Driving cycle development of BAS KITe in Kuala Terengganu city to optimize the energy consumption and emissions

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Abstract. Public bus has become the needs to the people especially in the city area. In Kuala Terengganu city, the public bus service was created to upgrade the public transport system in Terengganu State by providing city bus service called as ‘BAS KITe’. Concerning of the real world city, driving cycles for BAS KITe is needed in order to improve the energy consumption and emissions for every operation routes. Driving cycle represents a traffic behavior in a specific area or city. The objectives of this paper are; to characterize and develop driving cycle of BAS KITe in Kuala Terengganu city along its operation route, to analyze fuel economy and emissions using the driving cycle developed, and to compare the fuel economy and emissions with conventional bus and split single mode plug-in hybrid electric bus (PHEB) using Vehicle System Simulation Tool Development (AUTONOMIE) software. The methodology involves three major steps, which are route selection, data collection using on-road measurement method and driving cycle development using k-means method. Through the analysis of energy consumption and emissions, real world driving cycle is designed with 41 final micro-trips and it can be proved that PHEB can reduce the energy consumption thereby minimizing the impact on the environment and economy.

1. Introduction

In Kuala Terengganu (KT), the public bus service was created to upgrade the public transport system in Terengganu State by providing city bus services. This bus called as BAS KITe. The uniqueness and services of the BAS KITe has attracted almost 57,314 passengers in year 2017. However, in order to accommodate such passengers, Cas Ligas Sdn Bhd, the company that handles BAS KITe, has spent almost RM 176,273.62 per year 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. The performance of an HEB is determined by the control strategy.

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 [1]. Driving cycle is a representative speed-time profile of driving behavior of specific region or city [2]. Driving cycle has important applications, such as vehicle powertrain design, determination of fuel consumption, and determination of vehicle tail pipe emissions [3].
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. As for the driving cycle in Chennai, micro-trip based cycle construction is chosen in order to develop final driving cycle [4]. According to [5], the driving cycle of the Shanghai hybrid electric bus was developed using $k$-means clustering method. Considering the characteristics of frequent stopping and repetition during the bus driving cycle, the bus-station-based driving cycle segment-division method and the whole-trip-based bus driving cycle construction method are proposed. Driving cycles have been developed for different cities to represent their local traffic and driving situations. The driving cycle of hybrid bus in typical Chinese city is developed and used to determine the emission characteristics [6]. However, the driving cycle for Kuala Terengganu, specifically on public bus has not been developed and discussed yet.

As for this project, micro-trip based cycle construction by clustering the micro-trips using $k$-means method as used in the previous research was chosen, since this method is easy and need less computation. However, some improvements are added in the methodology, suitable with the Kuala Terengganu’s geography, weather, and driving pattern. The objectives of this paper are to characterize and develop driving cycle of $BAS KITe$ in Kuala Terengganu city along its operation route (Route C01) using $k$-means method, to analyze fuel economy and emissions using the driving cycle developed and to compare the fuel economy and emissions with conventional engine bus and split single mode plug-in hybrid electric bus (PHEB) using Vehicle System Simulation Tool Development (AUTONOMIE) software.

2. Methodology

Figure 1 shows the flow chart and research activities on how to develop $BAS KITe$ driving cycle in Kuala Terengganu (KT) along one of its operation routes named Route C01. The inputs of $BAS KITe$ driving cycle are second-by-second speed. The data are collected with 10 runs of data. In this research, the on-board measurement method will be used using a Global Positioning System (GPS). The data gathered then will be divided into several micro-trips and from each micro-trip, the features such as average speed and percentage of idle will be calculated. The clustering of the micro-trips using $k$-means method will be took place in order to find the final driving cycle of $BAS KITe$ along Route C01. Then, using the developed driving cycle of $BAS KITe$, the fuel economy and emissions will be analyzed using AUTONOMIE software and will be compared to other vehicles’ powertrain such as conventional engine bus and split single mode PHEB.
While, Table 1 shows the assessment parameters in order to characterize the driving data. Cycle assessment is a vital component in order to characterize and validate the driving cycle. For this project, the parameters involve are; average speed, average running speed, average acceleration and average deceleration, and root mean square of acceleration. This paper also defines four driving modes, which are idling mode, accelerating mode, decelerating mode and cruising mode. 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.

Table 1. Assessment parameters of BAS KITE driving cycle

| Parameters                        | Unit     | Equation                                                                 |
|-----------------------------------|----------|--------------------------------------------------------------------------|
| Average speed of whole driving cycle | Km/h     | \( V_1 = 3.6 \frac{\text{dist}}{T_{\text{total}}} \)                      |
| Average running speed             | Km/h     | \( V_2 = 3.6 \frac{\text{dist}}{T_{\text{drive}}} \)                     |
| Average acceleration of all acceleration phase | m/s²     | \( a = \frac{1}{n} \sum_{i=1}^{n} \begin{cases} \frac{a_i}{0} & (a_i > 0) \\ 0 & (else) \end{cases} \) |
| Average deceleration of all deceleration phase | m/s²     | \( d = \frac{1}{n} \sum_{i=1}^{n} \begin{cases} \frac{a_i}{0} & (a_i < 0) \\ 0 & (else) \end{cases} \) |
| Time proportion of idling         | %        | \( \% \text{ idle} = \frac{T_{\text{idle}}}{T_{\text{total}}} \)          |
| Time proportion of cruising       | %        | \( \% \text{ cruise} = \frac{T_{\text{cruise}}}{T_{\text{total}}} \)      |
Time proportion of acceleration \[\% \]  
\[\% \text{acc} = \frac{T_{\text{acc}}}{T_{\text{total}}}\]

Time proportion of deceleration \[\% \]  
\[\% \text{dec} = \frac{T_{\text{dec}}}{T_{\text{total}}}\]

Root mean square acceleration \[\text{m/s}^2\]  
\[\text{RMS} = \sqrt{\frac{1}{T} \int_0^T (a)^2 \, dt}\]

2.1. Route selection

Figure 2 highlights the selected route for *BAS Kite* driving cycle started from bus terminal Majlis Bandaraya Kuala Terengganu (MBKT), brings to Pantai Batu Burok, Noor Arfa Craft Complex, Terengganu’s Science & Creativity Centre, the famous Floating Mosque, and lastly ended at the same bus terminal MBKT. According to Cas Ligas Sdn Bhd, this selected route is one of the *BAS Kite* operation routes named Route C01.

![Figure 2. BAS Kite operation route; Route C01.](image)

2.2. Data collection

Data was collected along the selected road as in Figure 2 with 10 runs. For *BAS Kite* driving cycle, on-board measurement technique will be used for the data collection since it is more suitable for KT drivers’ irregular behavior to avoid a risk such as accident and sudden loss of control. 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]. Speed-time data are collected by using GPS based on on-board measurement method along the selected route.

2.3. *BAS Kite* driving cycle development

The development of a drive cycle is based on micro-trips. Micro-trip is a trip between two successive time points at which the vehicle velocity is zero [8]. Each micro trip starts with an idle phase and ends with a decelerating phase, which reduces to zero. The whole data has to be separated into number of micro-trips. A large number of micro trips can be acquired after this process for all collected data. Then, the micro-trips are clustered into several groups depending on the traffic situations such as congested traffic flow, medium traffic flow and clear traffic flow. K-means approach will be using in order to cluster the micro-trips.
The procedure follows a simple and easy way to classify a given data set through a certain number of clusters (assume \( k \) clusters) fixed a priori. The \( k \)-means algorithm attempts to solve the clustering problem by optimizing a given metric [9]. There are a lot of pros by using this \( k \)-means technique such as cluster centers can minimize conditional variance (a good representation of data), simple and fast method, and easy to implement. The steps of the \( k \)-means algorithms are described briefly below [10]:

Step 1: Decide on a value for \( k \). In this study, the value of \( k \) is based on traffic condition.
Step 2: Initialize the \( k \) cluster centers (randomly, if necessary)
Step 3: Decide the class memberships of the total data, \( N \) by assigning them to the nearest cluster center.
Step 4: Re-estimate the \( k \)-cluster centers, by assuming the memberships found above are correct.
Step 5: If none of the \( N \) data changed memberships in the last iteration, exit. Otherwise go to Step 3.

The approach in developing the driving cycle in this paper is by micro-trips clustering. In order to cluster the micro-trips, driving features must be extracted first. There are a lot of driving features that can be extracted from the micro-trips as mentioned earlier in Table 1. Nevertheless, for this purpose, only two features will be used which are average speed and percentage of idle. These two features have been chosen since they will give greatest effect on the emission [9].

After the extraction of the parameters, the average speed and percentage idle is plotted. Hence, the micro-trips are clustered into three clusters using \( k \)-means clustering method depending on the traffic condition. 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 consider as the representative micro-trips. The micro-trips then will be combined in order to produce final driving cycle of BAS KITE along Route C01.

3. Results and discussion
In this section, the results of the development of driving cycle will be analysed and discussed. Also, the analysis of the fuel economy and gas emission of BAS KITE will 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 analysis
Figure 3 shows 2-dimensional feature space plotted of all the average speed and percentage idle of each micro-trip for all 10 runs data. While Figure 4 shows the micro-trips that are clustered into three clusters using \( k \)-means clustering method. Each group has its own characteristics and stands for different traffic condition. Cluster 1 stands for clear traffic condition, cluster 2 stands for medium traffic condition and lastly, cluster 3 stands for congested traffic condition.
Figure 3. Average speed of micro-trips VS Percentage idle of micro-trips.

Figure 4. Clustering of micro-trips.

Figure 5, Figure 6 and Figure 7 show the selected micro-trips for each group after the representatives of micro-trips from each cluster is determined. Hence, after combining all the representative micro-trips for all clusters, the final proposed of BAS KITE driving cycle along Route C01 is developed as shown in Figure 8. The distance travelled for Route C01 is 27 km and the total final micro-trips are 41. As in the figure, it shows that the pattern of driving cycle is irregular. This is due to other external factors such as traffic light, road conditions, drivers’ behaviour and environmental factors [11].
Figure 5. Congested traffic condition.

Figure 6. Medium traffic condition.
Table 2 shows the characteristics of **BAS KITe** driving cycle along Route C01 in terms of nine parameters such as average speed, average driving speed, average acceleration and deceleration, time proportion of idling, cruising, acceleration and deceleration and root mean square of acceleration. From the table, it shows that the driving cycle run in low speed since bus is categorized as heavy-duty vehicle and it is operated in city routes. The driving cycle also contain many micro-trips since public bus will undergo lots of ‘stop-go’ condition in order to drop off and pick up the passengers.
Table 2. Assessment parameters of \textit{BAS KITE} driving cycle along Route C01.

| Parameters                                      | Unit          | Value |
|------------------------------------------------|---------------|-------|
| Average speed of whole driving cycle           | Km/h          | 21.26 |
| Average running speed                          | Km/h          | 24.81 |
| Average acceleration of all acceleration phase | m/s           | 0.42  |
| Average deceleration of all deceleration phase | m/s           | 0.47  |
| Time proportion of idling                      | %             | 12.90 |
| Time proportion of cruising                     | %             | 0.61  |
| Time proportion of acceleration                 | %             | 45.71 |
| Time proportion of deceleration                | %             | 40.78 |
| Root mean square acceleration                  | m/s           | 0.62  |

3.2. \textit{Fuel rate and emissions analysis}

After the driving cycle has been developed, the fuel rate such as fuel consumption and fuel economy, and emission 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 3 shows the comparison of fuel rate and emissions of \textit{BAS KITE} driving cycle for Route C02 using split single mode 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 engine with the lowest value of fuel consumption and emission with 0.3 l/100km and 7.1 g/mile respectively, and the highest value of fuel economy with 332.69 km/l. 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 have the facility to utilize regenerative braking. PHEBs’ ability to run solely on electricity for most of the time makes its carbon footprint smaller [12]. As well as they consume less fuel as well and thus, reduce the associated cost.

Table 3. Fuel rate and emissions of \textit{BAS KITE} driving cycle

|                      | PHEB       | Conventional bus |
|----------------------|------------|------------------|
| Fuel economy (km/l)  | 332.69     | 12.37            |
| Fuel consumption (l/100km) | 0.3       | 8.09             |
| CO2 emissions (g/km) | 7.1        | 191.29           |

4. \textit{Conclusion}

The \textit{BAS KITE} driving cycle is successfully developed and can be concluded that the proposed method which is micro-trips clustering by \textit{k}-means method is possible to generate a \textit{BAS KITE} driving cycle. The analysis of energy consumption and emissions of PHEB is successfully obtained using AUTONOMIE software and the final \textit{BAS KITE} driving cycle is set as the input. It is also can be concluded that PHEB powertrain is the best alternative to overcome exhaust emission and fuel economy problems. Further study has to be made on other public services in Kuala Terengganu city.
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