Energy efficiency evaluation from micro trip database of HDV bus tracking system

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Abstract
Fuel consumption (L/100 km) is one of the most important parameters for assessing fuel economy and energy efficiency in the road transport sector. However, the fuel consumption database for Thailand heavy duty vehicles (HDVs) is usually collected from road-side surveys, as whole trip summaries, e.g., total consumed fuel quantity, and measured driving distances. Therefore, the effects of trip details, e.g., topography, route curvature, and driving style on fuel consumption, cannot be calculated. Nowadays, the modern vehicle tracking system, which can acquire vehicle traveling information at every second, including real-time fuel consumption, provides numerous sets of micro trip data. Therefore, this study aims to indicate important parameters effected on the fuel consumption of HDV buses, from the analysis of micro trip databases. Out of a number of fixed HDV buses routes, the Bangkok – Nakhon-Ratchasima route (about 300 km) was selected from seven HDV bus routes because this route has sufficient elevation gain (uphill) and elevation loss (downhill) for the analysis. From the analysis results, the correlation between fuel consumption and elevation gain was distinctively observed, while the relationship with other energy-related parameters were not observable. During the vehicle ascending, fuel consumption increased linearly as 0.75 L/100 km by an elevation gain in m/km \((y = 0.75x + 29.71)\). However, from elevation gain above 50 m/km fuel consumption fluctuated around a constant value of 59.03 ± 7.25 L/100 km.

Keywords: Micro trip database, Fuel consumption, Topography, Energy efficiency

1. Introduction
Proportional to national economic developments, the energy consumption of Thailand gradually increases. Consequently, the transport sector shares the largest contribution, as shown in Table 1 and Figure 1 [1]. In addition, the majority of energy consumption in the transport sector, depends only on fossil fuel. This causes a national trade deficit for imported fossil fuel, inevitable Greenhouse Gas (GHG) emissions and insecurity for our national energy resources.
Table 1. Thailand historical records of final energy consumption by economic sector [1]

| Economic Sector | Final energy consumption [ktoe] | Increment |
|-----------------|---------------------------------|-----------|
| 2015            | 2016                            | 2017      | 2018      | 2019      | 2018  |
| Agriculture     | 3,082                           | 2,987     | 2,652     | 2,876     | 2,940  | 8.4% |
| Industrial      | 21,083                          | 29,475    | 28,459    | 30,440    | 31,144 | 7.0% |
| Household       | 8,935                           | 11,071    | 10,870    | 11,001    | 11,171 | 1.2% |
| Commercial      | 4,270                           | 6,215     | 6,452     | 6,549     | 6,846  | 1.5% |
| Transport       | 21,714                          | 30,181    | 32,319    | 33,086    | 33,607 | 2.4% |

Total: 59,084 79,929 80,752 83,952 85,708 4.0% 2.1%

Figure 1. Contribution of energy consumption by economic sector [1]

Figure 2. (a) Projection of final energy demand and target of EEP2018 plan and (b) EEP2018 target for transportation sector [4]

Consider on these issues, the government has announced several national energy plans including the Energy Efficiency Plan (EEP2018) [2, 3, 4]. The final target is to achieve 30% reduction of Energy Intensity (EI, energy demand per economic activity) within 2037 as shown in Figure 2(a). The EEP measures for transport sector contribute to 36% out of this target, composed of four policy frameworks implemented on four transport modes including marine, aviation, rail and the road transport. The most important mode is the road transport, which is accounted for 66% of total transport EEP target as shown in Figure 2(b).

Road transport comprises of light- and heavy- duty vehicles (LDVs and HDVs) for transporting passengers and goods. One of the most important parameters involved in EI analysis, is the vehicle fuel consumption, defined as a consumed fuel quantity in a unit of driving distance, e.g., liter/100km, kgCNG/100km (informal recognized as fuel economy, km/liter or km/kgCNG), apart from the average vehicle driving distance (vehicle kilometer of travels, VKT), vehicle number, type of fuel used etc. The fuel consumption is required for evaluating fuel cost from a vehicle owner viewpoint [5, 6] (beside of vehicle purchasing cost, maintenance cost, etc.) and for the policymakers to project policy impacts [7, 8, 9, 10]. Fuel consumption depends on many parameters, e.g. vehicle deterioration, load factor, driving
behavior (driver), and road conditions, etc. Therefore, the aim of this study is to identify and evaluate the impacts of those parameters on the vehicle fuel consumption of bus transport.

2. Energy Efficiency Observation for Heavy Duty Vehicles

As mentioned above, the fuel consumption and other energy-related parameters are important for road transport EI analysis. Therefore, the Energy Policy and Planning Office (EPPO) has been continuously conducting field research projects to update those important parameters as the Thailand transport database [11, 12, 13, 14]. In the report, the fuel consumption data was collected as well as average vehicle driving distance (vehicle kilometer of travels, VKT), share of various vehicles by regions and fuel systems, and also vehicle owner information from the collected sample group. The data was collected from various vehicle types, according to registration types under the motor vehicle act and land transport vehicle act. The fuel consumptions of diesel HDV buses are 12.5, 21.6 and 15.2 L/100km for fixed route-, none fixed route- and private buses in the latest report (8.0, 4.6 and 6.6 km/L). This information included all legislation vehicles in the passenger bus category, which include passenger vans, light buses, mini-buses, coaches, mini-coaches, and double-decker buses etc. [15].

On the other hand, the Department of Land Transport (DLT) has implemented the vehicle location-tracking project for safety reason. Every public vehicle, which is used for carrying passengers or goods, must install vehicle-tracking equipment [16, 17] and this equipment must be able to transfer the vehicle GPS (Global Positioning System) location to DLT – GPS tracking system management center (DLT GPS) in real time. The current technology of vehicle tracking equipment has been further developed to obtain larger information such as vehicle identification, driver identification, as well as all energy-related parameters. Referring to advance vehicle tracking technology and requirement for annual vehicle registration, the Department of Alternative Energy Development and Efficiency (DEDE) initiates the on-going research project entitled Feasibility Study on Energy Efficiency in HDV Transport, which composes four sub projects including various HDV: the agricultural product trucks, container trucks, oil tanker trucks, and heavy-duty buses for passenger transport. The major goal of this project is to initiate a new survey approach for acquiring energy efficiency indicators in real time. The project offers a partial subsidizing for the HDV operator companies, for upgrading their GPS location tracking systems into these new advanced systems. In this initial state, the target of sample size is set at 400 vehicles in each group of HDVs, equivalent to totally 1,600 sample vehicles. This new survey approach provides advantage in acquiring energy-related parameters in HDVs, for example:

- The vehicle and driver identification can be used to categorize database into various types of HDVs which is useful for the policymaker to analyze their implementation of energy efficiency measures.
- In the most successful case, if this advance vehicle tracking is widely accepted, there will be many energy-related databases available from a number of HDV sample volumes.
- Moreover, the real-time energy-related database can help the energy-policymakers or the traffic authorizers to gain efficient-control over transport infrastructure.

This study uses the acquired data from this DEDE project.

3. Methodology

This section explains the vehicle details, data collection method and data analysis in this study. The collected data from GPS tracking equipment used in this study composes three functional modules, i.e., vehicle position tracking, driver identification and the vehicle operational information which are tapped from the vehicle CAN bus system. On the other hand, the considered driving route are selected from all operational routes of 400 samples of HDV buses which serve passenger transport all over the country. The Bangkok – Nakhon-Ratchasima route is considered for this study because it has appropriate length (around 400 km), has sufficient elevation gain (uphill) and elevation loss (downhill) and there are 7 HDV buses operated on this route more than the others. The operational driving routes of all HDV buses and information of selected route are shown in Figure 3. This route starts from Bangkok and ends
at Mittraphap road, Donwai, Nonsung, Nakhon-Ratchasima. The highest altitude is in Pakchong district measured about 400 m above sea level and 172 km far from the starting point.

3.1. Considered HDV bus
All the selected HDV buses in this study were built up from SCANIA buses. These vehicles provide both CAN bus systems and OBD-II connectible ports. The specifications are shown in Table 2.

3.2. Data collection
The data of seven HDV buses were collected for 30 days. All the collected information was acquired, transmitted through the mobile network and recorded in the cloud database system. Then the administrators, bus operators, vehicle owners can achieve the data via a web-based system. Figure 4 shows the schematic diagram of data and information flow.

Figure 3. Driving routes of the sample vehicles (a) Driving route of all 400 sample vehicles, (b) selected driving route in this study (Bangkok – Nakhon-Ratchasima) and (c) altitude and distance from Bangkok
Table 2. Specification of considered HDV buses

| Origin of engine and chassis part | SCANIA |
|----------------------------------|--------|
| Engine size (BHP)                | 310 – 420 |
| Fuel use                         | Diesel fuel |
| Seat number                      | 44 (max) |
| Total weight (ton)               | 18 – 24 (21 – 27 included passenger) |
| Load factor (of maximum passenger number) | 80% – 100% |
| Wheel number                     | 8 wheels |

Sample photo (taken from bus company)

Figure 4. Schematic diagram of data collection methodology

The data flow consists of four parts. First, all vehicle operational information was read and transmitted with the vehicle Engine Control Unit (ECU). Then the information was acquired and shown on the vehicle user interface (vehicle dashboard). The vehicle tracking equipment also collected all CAN bus information as well as observing the vehicle GPS position and motion from the GPS, and motion sensing functional module. Finally, all the information was preliminary analyzed, recorded in the database and provided on an internet website. The preliminary real-time data, which was taken from the internet web site went through pre-processing, are shown in Figure 5. Then the daily data was divided into small trips between Bangkok – Nakhon-Ratchasima, for departing- and returning trips separately. To ensure that all the information was correctly observed, the validated routines were performed for all considered vehicles. The road altitude information was randomly checked with Google Earth software [18]. The driving distance was validated between GPS information and recorded vehicle odometer. The fuel consumption results which were determined from fuel consumed quantity of real-time vehicle CAN bus were validated with the recorded fuel expense given from the HDV bus company.
Table 3. List of considered energy-related parameters to be analyzed with fuel consumption

| Parameters                        | Unit   |
|-----------------------------------|--------|
| Averaged speed                    | km/h   |
| Percentage of idling operation    | %      |
| Percentage of moving acceleration | %      |
| Percentage of moving deceleration | %      |
| Load factor                       | %      |
| Elevation gain ratio              | m/km   |
| Elevation loss ratio              | m/km   |

Figure 5. Preliminary analyzed data from the web based system

3.3. Data analysis

From the preliminary results shown in Figure 5, the energy-related parameters were analyzed to identify and correlate the ones that effect fuel consumption (FC). The considered parameters are shown in Table 3. The situations of vehicle operational status were collected in the percentage unit. The boundary limits of vehicle accelerated and decelerated situations were set at +2 and -2 m/s². The elevation gain and elevation loss ratios are calculated as shown in Figure 6.
4. Results and discussion

The relationship between considered energy-related parameters and fuel consumption (FC) were analyzed by using linear regression analysis. Then the influence parameters were indicated according to the regression results. The 30 points of daily-averaged data were analyzed first. The results show that there are only four measured parameters in Table 3 exhibit observable linear relationship with the fuel consumption data as shown in Figure 7.

Next, the real-time micro trip data of four energy-related parameters previously found linked with fuel consumption was used to perform further analysis. The micro trip results show fuel consumption consistently increases with elevation gain ratio as shown in Figure 8, while the impacts of other parameters do not show observable evidence. By dividing elevation gain ratio into intervals of 10, the results show a different trend at 50 m/km as shown in Figure 9. For the range lower than 50 m/km, the fuel consumption increases linearly with a slope of 0.75 (L/100km by m/km, $y = 0.75x + 29.71$). After that, the fuel consumption fluctuates around a constant value of about 59.03 ± 7.25 L/100km.

![Figure 7](image1.png)

**Figure 7.** Observed linear relationship between influential parameters and fuel consumption
(a) Averaged speed (b) Percentage of idling operation
(c) Elevation gain ratio and (d) Elevation loss ratio
Figure 8. Relationship between elevation gain ratio and measured fuel consumption

Figure 9. Different relationship for low and high elevation gain ratio

5. Conclusion
In this study, the fuel consumption of HDV buses was evaluated with recourse to micro trip database obtained from a vehicle positioning and energy consumption tracking system. The results of this study are a part of a research project which aims to conduct a feasibility study on including energy consumption tracking with the vehicle tracking device which has become the safety installation requirement of the Department of Land Transport. The real time database was analyzed to identify and evaluate the impacts of considered energy-related parameters on the fuel consumption of HDV buses. The results proved that fuel consumption depends on energy-related parameters such as vehicle deteriorated situation, load factor, driving behavior, and road condition, including the changing of vehicle altitude. However, in this study, the impacts of other parameters are in a minor evidence, except for the elevation gain ratio. The results show that fuel consumption linearly increases with elevation gain in a slope of 0.75 L/100km by m/km of elevation gain ratio. However, the fuel consumption achieves a maximum constant around 59.03 L/100km when the elevation gain ratio reaches 50 m/km.

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