Consumption Evaluation of Energy Consumption and Emissions of BAS KITe in Kuala Terengganu from the Development of Its Driving Cycle

I.N. Anida¹, J.S. Norbakyah¹, M. Zulfadli², M.H. Norainiza², A.R. Salisa¹
¹School of Ocean Engineering, Universiti Malaysia Terengganu
21030 Kuala Nerus, Terengganu, Malaysia. Tel: +609-668 3159/3447. Email: salisa@umt.edu.my
²Cas Ligas Sdn Bhd., Level 9, Permint Tower, Jalan Sultan Ismail, 20200 Kuala Terengganu, Terengganu, Malaysia. Tel: +609-627-8171

Abstract. Public transportation transforms communities and the lives of the people dwelling in them via spurring monetary development, promoting sustainable existence and providing a greater first-rate of life. In Kuala Terengganu, an iconic and famous public bus is called ‘BAS KITe’ . In order to evaluate the energy consumption and emissions of BAS KITe , its driving cycle needs to be developed. Driving cycle represents traffic behaviour in a specific area or city. Objectives of this paper are; to characterize and validate the parameters of BAS KITe driving cycle with existing driving cycle, to develop BAS KITe driving cycle using k-means method, and to analyse the energy consumption and emissions of BAS KITe driving cycle for conventional and plug-in hybrid electric types using AUTONOMIE software. The methodology consists of data collection, route selection and cycle development. From the validation, it can be concluded that the MATLAB code is acceptable for further analysis. The BAS KITe driving cycle is developed with 36 final micro-trips and 21.49 km/h of average speed. Hence, energy consumption and emissions analysis shows that the PHEB powertrain gives the best result with reduced energy consumption and emissions thereby minimizing the impact on the environment and economy.

1. Introduction
American Public Transportation Association (APTA) proves that public transportation transforms communities and the lives of the people residing in them via spurring economic development, merchandising sustainable life and presenting a greater satisfactory of life. Every phase of world society - individuals, families, communities, and organizations - advantages from public transportation such as public transportation can furnish financial opportunities, safer, saves money, reduces energy consumption, reduces the emission and enhances non-public possibilities.

In Kuala Terengganu (KT), the public bus service was created to upgrade the public transport system in Terengganu State by providing city bus services. The objectives of this service are, to increase the level of intermediary mobility from one area to another, to provide a service system for travellers' convenience and to providing cheaper, efficient and comfortable public services. The uniqueness and services of the BAS KITe has attracted almost 57, 314 passengers in year 2017. Cas Ligas Sdn Bhd, the company that handles BAS KITe, reported that they have spent total of RM 144,519.59 in 2016 and RM 176,273.62 in 2017 on diesel.

Thus, the alternative to reduce the fuel consumption has been discussed. Hybrid electric bus (HEB) has become an effective solution to meet the tightening emission regulations and the need of more fuel-efficient vehicles. It is because the HEB has better energy economy and emissions
performance than the internal combustion engine bus [1]. The driving cycle for new energy vehicle such as hybrid vehicle can provide a reliable basis for the improvement of motor control strategy and vehicle matching and can be applied to the evaluation of the hybrid vehicle's engine economic performance and emission performance [2]. Driving cycle is a representative speed-time profile of driving behavior of specific region or city [3] and also characterizes the behavior of vehicle on the road and it is used in the emission testing of vehicles for certification of emission norms [4].

Many well-known international bus driving cycles have been developed for different cities to represent their local traffic and driving situations such as the Central Business District Cycle (CBDC), Dutch Urban Bus Drive Cycle (DUBC), Overall Bus Driving Cycle (OBDC), Delhi Bus Driving Cycle (DBDC) and also Chennai Bus driving cycle [5]. The driving cycle of typical bus lines in Hefei, China also has been discussed [6]. However, the driving cycle for Kuala Terengganu, specifically on public bus has not been developed and discussed yet.

The objectives of this paper are to characterize and validate the parameters of BAS KItE driving cycle with existing driving cycle, to develop BAS KItE driving cycle along its operation routes by using k-means clustering method, and to analyse the energy consumption and emissions of BAS KItE driving cycle for conventional bus and plug-in hybrid electric bus (PHEB) types using Vehicle System Simulation Tool Development (AUTONOMIE) software.

2. Methodology
The methodology of developing a BAS KItE driving cycle consists of three main steps which are; route selection, data collection and also cycle development. Figure 1 shows the flow chart of the methodology and research activity. The inputs of BAS KItE driving cycle are second-by-second speed. The flow chart begins with the selection of BAS KItE operation routes for references cycle. Then, collection of driving speed-time data along the operation routes, BAS KItE driving cycle characterization, validation of BAS KItE driving cycle with existing standard driving cycle, development of BAS KItE driving cycle and lastly the analysis of energy consumption and emissions of BAS KItE driving cycle by using AUTONOMIE software.

![Flow chart of research activities](image_url)
2.1 Route Selection

Figure 2 and Figure 3 highlights the two operation routes of *BAS KItE* services. First route which is Route C01 begins at MBKT Bus Terminal then straight to Pantai Batu Burok, Noor Arfa Craft Complex, Terengganu’s Science & Creativity Centre and the famous Floating Mosque. While the second route which is Route C02 starts at MBKT Bus Terminal and brings to Terengganu’s State Museum, the iconic Crystal Mosque, Pasar Payang and Pulau Warisan.

![Figure 2: Route C01](image1)

![Figure 3: Route C02](image2)

2.2 Data Collection

Data was collected along the selected road as in Figure 2 and Figure 3 with 10 runs for each route. There will be 20 runs of data all together. There are two main types of techniques or ways to collect the data which are chase car technique and on-board measurement technique. Chase car technique is when instrumented vehicle record the second-by-second speed data as it follows the target vehicles. While on-board measurement technique is when speed-time data collections were carried out using a real time logging system equipped on a selected vehicle along the predetermined route [7]. Data also can be collected by combining those two methods and it is known as hybrid method. For *BAS KItE* in KT city driving cycle, on-board measurement technique will be used for the data collection since it is more suitable for KT drivers’ irregular behaviour to avoid a risk such as accident and sudden loss of control.
2.3 Cycle assessments of BAS KITe driving cycle

Cycle assessment is one of the major components in developing driving cycles, because the assessment criteria assures that the developed cycle truly represents the actual driving pattern on road in that particular area or region and also to characterize and validate the driving cycle. Table 1 shows the assessment parameters of BAS KITe driving cycle. Those nine parameters have been chosen as the assessment parameters because they are the fundamental assessment in order to determine the characterization of the driving cycle.

| No | Variable                                      | Unit       | Formula                        |
|----|-----------------------------------------------|------------|--------------------------------|
| 1  | Average speed of whole driving cycle, V<sub>1</sub> | km/h       | V<sub>1</sub> = 3.6 \frac{\text{miles}}{\text{h}} |
| 2  | Average running speed, V<sub>2</sub>           | km/h       | V<sub>2</sub> = 3.6 \frac{\text{miles}}{\text{h}} |
| 3  | Average acceleration of all acceleration phase, a | m/s\(^2\) | a = \frac{\sum \left(1 \cdot (a_i > 0) + 0 \cdot (a_i < 0)\right)}{T_{\text{trip}}} |
| 4  | Average deceleration of all deceleration phase, d | m/s\(^2\) | d = \frac{\sum \left(1 \cdot (a_i > 0) + 0 \cdot (a_i < 0)\right)}{T_{\text{trip}}} |
| 5  | Root Mean Square Acceleration, RMS             | m/s\(^2\) | RMS = \sqrt{\frac{1}{T_{\text{trip}}} \int (a)^2 dt} |
| 6  | Time proportion of driving 4 modes, i.e. Idling Pi, v(t) = 0 | %         | % acc = \frac{T_{\text{acc}}}{T_{\text{trip}}} |
| 7  | Acceleration P<sub>a</sub>, v(t) ≥ 3 km/h, a(t) ≥ 0.1 m/s\(^2\) | %         | % cruise = \frac{T_{\text{cruise}}}{T_{\text{trip}}} |
| 8  | Cruising P<sub>c</sub>, v(t) ≥ 3 km/h, -0.1 ≤ a(t) < 0.1 m/s\(^2\) | %         | % dec = \frac{T_{\text{dec}}}{T_{\text{trip}}} |
| 9  | Deceleration P<sub>d</sub>, v(t) ≥ 3 km/h, a(t) < -0.1 m/s\(^2\) | %         | % |
extraction of the parameters, the average speed and percentage of idle is plotted in 2-dimensional feature space as in Figure 4.

![Figure 4: Average speed of micro-trips VS percentage idle of micro-trips](image)

Accordingly, Figure 5 shows the micro-trips that are clustered into 3 groups using k-means clustering method. Each group has its own characteristics and stands for different traffic condition. Group 1 stands for clear traffic flow condition, group 2 stands for medium traffic flow condition and lastly, group 3 stands for congested traffic flow condition.

![Figure 5: Clustering of micro-trips](image)

Hence after all the micro-trips have been clustered, the representatives of micro-trips from each cluster are determined in order to produce the driving cycle. The closest micro-trips to the cluster center will be considered as the representative micro-trips. The representative of micro-trips for each groups are presented in Figure 6, Figure 7 and Figure 8. The micro-trips then will be combined in order to produce final driving cycle of BAS KITe.

![Figure 6: Congested traffic flow condition](image)
3. Results and Discussion

In this section, validation of BAS KITe driving cycle and existing driving cycle of MATLAB code has been presented. The BAS KITe driving cycle will be analysed and discussed. Also, the analysis of the fuel economy and gas emission of BAS KITe be determined and the comparison between conventional engine bus, and split single mode PHEB using the driving cycle developed will also be discussed.

3.1 BAS KITe driving cycle validation

The validation of the MATLAB code has been made using the standard data of Extra Urban Driving Cycle (EUDC), US06 Supplemental Federal Test Procedure driving cycle (SFTP US06), Unified Cycle Driving Schedule Test Procedure driving cycle (LA92) and New York City Cycle (NYCC). As such, a total of nine parameters were tested to measure the accuracy of the MATLAB code with minimal variance. TABLE 2-5 shows the percentage difference between standard data retrieved from a few published journals and calculated data of driving cycle using MATLAB code for EUDC, SFTP US06, LA92 and NYCC.

From the results in Table 2-5, most of the data are lower than 10% of percentage difference except for the percentage of cruising for LA-92. Thus, it can be concluded that the MATLAB code are acceptable for further analysis.
Table 2: Percentage Difference of EUDC

| EUDC                | Journal | Calculated | Different |
|---------------------|---------|------------|-----------|
| Distance (km)       | 6.95    | 6.94       | 0.14%     |
| Total time (s)      | 400.00  | 400.00     | 0%        |
| Average speed (km/h)| 62.60   | 62.44      | 0.26%     |
| Average running speed (km/h) | 69.60 | 69.74 | 0.20% |
| Average acceleration (m/s²) | 0.378 | 0.378 | 0%  |
| Average deceleration (m/s²) | 0.926 | 0.926 | 0%  |
| RMS acceleration (m/s²) | 0.411 | 0.377 | 8.63% |
| Time proportion of idling (%) | 10.0 | 10.2 | 1.98% |
| Time proportion of cruising (%) | 53.8 | 53.6 | 0.37% |
| Time proportion of acceleration (%) | 25.8 | 25.7 | 0.39% |
| Time proportion of deceleration (%) | 10.5 | 10.5 | 0%  |

Table 3: Percentage Difference of SFTP US06

| SFTP US06      | Journal | Calculated | Different |
|----------------|---------|------------|-----------|
| Distance (km)  | 12.89   | 12.87      | 0.16%     |
| Total time (s) | 596.00  | 601.00     | 0.84%     |
| Average speed (km/h) | 76.90 | 77.20 | 0.39% |
| Average running speed (km/h) | 83.0 | 83.44 | 0.53% |
| Average acceleration (m/s²) | 0.666 | 0.670 | 0.60% |
| Average deceleration (m/s²) | 0.724 | 0.728 | 0.55% |
| RMS acceleration (m/s²) | 0.981 | 0.986 | 0.51% |
| Time proportion of idling (%) | 6.5  | 6.7  | 3.03% |
| Time proportion of cruising (%) | 5.5  | 5.5  | 0%   |
| Time proportion of acceleration (%) | 45.8 | 45.8 | 0%  |
| Time proportion of deceleration (%) | 42.2 | 42.1 | 0.24% |

Table 4: Percentage Difference of LA92

| LA92         | Journal | Calculated | Different |
|--------------|---------|------------|-----------|
| Distance (km)| 15.80   | 15.79      | 0.06%     |
| Total time (s)| 1436.00 | 1436.00   | 0%        |
| Average speed (km/h) | 39.4  | 39.6  | 0.50% |
| Average running speed (km/h) | 47.0  | 47.31 | 0.66% |
| Average acceleration (m/s²) | 0.668 | 0.673 | 0.75% |
| Average deceleration (m/s²) | 0.749 | 0.754 | 0.67% |
| RMS acceleration (m/s²) | 0.791 | 0.796 | 0.63% |
| Time proportion of idling (%) | 15.1 | 15.2 | 0.66% |
| Time proportion of cruising (%) | 12.5 | 15.0 | 18.18% |
| Time proportion of acceleration (%) | 38.3 | 38.2 | 0.26% |
| Time proportion of deceleration (%) | 34.1 | 34.1 | 0%  |
Table 5: Percentage Difference of NYCC

| Parameters                        | NYCC   | Journal | Calculated | Different |
|-----------------------------------|--------|---------|------------|-----------|
| Distance (km)                     | 1.90   | 1.90    | 0%         |           |
| Total time (s)                    | 599.00 | 599.00  | 0%         |           |
| Average speed (km/h)              | 11.4   | 11.4    | 0%         |           |
| Average running speed (km/h)      | 17.5   | 17.6    | 0.57%      |           |
| Average acceleration (m/s²)       | 0.616  | 0.621   | 0.81%      |           |
| Average deceleration (m/s²)       | 0.601  | 0.605   | 0.66%      |           |
| RMS acceleration (m/s²)           | 0.668  | 0.672   | 0.60%      |           |
| Time proportion of idling (%)     | 31.9   | 32.1    | 0.63%      |           |
| Time proportion of cruising (%)   | 2.0    | 2.0     | 0%         |           |
| Time proportion of acceleration (%)| 32.6  | 32.6    | 0%         |           |
| Time proportion of deceleration (%)| 33.4  | 33.4    | 0%         |           |

3.2 BAS KITe driving cycle analysis

After all the driving cycle data along two different routes has been gathered; the final development of BAS KITe driving cycle can be achieved. Figure 9 shows the final BAS KITe driving cycle. The total distance is 16.0 km and the total micro-trips are 36. The characteristic of BAS KITe driving cycle in terms of nine assessment parameters is tabulated in Table 6.

![Figure 9: BAS KITe driving cycle](image)

Table 6: Assessment Parameters of BAS KITe Driving Cycle

| Parameters                        | BAS KITe driving cycle |
|-----------------------------------|------------------------|
| Distance travelled (km)           | 16.00                  |
| Average speed (km/h)              | 21.49                  |
| Average running speed (km/h)      | 25.13                  |
| Average acceleration (m/s²)       | 0.45                   |
| Average deceleration (m/s²)       | 0.49                   |
| RMS (m/s²)                        | 0.65                   |
| Percentage idle (%)               | 13.07                  |
| Percentage cruise (%)             | 0.04                   |
| Percentage acceleration (%)       | 45.62                  |
| Percentage deceleration (%)       | 41.27                  |
The following observations are made from the developed driving cycle:

1) Speed range below 10 km/h was dominant. This is due to congested traffic condition of KT city routes and also due to role of public bus itself which lead to have more stop-go condition.

2) The micro-trips at the higher speed range are longer compared to the micro-trips at lower speed range. This is because the vehicle experiencing a free flow moves at higher speed range with less frequent stop due to less traffic condition.

3) A 21.49 km/h average speed was recorded in the developed BAS KITe driving cycle shows the vehicles are moving at lower speed and more micro-trips are found below the average speed. Therefore, more fuel consumption and emission takes place during that period due to frequent stop along the road.

3.3 Energy consumption and emissions analysis

After the driving cycle has been developed, the energy consumption such as fuel consumption and fuel economy, and emissions can be determined using AUTONOMIE software version v1210. AUTONOMIE is a tool for automotive control system design, simulation and analysis. It is mathematically-based forward simulation software based on MATLAB, with MATLAB data and configuration files and models built in Simulink. Table 7 shows the comparison of energy consumption and emissions of BAS KITe driving cycle using split single mode plug-in hybrid electric bus (PHEB) powertrain and conventional engine bus powertrain.

From the table, it clearly shows that split single mode of PHEB is the best powertrain compared to conventional bus with the lowest value of fuel consumption and emission with 0.3 l/100km and 7.05 g/km respectively, and the highest value of fuel economy with 788.57 mile/gallon. It is because PHEBs start in ‘all electric’ mode runs on electricity and when the batteries are low in charge, it calls on the internal combustion engine (ICE) to provide a boost or to charge up the battery pack. The ICE is used here to extend the range. PHEBs can charge their batteries directly from the grid and they also have the facility to utilize regenerative braking. PHEBs’ ability to run solely on electricity for most of the time makes its carbon footprint smaller [11]. As well as they consume less fuel as well and thus reduce the associated cost.

|                      | PHEB     | Conventional |
|----------------------|----------|--------------|
| Fuel economy (mile/gallon) | 788.57   | 29.02        |
| Fuel consumption (l/100km)   | 0.3      | 8.1          |
| CO2 emission (g/km)       | 7.05     | 191.74       |

4. Conclusions

The development of BAS KITe driving cycle is done using micro-trips clustering by k-means method. The data are collected from predetermined initial location to final location along two different operation routes of BAS KITe services. The BAS KITe driving cycle is successfully obtained and can be concluded that the proposed method is possible to generate a BAS KITe driving cycle for PHEB powertrain to overcome exhaust emissions and fuel consumption problems. Further study has to be made on other public services in Kuala Terengganu city.

Acknowledgments

All the gratitude and acknowledgement goes to the financial support and collaboration of this work which; Knowledge and Technology Assimilation Grant (KTAG) Scheme 2018, Universiti Malaysia Terengganu and Cas Ligas Sdn Bhd.
References

[1] P. Shen, Z. Zhao, J. Li, and X. Zhan. “Development of a typical driving cycle for an intra-city hybrid electric bus with a fixed route.” In Transportation Research Part D, vol. 59, pp. 346-360, 2018.

[2] O. Shiqi, Z. Yafu, P. Jia, T. Baoyu, and L. Jing. “Development of hybrid city bus’s driving cycle.” In 2011 International Conference on Electric Information and Control Engineering, IEEE, May 2011.

[3] I. N. Anida, A. Z. Fathonah, W. H. Atiq, J. S. Norbakyah, and A. R. Salisa. “Driving cycle analysis for fuel economy and emissions in Kuala Terengganu during peak time.” In Journal of Telecommunication, Electric and Computer Engineering, vol. 10, no. 2-5, pp. 21-24, 2018.

[4] N. H. Arun, Srinath Mahesh, Gitakrishnan Ramadurai, and S. M. Shiva Nagendra. “Development of driving cycles for passenger cars and motorbikes in Chennai, India.” In Sustainable Cities and Society, 2017.

[5] K. S. Nesamani and K. P. Subramanian. “Development of a driving cycle for intra-city buses in Chennai, India.” In Atmospheric Environment, vol. 45, pp. 5469-5476, 2011.

[6] Z. Junhu, S. Qin, and Z. Jieyu. “The city bus driving cycle construction”. In 2011 Second International Conference on Mechanic Automation and Control Engineering, IEEE, August 2011.

[7] U. Galgamuwa, L. Perera and S. Bandara. "Developing a General Methodology for Driving Cycle Construction Comparison of Various Established Driving Cycles in the World to Propose a General Approach.” In Journal of Transportation Technologies, vol. 5, pp. 191-203, 2015

[8] I. N. Anida, I. S. Ismail, J. S. Norbakyah, W. H. Atiq, and A. R. Salisa. “Characterisation and development of driving cycle for work route in Kuala Terengganu”. In International Journal of Automotive and Mechanical Engineering, vol. 14, no. 3, pp. 4508-4517, September 2017.

[9] U. Maulik and S. Bandyopadhyay , “Genetic algorithm based clustering technique”, in Pattern Recognition, vol. 33(9), pp. 1455-1465, 2000.

[10] A. Fotouhi and M. Montazeri-Gh. “Tehran driving cycle development using the k-means clustering method”, in Scientia Iranica, Transactions A: Civil Engineering, vol. 20(2), pp. 286-293, 2013.

[11] F. Un-Noor, S. Padmanaban, L. Mihet-Popa, M. N. Mollah, and & E. Hossain. “A comprehensive study of Key Electric Vehicle (EV) components, technologies, challenges, impacts, and future direction of development.” In Energies, vol. 10, pp. 1217, 2017.