

A Statistical Characterization of School Bus Drive Cycles Collected via Onboard Logging Systems

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ABSTRACT

In an effort to characterize the dynamics typical of school bus operation, National Renewable Energy Laboratory (NREL) researchers set out to gather in-use duty cycle data from school bus fleets operating across the country. Employing a combination of Isaac Instruments GPS/CAN data loggers in conjunction with existing onboard telemetric systems resulted in the capture of operating information for more than 200 individual vehicles in three geographically unique domestic locations. In total, over 1,500 individual operational route shifts from Washington, New York, and Colorado were collected.

Upon completing the collection of in-use field data using either NREL-installed data acquisition devices or existing onboard telemetry systems, large-scale duty-cycle statistical analyses were performed to examine underlying vehicle dynamics trends within the data and to explore vehicle operation variations between fleet locations. Based on the results of these analyses, high, low, and average vehicle dynamics requirements were determined, resulting in the selection of representative standard chassis dynamometer test cycles for each condition.

In this paper, the methodology and accompanying results of the large-scale duty-cycle statistical analysis are presented, including graphical and tabular representations of a number of relationships between key duty-cycle metrics observed within the larger data set. In addition to presenting the results of this analysis, conclusions are drawn and presented regarding potential applications of advanced vehicle technology as it relates specifically to school buses.

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INTRODUCTION

Understanding vehicle usage plays a fundamental role in assessing the performance potential of new vehicle technologies, leading to more informed decision making, better test procedures [1, 2, 3, 4, 5, 6, 7], more commercially successful designs, and lowered manufacturing and operating expenses. Of the methods available for modeling vehicle usage, operational drive/duty cycles have shown the ability to accurately represent vehicle operating information in an efficient and streamlined manner well suited to downstream analysis [8, 9, 10, 11, 12, 13, 14, 15, 16, 17]. Typically consisting of speed and time information, these seemingly simple pieces of information, when properly understood, have been used to assess the value of new technology and to aid in corresponding development and deployment.

In an effort to better understand the operating characteristics of school buses across the country and examine the dynamics challenges associated with the school bus vocation, National Renewable Energy Laboratory (NREL) researchers, with the cooperation of local school districts and Zonar Systems, collected drive cycle information on class 6 and 7 school buses operating in three unique geographic locations. The class 6 and 7 school buses, with typical capacities of 71 to 84 passengers, were located in the states of Washington, New York, and Colorado. Although smaller-sized vehicles exist that fall under the vocational category of school buses, no data was collected or examined associated with this special subset, as vehicles falling within this group display operating characteristics dissimilar to their larger counterparts.

Upon completion of the data collection phase of this study, detailed drive cycle analysis were performed to characterize typical school bus operating behavior. Examining a number of metrics associated with vehicle energy consumption and driving behavior, statistical relationships between key metrics of interest were explored, and representative standard chassis dynamometer test cycles were chosen corresponding to high, average, and low driving aggressiveness.

APPROACH

Data Collection and Drive Cycle Analysis

Drive cycles used to model vehicle operation are composed of corresponding vehicle speed vs. time points. To capture the in-use drive cycle information analyzed as part of this study and to attempt to characterize the operation of school buses across the country, NREL researchers instrumented school buses located in three unique geographic regions (Colorado, Washington, New York) with onboard mounted Isaac Instruments DRU 900 and DRU 908 data loggers configured to collect 1-Hz global positioning system (GPS) data. The data sampling rate of 1 Hz was chosen based on the results of previous studies [1, 2, 3, 4, 6, 7]. In addition to the deployment of manually installed devices, data were also collected using preinstalled Zonar Systems telemetric GPS devices at the same 1-Hz sampling rate. Employing both systems, data from a total of 1,718 route shifts reflecting the operation of 212 vehicles were captured over a period of several weeks. An example of the Isaac Instruments data loggers employed as part of this study is shown in [Figure 1](#).



Figure 1. Isaac Industries data logging device

Of the 1,718 route shift data collected as part of this study, 814 cycles were collected from source vehicles operating in Colorado, 874 from buses in Washington, and the 30 remaining from vehicles in New York. The

distribution of source vehicles similarly paralleled the drive cycle distribution by geographic region. Of the 212 vehicles from which data were collected, 102 of these vehicles were located in Colorado, 107 in Washington, and 3 in New York. Both the Colorado and Washington locations included large numbers of vehicles with preinstalled telemetric GPS data logging devices, allowing for large-scale data acquisition, while the vehicles examined in New York required manual instrument installation, resulting in limited-scale deployment of data logging devices.

Once the 1-Hz drive cycles had been captured, the raw field data stored on the data acquisition devices were downloaded onto a local computer for post processing and analysis. The raw drive cycles were filtered and analyzed using NREL's Drive Cycle Rapid Investigation, Visualization, and Evaluation tool (DRIVE) [18, 19] to generate individual drive cycle summary statistics. Using NREL's DRIVE tool, each drive cycle collected was characterized according to a total of 172 unique metrics, including key metrics such as operating speed distribution, stops per mile, acceleration rate, and vehicle kinetic intensity, a measure of the energy consumption nature of a cycle [6]. The analytical procedure performed as part of the DRIVE software was repeated using batch processing techniques, generating group-level statistics through the aggregation of individual drive cycles. Depending on how the data were aggregated into groups, researchers were able to examine statistical trends and relationships on multiple scales, ranging from the small-scale individual vehicle level, to geographic grouping, and finally to large-scale aggregation. As this study was concerned with characterizing overall school bus operation, the results presented herein reflect the analysis performed on the global conglomeration of experimental data.

Representative Test Cycle Selection

Once the data collection and preliminary drive cycle analysis had been completed, standard chassis dynamometer test cycles were chosen that reflected high, average, and low operating aggressiveness. For this particular study, the terms high, average, and low aggressiveness reflect the nature of energy consumption of the cycle, with the highly aggressive cycle representative of energy consumption primarily through stop-and-go driving behavior associated with urban driving conditions, and the low aggressive cycle representative of energy consumption through aerodynamic drag consistent with high-speed cruising associated with highway driving. As energy consumption was the key focus of cycle selection, the test cycles chosen as part of this study were selected using a multivariate least squares approach. The metrics kinetic intensity, stops per mile, and standard deviation of speed are examples of the primary selection parameters. To visualize the multivariate selection approach, a simplified single variable ranking example can be observed in [Figure 2](#).

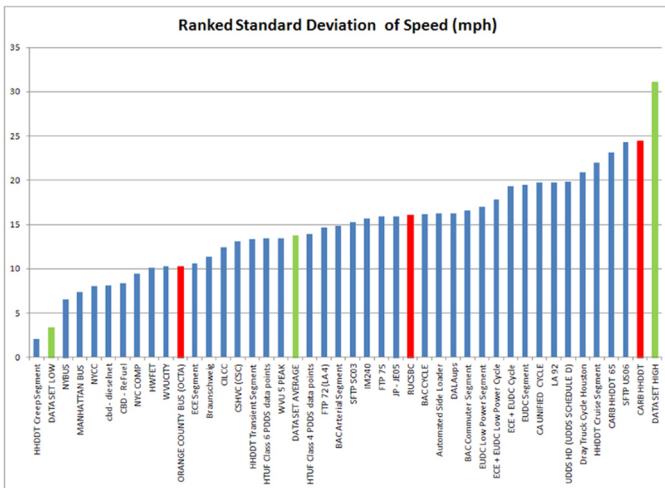


Figure 2. Example single metric ranking distribution

RESULTS

Operating Duration, Distance, and Driving Speed Distribution

Analyzing the aggregated results of the drive cycle analysis performed on the school bus data, one observes normality in the distribution of route duration data. Examining the distribution in Figure 3, it is shown that the average operational shift is 2.63 hours in duration, with a minimum duration of 0.14 hour and a maximum observed duration of 7.94 hours. Calculating the standard deviation in route duration, we find sigma to be 1.14 hours. Employing standard confidence interval assumptions based on normally distributed data and combining the observed average route duration with the calculated set standard deviation, the 99.7% confidence interval for route duration was found to be zero to 6.04 hours. While the route duration statistics may appear small in comparison to other vocations, it is important to note that typical daily school bus operation consists of two route shifts, which when examined on a daily level would result in the doubling of the duration values mentioned previously. Taking into account dual shifts associated with daily behavior, the average school bus is typically in operation for 5.26 hours out of a standard 8-hour work day. This difference in operating time may allow for potential inter-shift charging opportunities should battery electric or plug-in hybrid electric vehicle technology be implemented in future school bus design.

Similar to the distribution of the route duration metric, the driving distances calculated as part of the drive cycle analysis performed on the aggregate data set revealed strong normality, as shown in Figure 4. Of the over 1,500 individual operating shifts analyzed as part of this study, the average driving distance observed was 31.73 miles, with a maximum observed driving distance of 127.36 miles and a minimum distance of 1.45 miles. Calculating the set standard deviation, sigma was found to be 15.17 miles. Again assuming normality based on the driving distance distribution, a 99.7% confidence interval on route distance was determined and found to be zero to 77.23 miles. Similarly to route duration, doubling the route distance to reflect daily operating distances, it is found that on average school buses travel 73.46 miles, with a 99.7% cutoff on driving distance of 154.46 miles. Given the relatively low mileage average route mileage requirements, there is significant potential for hybridization or electrification as energy storage requirements can be minimized to take advantage of the limited range requirements and potential for inter-shift charging.

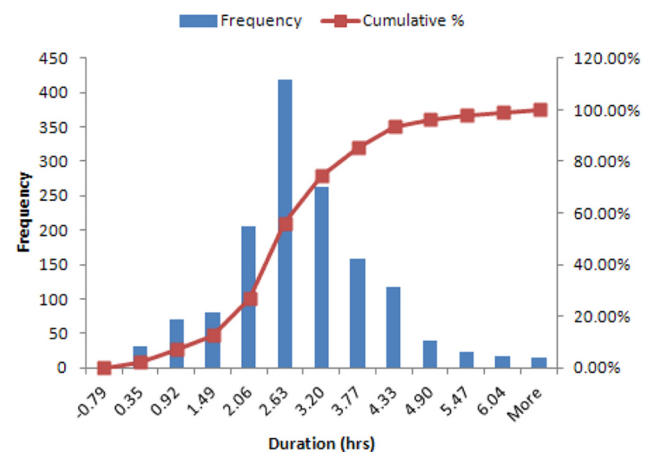


Figure 3. Route duration - 3-sigma distribution

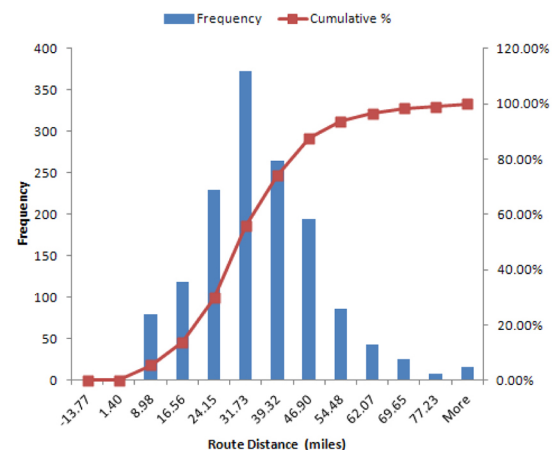


Figure 4. Route distance - 3-sigma distribution