Figure 5.

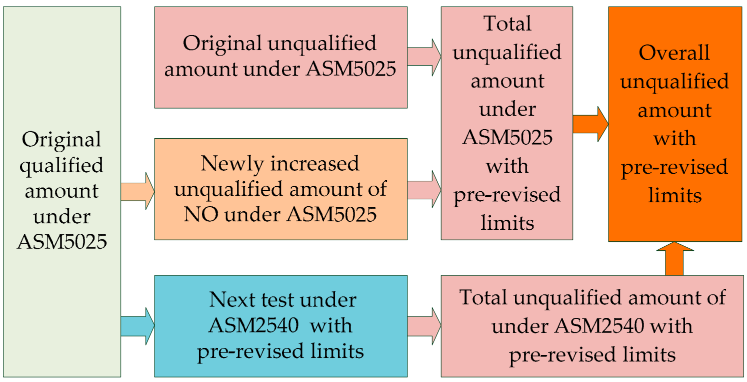

Figure 5. Prediction and analysis processes for total unqualified amount.

Firstly, aimed at testing the total qualified in-use vehicles under ASM5025 test conditions with the pre-revised limits, and finding the newly added unqualified vehicles, then the remaining qualified vehicles tested in the previous stage are continued to be tested to determine the total UA under

ASM2540 test conditions. At last, the overall UA consists of ASM5025 and ASM2540 test conditions with the pre-revised standard.

(2). The increment of unqualified vehicles based on the pre-revised Class I and Class II standard limits is shown in Tables 10 and 11.

Table 10. Unqualified increment under the pre-revised Class I standard limits.

RM (kg)	ASM5025				ASM2540			
	Original Limits	Pre-Revised Limits	Tightened Proportion (%)	Unqualified Increment	Original Limits	Pre-Revised Limits	Tightened Proportion (%)	Unqualified Increment
RM ≤ 1020	3200	2800	12.5	1	3000	2500	16.67	16
1020 < RM ≤ 1250	2800	2300	17.9	10	2600	2100	19.23	31
1250 < RM ≤ 1470	2400	2100	12.5	8	2300	2000	13.04	30
1470 < RM ≤ 1700	2100	1800	14.3	20	2000	1600	20.00	85
1700 < RM ≤ 1930	1800	1600	11.1	14	1600	1500	6.25	14
1930 < RM ≤ 2150	1600	1400	12.5	7	1400	1300	7.14	5
2150 < RM ≤ 2500	1300	1200	7.69	6	1200	1100	8.33	13
	Average tightened proportion (%)		12.64	66	Average tightened proportion (%)		12.95	194
Total tightened proportion: 12.80% Total unqualified increment: 270								

Table 11. Unqualified increment under the pre-revised Class II standard limits.

RM (kg)	ASM5025				ASM2540			
	Original Limits	Pre-Revised Limits	Tightened Proportion (%)	Unqualified Increment	Original Limits	Pre-Revised Limits	Tightened Proportion (%)	Unqualified Increment
RM ≤ 1020	1300	1000	23.08	421	1200	900	25.00	813
1020 < RM ≤ 1250	1100	900	18.18	599	1000	800	20.00	913
1250 < RM ≤ 1470	1000	800	20.00	1410	900	700	22.22	1501
1470 < RM ≤ 1700	900	700	22.20	716	800	650	18.75	537
1700 < RM ≤ 1930	700	600	14.29	336	650	550	15.38	212
1930 < RM ≤ 2150	600	500	16.67	283	550	450	18.18	171
2150 < RM ≤ 2500	500	450	10.00	132	450	400	11.11	90
	Average tightened proportion (%)		17.78	4927	Average tightened proportion (%)		18.66	5434
Total tightened proportion: 18.22% Total unqualified increment: 10,361								

(3). According to the proposed pre-revised limits, the newly increased UR is 13.94% under ASM test conditions, where the synchronous new unqualified increment both ASM5025 and ASM2540 test conditions is 2806. Therefore, the overall UR is predicted to be 22.04% with the implementation of the re-revised limits, and the 22.04% is the sum of the original UR 8.55% and the newly increased UR 13.94%.

(4). As shown in Table 10, we can find that the new unqualified increment of vehicles of Class I standard limits is low significantly, which has little effect on the overall UR with the total unqualified increment of 270 and the increase proportion of 0.47%. On the contrary, it is clear that the UR of vehicles required by Class II standard limits changes remarkably, caused generally by the vehicles whose reference mass is less than 1700. As shown in Table 11, the total UA of vehicles increases by 10,361, and the proportion increases by 17.86%.

The predicted UR of exhaust pollutants under ASM test conditions increases by 22.04%, which is 2.6 times than the previous UR of 8.55% if the pre-revised standard are adopted. Obviously, the bigger tightened proportion directly results in a great increment of UR for in-use vehicles.

3.4.3. UR Prediction Based on the Revised Standard

Table 11 shows that the UR increases significantly for vehicles required by Class II limits when the RM is less than 1700, and thus the emission limits of NO according to the corresponding reference mass should be further loosened up properly. The increment of unqualified vehicles is shown in Table 12 after revising emission limits once more.

Table 12. Increment prediction of unqualified vehicles after revising the Class II emission limits once more.

RM (kg)	ASM5025				ASM2540			
	Original Limits	Loosened up Limits	Tightened Proportion (%)	Unqualified Increment	Original Limits	Loosened up Limits	Tightened Proportion (%)	Unqualified Increment
RM ≤ 1020	1300	1100	15.4	323	1200	1000	16.7	586
1020 < RM ≤ 1250	1100	1000	9.10	599	1000	900	10.0	913
1250 < RM ≤ 1470	1000	900	10.0	1410	900	800	11.1	1501
1470 < RM ≤ 1700	900	800	11.1	479	800	700	12.5	440
1700 < RM ≤ 1930	700	650	7.14	336	650	550	15.4	212
1930 < RM ≤ 2150	600	550	8.33	283	550	450	18.2	171
2150 < RM ≤ 2500	500	500	0.00	132	450	400	11.1	90
	Average tightened proportion (%)		10.18	3562	Average tightened proportion (%)		13.57	3913
Total tightened proportion: 11.88% Total unqualified increment: 7475								

As shown in Table 12, the loosened up emission limits of NO is tightened by 11.88% compared with the original limits required by *DB 23/1061-2006*, and it is relaxed by 6.34% compared with the pre-revised limits. Therefore, the increment of unqualified vehicles has been reduced by 2886, and the overall UR decreases accordingly.

The newly increased UR is predicted to 9.49% under ASM test conditions if the revised standard can be performed, where the synchronous new increment of unqualified vehicles both ASM5025 conditions and ASM2540 conditions is 2242. It is clear that the overall UR is 18.04%, which is reduced by 4.00% more than the pre-revised limits and meets the recommended UR of 10–25% required by MEPOPRC. In fact, the realistic UR of exhaust pollutants of in-use vehicles will be lower than the above prediction value along with the development of advanced emission control technology, and more and more new vehicles emerge on the road.

4. Conclusions

Statistical analysis of the UR and change regulation of the in-use vehicles exhaust pollutants is carried out under ASM test conditions according to the service life interval. Results show that the determination of emission limits has a direct effect on the UR of in-use vehicles, and the UR is at least 14.55%, the maximum reaches 26.1%, which basically meets the requirement that the UR is controlled by 10–25%. The increase of service life promotes the deterioration of vehicle emission control systems, which directly leads to the increase of exhaust pollution intensity. The UR of exhaust pollutants HC, CO and NO under ASM5025 test conditions is larger than ASM2540 test conditions, and there is an overall growth trend of UR with the addition of service life. When the service life is more than nine years, the average annual change value increases significantly, which shows that the technical performance of vehicle emission pollution control system has a remarkable influence on pollutant emissions; therefore, these heavy pollution vehicles should be supervised emphatically.

Revisions of emission standards in Hei Longjiang province follow the principle of new vehicles meeting new standards and old vehicles meeting old standards and the strategy of implementation of strict vehicle emission standards in continual phases after loosening up initially. The standard revision process is presented through determining the revision object of EPL and predicting UR based on the pre-revised limits and post-revised limits. Compared with the original standard, the overall tightened proportion is 12.34%, and the UR is expected to 18.04% under revised emission standards, so there is enough space to be further tightened. The management level of exhaust pollutants of in-use vehicles will be improved through supervising and adjusting of emission level and UR continuously in Hei Longjiang Province.

Further work is needed to make this work more comprehensive. First, the test data of exhaust pollutants is currently only focused on local vehicle detection stations, which is hardly representative. Using a different city's test data may produce different results, and finding an optimum analysis method would be an important aspect in our future work. Furthermore, when a great development of hybrid vehicles is occurred, it is also important to re-revise the emission standard.

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Abbreviations

The following abbreviations are used in this manuscript:

MEPOPRC	Ministry of the Environmental Protection of the People's Republic of China
CO_2	carbon dioxide
CO	carbon monoxide
NO_x	nitrogen oxide
ASM	acceleration simulation mode
EPL	exhaust pollutants limits
HC	hydrocarbon
NO	nitric oxide
RM	reference mass
UR	unqualified rate
UA	unqualified amount

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