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Characterisation and development of driving cycle for work route in Kuala Terengganu

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ABSTRACT

Driving cycle is essential for researchers and also vehicle developers to study the performance of the vehicle mainly via simulations. However, the driving cycles are not the same for different countries or cities, although they may seem identical. In this paper, several driving cycle data were collected for different routes in Kuala Terengganu city at peak hours which were then split into several micro-trips. A genetic algorithm was used as a procedure for selecting the optimised micro-trip to develop a complete Kuala Terengganu driving cycle. Then, the proposed driving cycle was compared with other existing driving cycles such as Urban Dynamometer Driving Schedule, Highway Fuel Economy Test Cycle, Supplemental Federal Test Procedure and Environmental Protection Agency. The proposed complete Kuala Terengganu driving cycle was successfully developed with 10 micro-trips and a total time of 1600s. The results showed that the comparison of percentages error for characteristic parameters for the KT and UDDS driving cycle was the lowest at 161.4 percent compared to others. This indicated that KT driving cycle and UDDS driving cycle is similar to each other as the driving cycle for cities. As a conclusion, the KT driving cycle was successfully obtained using the GA method with all of the percentage error for all parameters of below 10 percent, except for the percentage of cruise time. The results for the comparison also proved that the KT driving cycle is similar to UDDS driving cycle where both are the driving cycle for cities.

Keywords: Driving cycle; micro-trip; optimisation; genetic algorithms, UDDS, EPA, HWFET

INTRODUCTION

Vehicle driving cycle is a series of point for speed of vehicle versus time which is mainly used to evaluate the performance of either the vehicle or engine. Most of the researches on driving cycle are based on the conditions of vehicle in a specific location such as the United States FTP75, Europe ECE15, and Japan 10115. These driving cycles are widely applied for evaluating the performance of the vehicle emission, fuel consumption, traffic condition and also for designing, developing and modelling new vehicles, especially hybrid vehicles [1-3]. The construction of the driving cycle starts with the data collection of the actual driving cycle of the vehicle. Generally, there are two methods on data collection of the driving cycle known as the chase car method and on board measurement method [4]. The chase car method uses the vehicle that can measure the speed data. Then, the vehicle is used to chase the reference or target car in a predetermined route. Meanwhile, the on board measurement method uses a specific device for requiring the driving cycle data in the vehicle. The speed data is collected by the device when the vehicle travels through the selected route. In recent years, several methods were proposed for the development of the driving cycle such as micro-trip based cycle construction, segment-based cycle construction, pattern classification cycle construction, and modal cycle construction [4]. The construction of the driving cycle based on micro-trip is a combination of short driving cycle to form a complete driving cycle. Usually, these short driving cycles are taken from a collected driving cycle which is between two adjacent stops including idle periods. The combination of the micro-trip cycle to form the driving cycle can be based on two methods; driving cycle parameter and speed-acceleration frequency. As presented in [5-9] the characteristic parameters such as average speed, average driving speed, average acceleration, average deceleration, percentage of idle, cruise, acceleration, and deceleration are used as a guideline for choosing the micro-trip as members in the complete driving cycle. The selection of the micro-trip and complete driving cycle is based on comparison between the target parameters and also new parameters of the driving cycle. Meanwhile, the driving cycle construction based on speed-acceleration frequency is grouping the micro-trips based on their speed-acceleration parameters as presented in [10]. The micro-trips in the respective group are than selected to from the driving cycle based target parameter. The major limitation of micro-trip based cycle construction is that it is not possible to differentiate micro-trips by various types of driving conditions such as roadway type or Level of Service (LOS) as explained by [11]. However, since micro-trip based cycle construction covers each 'stop-go' condition, it will be a better approach for emission purpose and fuel estimation purpose.

In this paper, a new driving cycle was proposed and developed for Kuala Terengganu (KT) city in Malaysia. The route selection for the driving cycle data collection focused on the main route used by drivers to go to and back from work. Several micro-trips from the actual driving cycle data were selected for a complete drive cycle using Genetic Algorithms (GA) for error optimisation. The remainder of this paper is organised as follows. In Section 2, the data analysis is explained which covered the route and time of the driving cycle, micro-trip construction and driving cycle data characterisation. Next, the methodology of the construction of KT driving cycle city is explained in Section 3 including the optimisation using the GA method. The results and discussions including comparison of the driving cycle with existing driving cycles such as UDDS, HWFET, US60, and EPE are discussed in Section 4. Finally, the development of the KT driving cycles is concluded in Section 5.

METHODS AND MATERIALS

Data Analysis

There were three selected routes from the initial location to the final location for the test vehicle to collect the speed-time data. The data were collected at the peak hour where workers went to work (GTW) and also back from work (BFW) which was at 7 am and 5 pm, respectively. The route was selected based on the main route used by most of the drivers going to work from the initial location to the final location. The data were collected for different route at several times. This step was repeated for both GTW and BFW conditions.

Micro-trip

The development of the KT driving cycle was based on the micro-trips method. In this research, the micro-trip was considered as the short drive cycle with two idle points at the beginning and the end. From a total of 30 drive cycles, N from the data collection, there were 302 micro trips, M. Each of the micro trip was arranged by the assigned number, MT_i and the number of which drive cycle it belonged to, DC_j where i = 1,2,3…N and j = 1,2,3…M. Figure 1 shows an example of the micro-trip from the actual KT driving cycle.

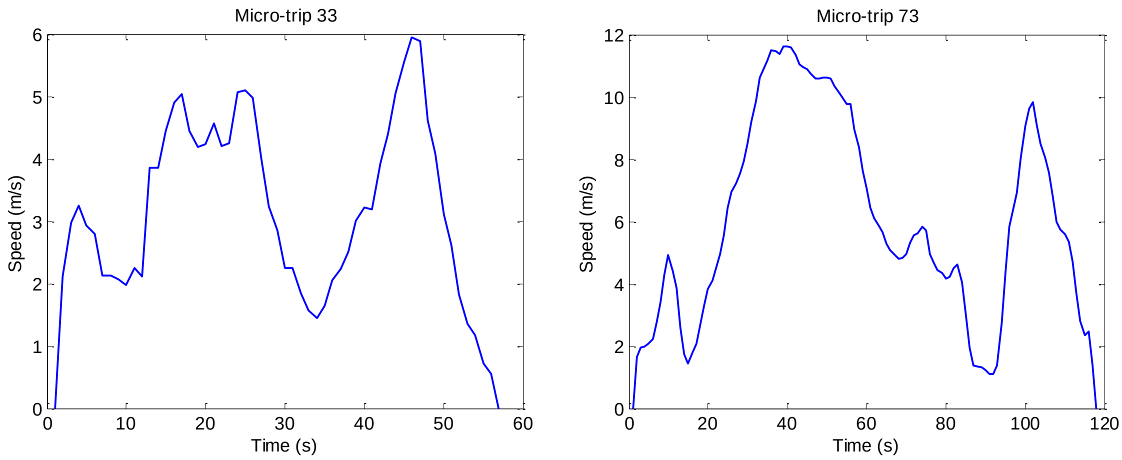

Figure 1. Example of micro-trip from actual KT driving cycle.

Table 1. General parameters for drive cycle characteristics.

No.	Parameters	Unit
1	Total Distance	m
2	Total time	s
3	Driving time	s
4	Idle time	s
5	Cruise time	s
6	Maximum speed	km/h
7	Average speed	km/h
8	Average driving speed	km/h
9	Standard deviation of speed	km/h
10	Maximum acceleration	m/s^2
11	Acceleration time	m/s^2
12	Average acceleration	m/s^2
13	Standard deviation of acceleration	m/s^2
14	Maximum deceleration	m/s^2
15	Deceleration time	m/s^2
16	Average deceleration	m/s^2
17	Standard deviation of deceleration	m/s^2
18	Percentage of time driving	%
19	Percentage of idle time	%
20	Percentage of cruise time	%
21	Percentage of acceleration	%
22	Percentage of deceleration	%
23	Root mean square	m/s^2

Data Collection

Table 1 shows some of the general parameters for drive cycle characterisation. In this research, nine parameters from the list were used as a baseline for micro-trips selection in the development of the driving cycle. The characteristic parameters of the driving cycle are shown in Table 2 which were used to calculate the target parameters. Target parameters were defined as the average values of the parameters for all collected driving cycle data. Table 3 shows some of the calculated target parameters based on equations from Table 2.

Table 2. Characteristic parameters of driving cycle.

No.	Parameters	Abbreviation	Unit
1	Average speed	V_{avg}	m/s
2	Average driving speed	V_{avg_drv}	m/s
3	Average acceleration	Acc_{avg}	m/s^2
4	Average deceleration	Dcc_{avg}	m/s^2
5	Percentage of idle time	%idle	%
6	Percentage of cruise time	%cruise	%
7	Percentage of acceleration	%Acc	%
8	Percentage of deceleration	%Dcc	%
9	Root mean square	RMS	m/s^2

Table 3. Mean value of parameter for each route.

Route (Run)	V_{avg} (m/s)	V_{avg_drv} (m/s)	Acc_{avg} (m/s^2)	Dcc_{avg} (m/s^2)	%idle (%)
1 (GTW)	12.2861	13.8390	0.3449	-0.3907	10.8043
1 (BFW)	6.7080	9.5858	0.3791	-.04087	31.6817
2 (GTW)	12.1608	13.7584	0.3385	-0.3753	11.2594
2 (BFW)	8.6277	12.0557	0.3352	-0.3846	28.7568
3 (GTW)	12.0903	14.0087	0.3636	-0.4241	13.2901
3 (BFW)	5.6126	9.8827	0.4160	-0.4597	42.9815
Average value (Target parameter)	9.5809	12.1886	0.3629	-0.4072	23.1290

Table 3. Continued.

Route (Run)	%cruise (%)	%Acc (%)	%Dcc (%)	RMS (m/s^2)	Time (s)
1 (GTW)	0.3600	47.0619	41.7738	0.5096	1090.4
1 (BFW)	1.2544	34.9846	32.0793	0.6802	2132.8
2 (GTW)	0.5247	46.3793	41.8366	0.5100	1105.6
2 (BFW)	1.4608	37.2787	32.5037	0.6438	1538.0
3 (GTW)	0.2862	46.4224	40.0013	0.5126	1044.6
3 (BFW)	0.3244	29.8390	26.8390	0.7544	2598.8
Average value (Target parameter)	0.7017	40.3276	35.8416	0.6018	1585.0

From Table 3, the characteristics of the driving cycle for each road were able to be analysed. The total time for data driving cycle, back from work of road 3 showed that the driver spent the longest time to drive from the final location back to the initial location. The idle time for the driving cycle was the longest compared to others which showed that there were more traffics and the vehicle needed to stop frequently.

Construction of KT Driving Cycle

Genetic algorithms (GA) is one of the evolutionary computing techniques based on both principles of natural selection and natural genetics; the process that drives biological evolution. The algorithm starts with creating a random initial population. Then, a series of new population is created based on the old population called generation. To create a new population, the algorithm applies a selection of individual as parents for the next population based on their fitness value. The next generation is produced by a combination of crossover and mutation of parents from the previous generation. The children from the previous generation became parents for the next generation. Usually, GA is required to find the minimum value of the fitness function. In GA, the term fitness function or objective function is the function that needs to be optimised. The fitness function consists of individual, which is the potential solution to the optimisation problem. A group or array of individuals known as population or in other word the population is the potential solution for optimisation problem. The smallest fitness function value for any individual in the population is the solution for the optimisation problems. The development and construction of the proposed KT driving cycle used the MATLAB platform. As explained earlier, the proposed driving cycle was a combination of several micro-trips from the actual driving data. The total time of the proposed driving cycle was the average value of total time from all collected data. The selection of micro-trips for the proposed driving cycle was used a procedure created in MATLAB. The procedure started with calculating all the characteristic parameters of the collected data and micro-trip data. Then the average values of the mean values of all collected data were calculated and they were known as the target value.

The GA was used by selecting a set of micro-trips MTset = $\{MT_1, \ldots, MT_k, \ldots, MT_K\}$, $1 \leq k \leq K$, to form a complete proposed driving cycle. Take note that, the GA used in this study utilised the optimisation toolbox available in MATLAB. The GA parameters were set to be default values. The objective of using GA was to find the optimised set of micro-trips by minimising the fitness function. The fitness function in this study referred to the total percentage error, e between individual errors of the calculated characteristic parameters of the proposed driving cycle with the target parameters. The fitness function, f_1 was defined as:

$$e = \frac{|calculated_l - target_l|}{target_l} \times 100\% \qquad (1)$$

$$LL = e - e \times 10\% \qquad (2)$$

$$UL = e + e \times 10\% \qquad (3)$$

$$f_1 = \arg\min \sum_{k=1}^{K} \sum_{l=1}^{L} (e), \qquad LL \geq e \geq UL \qquad (4)$$

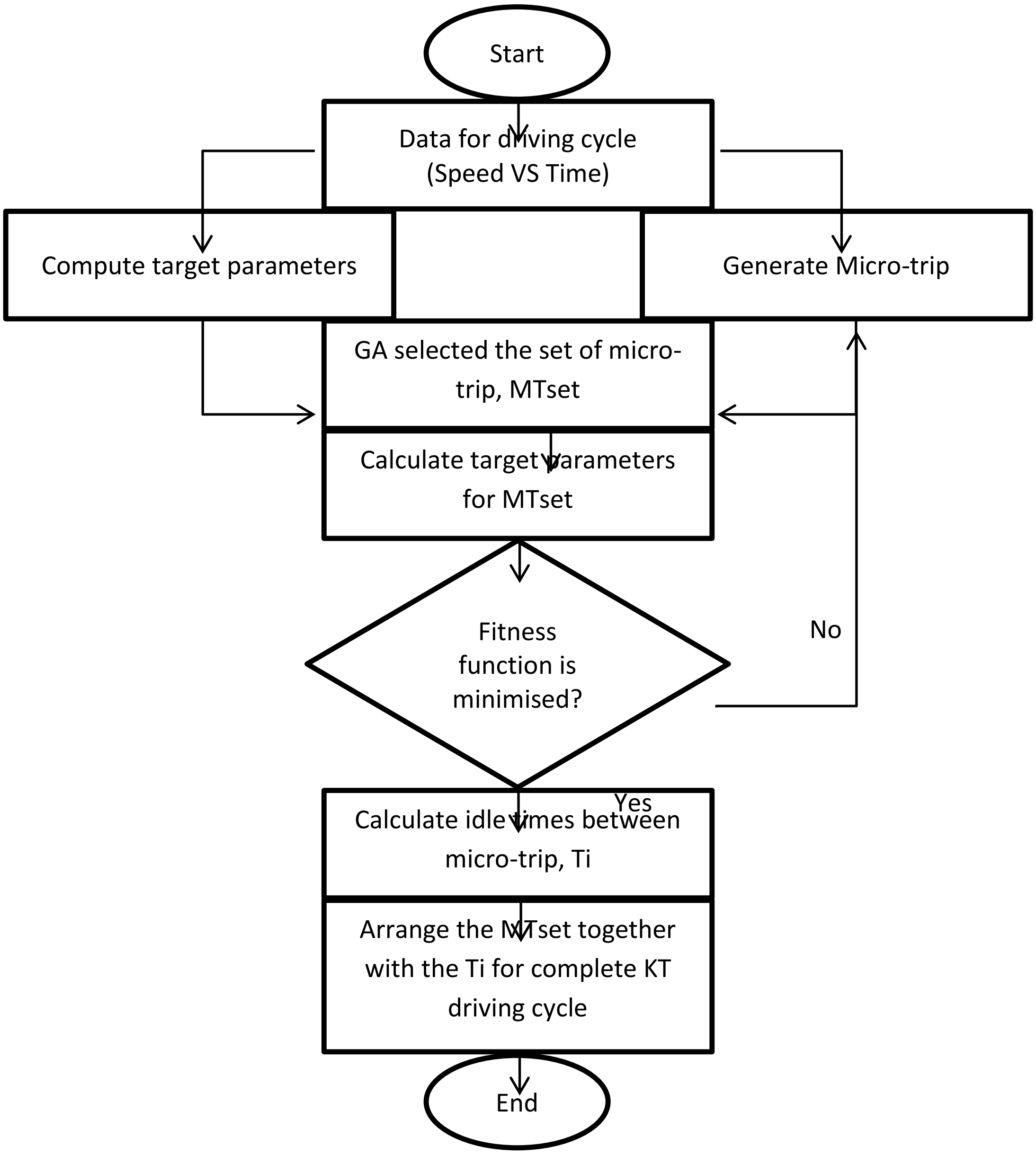

Figure 2. Flowchart of the construction of the KT driving cycle.

where *l* is the number of characteristic parameters of the driving cycle, *k* is the number of micro-trips for the complete driving cycle and K is the predetermined number of the micro-trip. The individual percentage error between the calculated characteristic parameters and target parameters was set to not be over the upper limit (UL) and not below than the lower limit (LL) where both were set to 10%. The total time, *T* for the proposed KT driving cycle was set to be 1600s. This value was taken considering the target value from the data collection was 1585s and also for its simplicity. Meanwhile, the idle times, T_i between the micro-trips were set to be the division of the remainder of the total micro-trip times, T_{MT} as shown in equation 5. The flowchart for the complete development of KT driving cycle is shown in Figure 2.

$$T_i = \frac{\left[T - \sum_{k=1}^{K}\left(T_{MT_k}\right)\right]}{K} \quad (5)$$

RESULTS AND DISCUSSION

Figure 3 shows the results from the simulation for the proposed KT driving cycle. The predetermined number of the micro-trip for the complete KT driving cycle was set to be 10. From the figure, it shows that the speed was quite high, indicating that the path was clear without much congested traffic. The micro-trips for the proposed driving cycle also contained a longer time which meant that the vehicle was not having regular 'stop-go' conditions which will save much more fuel consumption and emissions. It was noted that, the position of micro-trip in the complete proposed driving cycle may not be consistent each time the procedure was run. The performance of this driving cycle was analysed for percentage error between the target parameters and characteristic parameters. Then, the comparison between the proposed KT driving cycle and existing driving cycle was done. The existing driving cycles used for the comparison were Urban Dynamometer Driving Schedule (UDDS), Highway Fuel Economy Test Cycle (HWFET), Supplemental Federal Test Procedure (SFTP) (US06), and Environmental Protection Agency (EPA).

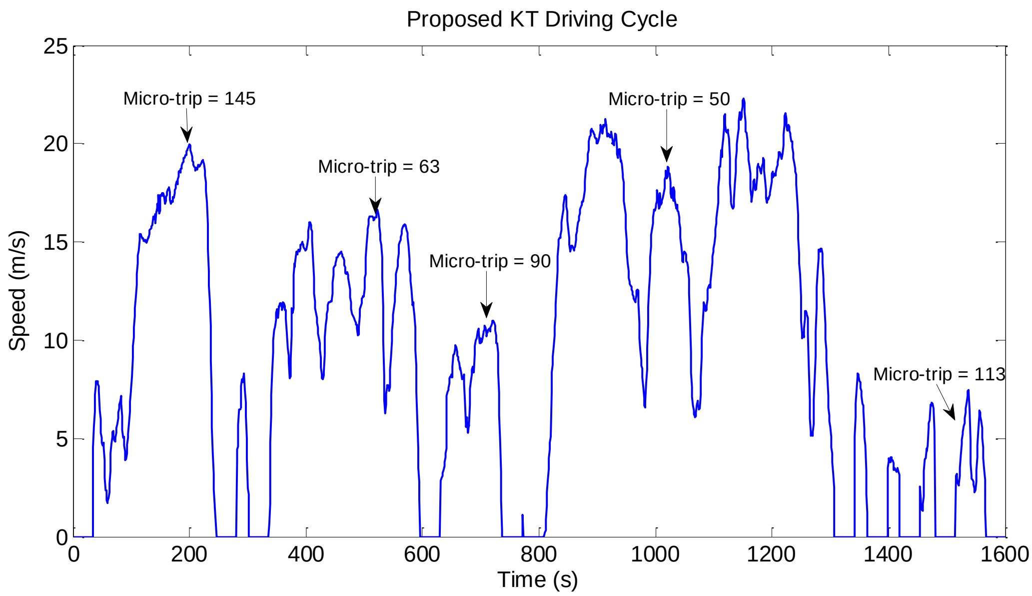

Figure 3. The proposed KT driving cycle.

Table 4 shows the results of the calculated characteristic parameters for the existing driving cycles which were calculated from the Autonomie software and the proposed KT procedure. Both of characteristic parameter's values calculated from Autonomie and proposed KT procedure gave similar results for all of the existing driving cycles. These results proved that the procedure used in this driving cycle development was correct.

Meanwhile, Table 5 shows the characteristic parameters for the proposed driving cycle, its target parameters, and also the percentage error between the calculated and target parameter. The percentage error for all parameters was below 10 percent as predetermined, except for the percentage of cruise time which was bigger than 10 percent. The exception was made for the percentage error of the percentage of cruise time because its value and error were too low, making the percentage error bigger. As presented in [12], there are a lot of factors that affect the results of the driving cycle which are drivers' behaviour, environmental factors and many more.

Table 4. Characteristic parameters using Autonomie and proposed procedure of KT driving cycle.

No.	Parameters	HWFET		UDDS	
		AN	KT	AN	KT
1	Max acceleration (m/s^2)	1.4305	1.4305	1.4752	1.4752
2	Mean acceleration (m/s^2)	0.1942	0.1942	0.5046	0.5046
3	Max deceleration (m/s^2)	-1.4752	-1.4752	-1.4752	-1.4752
4	Distance (miles)	10.2568	10.2568	7.4504	7.4504
5	Driving time (s)	764	764	1369	1369
6	Max speed (mph)	59.9000	59.9001	56.7000	56.7001
7	Mean speed (mph)	48.5847	48.5848	24.1417	24.1417

Table 4. Continued

No.	Parameters	US06		EPA	
		AN	KT	AN	KT
1	Max acceleration (m/s^2)	3.7548	3.7548	1.4752	1.4752
2	Mean acceleration (m/s^2)	0.6700	0.6700	0.3856	0.3856
3	Max deceleration (m/s^2)	-3.0843	-3.0843	-1.4752	-1.4752
4	Distance (miles)	8.0073	8.0073	17.7071	17.7071
5	Driving time (s)	600	600	2135	2135
6	Max speed (mph)	80.2928	80.2929	59.9000	59.9001
7	Mean speed (mph)	51.8455	51.8456	34.0703	34.0703

Table 5. Characteristic parameters of KT driving cycle.

Parameters	Value	Target	% Error
Average speed (m/s)	9.3960	9.5809	1.9303
Average driving speed (m/s)	12.3530	12.1886	1.3490
Average acceleration (m/s^2)	0.3634	0.3629	0.1421
Average deceleration (m/s^2)	-0.3940	-0.4072	3.2605
Percentage of idle time (%)	23.3125	23.1290	0.7934
Percentage of cruise time (%)	0.6250	0.7017	10.9347
Percentage of acceleration (%)	39.5625	40.3276	1.8973
Percentage of deceleration (%)	36.5000	35.8416	1.8369
Root mean square (m/s^2)	0.6020	0.6018	0.0326

The analysis on the comparison of KT driving cycle with the existing driving cycle is as shown in Table 6. The percentage errors between the KT and other driving cycles are also shown in the table together with the value for each parameter. Overall, the UDDS driving cycle showed that the total percentage errors for all parameters were smaller compared to other driving cycles because UDDS is a driving cycle for the city which is similar to KT driving cycle. Other driving cycles such as HWFET, US06 and EPA represented the highway or roadway conditions as explained in [13]. Thus, the results of the parameters will be much more different compared to a city driving cycle. The percentage error of the percentage of cruise time for all driving cycles was highly different compared to KT driving cycle. This result happened because of the behaviour of the drivers in KT city as well as the environmental driving factors. Different cities will reflect different driving habits and driving environments[14]. Since KT is not a big and busy city, the results differed and produced a certain amount of percentage errors with UDDS in which UDDS represented a big and busy city.

Table 6 Comparison of characteristic parameters between KT and existing driving cycles.

Parameters	KT	UDDS	HWFET	US06	EPA
		e (%)	e (%)	e (%)	e (%)
T (s)	1600	1369	765	601	2136
		14.4375	52.1875	62.4375	33.5000
V_{avg} (m/s)	9.3960	8.7520	21.5774	21.4416	13.3412
		6.8540	129.6445	128.1992	41.9881
V_{avg_drv} (m/s)	12.3530	10.7923	21.7193	23.1770	15.2308
		12.6342	75.8221	87.6224	23.2964
Acc_{avg} (m/s)	0.3634	0.5046	0.1942	0.6700	0.3856
		38.8553	46.5603	84.3698	6.1090
Dcc_{avg} (m/s)	-0.3940	-0.5779	-0.2217	-0.7283	-0.4406
		46.6751	43.7310	84.8477	11.8274
%idle	23.3125	17.6642	0.5229	6.6556	11.5637
		24.2286	97.7570	71.4505	50.3970
%cruise	0.6250	7.9562	16.6013	5.4908	11.0019
		1173.0	2556.2	778.5	1660.3
%Acc	39.5625	39.7080	44.1830	45.7571	41.2921
		0.3678	11.6790	15.6578	4.3718
%Dcc	36.5000	34.6715	38.6928	42.0965	36.1423
		5.0096	6.0077	15.3329	0.9800
RMS (m/s^2)	0.6020	0.6764	0.2939	1.0550	0.5615
		12.3588	51.1794	75.2492	6.7276
Total error		1334.4	3070.8	1403.7	1839.5
Total error without %cruise		161.4	514.6	625.2	179.2

CONCLUSIONS

The characterisation and development of driving cycle for work route in Kuala Terengganu have successfully been done by using GA as an optimisation method to find the optimum micro-trips for a complete proposed KT driving cycle. The data were collected from a predetermined initial location to the final location by three different routes at peak hours. The KT driving cycle was successfully obtained using the GA method with all percentage errors for all parameters of below 10 percent except for the percentage of cruise time. The results for the comparison also proved that the KT driving cycle is similar to UDDS driving cycle where both are the driving cycles for cities. This study should be explored further to analyse the fuel consumption or fuel economy and emissions.

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