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AN ASSESSMENT OF AUTOMOBILE EMISSIONS IN IRBID, NORTHWEST JORDAN

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Abstract*: Investigation of pollutants emitted by gasoline vehicles in metropolitan area of Irbid, Jordan has revealed four major factors affecting the emission rates of carbon monoxide (CO), carbon dioxide (CO2) and hydrocarbon (HC) and contributing to emission tests failure. These variables are vehicle age, fuel delivery system, fuel composition and availability of catalytic converter. Our observation also indicated that maintenance program has strong correlations with CO2 and HC but is poorly correlated with CO concentrations. Engine size and daily driving distance showed no statistically significant relationship with vehicular emissions. Structural equation modeling has been implemented to evaluate the cause-effect relationships among three constructs: vehicle variables, pollutants concentrations and emission test results. Results showed that fuel delivery system has significant effects on both CO and CO2 emissions and among the pollutants only CO2 has an influence on the emission test results. The highest total effect of fuel delivery system on CO2 concentrations and consequently on the test result is -0.0097.*

Keywords*: Air Pollution, motor vehicle emission, irbid, structural equations modeling, confirmatory factor analysis.*

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1. Introduction

Over the past several decades, Jordan observed rapid expansion of the transportation sector and increased fuel consumption triggered by rapid growth in population and urban areas. This has led to massive increase in number of vehicles and private motor vehicle per capita. Between 1970 and 2000, the number of registered cars has increased about 25-fold [1], and reached 700000 vehicles in 2005 [13]. The trend toward greater use of private vehicles and the increasing number of vehicles have significantly increased the emission rates and vehicles became a major source of air pollution in Jordan. It was estimated that the vehicular emissions from both gasoline and diesel-powered vehicles contribute about 67% to the national emission inventory [5].

In response to the growing public concerns over the increased vehicle emissions in major cities of Jordan, new motor vehicle emission regulations were developed. These rules defined a set of categories to improve air quality and restrain the air pollution from mobile polluting sources. To ensure that the emission regulations are followed, vehicle emissions inspection program was introduced. The inspection program, which is administered by the department of Traffic affiliated with the ministry of interior, became mandatory for all vehicles.

Motor vehicle emission standards and regulations dictate that gasoline-powered vehicles comply with emission limits which include HC, CO, CO_2 and O_2 tests. The cut points for acceptable levels based on the Jordanian emission standards are: ≤600ppm for HC, ≤5% for CO, ≥10% for CO_2 and ≤6% for O_2. Poor combustion efficiency in the engine will generally rise CO and O_2 contents in the exhaust and decrease CO_2. Gasoline-powered vehicles pass when the four emission tests are fulfilled. These diagnostic tests indicate whether the engine combustion and emission control systems function properly or maintenance programs should be implemented. Diesel-fuelled vehicles must fulfill the opacity test which indicates that the maximum allowable smoke level should not exceed 70%. Vehicles in violation of emission standards are fined and required to undergo the necessary maintenance and repairs. It is noteworthy that the current Jordanian exhaust emission standards treat old and new vehicles alike. In addition, these standards neither regulate the evaporative nor refueling emissions.

Many studies conducted worldwide have indicated that emission rate is a function of vehicle characteristics ([10]; [12]; [7]; [17]; [18]; [8]) of which only few have been conducted in Jordan ([2]; [3]).

It was estimated that about 73% of the vehicles in Jordan are fueled with gasoline, and the remainder is using diesel fuel (Jordan Traffic Institute, 2000).While gasoline-powered vehicles contribute major portions of exhaust gas emissions, the characteristics of gasoline cars that affect the emission rates have not been fully investigated in Jordan. This study attempts to identify the characteristics of gasoline-powered vehicles contributing to vehicular emission rates and emissions test failure in metropolitan area of Irbid, northwest Jordan.

2. Methodology

The emissions inspection data analyzed in this study were collected between March to June 2007 at two automotive emission testing centers located near the industrial area of Irbid. Two different emission testing instruments were used; the Visa Techno-test gas analyzer model Visa-4012 (Techno-test, Italy) and the Sun gas analyzer model Sun-SMP 4000 (Sun electric, UK). Diesel vehicles have been excluded because the emissions testing equipment was not available. 240 gasoline-fueled vehicles have been tested in this study.

The tailpipe emissions test results from individual vehicles at idle state were measured and compiled with the vehicle characteristics to evaluate the relationship between vehicle variables and emission results (CO, CO_2, HC, and O_2). The emissions inspection data collected from the vehicle owners include vehicle age, country of origin, fuel type, engine size, fuel delivery system, daily driving distance, and inspection and maintenance period.

3. Results and Discussion

3.1 Data Analysis

Various methods of analysis have been used, descriptive statistics and correlation analysis using the SPSS (Statistical Package for Social Sciences) version 15 for windows. The study also employed the structural equation modeling using AMOS (Analysis of Moment Structure) version 5 by focusing on standardized regression weight to identify the critical factors most contributing to the vehicle emission test result. Statistical significance was judged at the p-value ≤ 0.05 level.

3.2 Descriptive Statistics

Vehicle variables as country of origin, fuel type, fuel delivery system, emission testing results and the availability of catalytic converter along with the overall emissions tests results (pass/fail) are described by the frequencies and in percent in Table 1.

Table 1. Descriptive statistics of the qualitative variables.

Vehicle Variables	Category	Frequency	Percent
Country of origin	Korea	112	46.7
	Germany	90	37.5
	Japan	38	15.8
Fuel type	Normal	219	91.3
	Super	19	7.9
	Unleaded	2	0.8
Fuel delivery system	Carburetion	47	19.6
	Injection	193	80.4
Test result	Fail	101	42.1
	Pass	139	57.9
Catalytic Converter	No	227	94.6
	Yes	13	5.4
Model year	< 1990	48	20
	1990-2000	176	73.3
	≥ 2000	16	6.7

As can be seen in Table 1, 46.7% of the vehicles tested are Korean-made, 15.8% are Japanese and German-made cars account for 37.5%. As expected, the majority of vehicles are fueled with normal gasoline which is due to its cheaper price and availability in every gas station. 80% of the cars sampled are fuel-injected and the remainders have equipped with carburetors as the fuel-delivery system. Approximately 58% of the cars tested in this study have passed the Jordanian emission testing. 95% of the total samples are not equipped with catalytic converter or has been disassembled. Vehicles model year range from 1972 to 2005, of which 73% is between 1990 and 2000.

Emission concentrations (CO, CO2, HC), inspection and maintenance period , daily driving distance and engine size are expressed as minimum, maximum, mean and the standard deviation of the vehicle tested are summarized in Table 2. The average values of emission rates for all tests are within the acceptable levels based on the Jordanian standards. Cars are light duties with generally small engine sizes.

Table 2. Descriptive statistics of the quantitative variables.

Quantitative Variables	N*	Min	Max	Mean	Std. Dev.
Engine size (cc)	240	1000	2800	1557.9	250.1
CO (%)	240	0.00	10	2.3	2.6
CO_2 (%)	240	4.00	15.10	11.7	2.1
HC (ppm)	240	100	1580	283.8	196.5
O_2 (%)	240	1.00	13.80	5.2	2.7
Inspection and maintenance period (month)	240	1.0	9.0	4.0	1.3
Daily driving distance (km)	240	10	300	76.33	50.099

*: number of samples

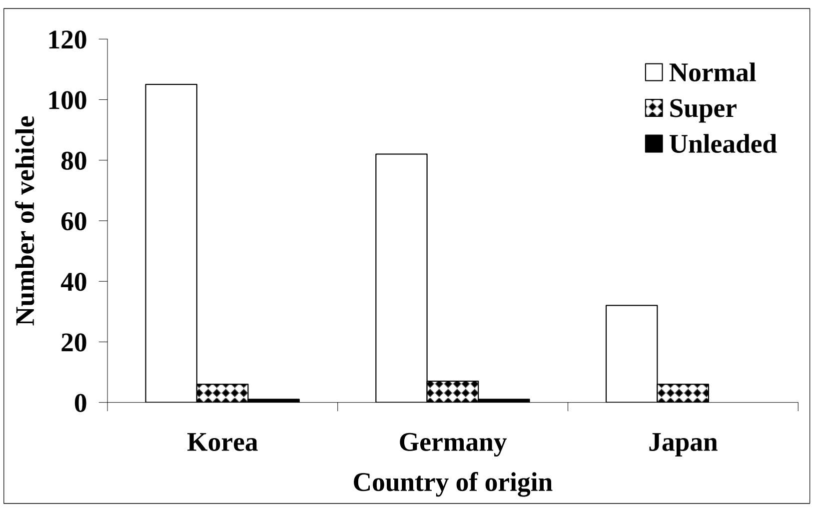

Figure 1. Distribution of vehicles (from Korea, Germany and Japan) by type of fuel.

Figure 1 compares fuel type in use by vehicles and indicates that the bulk of cars tested are fueled with normal gasoline, regardless of the vehicle's manufacturing country. Normal gasoline is cheaper and available and thus is commonly used. The variation in fuel composition of the three types of fuel is illustrated in Table 3. The normal fuel contains higher lead but lower aromatic contents compared to that of the unleaded fuel. Fuel composition affects the emission rate and results in the normal-gasoline-fueled cars being high emitters (Table 4). Following [2], only two types of gasoline fuel have been used in Jordan; octane 90 and octane 95.

Table 3. Fuel type specifications in Jordan[(1)].

Specification	Fuel type		
	Normal (regular)	**Super**	**Unleaded**
Color	Pink	Yellow	Blue
Sulfur (wt%)*	Max. 0.2	Max. 0.2	Max. 0.2
Octane number	Min. 88	Min. 96	Min. 95
Lead (g/l)	Max. 0.83	Max. 0.83	Max. 0.013

[(1)] Source: Annual report, Jordan Petroleum Refinery Co. *: measured in weight percentage.

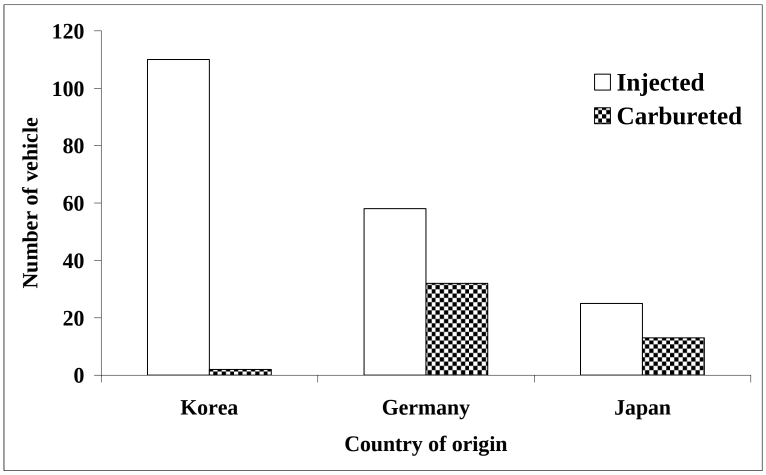

Figure 2. Vehicles' country of origin versus type of fuel delivery system.

It can be seen in Figure 2 that the majority of Korean-made cars are fuel-injected while about one third of the German and Japanese-made cars are carbureted. Vehicle emissions also vary by vehicle make (Table 4). Data presented in Table 4 compares the emission quantities by vehicles of different manufacturing country. German-made vehicles usually emit higher amounts of pollutants compared to Korean and Japanese cars. It is noteworthy that the German cars tested were with the model year of between 1972 and 2000 of which 38.9% of less than 1990.

Table 4. The average amount of pollutants emitted by German, Japanese and Korean-made vehicles

Emission	Korea	Germany	Japan
CO (%)	2.01	2.81	1.95
CO_2 (%)	11.93	11.22	11.97
HC (ppm)	251.61	322.48	287.03
O_2 (%)	5.08	5.2	5.29

Based on our observations (Table 4, Figure 3), German and Japanese auto makers are associated with increasing vehicle emissions and are the most likely to fail the Jordanian emission tests. About one half of the German and Japanese-made cars tested have failed the emission testing and 62% of Korean-made vehicles have passed the emission tests.

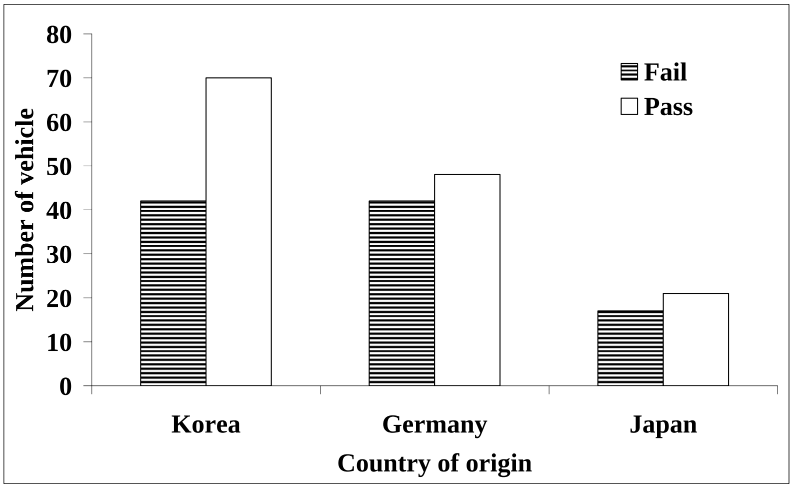

Figure 3. Emission testing results by vehicles country of origin.

3.3 Correlation Analysis

This correlation analysis was made to evaluate the relationship among emissions and the results are tabulated in Table 5. There are statistically strong correlations between HC and CO (positive), HC and CO_2 (negative), CO and CO_2 (negative), O_2 and CO_2 (negative), O_2 and HC (positive). O_2 is poorly correlated with CO. As combustion efficiency decreases, O_2 content and unburned HC in the exhaust rise and CO_2 fall.

Table 5. Correlations matrix among vehicle emissions.

		CO	**CO_2**	**HC**	**O_2**
CO	*R* P-value	1			
CO_2	*R* P-value	-0.693(*) 0.000	1		
HC	*r* P-value	0.463(*) 0.000	-0.545(*) 0.000	1	
O_2	*r* P-value	0.020 0.762	-0.304(*) 0.000	0.134(*) 0.038	1

r: Sample correlation coefficient; *: Correlation is significant at the 0.05 level (2-tailed).

The correlation analysis between vehicle parameters and emission rates is given in Table 6. Engine size appears to be less important with regards to emission rates, consistent with the observation of [4]. Inspection and maintenance period has a positive relationship with HC (0.132, P=0.041) but is negatively correlated with CO_2 (-0.131, P=0.043). Maintenance period appears to be less important with regards to CO emissions. It is noteworthy that relatively large number of vehicle owners doesn’t adhere to regular maintenance plan.

Table 6. Correlations between the pollutants concentrations and vehicle characteristics

Vehicle Characteristics	**CO**	**CO_2**	**HC**	**O_2**
	r **(p-value)**	***r*** **(p-value)**	***r*** **(p-value)**	***r*** **(p-value)**
Engine size	0.092 (0.155)	-0.063 (0.330)	-0.001 (0.985)	-0.036 (0.583)
Inspection and maintenance period	0.106 (0.100)	-0.131(*) (0.043)	0.132(*) (0.041)	0.154(*) (0.017)
Daily driving distance	-0.036 (0.581)	0.054 (0.405)	-0.104 (0.108)	-0.028 (0.663)
Age	0.229(*) (0.000)	-0.249(*) (0.000)	0.202(*) (0.002)	0.071 (0.275)
Fuel type	-0.160(*) (0.013)	0.176(*) (0.006)	-0.152(*) (0.019)	-0.034 (0.595)
Fuel delivery system	-0.268(*) (0.000)	0.262(*) (0.000)	-0.189(*) (0.003)	-0.053 (0.410)
Catalytic converter	-0.156(*) (0.016)	0.177(*) (0.006)	-0.147(*) (0.023)	-0.108 (0.095)

r: Correlation coefficient; *: Correlation is significant at the 0.05 level (2-tailed).

As can be seen in Table 6, there is strong correlation between age and exhaust gas emissions, which is negative with CO_2 and positive with both CO and HC. The variation in fuel composition affects the emitted pollutants. This is consistent with our observation that fuel type has significantly negative correlation with CO and HC which becomes positive with CO_2. Similar effects have been observed between fuel delivery system and catalytic converter and emission rates of CO, CO_2 and HC. These four factors appear to be the most contributors to increased vehicular emissions. Older vehicles, the use of normal gasoline, carbureted and non-catalyst-equipped petrol engine cars are the higher emitters. Poor correlations were found between engine size, daily driving distance and emission concentrations. Results also indicate that O_2 concentrations are independent of vehicle characteristics except for the maintenance period which is positively correlated with O_2 rates.

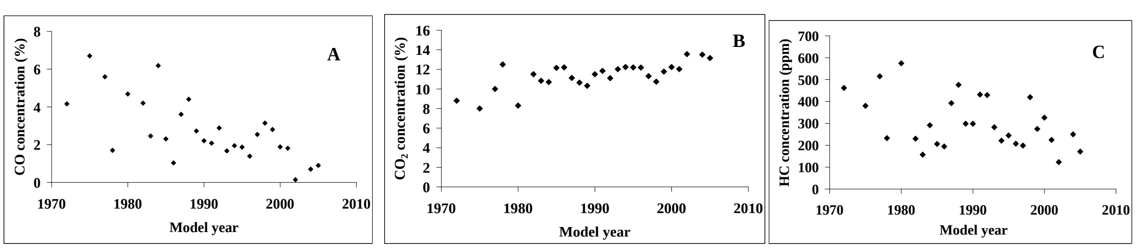

Figure 4. Vehicle exhaust emissions by model year.

Data presented in Figure 4 give a general indication of the magnitude and trend of mobile emissions compared with vehicle’s model year. There is a general decrease in the average emission concentrations of CO and HC and a decrease in CO_2 for the newer vehicles.

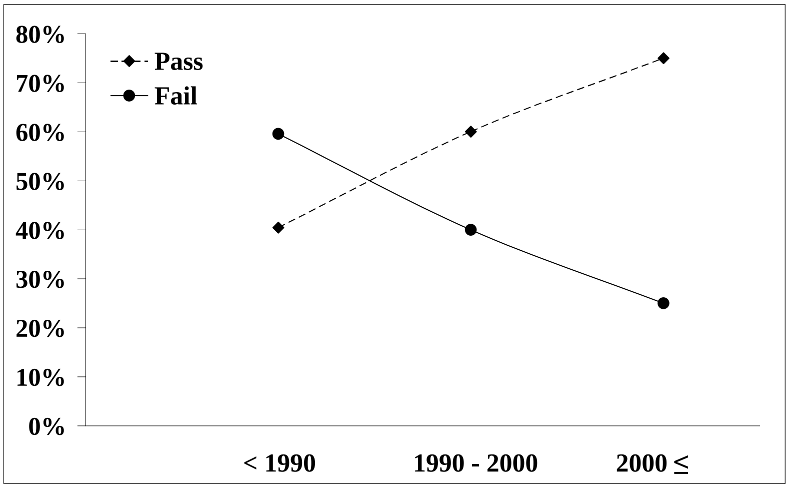

Figure 5. Emissions test results by model year.

Vehicles were classified based on model year into three categories, cars with model year of less than 1990, between 1990 and 1999, and of 2000 and newer. Figure 5 shows the dependence of emission test results on the vehicle's model year. Older vehicles are pollution violators and contribute significantly to the emission tests failure. The percentage of vehicles passed the emission testing increased with increasing model year.

3.4 Structural Equation Modeling Analysis

Based on the correlation analysis, four vehicle variables have been modeled to determine the critical variable most affecting emission rates and contributing to the emission test result. This model compares the magnitude of the direct effects of vehicles factors on pollutants concentrations and to compute the standardized total effects on the emission test results. Structural Equations Modeling (SEM) ([15]; [19]) was used to test cause-effect relationships among three constructs: vehicle variables (age, fuel delivery system, fuel type and catalytic converter), pollutants concentrations and emission test results. [11] investigated two different estimation methods for fitting the SEM deeply. The SEM was assessed by using established measure and evaluate criterion for model fit.

The measurement model is that part of a SEM model which deals with the latent variables and their indicators. A pure measurement model is a confirmatory factor analysis (CFA) model in which there is unmeasured covariance between each possible pair of latent variables. The measurement model is evaluated like any other SEM, using goodness of fit measures. Several standard indexes are commonly used to assess the quality of the model specification. One approach is to divide the Chi-square value by the degrees of freedom (DF) to evaluate how well the SEM fits the data. Alternative index is Root Mean Squared Error of Approximation (RMSEA).

Based on practical experience, the RMSEA value of about 0.05 or less would indicate a close fit of the model to the degrees of freedom. Another measure used to describe the discrepancy between predicted and observed covariance's is Goodness of Fit Index (GFI). The GFI was devised by [15], has values range from 0 to 1. A value of 1 indicates a perfect fit. Table 7 illustrates the results of model fit summary.

Table 7. Summary of goodness-of-fit measures (Model fit).

Fit Measure	Default Model	Independence Model
Discrepancy	152.887	193.835
DF	13	28
P-value	0.000	0.000
Discrepancy/DF	11.761	6.923
GFI	0.713	0.568
RMSEA	0.212	0.157

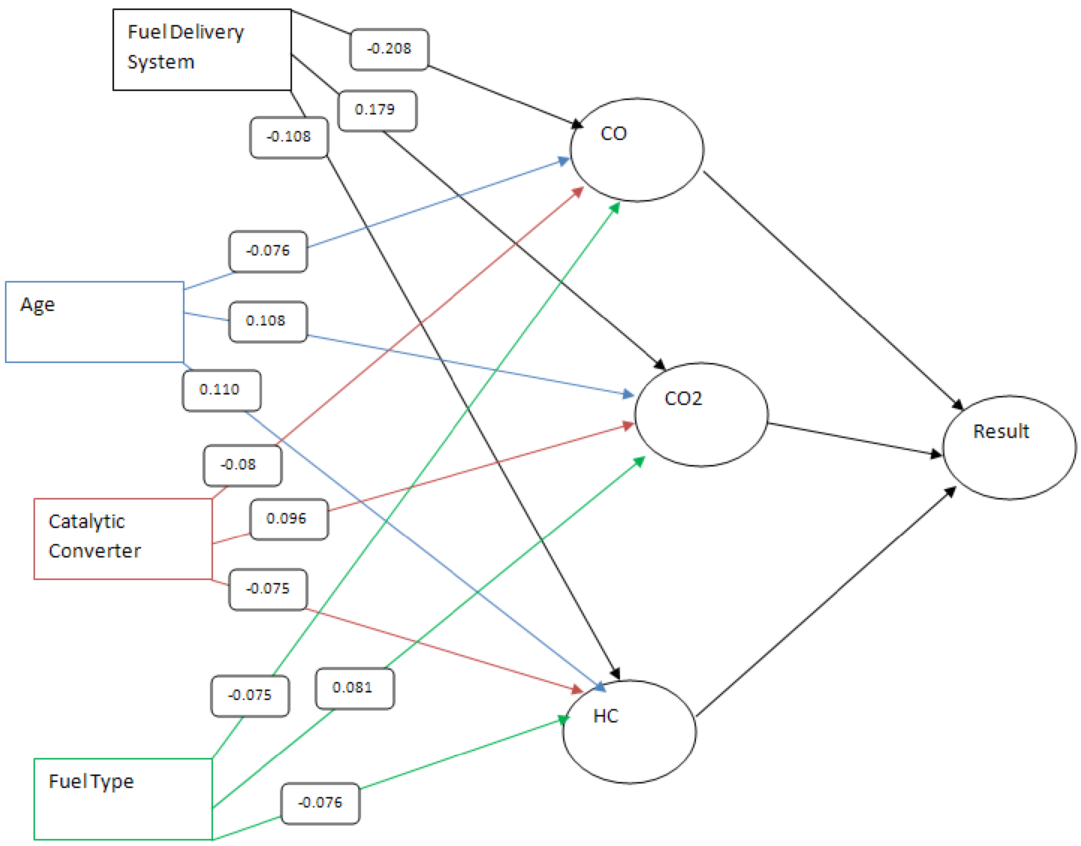

Figure 6. Structural model showing the effect of car parameters on the pollutant concentrations and the subsequent emission test results

Figure 6 shows the structural model for vehicles emission effectiveness. The model has 36 distinct sample moments, 23 distinct parameters to be estimated and 13 degrees of freedom. The fit indices generally indicate a fare fitting model although the normed chi-square (401.7) is above the recommended range, with P-value of less than 0.001. RMSEA (0.212) indicates a poor model fitting. The GFI (0.713) falls into a marginal level of fit. To clarify the model in Figure 6, the regression coefficients and the associated standardized regression coefficients were abstracted and tabulated in Table 8.

Table 8. Standardized regression weights.

			Estimated Coefficient	SE*	t	Standardized Estimate Coefficients	P-value
Fuel delivery system	→	**CO**	**-1.337**	**0.500**	**-2.674**	**-0.208**	**0.007**
		CO_2	**0.935**	**0.405**	**2.309**	**0.179**	**0.021**
		HC	-52.761	38.309	-1.377	-0.108	0.168
Catalytic converter	→	CO	-0.906	0.824	-1.100	-0.080	0.272
		CO_2	0.876	0.667	1.313	0.096	0.189
		HC	-64.069	63.153	-1.015	-0.075	0.310
Fuel type	→	CO	-0.600	0.582	-1.031	-0.075	0.302
		CO_2	0.522	0.471	1.108	0.081	0.268
		HC	-45.796	44.583	-1.027	-0.076	0.304
Age	→	CO	0.038	0.039	0.962	0.076	0.336
		CO_2	-0.044	3.012	1.340	0.108	0.180
		HC	4.035	0.032	-1.393	-0.110	0.164
Result	→	CO	-0.023	0.014	-1.705	-0.128	0.088
		CO_2	**0.114**	**0.018**	**6.406**	**0.507**	**0.000**
		HC	0.000	0.000	-0.805	-0.052	0.421

*: Standard Error. The highlighted numbers indicate statistically significant correlations

Results in Table 8 clearly show that there is a significant influence of the vehicle fuel delivery system on the pollutants level. The effect appears more significant on CO which is negative influence (effect = -0.208, P = 0.007) and positive on the CO_2 (effect = 0.179, P = 0.021). CO_2 has a strong negative influence on the test results (effect = 0.507, P = 0.000). These observations suggest that carbureted-vehicles are most affecting CO and CO_2 emission rates and subsequently the most contributors to the emission test failure.
In terms of total effect to the construct of test results, the highest total effect of fuel delivery system on CO_2 concentrations and consequently on the test result is -0.009728.

4. Conclusion

This study is intended to investigate and proposed statistical path model for the gasoline vehicular emissions in urban area of Irbid, Jordan. 240 gasoline-fueled vehicles have been tested. Diesel vehicles have been excluded because the emissions testing equipment was not available.
Different vehicle characteristics have been assessed including vehicle age, country of origin, fuel type, engine size, fuel delivery system, daily driving distance, and inspection and maintenance period. Based on our observation, the German and the Japanese cars are associated with increasing vehicle emissions and are the most likely to fail the Jordanian emission tests. Results also showed that vehicle age, fuel delivery system, fuel composition and availability of catalytic converter are the major factors affecting the emission rates of CO, CO_2 and HC and contributing to emission tests failure. Maintenance program is strongly correlated with CO_2 and HC but is poorly correlated with CO concentrations. Engine size showed no statistically significant relationship with vehicular emissions.

Utilizing the SEM abilities of AMOS, the CFA results were investigated for goodness of fit. The determination of model fit is not as straightforward as it is in other statistical approaches. In this study three different fitting indices were used to evaluate the proposed vehicles emission model in Jordan, namely, Chi Square goodness of fit index, GFI and RMSEA. Results showed that fuel delivery system is the most influential factor contributing to the emission levels. Vehicle delivery system has significant effects on both CO and CO_2 emissions and among the pollutants, only CO_2 has an influence on the emission test results.

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