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KUALA TERENGGANU DRIVING CYCLE DEVELOPMENT USING TARGET PARAMETER APPROACH

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Abstract: The driving cycle is critical in producing and evaluating the vehicle's performance. A driving cycle is a set of speed-time data used as a key input in car emission models. In this article, a driving cycle for Kuala Terengganu, Malaysia, is proposed and created. The driving cycle data collection route was chosen based on the most common path taken by drivers to get to work. The parameters for the driving data in each run are calculated and then the target value parameter is developed. The lowest percentage error is accepted as the KTDC (Kuala Terengganu Driving Cycle). Later, a Kuala Terengganu Driving Cycle (KTDC) is developed with 37.52 km/h in average speed and 8 micro-trips. Then, the KTDC is compared with the existing standard driving cycle such as NEDC and UDDS.

Keywords: Driving cycle, hybrid electric vehicles, emissions, assessment parameters, micro-trips.
Abbreviations: KTDC, KT, WLTC, NEDC, FTP, GPS.

Introduction

A driving cycle is a profile of speed and time used by drivers in a specific location or city (Kaymaz *et al*., 2019; Zhao *et al.*, 2020; Borlaug *et al*., 2020). The driving cycle describes how a vehicle behaves on the road and is used by various people, including those who create activity control frameworks and choose how to operate vehicles. It is also applied to the certification of emission standards during car emission testing (Arun *et al.,* 2017). Vehicle manufacturers, environmentalists and traffic engineers all frequently employ it in their applications.

A few well-known driving cycles, such as the Worldwide Harmonized Light Vehicle Test Cycle (WLTC), the New European Drive Cycle (NEDC), the Federal Test Procedure (FTP) and others, have their roots in Europe, the United States of America, Japan, China and India. However, other places, such as Toronto, Canada (Amirjamshidi & Roonda, 2015), Iran (Fotouhi & Montazeri-Gh, 2013), Singapore (Ho et al., 2014), Hong Kong (Hung et al., 2007) and others have established indigenous driving cycles.

The actual scenario in Kuala Terengganu (KT), the state capital of Terengganu, Malaysia, is not reflected in any of the designed driving cycles. Driving cycles are crucial for vehicle design and if automakers concentrate just on one driving cycle during the development of a vehicle, there is a chance that the design will be optimised for this particular driving cycle, leading to non-robust and sub-optimal results for other driving cycles. Hence, in order to aid other researchers in continuing the research on emissions and fuel consumption in KT city, an actual KT city work route driving cycle needs to be built and characterised.

Route selection, data collecting and cycle construction are the key processes in creating a driving cycle. Cycles can be built in a variety of ways. Be that as it may, four commonplace and popular strategies are micro-trips-based development, design classification cycle development, segment-based cycle development and modular cycle development. The micro-trips-based approach was used, similar to the work of Arun *et al.* (2017) and Amirjamshidi & Roonda (2015), where the relative error between the target and test micro-trips is established. Then, the percentage errors below 15% are acceptable and the results are merged as a driving cycle.

In contrast, Ho et al. (2014) explain that a semi-random strategy is used to choose the micro-trips from the road type and timings by grouped categories. The micro-trips are picked from the database and combined in a sequence to build a driving cycle in the same manner that the frequency distribution of the gathered speed-time data is matched to the frequency distribution of the driving cycle as in Slovenia (Lipar *et al.*, 2016). A stochastic and statistical methodology is utilised to generate and assess the representativeness of the driving cycle in Dublin, Ireland. (Brady & O'Mahony, 2016).

This article proposes and develops a new driving cycle for Malaysia's Kuala Terengganu (KT) metropolis. The primary route taken by drivers to get to work was the one that was chosen for the driving cycle data collection. The parameters for the driving data in each run are calculated and then the target value parameter is developed. The lowest percentage error is accepted as the KTDC (Kuala Terengganu Driving Cycle). This study aims to characterise and develop the driving cycle of Kuala Terengganu city at 8 a.m. along the main route and to compare the KTDC with other existing standard driving cycles.

The development of KTDC will be covered in this paper. The methodology, which includes route selection, data collecting and driving cycle development utilising a target parameter approach, will be explained in section 2. The analysis of the KTDC is detailed later in section 3. Also, the comparison between KTDC with the existing standard driving cycle is discussed.

Materials and Methods

Figure. 1 shows the flow chart and research activities on how to develop a KTDC along the main route for the Kuala Terengganu citizens to go to work at 8.00 a.m. The KTDC inputs were at a second-by-second speed. The data is collected with 10 runs of data at the peak time, which is 8 a.m. Due to its high traffic volume, the road was designated as a preferred route in Kuala Terengganu. The onboard measurement approach with a Global Positioning System (GPS) is used in this study. The data gathered is then stored and managed in MATLAB. Then the parameters for each run were extracted.

Data Collection

Figure 2 highlights the selected route for the KT driving cycle from Kampung Wakaf Tembesu to Wisma Persekutuan. Agreeing to the Ministry of Works Malaysia, this route is the foremost visit route utilised by Kuala Terengganu citizens (Ministry of Works Malaysia, 2020). This study gathers speed-time data across a pre-planned route from Kampung Wakaf Tembesu to Wisma Persekutuan utilising GPS and an onboard measurement method. Kampung Wakaf Tembesu was picked as the starting point due to its population. Since most government agencies are situated in or close to Wisma Persekutuan, it was decided to make this location the finishing point.

Data was collected at GTW time along the selected road with 10 runs. The three data collection strategies are the pursuit car technique, the onboard measurement technique and a mix of onboard measurement and circulation driving. When a chase car follows the target vehicles, an instrumented vehicle records second-by-second speed data. On-board measurement is when speed-time data is collected using a real-time logging device installed on a specific vehicle and driven along a specified route. Finally, the hybrid method, which combines onboard measuring and circulation driving, is a combination of the two techniques (Galgamuwa *et al.*, 2015). For

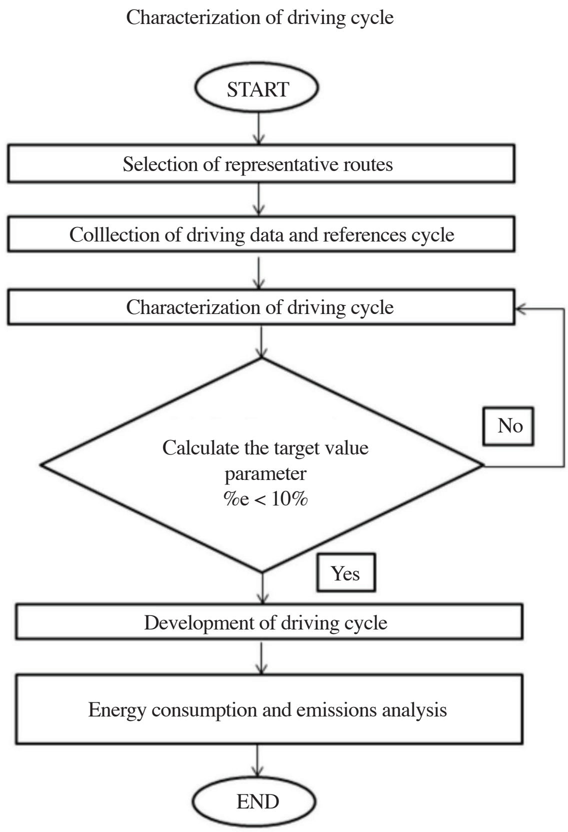

Figure 1: Research activities of the study

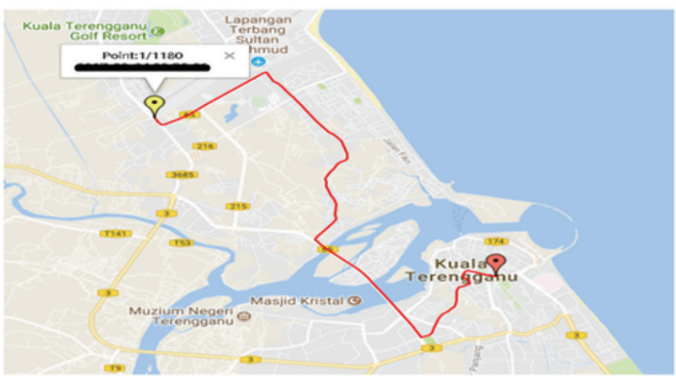

Figure 2: Representative route

KTDC, the onboard measurement procedure will be utilised for the data collection since it is more appropriate for KT drivers' sporadic conduct to dodge a hazard such as a mishap and unexpected loss of control.

Parameters for Driving Cycle Characteristics

The assessment parameters in Table 1 (Anida & Salisa, 2019) are used to characterise the driving data. In order to characterise and confirm the driving cycle, cycle assessment is essential.

Average speed, average running speed, average acceleration and deceleration and root mean square of acceleration are the parameters included in this project. Idling mode, accelerating mode, decelerating mode and cruising mode are the four driving modes defined in this study. Idling mode is when the speed is zero, while the car is not shut off, waiting to start or recover running. While the accelerating mode is a continuous process whose acceleration is bigger than 0.1 m/s2.

On the other hand, the decelerating mode is a continuous process whose deceleration is smaller than -0.1 m/s2. Lastly, cruising mode is a continuous process in which the absolute value of acceleration or deceleration is less than 0.1 m/s2 while the speed is not zero. These nine factors were chosen as the assessment parameters since they are the most important in determining the driving cycle's characterisation.

The target parameters will be calculated using the driving cycle's characteristic parameters, shown in Table 1. The average values of the parameters for all gathered driving cycle data were used to create the target parameters.

Development of KTDC

The development of a drive cycle is based on the target parameter approach, whereas the parameters for all runs will be calculated. Then, the average value of the parameters will be considered as the target value parameter. The percentage error will be calculated as in Equation 1. The least percentage error or percentage error that is less than 10% will be considered as the final KTDC.

δ (percentage error)
= (|*calculated* - *target*| / *target*) 100% **(1)**

Figure 3 shows the calculated and average value parameters of the KT route to work at 8.00 a.m. for all runs based on equations from Table 1. Table 2, on the other hand, lists the percentage error for each run

Table 1: Assessment parameter of KTDC

Parameters	Unit	Equation
Average speed of whole driving cycle	km/h	$V_1 = 3.6\frac{dist}{T_{total}}$
Average running speed	km/h	$V_2 = 3.6\frac{dist}{T_{drive}}$
Average acceleration of all acceleration phase	m/s²	$a = \left(\sum_{i=1}^{n}\begin{cases}1 & (a_i > 0)\\ 0 & (else)\end{cases}\right)^{-1} \left(\sum_{i=1}^{n}\begin{cases}a_i & (a_i > 0)\\ 0 & (else)\end{cases}\right)$
Average deceleration of all deceleration phase	m/s²	$d = \left(\sum_{i=1}^{n}\begin{cases}1 & (a_i < 0)\\ 0 & (else)\end{cases}\right)^{-1} \left(\sum_{i=1}^{n}\begin{cases}a_i & (a_i < 0)\\ 0 & (else)\end{cases}\right)$
Time proportion of idling	%	$\%\ idle = \frac{T_{idle}}{T_{total}}$
Time proportion of cruising	%	$\%\ cruise = \frac{T_{cruise}}{T_{total}}$
Time proportion of acceleration	%	$\%\ acc = \frac{T_{acc}}{T_{total}}$
Time proportion of deceleration	%	$\%\ dec = \frac{T_{dec}}{T_{total}}$
Root mean square acceleration	m/s²	$RMS = \sqrt{\frac{1}{T}\int_0^T (a)^2 dt}$

Run	V_1	V_2	*a*	*d*	RMS	%idle	%cruise	%acc	%dec
1	37.5	48.44	0.43	0.44	0.56	21.97	0.15	39.48	38.4
2	37.52	47.78	0.48	0.48	0.58	21	7.46	36.08	35.46
3	37.86	47.17	0.43	0.43	0.55	19.03	0.55	40.25	40.17
4	37.73	45.96	0.51	0.47	0.64	17.19	10.7	34.39	37.72
5	37.37	46.79	0.42	0.44	0.57	19.52	0	41.12	39.35
6	37.38	45.83	0.5	0.51	0.61	17.82	9.52	36.48	36.18
7	36.37	50.25	0.42	0.51	0.56	27.17	0.97	39.67	32.19
8	36.33	49.18	0.48	0.59	0.61	25.69	10.39	35.26	28.66
9	38.56	49.82	0.47	0.54	0.58	21.74	8.77	37.08	32.41
10	36.35	51.99	0.41	0.48	0.55	25.62	0	40	34.39
Average	**37.497**	**48.321**	**0.454**	**0.489**	**0.581**	**21.674**	**4.851**	**37.981**	**35.493**

Figure 3: Calculated parameters and average parameters

Table 2: Percentage error for each run

Run	Percentage error, δ (%)
1	14.398
2	7.634
3	16.228
4	20.986
5	16.887
6	16.089
7	15.723
8	21.710
9	12.468
10	17.036

Results and Discussion

After all the driving cycle data along the chosen route has been gathered, the final development of the KTDC can be achieved with the lowest percentage error which is 7.634 %. Figure 4 shows the final KTDC. The total distance is 13.46 km and the total micro-trips are 8. The characteristic of the KT driving cycle in terms of nine assessment parameters is tabulated in Table 3. The developed driving cycle yielded the following findings:

1) The speed range exceeding 10 km/h was the most prevalent. This is owing to KT city's moderate traffic conditions at peak hours.
2) When compared to micro-trips at lower speeds, micro-trips at greater speeds take longer. This is because a vehicle in a free-flow environment travels at a higher speed range with fewer stops due to less traffic congestion.
3) The designed KT driving cycle recorded an average speed of 37.52 km/h, indicating that the cars are going at a reduced speed and that more micro-trips are discovered below the average speed. As a result of the numerous stops along the road, there is an increase in fuel consumption and emissions during that time.

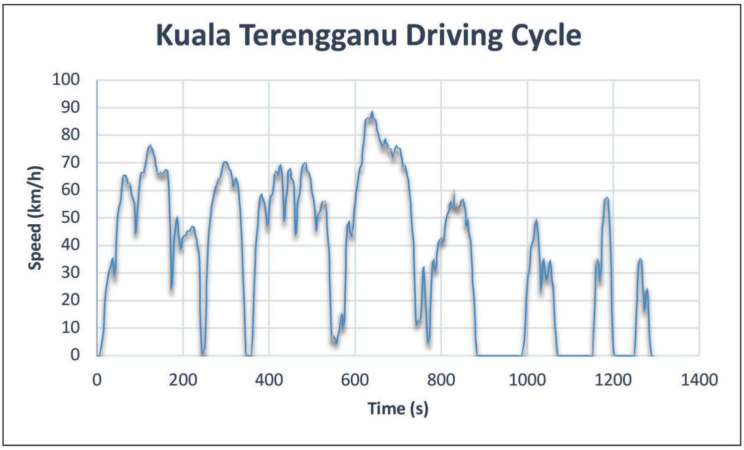

Figure 4: Proposed Kuala Terengganu driving cycle

Table 3: Assessment parameters of KTDC

Parameters	KTDC
Distance travelled (km)	13.46
Total time (s)	1299
Average speed (km/h)	37.52
Average running speed (km/h)	47.78
Average acceleration (m/s^2)	0.47
Average deceleration (m/s^2)	0.48
RMS (m/s^2)	0.58
Percentage idle (%)	21
Percentage cruise (%)	7.46
Percentage acceleration (%)	36.08
Percentage deceleration (%)	35.46

Table 4 tabulates the comparison of the KTDC and existing standard driving cycle, New European Driving Cycle (NEDC) and Urban Dynamometer Driving Schedule (UDDS). The NEDC is chosen as the comparison to the KTDC since in Malaysia, the local authorities still use NEDC for legislation and by the local manufacturers and suppliers for evaluation purposes. As for UDDS, the driving cycle was chosen since it was specifically designed for the urban driving situation. Figure 5 & 6 shows the driving cycle of NEDC and UDDS. The table shows that the values of the parameters for the three driving cycles are different. 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. 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.

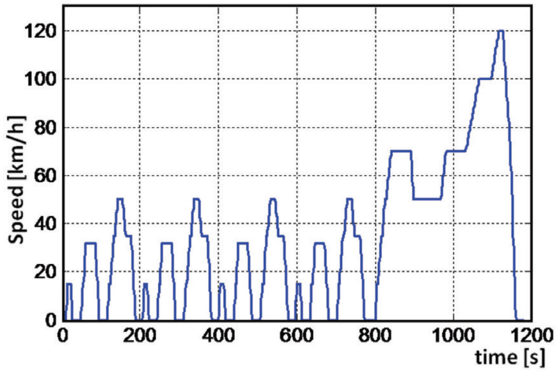

Figure 5: New European Driving Cycle (NEDC)

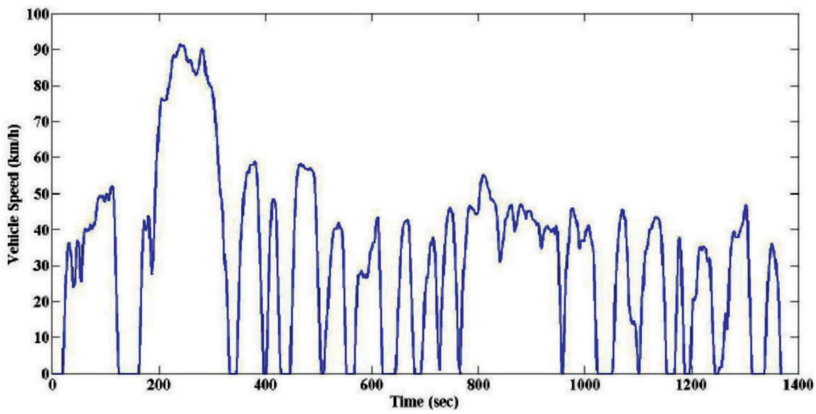

Figure 6: Urban Dynamometer Driving Schedule (UDDS)

Table 4: Comparison between KTDC, NEDC and UDDS.

Parameters	KTDC	NEDC	UDDS
Distance travelled (km)	13.46	11.02	12.89
Total time (s)	1299	1180	1369
Average speed (km/h)	37.52	33.6	31.51
Average running speed (km/h)	47.78	42.24	38.85
Average acceleration (m/s^2)	0.47	0.53	0.50
Average deceleration (m/s^2)	0.48	0.72	0.58
Root mean square (m/s^2)	0.58	0.14	0.68
Percentage idle (%)	21	16.95	17.66
Percentage cruise (%)	7.46	38.81	7.96
Percentage acceleration (%)	36.08	23.56	39.71
Percentage deceleration (%)	35.46	17.29	34.67

Conclusion

The target parameter approach is successfully used to design the KTDC. The data is collected from a specified starting point to a final destination along the major road for Kuala Terengganu residents who go to work at 8:00 a.m. The KTDC also has successfully been compared with other standard driving cycles such as NEDC and UDDS, for validation purposes. For future work, every state and city in Malaysia should be considered to develop an accurate Malaysian driving cycle.

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References

Amirjamshidi, G., & Roonda, M. J. (2015). Development of simulated driving cycles: Case study of the Toronto Waterfront area. *Transportation Research Part D*, *34*, 255-266.

Anida, I. N., & Salisa, A. R. (2019). Driving cycle development for Kuala Terengganu city using k-means Method. *International Journal of Electrical and Computer Engineering*, *9*(3), 1780-1787.

Arun, N. H., Mahesh, S., Ramadurai, G., & Shiva, S. M. (2017). Development of driving cycles for passenger cars and motorcycles in Chennai, India. *Sustainable Cities and Society*.

Arun, N. H., Mahesh, S., Ramadurai, G., & Shiva, S. M. (2017). Development of driving cycles for passenger cars and motorcycles in Chennai, India. *Sustainable Cities and Society*.

Borlaug, B., Holden, J., Wood, E., Lee, B., Fink, J., Agnew, S., & Lustbader, J. (2020). Estimating region-specific fuel economy in the United States from real-world driving cycles. *Transportation Research Part D*, *86*, 102448.

Brady, J., & O'Mahony, M. (2016). Development of a driving cycle to evaluate the energy economy of electric vehicles in urban areas. *Applied Energy*, *177*, 165-178.

Fotouhi, A., & Montazeri-Gh, M. (2013). Tehran driving cycle development using the k-means clustering method. *Scientia Iranica, Transactions A: Civil Engineering*, *20*(2), 286-293.

Galgamuwa, U., Perera, L., & Bandara, S. (2015). Developing a general methodology for driving cycle construction comparison of various established driving cycles in the world to propose a general approach. *Journal of Transportation Technologies*, *5*, 191-203.

Ho, S-H., Wong, Y-D., & Chang, V. W-C. (2014). Developing Singapore driving cycle for passenger cars to estimate fuel consumption and vehicular emissions. *Atmospheric Environment*, *97*, 353-362.

Hung, W. T., Tong, H. Y., Lee, C. P., Ha, K., & Pao, L. Y. (2007). Development of a practical driving cycle construction methodology: A case study in Hong Kong. *Transportation Research Part D*, *12*, 115-128.

Kaymaz, H., Korkmaz, H., & Erdal, H. (2017). Development of a driving cycle for Istanbul bus rapid transit based on real-world data using stratified sampling method. *Transportation Research Part D*, *75*, 123-135.

Ministry of Works Malaysia. (2020). 2019 Road Traffic Volume Malaysia (RTVM). *Ministry of Works Malaysia, Highway Planning Division*.

Nyberg, P., Frisk, E., & Nielsen, L. (2016). Driving cycle equilance and transformation. *IEEE Transactions on Vehicular Technology*.

P. Lipar, P., Strnad, I., Cesnik, M., & Maher, T. (2016). Development of urban driving cycle with GPS data post processing. *Traffic & Transportation*, *28*(4), 353-364.

Zhao, X., Zhao, X., Yu, Q., Ye, Y., & Yu, M. (2020). Development of a representative urban driving cycle construction methodology for electric vehicles: A case study in Xi'an. *Transportation Research Part D*, *81*,102279.