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DEVELOPMENT OF A DRIVING CYCLE FOR AMMAN CITY WITH PERFORMANCE EVALUATION FOR ICE VEHICLE

M. Abu mallouh
Department of Mechatronics Engineering
Hashemite University
Zarqa, Jordan

B.W. Surgenor
Department of Mechanical Engineering
Queen's University
Kingston, ON, Canada

E. Abdelhafez
Dept of Mechanical Engineering
Al-Zaytoonah University of Jordan
Amman, Jordan

M. Salah
Dept of Mechatronics Engineering
Hashemite University
Zarqa, Jordan

M.Hamdan
Dept of Mechanical Engineering
Al-Zaytoonah Univeristy of Jordan
Amman, Jordan

ABSTRACT

A good driving cycle is needed for accurate evaluation of a vehicle's performance in terms of emission and fuel consumption. Driving cycles obtained for certain cities or countries are not usually applicable to other cities or countries. Therefore, considerable research has been conducted on developing driving cycles for certain cities and regions. In this paper, a driving cycle for a taxi in Amman city, the capital of Jordan, is developed. Significant differences are noted when comparing the Amman driving cycle with other driving cycles. A model of a gasoline powered vehicle is used to conduct a performance comparison in terms of fuel economy and emissions utilizing the developed Amman driving cycle and six other worldwide driving cycles. The developed Amman driving cycle is very useful in obtaining accurate estimation of fuel economy and emissions for vehicles running on Amman roads and will be used in future work to study the performance of hybrid fuel cell/ battery vehicles.

INTRODUCTION

Vehicle performance in terms of emission and fuel consumption is commonly evaluated using representative driving cycles. A driving cycle defines when a vehicle is idling, accelerating, cruising, and decelerating in certain operating conditions [1]. Usually different cities and regions have different driving patterns. Thus, many worldwide driving cycles have been developed and adopted [2]. Examples of worldwide urban driving cycles for light vehicles are: New York City cycle (NYCC), Indian urban cycle (IUC), Japan 10 mode urban cycle (J10UC), France urban cycle (FUC), Europe dynamometer operating cycle (EDOC) and urban dynamometer driving schedule (UDDS). The parameters of these six driving cycles are listed in Table 1. There are significant differences between the presented driving cycles, in terms of speed, acceleration, deceleration, number of stops and duration as shown in Table 1. Thus, driving cycles obtained for certain cities or countries are not usually applicable to other cities or countries. Therefore, considerable research has been conducted to develop new driving cycles for different cities and regions.

In [3] driving cycles for Chinese cities were developed and compared with European and American driving cycles. It was concluded that European or US emission factors could be significantly different from those of Chinese cities. In addition, a motorcycle driving cycle was developed in [4] for urban and rural routes in Edinburgh. It was found that the main specifications of the Edinburgh driving cycle are different from other standard driving cycles. The Hong Kong driving cycle was developed in [5] as well. The authors found that the Hong Kong driving cycle was different from some driving cycles (*i.e.*, US 75, Perth cycle, and Melbourne peak cycle). A comprehensive analysis to develop a set of driving cycles that describes actual driving conditions in Europe was presented in [6]. Representative driving cycles are essential for designing and analyzing electrical and hybrid vehicles. In [7] the effect of driving patterns on configuration of hybrid vehicle battery system was studied. The effect of a real-world driving patterns on energy and power requirements of a converted plug-in hybrid electric two-wheeler was investigated in [8]. The effect of driving cycle fuel cell performance was investigated in [9] to predict the lifetime of the fuel cell.

In this study, a driving cycle for a taxi in Amman city, the capital of Jordan, is developed. The developed driving cycle is then used to quantify fuel consumption and emissions.

DEVELOPMENT OF AMMAN DRIVING CYCLE

The development of the Amman driving cycle is described in terms of method of data collection, analysis of data statistics and discussion of methodology. The data is summarized in Table 2.

Data Recorded

A GPS tracking device was installed in a midsized taxi to record vehicle velocity and travel distances while traveling through Amman urban areas. Driving data were recorded during both peak and light traffic hours with 0.1 sec sampling rate. The peak hours are between 7:30-8:30 am in morning and 4:00-5:00 pm in evening, while the light hours are otherwise. A total of 20 data sets were recorded with a total of 13.4 hours and a total travel distance of 348.8 km, which is about the range of travel distances reported in literature. The statistics for the recorded data are summarized in Table 2 where each data set is about 40 min long (*ie.* 2410 sec).

TABLE 1 – SAMPLE DRIVING CYCLE PARAMETERS

Parameter	NYCC	IUC	J10UC	FUC	EDOC	UDDS
Time (s)	598	1244	135	559	1180	1369
Distance (km)	1.9	10.6	0.7	3.5	11.0	12.0
Maximum speed (km/h)	44.3	90.0	49.0	57.2	120.0	91.2
Average speed (km/h)	11.3	31.1	17.6	22.3	33.6	31.5
Maximum acceleration (m/s^2)	2.7	0.6	0.8	2.2	1.1	1.5
Average acceleration (m/s^2)	0.6	0.6	0.7	0.7	0.6	0.5
Maximum deceleration (m/s^2)	-2.6	-1.4	-0.8	-2.1	-1.4	-1.5
Average deceleration (m/s^2)	-0.6	-0.8	-0.7	-0.6	-0.8	-0.6
Number of stops	18	13	2	5	13	17
Stop duration (s)	210	388	39	138	294	259
Number of stops per km	10.0	0.3	3.0	1.0	1.2	1.4
Stop duration per km	110.5	36.6	55.7	39.4	26.7	21.6

TABLE 2 – PARAMETERS OF RECORDED DATA SETS

Data set	Distance (km)	Max. Speed (km/h)	Average Speed (km/h)	Average Acceleration (m/s2)	Average Deceleration (m/s2)	Stops Number	Stop Duration (sec)	Stop Number/km	Stop Duration (sec)/km
1	15.7	77.8	23.4	0.6	-0.7	36	708	2	45.2
2	16.6	95.7	24.8	0.6	-0.7	35	810	2	48.7
3	16.9	81.6	25.3	0.6	-0.6	35	594	2	35.1
4	10.9	70.5	16.3	0.6	-0.6	51	656	5	60.0
5	11.4	67.9	17.0	0.6	-0.6	28	857	3	75.3
6	28.3	105.5	42.2	0.4	-0.5	15	465	1	16.4
7	19.9	79.0	29.7	0.5	-0.6	19	282	1	14.2
8	25.1	103.0	37.5	0.6	-0.7	17	437	1	17.4
9	15.3	77.5	23.0	0.5	-0.6	17	938	1	61.1
10	21.7	85.3	32.4	0.5	-0.5	14	301	1	13.9
11	15.2	72.0	22.6	0.5	-0.6	34	515	2	34.0
12	13.2	77.4	19.8	0.4	-0.5	19	1030	1	77.8
13	17.8	114.3	26.6	0.6	-0.7	29	671	2	37.7
14	16.7	76.5	24.9	0.5	-0.6	35	496	2	29.8
15	18.0	87.2	26.9	0.4	-0.5	12	943	1	52.3
16	23.7	91.6	35.4	0.5	-0.6	32	443	1	18.7
17	16.1	89.2	24.0	0.6	-0.7	35	743	2	46.3
18	21.5	94.0	32.2	0.5	-0.6	19	504	1	23.4
19	9.5	68.4	14.2	0.6	-0.6	45	1016	5	106.5
20	15.3	95.1	22.8	0.6	-0.7	37	714	2	46.7
Mean	17.4	85.5	26.1	0.5	-0.6	28	656	2	43.0

Data Statistics

Table 3 shows the frequency distribution of travel speed and its cumulative frequency distribution during light and peak traffic conditions. From Table 3, it is clear that the vehicle speed in the light traffic condition is higher than its peer in the peak traffic condition. As an example, the frequency distribution of vehicle speed for the range zero to 5 km/h is 19.38% and 42.06% under the light and peak traffic conditions, respectively. In addition, the speed distribution for the light traffic is concentrated in the middle region of speed range while in the peak traffic the vehicle speed distribution is shifted towards the low speed region. Thus, the traffic conditions (*i.e.*, light and peak) have a big impact on the driving patterns in terms of vehicle speeds and accelerations.

TABLE 3 - FREQUENCY DISTRIBUTION OF TRAVEL SPEEDS FOR LIGHT AND PEAK TRAFFIC

Travel Speed (km/h)	Frequency Distribution (%)		Cumulative Frequency Distribution (%)	
	Light Traffic	Peak Traffic	Light Traffic	Peak Traffic
$0 \le v < 5$	19.38	42.06	19.38	42.06
$5 \le v < 10$	2.65	11.32	22.04	53.38
$10 \le v < 15$	2.65	9.83	24.68	63.21
$15 \le v < 20$	3.50	8.16	28.18	71.37
$20 \le v < 25$	3.73	5.89	31.91	77.26
$25 \le v < 30$	4.84	5.05	36.74	82.31
$30 \le v < 35$	5.33	4.76	42.07	87.07
$35 \le v < 40$	5.40	2.83	47.47	89.90
$40 \le v < 45$	6.22	1.69	53.69	91.59
$45 \le v < 50$	5.82	2.02	59.51	93.61
$50 \le v < 55$	4.08	1.38	63.58	94.99
$55 \le v < 60$	3.39	2.53	66.97	97.52
$60 \le v < 65$	3.95	1.15	70.93	98.67
$65 \le v < 70$	5.94	1.33	76.87	100.00
$70 \le v < 75$	6.34	Not Applicable	83.21	Not Applicable
$75 \le v < 80$	3.96		87.17	
$80 \le v < 85$	3.75		90.92	
$85 \le v < 90$	2.19		93.11	
$90 \le v < 95$	4.04%		97.15%	
$95 \le v < 100$	1.90%		99.05%	
$100 \le v < 105$	0.85%		99.90%	
$105 \le v < 110$	0.10%		100.00%	

Methodology

There are many approaches for developing driving cycles. The authors of [10] presented a comprehensive review of existing methodologies for developing driving cycles. In this paper, the Amman driving cycle is developed using the same approach introduced in [11] which is based on selecting a data set, from the data sets presented in Table 2, whose characteristics are most similar to those of all recorded driving data. In this approach, initially the mean values of all recorded driving data are calculated. Then the factor scores for each data set are derived utilizing the factor analysis method in statistics. At the end, the smallest Euclidean distances between the mean and each other driving data are found. It should be noted that the dissimilarity between all recorded driving data can be found via computing the Euclidean distance. By going back to the steps mentioned earlier, a driving cycle for Amman city can be developed. It is clear that the transient nature of the Amman driving cycle, shown in Figure 1, has frequent stops, accelerations, and decelerations. Table 4 shows the frequency distribution and its cumulative frequency distribution at each range of vehicle speed. It is clear that 75% of the speed distribution of Amman driving cycle is below 40 km/h.

By comparing the parameters of the developed Amman cycle in Table 5 with the ones listed in Table 1, the differences in maximum and average speeds of the Amman driving cycle and most of the other driving cycles can be observed. Although the average acceleration of the Amman driving cycle is close to the values for the NYCC and IUC cycles, the number of stops per km for the Amman driving cycle is different from the values for all other driving cycles. The stop duration per km of the Amman driving cycle is higher than the values for the France and Indian driving cycles and less than the values for the NYCC and J10UC cycles. Thus, the developed Amman cycle is unlike any of the other driving cycles introduced in the literature (refer to Table 1 for more details).

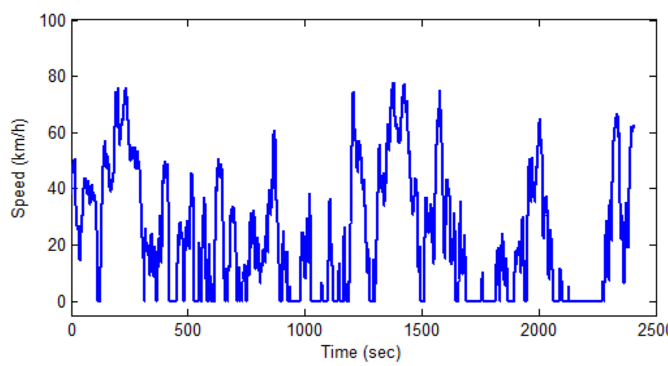

FIGURE 1 – THE DEVELOPED AMMAN DRIVING CYCLE

TABLE 4 - FREQUENCY DISTRIBUTION OF TRAVEL SPEEDS FOR AMMAN DRIVING CYCLE.

Travel Speed (km/h)	Frequency Distribution (%)	Cumulative Frequency Distribution (%)
$0 \leq v < 5$	29.25	29.25
$5 \leq v < 10$	6.25	35.50
$10 \leq v < 15$	8.05	43.56
$15 \leq v < 20$	7.85	51.41
$20 \leq v < 25$	7.14	58.55
$25 \leq v < 30$	5.84	64.40
$30 \leq v < 35$	5.10	69.50
$35 \leq v < 40$	5.55	75.05
$40 \leq v < 45$	5.30	80.35
$45 \leq v < 50$	4.53	84.89
$50 \leq v < 55$	3.82	88.71
$55 \leq v < 60$	3.45	92.16
$60 \leq v < 65$	3.45	95.61
$65 \leq v < 70$	1.75	97.36
$70 \leq v < 75$	1.99	99.35
$75 \leq v < 80$	0.65	100.00

TABLE 5 - PARAMETERS OF THE DEVELOPED AMMAN DRIVING CYCLE.

Parameter	Value
Time (s)	2410
Distance (km)	15.7
Maximum speed (km/h)	77.8
Average speed (km/h)	23.4
Average acceleration (m/s^2)	0.6
Average deceleration (m/s^2)	-0.7
Number of stops	36.0
Stop duration (s)	708.0
Number of stops per km	2
Stop duration (s) per km	45.2

EFFECT OF DRIVING CYCLE ON PERFORMNCE

A model for an internal combustion engine (ICE) sized for Amman taxi vehicles was developed using the Powertrain System Analysis Toolkit (PSAT) software package for the purposes of investigating ICE vehicle performance. The performance of the ICE vehicle model was investigated in terms of fuel economy and emission, as shown in Table 6, using the Amman driving cycle given in Figure 1. It is found that the fuel economy with the Amman driving cycle (*ie.*, 8.92 L/100km) is very close to the fuel economy average values reported by the drivers of the vehicles, which indicates that the developed driving cycle is an accurate representation of a taxis driving cycle in Amman city. As expected, Table 6 shows that the fuel economy and emissions obtained with the Amman driving cycle are very different from the values obtained with other cycles.

TABLE 6 - PERFORMANCE OF THE MODELLED ICE VEHICLE WITH DIFFERENT DRIVING CYCLES

Driving cycle	Fuel economy (L/100km)	CO2 emission (g/km)
Amman	8.92	211.1
NYCC	6.38	151.0
IUC	10.86	256.9
J10UC	7.19	170.1
FUC	9.96	235.7
NEDC	6.00	141.9
UDDS	6.34	150.0

CONCLUSIONS

In this paper, the driving cycle for a taxi in Amman city was developed based on the factor analysis method and Euclidean distance approach. For the development of the driving cycle, data was obtained from a GPS device mounted inside a light duty vehicle (taxi) traveling in the streets of Amman city. The proposed driving cycle is developed for the first time to represent the typical driving pattern in Amman city. When the Amman driving cycle is compared with other worldwide driving cycles, it was evident that it is unlike any of the other driving cycles. In addition, an ICE vehicle model was developed and used to evaluate fuel economy and emissions using the Amman driving cycle and other worldwide cycles. It is found that the fuel economy and emission values obtained by Amman driving cycle are very different from the values obtained with other driving cycles.

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