

# A Survey and Comparison the Amount of Important Pollutants in the Exhaust of Light Gasoline Vehicles Referring to the Technical Inspection Centers in Urban Areas: A Case Study in Iran

Abbas Khodabakhshi<sup>1</sup>, Moluk Hadi Alijanvand<sup>2,3</sup>, Fazel Mohammadi-Moghadam<sup>1</sup>, Abdullah Mutauligalleh kolaie<sup>4</sup>, Soghra Ebrahimi<sup>1</sup>

<sup>1</sup>Department of Environmental Health Engineering, School of Health, Shahrekord University of Medical Sciences, Shahrekord, Iran, <sup>2</sup>Modeling in Health Research Center, Shahrekord University of Medical Sciences, Shahrekord, Iran, <sup>3</sup>Department of Epidemiology and Biostatistics, School of Health, Shahrekord University of Medical Sciences, Shahrekord, Iran, <sup>4</sup>Management of the Union of Public Transport Organizations and Executive Affairs of Technical Inspection of Cars in Iran

## Abstract

**Aims:** Traffic congestion and the increase in the number of vehicles lead to an increase in vehicle emissions, consequently causing, a decrease in ambient air quality. The objective of this study is to investigate and compare the concentrations of exhaust gases, namely carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), hydrocarbon (HC), and oxygen (O<sub>2</sub>), emitted by cars tested at the Technical Inspection Centers in Shahrekord and Rasht. **Methods:** In this cross-sectional study, primary data from 82,316 cars examined at the technical centers in Shahrekord and Rasht were collected and subjected to statistical analysis. The car frequencies considered were 1000 and above. Overall, 16 types of Iranian and foreign cars were assessed, with 51,919 cars from Rasht and 30,397 cars from Shahrekord. The statistical analysis employed a six-way multivariate analysis of variance. **Results:** The proportion of carbureted cars that were rejected exceeded that of injection cars, while the percentage of cars rejected due to CO<sub>2</sub> emissions was lower than that of authorized cars ( $P < 0.05$ ). Furthermore, the likelihood of these associations occurring in Shahrekord city was higher than in Rasht city, with a chance ratio and confidence interval (CI) of 95. The odds ratios (ORs) (95% CI) were 1.936 (1.829–2.050) and 3.036 (2.924–3.151), respectively. Moreover, the rejection rates were higher ( $P < 0.05$ ) for cars manufactured in Iran compared to foreign-made cars, private vehicles compared to public vehicles, and cars with CO pollution compared to licensed cars. The likelihood of these associations transpiring in Shahrekord city, in comparison to Rasht city, were as follows: OR (95% CI) of 0.793 (0.755–0.834), 0.667 (0.743–0.598), and 0.018 (0.016–0.020), respectively. The audit analysis, which involved a linear combination of O<sub>2</sub>, CO, CO<sub>2</sub>, HC, and vehicle age, successfully differentiated between cars in Shahrekord and Rasht, yielding a correct prediction rate of 81.3% (Wilks' Lambda statistic = 0.687, Eigen value = 0.455, Canonical correlation value = 0.60 with a  $P < 0.0001$ ). **Conclusion:** The findings of this study offer a practical approach to address the complexities arising from the emission of polluting gases, contributing to the global warming phenomenon.

**Keywords:** Air pollution, exhaust emissions, lambda coefficient, Rasht, Shahrekord

## INTRODUCTION

In recent years, developing countries have experienced significant economic growth, yet progress in environmental activities and urban infrastructure development has been limited. However, there has been a dramatic increase in car production and usage, leading to various problems.<sup>[1]</sup> One of the notable consequences of transportation is the rise in energy consumption within this sector, resulting in significant environmental issues such as global climate change and air

**Address for correspondence:** Dr. Soghra Ebrahimi, Faculty of Health, Shahrekord University of Medical Sciences, Shahrekord, Iran. E-mail: ebrahimi.s1271@gmail.com

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pollution in urban areas. The increased traffic, primarily concentrated in urban regions, has led to increased production and emission of pollutants with higher concentrations in these areas.<sup>[2]</sup>

Statistics indicate that in 2018, the transportation sector accounted for 97% of carbon monoxide (CO) emissions and 79% of hydrocarbon (HC) emissions in the country. Fixed sources contributed 10%–15% to air pollution, while mobile sources, such as vehicles, contributed 85%–90%.<sup>[3,4]</sup> It is evident that vehicles, especially passenger cars, are one of the main sources of pollution in urban areas of our country. Therefore, any efforts to control and reduce air pollutants and improve air quality in different regions of Iran should primarily focus on addressing mobile sources.<sup>[3]</sup> Air pollution is a consequence of industrial development, which escalates with population growth, urban expansion, transportation development, and fuel consumption.<sup>[1,2,5]</sup> The World Health Organization (WHO) estimates that the annual cost of air pollution in Austria, France, and Switzerland for the health sector is around 30 billion pounds, with half attributed to vehicles.<sup>[6]</sup> The WHO considers air pollution as the fourth leading risk to overall health,<sup>[7]</sup> categorizing it as a Group 1 carcinogen. High exposure to various pollutants increases the risk of cardiovascular diseases, including heart attacks and atherosclerosis, resulting from the nonsystematic blockage of heart vessels.<sup>[8]</sup>

Climate change and air pollution are two significant environmental challenges that humanity will face in the coming decades, with the transportation sector playing a pivotal role in both cases. Transportation not only stands as a crucial source of air pollution in urban areas but also on a global scale. Recent estimations reveal that transportation contributes 21% of global carbon dioxide (CO<sub>2</sub>) emissions, 37% of nitrogen oxides (NO<sub>x</sub>), 19% of volatile organic compounds (VOCs), 18% of CO, and 14% of black carbon.<sup>[9]</sup> Numerous studies have established that car emissions are responsible for environmental issues such as global warming, the formation of photochemical smog, and acid rain. Global warming leads to rising temperatures, extreme weather events, and changes in weather patterns worldwide.<sup>[10]</sup>

Motor vehicles, particularly private cars, constitute 90% of the total energy consumed in the transportation sector and stand as one of the primary artificial sources of air pollution. Vehicle-related air pollution stems from by-products generated during the combustion process (exhaust emissions) and fuel evaporation.<sup>[11,12]</sup> The main sources of air pollutants in cities are fuel combustion in cars, gas emissions, and visible exhaust fumes, all contributing to air pollution. Gasoline has been the predominant fuel type for passenger cars in Iran for many years.<sup>[5,13]</sup> Gasoline engines, although less efficient than diesel engines, produce higher amounts of CO<sub>2</sub>, CO, and unburned HCs. However, they emit lower levels of NO<sub>x</sub>, sulfur dioxide (SO<sub>2</sub>), and particles compared to diesel engines.<sup>[13]</sup> In gasoline vehicle engines, the primary emissions consist of NO<sub>x</sub>, CO, HCs, and VOCs.<sup>[14]</sup>

The combustion of fossil fuels in various sources leads to the release of pollutants such as CO<sub>2</sub>, CO, unburned HCs, NO<sub>x</sub>, SO<sub>2</sub>, lead (Pb), and particulate matter (PM). Consequently, urban air quality is compromised, posing health risks. Emission of pollutants accounts for 70%–80% of total air pollution in developing countries.<sup>[15,16]</sup>

It is important to recognize that actual gaseous pollutant emissions depend on factors such as vehicle specifications, emission control technology, operating conditions, and fuel specifications.<sup>[17]</sup> Previous studies have shown that heavy operation, high mileage, and inadequate maintenance contribute to engine and catalyst degradation, consequently increasing pollutant emissions from in-use vehicles.<sup>[18]</sup> Given that mobile sources (vehicles) account for the majority of energy consumption and air pollution, it is crucial to consider suitable solutions to address this issue. Vehicle technical inspections stand as one of the most effective methods to control air pollution and improve vehicle safety. In Iran, vehicle technical inspections were incorporated into driving laws in 1974, and in 1990, the central headquarters for technical inspections of cars in Tehran was established under the purview of the Transportation and Traffic Department of Tehran Municipality.<sup>[19]</sup>

The height difference between Islamabad and Khanjrab Pass has a significant effect on the emission characteristics of cars because the heights change the driving behaviors and affect the load and pressure conditions inside the combustion engines.<sup>[20,21]</sup> Human *et al.*<sup>[22]</sup> measured emissions from two diesel engines, one naturally aspirated and one turbocharged, both at low altitudes and in simulated high-altitude conditions. Results indicated that engine operation at 1800 m above sea level resulted in emissions of NO<sub>x</sub> reduced by approximately 10%, whereas emissions of CO, HCs, PM, and aldehydes were higher than those at low altitude by a factor of 2–4 and 1.2–2 for the naturally aspirated and turbocharged engines, respectively. He *et al.*<sup>[23]</sup> coupled an engine bench with an altitude simulation system to evaluate the effects of altitude from sea level to 2000 m. Their experimental results indicated that CO, HC, and smoke emissions increased by 35%, 30%, and 34%, respectively, every 1000 m. However, high-altitude NO<sub>x</sub> emissions depend on the engine type and operating conditions. Wang *et al.*<sup>[24]</sup> found that CO emissions from a light-duty diesel vehicle were 209% higher at an altitude of 2990 m than at sea level, whereas NO<sub>x</sub> emissions decreased after rising with altitude.

Considering the extensive effects of car exhaust pollutants on the environment, economy, and most importantly human health, and considering the increasing growth of cars in the cities of Shahrekord and Rasht, which have led to an increase in air pollution. This study aims to compare and determine the relationship between exhaust emissions and factors such as car model, country of manufacture, frequency of visits, year of car manufacture, fuel supply system (injector-carburetor), and lambda coefficient in these two cities, which in terms of altitude, and the temperature is very different.

## MATERIALS AND METHODS

### Area of the study

Shahrekord, capital of Chaharmahal and Bakhtiari province, had a population of 190,441 in 2016. As the highest provincial capital in Iran at 2060 m above sea level [Figure 1], Shahrekord is nicknamed the “Roof of Iran.” Shahrekord’s high elevation produces mild summers and frigid winters. With growing vehicle traffic dominated by domestic lightweight cars, air pollution has increased in the city.<sup>[25]</sup>

Rasht, the capital of Gilan province, covers an area of 137 km<sup>2</sup> at an average elevation of 50 m above sea level [Figure 1]. Its proximity to the Caspian Sea results in high humidity and rainfall. Gilan’s climate is characterized as the temperate Caspian climate zone. Surrounded by mountains, cooled air traps pollutants near ground level in Rasht. The primary source is fossil fuel emissions from nonstandard vehicles and public transportation. According to the 2016 official census, Rasht’s population is 679,995. As the capital, over 1,000,000 people commute into the city daily. During peak tourist seasons and holidays, the population exceeds 2 million, making Rasht the most densely populated city in Iran given its size.

### Study population and sampling method

This cross-sectional case study utilizes descriptive-analytical data extracted from the Samfa system census records.<sup>[26]</sup> An agreement between Shahrekord University of Science and Medicine and the Union of National Public Transport Organizations allowed collection of technical inspection center data for two Iranian cities, Shahrekord and Rasht. Data from 1400 (2021) were obtained and analyzed. Primary vehicle data were gathered from 6 Rasht and 2 Shahrekord technical inspection centers. Criteria for review and comparison included rejection and acceptance based on exhaust emission measurements during testing. Data collection involved vehicle specifications, emission tests, and preliminary technical inspection results (pass/fail) recorded in the Iran’s integrated technical examination system.

A total of 82,316 light vehicles were inspected at the two city centers (51,919 in Rasht, 30,397 in Shahrekord). Emissions were compared.

The study population consisted of common Iranian (Pride, Peugeot 405, Peugeot 206, MVM, L90, Peugeot Pars, Peugeot) and foreign (Japan, Korea, China) light vehicles referred for inspection. Variables included manufacture country, fuel delivery (carburetor or injector), usage (public or private), model, manufacture year, visit frequency (1–5 times), exhaust emissions (CO, HC, CO<sub>2</sub>, oxygen [O<sub>2</sub>]), and lambda coefficient. Only vehicles with over 1000 inspection visits were included.

Data analysis utilized the standards in Table 1. Vehicles above and below specified emission levels were considered impermissible and permissible, respectively.

### Statistical methods

Quantitative variables were summarized using mean and standard deviation, while qualitative variables used frequency and percentage. Chi-squared and Cochran-Mantel-Henzel tests accounted for Shahrekord and Rasht city effects when investigating relationships between qualitative variables and technical inspection results (accept/reject). Preliminary comparisons of mean pollution indicators (CO, HC, O<sub>2</sub>, and CO<sub>2</sub> emission rates) between Rasht and Shahrekord used independent *t*-tests. A six-way multivariate analysis of variance (MANOVA) considered two-way interactions between fuel delivery system (injection, carburetor), manufacturing country (Iranian/foreign), city, vehicle age (<5, 5–10, 10–20, 15–20, >20 years), lambda coefficient (<0.95, 0.95–1.05, >1.05), and inspection result (accept, reject). This optimal MANOVA model compared mean emission indices using multivariate O<sub>2</sub>, CO, and HC emission out comes. Linear discriminant analysis differentiated Rasht and Shahrekord vehicles based on predictive variables. Kappa coefficients evaluated agreement between predicted city from the analysis and actual city in

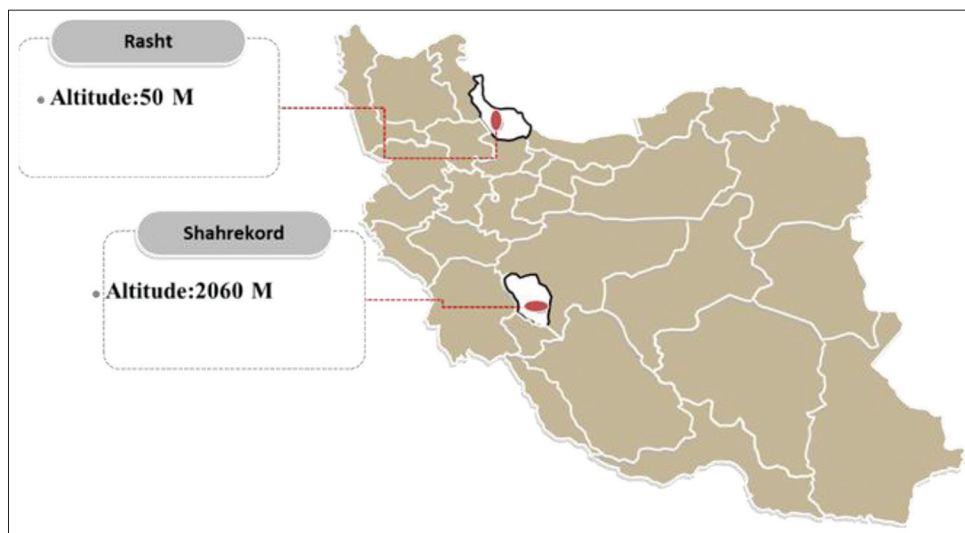


Figure 1: Geographical location of Shahrekord and Rasht

the dataset. Analyses were performed in SPSS software version 20 (IBM, Chicago, IL) with a 0.05 significance level.

## RESULTS

### Frequency percentage of studied cars

In this study, we collected and analyzed primary data from 82,316 light cars across eight technical examination centers, with six centers located in Rasht and two in Shahrekord. The main focus of our research was to investigate the levels of exhaust pollutants, specifically O<sub>2</sub>, HC, CO, CO<sub>2</sub>, and Lambda coefficient ( $\lambda$ ) emitted by light vehicles in the cities of Shahrekord and Rasht [Figure 2].

### Presenting and analyzing the results of technical inspections

Figure 3a presents the frequency distribution of cars categorized by their type and country of manufacture. The analysis reveals that Iran's Pride exhibits the highest frequency, while Iran's Peugeot RD has the lowest frequency. Furthermore, Figures 3b and c provide separate frequency distributions for cars in the cities of Shahrekord and Rasht, respectively. Lastly, Figure 3d displays the results of the technical examination, showcasing the outcomes of car acceptance and rejection.

### Comparing the homogeneity of the distribution of each qualitative variable based on the result of the technical examination in the cities of Shahrekord and Rasht

Table 2 provides an overview of the homogeneity in the distribution of each qualitative variable, based on the results of the technical examination in the cities of Shahrekord and Rasht. Table 2 presents the homogeneity of variables such as the country of manufacture, type of fuel delivery system, type of car use (private or public), frequency of visits, age, and the

emission levels of CO, HC, O<sub>2</sub>, and CO<sub>2</sub> pollutants. It also indicates the likelihood of a significant relationship between different variables and the results of the technical examination.

The results of the independent *t*-test reveal that, despite the significant difference resulting from the large sample size of the study ( $P > 0.0001$ ), there is no significant difference observed between the mean age of cars and the mean levels of O<sub>2</sub> and CO emissions in Shahrekord and Rasht. However, a significant difference does exist in the mean emission levels of HC and CO<sub>2</sub>, as indicated in Table 3.

The estimated marginal mean of the studied pollutants using the MANOVA model is shown in Figures 4-7.

## DISCUSSION

### Frequency percentage of studied cars

In this study, 93% of the cars examined were found to have injectors, while 7% were carburetors [Figure 2]. The sample size considered was 1000 cars or more. A total of 16 Iranian and foreign car types were analyzed. Among them, Shahrekord Pride had the highest frequency (38%), while the Iranian Peugeot RD had the lowest frequency (1%) [Figure 3a]. Figure 3c illustrates the distribution of cars by city, with Shahrekord having the highest frequency of Pride and Rana being the least frequent. In Rasht, the highest frequency was observed for Iran's Pride and the lowest for Peugeot Roa.

Figure 3d presents the results of the technical examination for different car models. In Shahrekord, Pride had the highest frequency, while Rana (Iran) had the lowest. In Rasht, Pride had the highest frequency, and Peugeot RD had the lowest. The acceptance rate varied among the cars, with the highest rejection percentage observed for the Iranian Peugeot RD and the lowest for Toyota from Japan. The inadequate quality of Peugeot RD car parts led to incomplete combustion in the engine's combustion chamber and improper air-fuel mixing, causing the car to fail the technical examination.

It should be noted that certain Iranian and foreign cars had similar pass rates in the technical examination. Various factors, such as vehicle type, technical condition, emission control devices, operating conditions, road conditions, maintenance frequency, fuel type, maintenance levels, and road characteristics (altitude, temperature, humidity, road conditions, and traffic) can influence vehicle exhaust emissions.<sup>[16]</sup> In comparison to European cars, Asian vehicles were found to be more likely to violate CO emission criteria. Cars older than

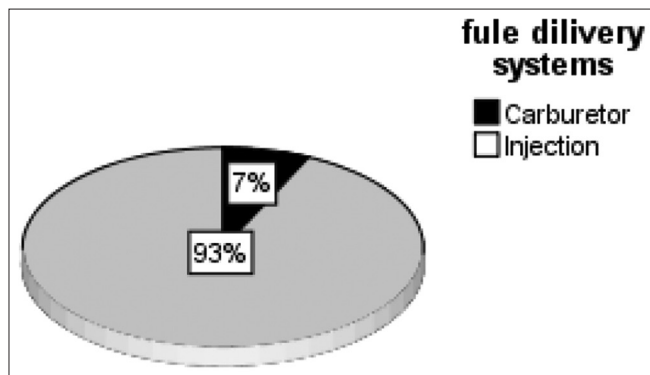
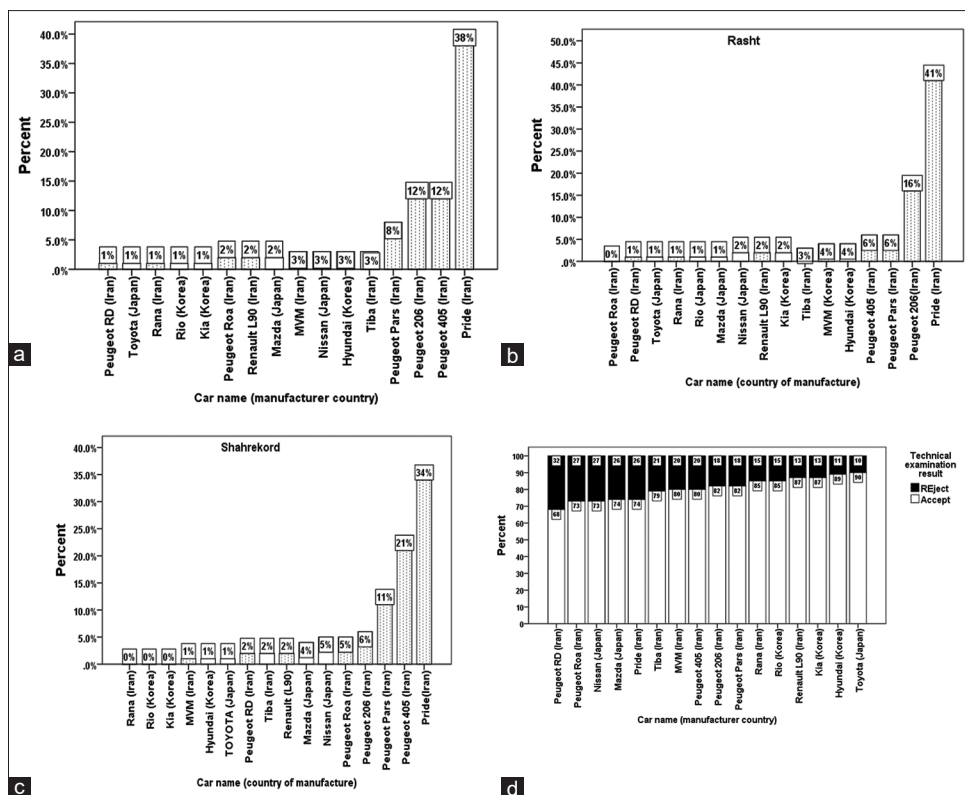


Figure 2: The frequency of cars according to the type of fuel delivery systems

Table 1: The permissible limit of light vehicle emissions (approved by Iran's Supreme Environmental Protection Council 2015) Iran<sup>[3]</sup>

Pollutant/car type	CO <sub>2</sub> (%)	$\lambda$	O <sub>2</sub> (%)	HC (%)	CO (%)
Injection-type light cars (model 83 and later)	14	1±0.05	3	250	0.7
Injection-type light cars (model 83 and before)	14	1±0.05	3	250	2.5
Carburetor light cars (all models)	14	1±0.05	3	400	2.5

HC: Hydrocarbon, CO: Carbon monoxide, CO<sub>2</sub>: Carbon dioxide, O<sub>2</sub>: Oxygen



**Figure 3:** The results of the technical examination of the car (a) (total percentage) (b) Rasht, (c) Shahrekord, (d) according to the name and country of the car manufacturer

15 years and those with mileage exceeding 150,000 km were more prone to higher CO emissions.<sup>[27]</sup> Hassani *et al.* research demonstrated a significant increase in CO and HC emissions in cars over 15 year old compared to those under 5 year old.<sup>[7]</sup>

**The estimated marginal mean of the studied pollutants using the multivariate analysis of variance model**

The estimated marginal mean of the studied pollutants, obtained through the application of the MANOVA model, is visually represented in Figures 4-7. It is worth noting that the rejection rate for foreign cars is lower compared to that of Iranian cars, and the likelihood of a meaningful relationship between the country of manufacture and the outcome of the technical inspection is higher in Rasht than in Shahrekord ( $P < 0.05$ ). Injection cars exhibit a lower rejection rate in comparison to carburetors, as do public cars when contrasted with private cars. In the context of Shahrekord, there exists a higher probability of a significant relationship between the type of fuel supply system and the result of the technical examination. Similarly, public cars manifest a lower rejection rate than private cars ( $P < 0.05$ ), and the likelihood of a significant relationship between car usage (public vs. private) and the technical examination result is greater in Rasht than in Shahrekord. Riveros *et al.*'s research findings demonstrate that vehicles employed in public transportation yield higher levels of CO and HC emissions when compared to private cars.<sup>[28]</sup>

Rejected cars showed a higher percentage of emissions for O<sub>2</sub>, HCs, and CO compared to approved cars ( $P < 0.05$ ). The

likelihood of a significant relationship between O<sub>2</sub> and HC emissions and the technical examination result was similar in Rasht and Shahrekord, whereas the chance of such a connection occurring with CO emissions was higher in Rasht. However, the percentage of rejected cars with CO<sub>2</sub> emissions was lower than that of approved cars ( $P < 0.05$ ), and the likelihood of this relationship occurring was higher in Shahrekord than in Rasht.

**Carbon monoxide**

Regarding CO emissions, Figure 3 displays the marginal mean obtained from the MANOVA. It indicates that rejected cars have higher CO emission levels compared to accepted cars. Shahrekord and Rasht exhibit similar mean CO emission levels. Carburetor cars have higher CO emissions than injectors, while Iranian and foreign cars have comparable mean CO emission levels. Nevertheless, Dargahi and Alawi study demonstrated that foreign-made cars have lower CO and HC emissions compared to domestic cars.<sup>[29]</sup>

When  $\lambda < 0.95$ , a noteworthy observation is the more pronounced slope in the decreasing trend of the mean CO levels in accepted cars compared to the rejected ones. Furthermore, there exists a substantial disparity between the mean CO levels of rejected and accepted cars. However, for  $\lambda > 1.05$ , the decreasing trend in the mean CO levels occurs at a reduced slope, while the range  $\lambda = 0.95 - 1.05$  demonstrates a consistent level. In the case of newly manufactured passable cars with a service life exceeding 5 years and falling within the 5–10 years range, a decreasing trend in mean CO levels

**Table 2: Comparison of the homogeneity of the distribution of each qualitative variable based on the result of the technical examination separately in the cities of Shahrekord and Rasht**

City	Variable	The result of the technical examination of the car			P	OR* (CI)
		Reject	Accept	Total		
Rasht	Manufacturing country					
	Iranian	10,604 (23.7)	34,073 (76.3)	44,677	<0.0001*	0.793 (0.755–0.834)
Foreign	1284 (17.7)	5958 (82.3)	7242			
Shahrekord	Manufacturing Country					
	Iranian	5335 (20.4)	20,941 (79.6)	26,296	<0.861	
Foreign	840 (20.5)	3261 (79.5)	4101			
Rasht	Type of fuel system					
	Carburetor	1349 (37.3)	2268 (62.7)	3617	<0.0001*	1.936 (1.829–2.050)
Injector	10,539 (21.8)	37,763 (78.2)	48,302			
Shahrekord	Type of fuel system					
	Carburetor	622 (28.5)	1558 (71.5)	2180	<0.0001*	
Injector	5573 (19.8)	22,644 (80.2)	28,217			
Rasht	Type of car use					
	Private	11,767 (23)	39,343 (77.0)	51,110	<0.0001*	0.667 (0.598–0.743)
Public	121 (19.8)	688 (85.2)	809			
Shahrekord	Type of car use					
	Private	5916 (20.7)	22,691 (79.3)	28,607	<0.0001*	
Public	279 (15.6)	1511 (84.4)	1790			
Rasht	O <sub>2</sub>					
	Allowed	9511 (19.2)	40,023 (80.8)	49,534	<0.0001	0.001 (0.000–0.001)
Pollutant	2377 (99.7)	8 (0.3)	2385			
Shahrekord	O <sub>2</sub>					
	Allowed	4952 (17.0)	24,197 (83.0)	29,149	<0.0001*	
Pollutant	1243 (99.6)	5 (0.4)	1248			
Rasht	HC					
	Allowed	4841 (16.7)	24,196 (83.3)	49,828	<0.0001*	0.001 (0.001–0.002)
Pollutant	2081 (99.5)	10 (0.5)	2091			
Shahrekord	HC					
	Allowed	4841 (16.7)	24,196 (83.3)	29,037	<0.0001*	
Pollutant	1354 (99.6)	6 (0.4)	1360			
Rasht	CO <sub>2</sub>					
	Allowed	6288 (37.8)	10,361 (62.2)	16,649	<0.0001*	3.036 (2.924–3.151)
Pollutant	5600 (15.9)	29,670 (84.1)	35,270			
Shahrekord	CO <sub>2</sub>					
	Allowed	5287 (24.1)	16,668 (75.9)	21,955	<0.0001*	
Pollutant	908 (10.8)	7534 (89.2)	8442			
Rasht	CO					
	Allowed	8579 (17.8)	39,712 (82.2)	48,291	<0.0001*	0.018 (0.016–0.020)
Pollutant	3309 (91.2)	319 (8.8)	3928			
Shahrekord	CO					
	Allowed	3352 (12.3)	23,906 (87.7)	27,258	<0.0001*	
Pollutant	2843 (90.6)	296 (9.4)	3139			

\*significance, OR: Odds ratio, CI: Confidence interval, HC: Hydrocarbon, CO: Carbon monoxide, CO<sub>2</sub>: Carbon dioxide, O<sub>2</sub>: Oxygen

is evident when compared to the rejected ones, with emission levels remaining relatively constant. Nevertheless, as the manufacturing year of the cars increases, the mean CO emission level also rises significantly ( $P < 0.0001$ ). In a study conducted by Mozafari *et al.* in 2011, investigating pollutant emissions from gasoline car exhausts in Shahrizad based on the year of manufacture, the results indicated a decline in the volume percentage of HC, CO, and ozone gases in comparison to older cars.<sup>[13]</sup> Similarly, the research conducted

by AIKheder *et al.* in 2020 aligns with the findings of the present study.<sup>[27]</sup>

### Carbon dioxide

The results depicted in Figure 4, reflecting the marginal mean of CO<sub>2</sub> emissions obtained through the MANOVA, reveal an increase in the level of CO<sub>2</sub> emission in accepted cars when compared to the rejected ones. A notable upward trend with a steeper slope is observed in the city of Shahrekord.

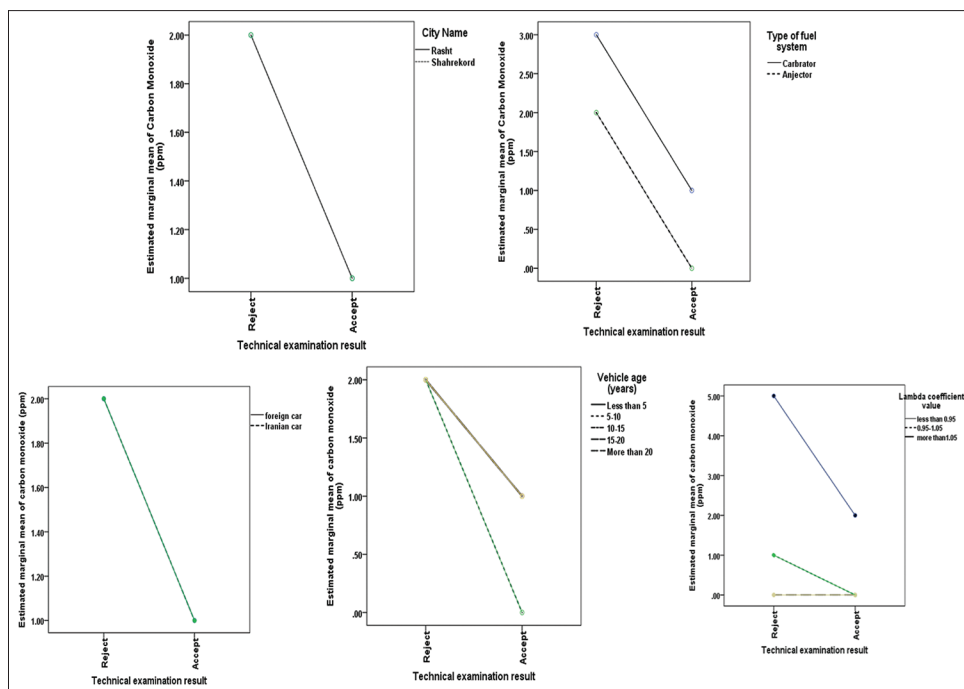


Figure 4: The estimated marginal mean of carbon monoxide from multivariate analysis of variance model

Table 3: Comparison of mean age and car pollution indicators in Shahrekord and Rasht

Variable	City, mean ± SD		P*
	Rasht	Shahrekord	
Vehicle age	11.46±4.68	11.87±5.17	<0.0001
O <sub>2</sub>	1.84±1.28	1.72±1.47	<0.0001
CO	0.57±1.11	0.63±1.13	<0.0001
HC	119.53±150.47	130.85±195.47	<0.0001
CO <sub>2</sub>	14.11±1.44	12.16±2.62	<0.0001

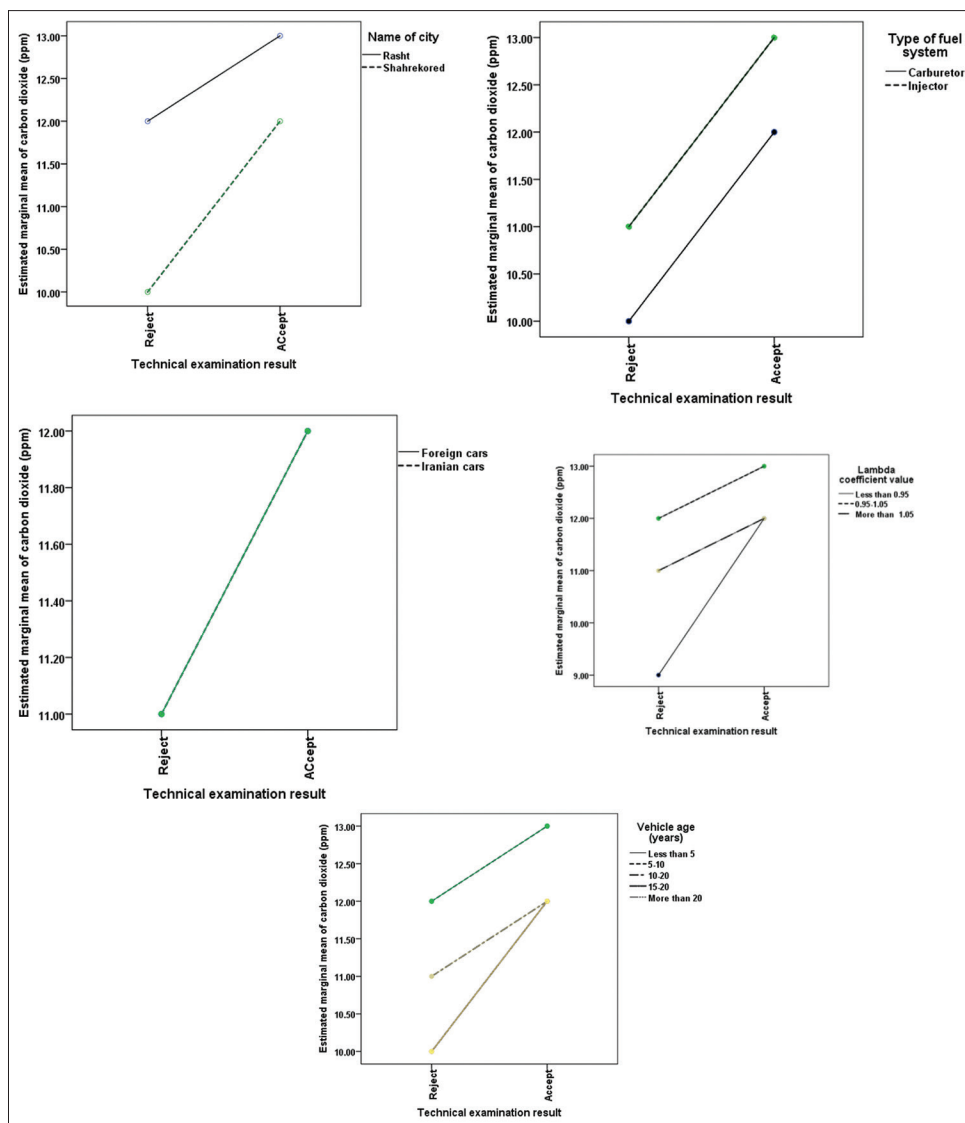
\*Independent *t*-test and the significance level of the test is 0.05.  
 HC: Hydrocarbon, CO: Carbon monoxide, SD: Standard deviation,  
 CO<sub>2</sub>: Carbon dioxide, O<sub>2</sub>: Oxygen

Furthermore, the level of CO<sub>2</sub> emission in cars in the city of Rasht surpasses that of Shahrekord ( $P < 0.0001$ ). In terms of fuel supply systems, the estimated marginal mean of CO<sub>2</sub> emissions in injector cars surpasses that of carburetor cars, exhibiting a consistent slope across both rejected and accepted cars. The elements pertaining to meteorological events that have a direct or indirect impact on a vehicle’s fuel consumption are collectively referred to as weather conditions. The current vehicle certification test is conducted under specific circumstances of temperature, pressure, and humidity, which fail to capture the yearly fluctuations in weather experienced by drivers. Among these conditions, wind, temperature, and altitude (ambient pressure) tend to exert the most significant influence on the fuel consumption and CO<sub>2</sub> emissions of passenger cars. As altitude increases, fuel usage is known to decrease due to lower atmospheric pressure resulting in denser air and reduced air resistance. At an elevation of 1000 m above sea level, air density is approximately 10% lower than what

is anticipated for the official testing of vehicle road loads (air drag) and fuel usage. Consequently, this reduction in air drag can lead to a 23% reduction in fuel costs.<sup>[30]</sup>

In addition, the results indicate a decreasing trend in the emission levels of outgoing pollutants with an increase in the year of car manufacture. This can be attributed to the improvement in the fuel processing of newer cars, reflecting the efforts of car manufacturers in producing vehicles with reduced pollution and enhanced environmental compatibility. These findings align with the research conducted by Riveros *et al.* in 2002.<sup>[28]</sup> Furthermore, the mean CO<sub>2</sub> emissions in Iranian and foreign cars are comparable, indicating a lack of adherence to the permissible emission thresholds in technical inspection centers. In terms of acceptable cars, those falling within the range of  $\lambda = 0.95-1.05$  exhibit the highest estimated marginal mean CO<sub>2</sub> levels, while for values lower than  $\lambda = 0.95$  and  $\lambda > 1.05$ , the same level of estimated marginal mean CO<sub>2</sub> is observed. Similarly, in the case of rejected cars,  $\lambda = 0.95-1.05$  and  $\lambda = 1.05$  and  $0.95 =$  display the highest estimated mean CO<sub>2</sub> margins, respectively ( $P < 0.0001$ ).

Accepted and rejected cars with a manufacturing age of <10 years demonstrate the highest mean estimated marginal CO<sub>2</sub> levels, while cars older than 10 years exhibit lower mean estimated marginal CO<sub>2</sub> levels. However, cars aged between 10 and 15 years display higher mean estimated marginal CO<sub>2</sub> levels compared to those exceeding 15 years ( $P < 0.0001$ ). The research conducted by Ghorbani *et al.* in 2022 revealed an inverse correlation between the year of car manufacture and CO<sub>2</sub> and NO<sub>x</sub> pollutants, with a positive correlation observed between HC and CO pollutants.<sup>[13]</sup> Similarly, the findings of Sofwan and Latif research in 2021 indicated that



**Figure 5:** The estimated marginal mean of carbon dioxide in the multivariate analysis of variance model

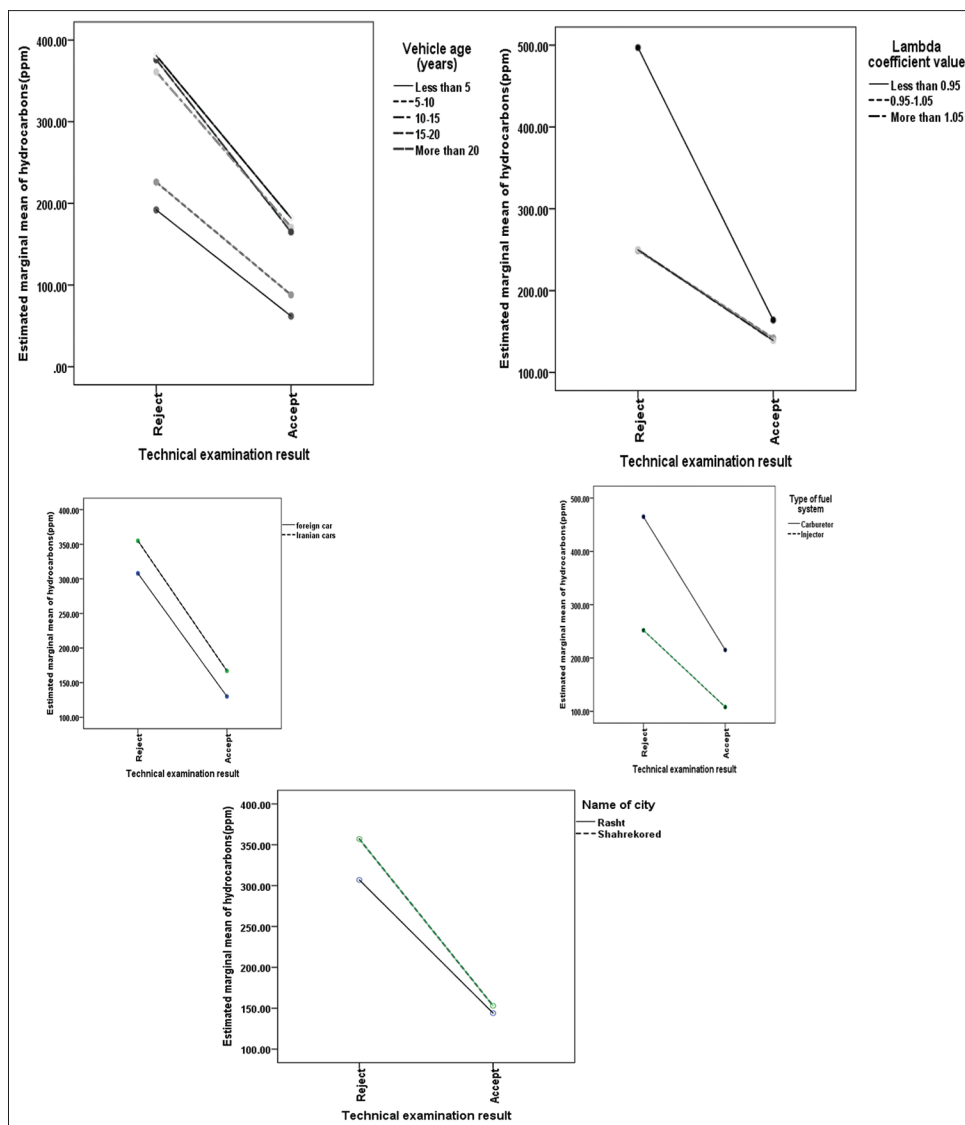
lower CO and NOx emissions were correlated with higher CO<sub>2</sub> emissions. Poor fuel efficiency, indicative of high fuel consumption, resulted in increased CO<sub>2</sub> emissions. In addition, higher vehicle velocities were found to cause an increase in combustion temperature, leading to greater NOx emissions.<sup>[31]</sup>

### Hydrocarbon

The results depicted in Figure 5 present the marginal mean of HC emissions obtained through the MANOVA. It is observed that the emission level of HC in rejected cars surpasses that of accepted cars, with a decreasing trend observed in the direction of rejected cars in comparison to accepted cars. Moreover, the mean HC emissions in both rejected and accepted cars are higher in Shahrekord when compared to Rasht, and this difference in pollutant emission means is statistically significant ( $P < 0.0001$ ). Notably, HC emission levels are higher in rejected carburetor cars than in injection cars. The findings of Pandey *et al.*'s research in 2016 indicated that vehicles equipped with injector transfer systems exhibited

lower HC and monoxide emissions compared to those with carburetors.<sup>[32]</sup>

Furthermore, the mean HC emission in Iranian cars is higher than that of foreign cars. When  $\lambda < 0.95$ , the decreasing trend of HC emissions in accepted cars is observed with a steeper slope than that of rejected cars, and there exists a substantial difference in the mean HC emissions between rejected and accepted cars. However, for  $\lambda > 1.05$  and  $\lambda = 0.95-1.05$ , a decreasing trend in the mean HC emissions is observed with a reduced slope, and the difference in mean HC emissions between the last two groups of failed and accepted cars is not as significant. It is worth noting that altitude alters the atmospheric conditions that influence the performance of internal combustion engines. As altitude increases, the ambient air pressure and O<sub>2</sub> content decrease, leading to a decline in the air-fuel ratio and a deterioration in combustion, resulting in increased CO and HC emissions. The lower O<sub>2</sub> concentrations at higher altitudes hinder the generation of NOx, but a higher



**Figure 6:** The estimated marginal mean of hydrocarbon from multivariate analysis of variance model

equivalence ratio and delayed ignition delay cause an increase in combustion temperature.<sup>[23,33-35]</sup>

In addition, it should be acknowledged that the mean HC emission in newly approved cars with an age of <5 years and those falling within the 5–10 years range exhibits a decreasing trend when compared to the rejected ones, while the level of HC emission increases with the age of the cars. The findings of Riveros *et al.*'s research demonstrated that the level of pollution increases with the age of the vehicles.<sup>[28]</sup> Furthermore, the results of the research conducted by AlKheder *et al.* in 2020 align with the findings of the present study.<sup>[27]</sup>

### Oxygen

Figure 6 presents the marginal mean of O<sub>2</sub> emissions obtained through the MANOVA. It is observed that the level of O<sub>2</sub> emission in accepted cars has decreased in comparison to the rejected ones. In addition, both Shahrekord and Rasht cities exhibit similar mean O<sub>2</sub> emissions. Notably, failed carburetor

cars display a steeper slope in the level of O<sub>2</sub> emissions compared to injector cars. Furthermore, the mean O<sub>2</sub> emissions in Iranian and foreign cars are comparable. When  $\lambda > 1.05$ , a decreasing trend in the mean O<sub>2</sub> emissions of accepted cars is observed with a steeper slope than that of failing cars. However, at  $\lambda < 0.95$  and  $\lambda = 0.95-1.05$ , the level of O<sub>2</sub> emission remains constant.

The mean O<sub>2</sub> emissions in newly manufactured cars with an age of <5 years and those falling within the 5–10 years range remain constant. However, in accepted cars with an age of 10–15 years, the decreasing trend of emissions exhibits a less steep slope than that of the failed ones. It is important to note that complete combustion of gasoline under optimal conditions and a proper stoichiometric ratio results in the production of CO<sub>2</sub> and water vapor, with a lambda coefficient equal to 1 or higher. With an increase in the lambda coefficient, the availability of O<sub>2</sub> increases, as does the likelihood of O<sub>2</sub> leaving without participating in the reaction. Consequently,

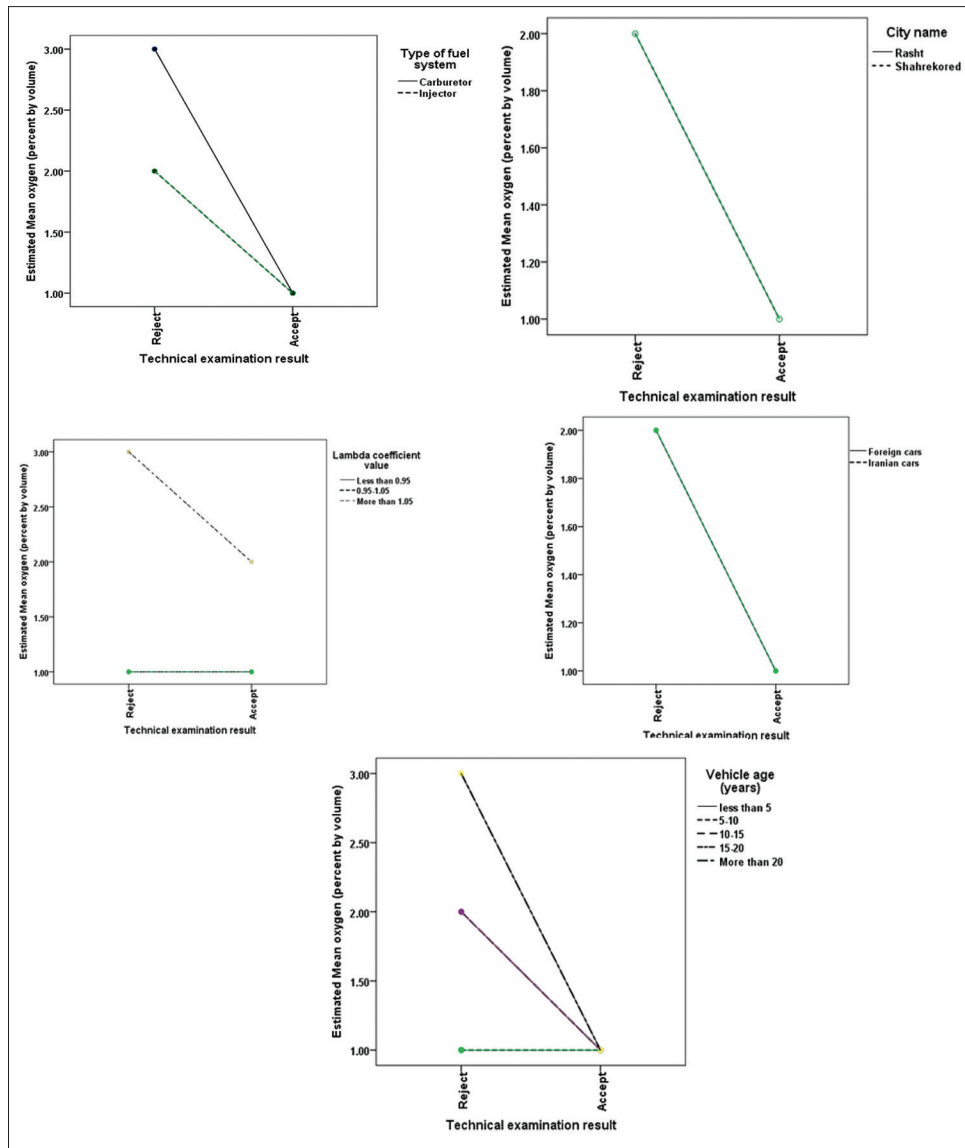


Figure 7: The estimated marginal mean of oxygen from the multivariate analysis of variance model

the possibility of an increased concentration of O<sub>2</sub> being emitted from the exhaust is enhanced with an increase in the lambda coefficient, as observed in the present study. The findings of Dehghan *et al.*'s research in 2013 and Wu *et al.*'s research in 2004 also demonstrated that an increase in the lambda coefficient leads to an increase in the O<sub>2</sub> output from the exhaust.<sup>[36,37]</sup> Furthermore, the results of Mozafari *et al.*'s research in 2011, which investigated the emissions of pollutants from the exhaust of gasoline vehicles in Yazd based on the year of manufacture, showed a decrease in the volume percentage of HC, CO, and O<sub>2</sub> gases in comparison to older cars.<sup>[32,38]</sup>

### Discriminant analysis

The discriminant function (D), derived from the linear combination of variables predicting the levels of O<sub>2</sub>, CO, CO<sub>2</sub>, HC, and the age of the vehicle, as described by equation number (1), exhibited promising performance. The function achieved a Wilks' Lambda statistic value of 0.687, an Eigen

value of 0.455, and a canonical correlation value of 0.60, all with a statistically significant  $P < 0.0001$ . This discriminant function was able to accurately classify 81.3% of the cars into two groups, namely Shahrekord and Rasht.

Furthermore, the Kappa agreement coefficient, which measures the agreement between the predicted cities based on the audit analysis and the registered cities associated with the cars in the dataset, also yielded a commendable value of 0.6, with a  $P < 0.0001$ . This result further confirms the robust performance of the discriminant function in accurately predicting the cities.

$$D = 0.456 Co - 0.034 HC + 0.807O_2 + 1.352Co_2 - 0.022 Age \quad (1)$$

### CONCLUSION

The findings of this study not only identified cars with a high percentage of rejections but also revealed higher mean CO and O<sub>2</sub> emissions in the rejected cars, older cars, and carbureted

cars. Moreover, higher HC emissions were observed in cars that underwent technical inspection in Shahrekord city, in Iranian and carbureted cars, and in cars with a higher age of manufacture. On the other hand, accepted cars exhibited higher mean CO<sub>2</sub> emissions, technical inspection reports were more prevalent in Rasht, and lower age of manufacture and injection were associated with these cars.

These results, combined with the high predictability based on the concentration values of emitted gases and the age of the vehicle, emphasize the importance of tailoring environmental protection measures to the specific characteristics of each city's vehicle fleet. By implementing the practical approach suggested by this study, it is possible to effectively address the complications arising from the emission of polluting gases, which contribute to the global warming phenomenon.

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### Ethics code

IR.SKUMS.REC.1401.122.

### Conflicts of interest

There are no conflicts of interest.

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