Development of *Penambang* Boat Driving Cycle to Evaluate Energy Consumption and Emissions

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**Abstract.** *Penambang* Boat is a service that has been developed in the Kuala Terengganu River to boost the public transport network in Terengganu. As far as real-world cities are concerned, the *Penambang* Boat process is important for each running waterway to increase energy efficiency and reduce pollution. This research study is to define and validate the parameters of this driving cycle and to develop the *Penambang* Boat driving cycle on the Kuala Terengganu River throughout its operation path, to analyze fuel economy and emissions using Advance Vehicle Simulator (ADVISOR) software. Through the analysis of energy consumption and emissions, the last two of the micro trips were chosen and the real driving cycles are developed. The results show that the fuel consumption is 8.7 l/100km, the CO emission is 3.479 g/km, the HC emission is 3.718 g/km and lastly the NOx emission is 0.003 g/km. *Penambang* Boat has been shown the needs to reduce the power consumption and thus minimize the impacts on the environment and economy.

1. **Introduction**

Many studies show that every conventional engine type emission rates of carbon dioxide and fuel consumption were high. To develop the driving cycle which satisfies the pollution regulatory requirements and high energy performance, the priority needed to improve the modern motor driving cycle. Nowadays, issue on fuel price, fuel consumption and emissions have attracted society’s attention to alternative vehicles. It has become increasingly serious issues, thus greatly promoting research on and applications of energy-saving and emission reducing technologies in the automobile industry according to [1]. The Penambang Boat service has invested a certain amount on fuel annually. The solution was therefore addressed to reduce fuel usage. Driving cycle is a data collections of vehicle speed against time collected from the real data situation. This cycle is commonly developed as for few specific region or city, certain road and routes and vehicle types. Driving cycle study is essential to the vehicle developers as well as researchers to study the performance of the proposed transport and vehicle through simulations. However, the driving cycles are not equivalent when comes to different countries or cities, even though they may look identical according to [2].

With the development of this driving cycle, it represents a typical driving graph for the specific area or region either free flow or saturated traffic. Driving cycle also based upon operating factors situations such as the idle state, acceleration and deceleration also in steady state to portray the pattern type in a place of the region according to [3]. Analysis has been conducted on this driving cycle by using collection of data trip from the vehicles in real life operation. With the driving cycle analysis, the
vehicles performance can be assessed. Furthermore, this study used three major tasks that are data collection, driving cycle development and route selection. Thus, the real driving cycle simulation characteristics must be executed. Few methods were proposed for the development of the driving cycle such as micro-trip-based cycle construction and modal cycle construction.

For this driving cycle in Kuala Terengganu a micro-trip method is used to develop driving cycle. Based on the driving cycle of the Kuala Terengganu river route driving cycle was developed using k-means clustering method and Global Positioning System (GPS) according to [4]. Furthermore, this driving cycle has been compared with another research results. There are two methods for obtaining and tabulating driving cycle data, chasing boat or embarking techniques using GPS or both, that can be emphasized. In this analysis, the GPS technique is used to collect the speed-time data of a boat. It has been analyzed and characterized once the data is obtained. Driving speed data has been obtained using GPS technique. This technique involves the processing in the real world of a series of speed-time data, where the time-related speed of the ship is registered. This process has been repeated in order to obtain large amounts of data.

2. Methodology
There are few main tasks to be tackled in order to complete this project, which are; route selection for Penambang Boat driving cycle development, data collection method, characterization and validation of ‘Bot Penambang’ driving cycle and also development of a driving cycle using k-means clustering method. Also, the analysis of energy consumption and emissions using ADVISOR software has been discussed.

2.1 Route Selection
Determining the representative routes throughout the interested area is the most important part for the development of the driving cycle. Kuala Terengganu (KT) River is located between Kuala Terengganu and Kuala Nerus between the Sultan Mahmud Bridge and Drawbridge. Figure 1 shows the river map.

![Figure 1. Route of Penambang Boat](image)

2.2 Data Collection
The selected route for Penambang Boat driving cycle started from Seberang Takir jetty of Kuala Terengganu. The data were collected on the selected route and the data has been collected by using Speedometer GPS android application. The data series of Penambang Boat driving cycle are speed in second by second. Collections of data have been held with 10 runs of data under 2 commute routes combined as one complete cycle. In this research, the on-board measurement method has been used using a Global Positioning System.

2.3 Penambang Boat cycle assessments
Cycle assessment is a crucial component in order to characterize and validate the driving cycle. For this project, the parameters involved are average speed, average running speed, average acceleration and average deceleration, and the root mean square of acceleration. Each driving cycle has its own characteristics in term of the cycle assessments or parameters. Before developing a real driving cycle, it is a must to characterize the driving cycle first. For Penambang Boat driving cycle, the selection of the
cycle assessment has to be made and must be validated using existing data for standard driving cycle such as LA92, EUDC, NYCC, HWFET and IM240. Table 1 shows the equation that be used for every parameter calculating in *Penambang* Boat driving cycle. Nine parameters have been chosen as the assessment parameters since they are the fundamental assessment in order to characterize the driving cycle.

**Table 1**: Equation for parameters

| Parameters                                | Unit  | Equation |
|-------------------------------------------|-------|----------|
| Average speed                             | Km/h  | \( V_1 = \frac{3.6 \text{ms}}{T_{\text{total}}} \) |
| Average running speed                     | Km/h  | \( V_2 = \frac{3.6 \text{ms}}{T_{\text{drive}}} \) |
| Average acceleration of all acceleration phase | m/s² | \( a = \frac{1}{T_{\text{total}}} \sum_{i=1}^{T_{\text{total}}} \left( \frac{\text{a}_{i}}{T_{\text{total}}} \right) \) |
| Average deceleration of all deceleration phase | m/s² | \( d = \frac{1}{T_{\text{total}}} \sum_{i=1}^{T_{\text{total}}} \left( \frac{\text{d}_{i}}{T_{\text{total}}} \right) \) |
| 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             | m/s²  | \( \text{RMS} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (a_i)^2} \) |

2.4 **Driving cycle development**

The development of *Penambang* Boat driving cycle used the combination of micro-trips-based approach and pattern classification approach by using *k*-means clustering method. The inputs of *Penambang* Boat driving cycle are second-by-second speed. The data gathered has been divided into several micro-trips and from each micro-trip, the features such as average speed and percentage idle be calculated. The clustering of the micro-trips using *k*-means method took place in order to find the final driving cycle of *Penambang* Boat along selected route.

2.5 **K-mean clustering**

*K*-means is one of the simplest unsupervised learning algorithms that solve clustering issue. The *k*-means algorithm endeavors to solve the clustering issue by optimizing a given metric. There is a parcel of benefits by using this *k*-means strategy such as cluster centers can minimize conditional change (a great representation of data), straight forward and quick strategy, and simple to actualize. In this algorithm, mostly Euclidean distance is used to find distance between data points and centroids. Figure 2 shows the micro-trips clustering and its centroid.

![Figure 2: Micro-trips clustering](image-url)
2.6 Penambang Boat Driving cycle development
The micro-trips have been clustered into two groups. The representatives of micro-trips are determined in order produce the driving cycle for each cluster. The closest micro-trips to the cluster centre or centroid have been considered as the representative micro-trips. The selected micro-trips for each group are presented as in Figure 3 and Figure 4. The micro-trips then combined in order to produce the final driving cycle of Penambang Boat along the selected route.

2.7 Fuel rate and emissions analysis using ADVISOR software
The primary goal is to develop a viable driving cycle to assess exhaust emissions, which are Hydrocarbon (HC), Carbon monoxide (CO), Nitrogen oxide (NOx), and Particulate matter (PM) and fuel expenditure of boats that travel in Terengganu Rivers. After the driving cycle has been developed, the data of energy consumption and emissions has been analyzed by using ADVISOR software.

3. Result and Discussion
The validation of driving cycle assessment has been discussed. Also, the development driving cycle has been analyzed. Furthermore, the analysis of the fuel rate and gas emission determined and the comparison between Penambang Boat driving cycle with another conventional vehicle has also been compared. The overall route analysis also discussed.

3.1 Validation of cycle assessments
Table 2 and Table 3 shows the percentage difference between standard data retrieved from a few published journals and calculated data of driving cycle using MATLAB code for LA92, EUDC, NYCC and SFTP US06. As in the tables, the average percentage different of error is 0.4% and the minimum error different percentage is 0%. Thus, the percentage error data are lower than 10% of percentage difference so it can be concluded that the MATLAB code is acceptable for further analysis as clarified by [5].

| Parameters            | NYCC          | EUDC          |
|-----------------------|---------------|---------------|
|                       | Journal       | Calculated    | Different (%) | Journal       | Calculated    | Different (%) |
| Distance (m)          | 1902.76       | 1898.44       | 0.22          | 6955.07       | 6954.93       | 0.002         |
| Total time (s)        | 599           | 599           | 0             | 400           | 401           | 0.25          |
| Average speed (km/h)  | 11.4          | 11.4          | 0             | 62.6          | 62.6          | 0.32          |
| Average running speed (km/h) | 17.5 | 17.5 | 0 | 69.6 | 69.7 | 0.14 |
| Average acceleration (m/s²) | 0.616 | 0.621 | 0.81 | 0.378 | 0.377 | 0.27 |
| Average deceleration (m/s²) | 0.601 | 0.605 | 0.66 | 0.926 | 0.926 | 0 |

Figure 3: Clear flow

Figure 4: Medium flow
Table 3: Percentage difference of SFTP US06 and LA92

| Parameters                          | SFTP US06 | LA92     | Journal       | Calculated  | Different (%) | Journal       | Calculated  | Different (%) |
|------------------------------------|-----------|----------|---------------|-------------|---------------|---------------|-------------|---------------|
| Distance (m)                       | 12893.77  | 12887.58 | 0.05          |             |               | 12893.77      | 12887.58    | 0.05          |
| Total time (s)                     | 596       | 601      | 0.84          |             |               | 596           | 601         | 0.84          |
| Average speed (km/h)               | 76.90     | 77.19    | 0.38          |             |               | 76.90         | 77.19       | 0.38          |
| Average running speed (km/h)       | 83.0      | 83.44    | 0.53          |             |               | 83.0          | 83.44       | 0.53          |
| Average acceleration (m/s²)        | 0.666     | 0.670    | 0.60          |             |               | 0.666         | 0.670       | 0.60          |
| Average deceleration (m/s²)        | 0.724     | 0.728    | 0.55          |             |               | 0.724         | 0.728       | 0.55          |
| Percentage idle (%)                | 6.5       | 6.6      | 1.54          |             |               | 6.5           | 6.6         | 1.54          |
| Percentage cruise (%)              | 5.5       | 5.5      | 0             |             |               | 5.5           | 5.5         | 0             |
| Percentage acceleration (%)        | 45.8      | 45.8     | 0             |             |               | 45.8          | 45.8        | 0             |
| Percentage deceleration (%)        | 42.2      | 42.1     | 0.24          |             |               | 42.2          | 42.1        | 0.24          |

3.2 Penambang Boat Driving Cycle

The final development of the Penambang Boat driving cycle can be achieved. Figure 5 shows the final cycle of the Penambang Boat. The total distance is 0.541 km and the total micro-trips is 2. The characteristics of the Penambang Boat driving cycle in terms of nine assessment parameters are shown in Table 4.

Figure 5. Penambang Boat Driving Cycle

Table 4. Driving cycle parameter assessments

| Parameters             | Penambang Boat driving cycle |
|------------------------|-----------------------------|
| Distance (km)          | 0.541                       |
| Total time (s)         | 636                         |
| Average speed (km/h)   | 3.06                        |
3.3 Comparison of Penambang Boat driving cycle with existing driving cycle

To evaluate the developed Bot Penambang driving cycle, a comparison was made between the existing cycles as listed in Table 5. The Penambang Boat driving cycle data is near to the NYCC driving cycle for average system speed and average running speed data. The average acceleration and deceleration with the EUDC, NYCC and US06 SFTP driving cycle is below 1.0. While the percentage idle, acceleration and deceleration is near to the US06 SFTP driving cycle.

Table 5. Comparison Penambang Boat driving cycle and existing driving cycle

| Parameters          | Penambang Boat | EUDC | NYCC | SFTP US06 |
|---------------------|----------------|------|------|-----------|
| Distance (km)       | 0.541          | 6.955| 1.903| 12.894    |
| Total time (s)      | 636            | 400  | 599  | 596       |
| Average speed (km/h)| 3.06           | 62.6 | 11.4 | 76.90     |
| Average running speed (km/h) | 3.14         | 69.6 | 17.5 | 83.0      |
| Average acceleration (m/s²) | 0.030       | 0.378| 0.616| 0.666     |
| Average deceleration (m/s²) | 0.029       | 0.926| 0.601| 0.724     |
| Percentage idle (%) | 2.04           | 10.0 | 31.9 | 6.5       |
| Percentage acceleration (%) | 48.09       | 25.8 | 32.6 | 45.8      |
| Percentage deceleration (%) | 0            | 53.8 | 2.0  | 5.5       |
| Percentage cruise (%) | 0             | 53.8 | 2.0  | 5.5       |

3.4 Fuel rate and emissions analysis using ADVISOR software

Table 6 shows the result of final Penambang Boat driving cycle fuel consumption and emission analysis retrieved from ADVISOR software. From the energy consumption and emissions analysis of Penambang Boat driving cycle, it can be concluded that this boat gives the best result in order to prevent the over use of fuel and prevent the increasing various pollution in Kuala Terengganu city and river.

Table 6. Energy consumption and emissions of Penambang Boat driving cycle

| Parameter                | Value |
|--------------------------|-------|
| Distance (km)            | 0.9   |
| Fuel consumption (l/100km)| 8.7   |
| CO emission (g/km)       | 3.479 |
| HC emission (g/km)       | 3.718 |
| NOx emission (g/km)      | 0.003 |
| PM emission (g/km)       | 0     |

4. Conclusion

The primary objective of this work, which is to develop a driving cycle of Penambang Boat at Seberang Takir Jetty, Terengganu along operational routes using k-means method, had been successfully accomplished. The nine parameter that commonly used has been applied to assess the driving characteristics for Penambang Boat driving cycle. In fact, the exclusivity of the methodology employed
in this study is that the driving cycle was developed using a combination method of micro-trips base approach and pattern classification approach using \( k \)-means clustering method. Penambang Boat has been shown the needs to reduce the power consumption and thus minimize the impacts on the environment and economy.

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